ARTICLE

Renewable energy sources, technological innovations, role, and their impact on sustainable development goals (SDGs): From concept, definition, examples to a comprehensive bibliometric analysis data

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ABSTRACT

This study conducted a comprehensive bibliometric analysis of research trends on renewable energy sources, technological innovations, and their impact on achieving sustainable development goals (SDGs). Using data from the Scopus database, the analysis examined publications (2014-2024), including data collection, screening, and analysis using tools such as VOSviewer and Microsoft Excel to map the intellectual structure of the field, identify key research clusters, and visualize trends. The results indicated a significant rise in scientific publications, reflecting increases in research activities in renewable energy and technological innovation. Key research clusters focused on technological optimization, energy transitions, and the societal impact of renewable energy. The study emphasized how crucial technological advancements (artificial intelligence (AI) and the Internet of Things (IoT)) have become for enhancing energy systems' efficiency and optimization. These technologies enabled real-time energy management and predictive analytics, enhancing both energy use and system reliability. The findings highlighted the crucial role of renewable energy and technological innovation in supporting SDGs, particularly in sustainable cities, clean energy, and climate action. The study offered insights into future research directions and emphasized the need for ongoing technological advancements and global collaboration to achieve sustainability goals.

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KEYWORDS

Bibliometric analysis, Impact, Renewable energy sources, Role, SDGs, Technological innovation

INTRODUCTION

Rapid population growth and social and economic advancement have raised demand for energy and services related to energy. Every society requires access to energy to meet basic needs, improve welfare, and support production processes in various sectors (Reddy 2015). In 2014, global primary energy consumption reached approximately 160,310 million MWh and is expected to increase drastically to 240,318 million MWh by 2040. However, the most widely used energy source, namely fossil fuels, is experiencing a significant decline. Based on current average usage estimates, oil and gas reserves are expected to run out in 50 years, while coal and uranium can last for approximately another 100 years (Weliwaththage and Yildirim 2020).

Additionally, the extensive and ongoing use of fossil fuels has detrimental effects on the environment, including climate change, air pollution, and the depletion of non-renewable natural resources (Amin et al. 2022). In this case, renewable energy becomes an essential way to lessen environmental effects and reliance on fossil fuels. In addition to providing more sustainable options, renewable energy sources (RES), including solar, wind, and hydro, assist in accomplishing the Sustainable Development Goals (SDGs). Renewable energy helps mitigate climate change, facilitate the transition to a low-carbon economy, and promote the supply of reasonably priced clean energy (Sen and Ganguly 2017). Research on renewable energy has grown significantly in recent years, in line with global efforts to achieve the SDGs. Numerous studies have looked at how renewable energy might help meet the SDGs overall. Research conducted by Owusu and Asumadu-Sarkodie (2016) using renewable energy sources like solar and wind speeds up access to clean energy and lowers carbon emissions, both of which are important for inexpensive and clean energy. Guang-Wen et al. (2021) investigated the connection between renewable energy consumption and SDGs indicators in 137 countries, where they found that renewable energy is closely related to energy efficiency and emission reduction, which are important aspects of achieving the SDGs.

However, although many studies have provided insights into the benefits of sustainable energy, the literature still lacks an in-depth discussion on the interaction between technological innovation in renewable energy and its contribution to the SDGs. Most studies focused more on technology development and efficiency, but have not explored how these technologies can be applied holistically to support the achievement of certain SDGs.

This study conducted a thorough bibliometric evaluation of research trends in the field of renewable energy and its technological innovation and assessed the contribution of these studies to supporting the fulfillment of the SDGs. The bibliometric method was selected because of its ability to identify patterns and trends in scientific publications systematically and quantitatively, providing a comprehensive picture of how this topic has developed in the last decade. The uniqueness of the study was in its analysis, which focuses on the connection between the accomplishment of the SDGs and innovation in different renewable energy technologies, a topic that has not been widely discussed in previous studies. This analysis is expected to provide new insights into future research directions and the role of renewable energy in supporting SDGs.

METHOD

This research adopted a literature approach supported by bibliometric evaluation to map and evaluate research trends related to renewable energy, technological innovation, its impacts, and its contribution to the accomplishment of the SDGs. The bibliometric approach allowed for quantitative analysis of scientific publications to identify patterns, trends, and relationships between various topics within the relevant academic literature. The methodology involved three main steps: data collection, bibliometric analysis, and result interpretation. **Figure 1** illustrates the methodological design stages employed in the bibliometric analysis related to innovation in renewable energy technologies and their contribution to SDGs. The following explains each step:

(i) Step 1: Data Collection and Selection. Data for this study were collected from the Scopus database, which includes publications from the period between 2014 and 2024. The data was retrieved on 25 September 2024, using the search terms "SDGs" OR "Renewable Energy" AND "Technology Innovation." The search results were focused on specific document types, such as journal articles and review papers. The search identified more than 38,908 articles. The collected data was extracted in CSV and RIS formats. Scopus was chosen as the primary data source due to its comprehensive coverage of millions of scientific articles across various fields, including renewable energy and technological innovation, and their role in the SDGs.

(ii) Step 2: Data Screening and Processing. After the data was collected, a screening process was conducted to guarantee the articles' pertinence to the research topic. Each article was analyzed based on its title, abstract, keywords, and publication year. Articles that were not relevant or lacked complete information were excluded from the dataset. The filtered data were saved again in CSV and RIS formats for further analysis. This process resulted in 37,485 articles that met the research criteria and were ready for in-depth analysis.

(iii) Step 3: Bibliometric Analysis and Visualization. The selected and processed documents were analyzed using software such as Microsoft Excel and VOSviewer. Microsoft Excel was used to organize the data into informative graphs and tables, while VOSviewer was employed to generate detailed network maps of the relationships between the articles. At this stage, phrases or keywords were filtered in the network visualization produced by VOSviewer to highlight key relationships between technological innovation in renewable energy and its contribution to the SDGs. Complete guidelines for using VOSviewer for data analysis and visualization are located in the related literature (Rochaman et al. 2024; Al Husaeni and Al Husaeni 2022; Azizah et al. 2021; Al Husaeni and Nandiyanto 2022). The visualizations helped in depicting the connections between key elements of this study.

(iv) Step 4: Result Interpretation and Conclusion. The final stage of this research involved interpreting the analysis results to identify key patterns and trends related to the contribution of technological innovations in renewable energy to the SDGs. At this point, the main relationships found through network analysis were examined to provide information about potential avenues for future study and the worldwide impact of renewable energy on SDGs. Conclusions were drawn according to the findings of the analysis and their implications for future strategies in sustainable energy research.

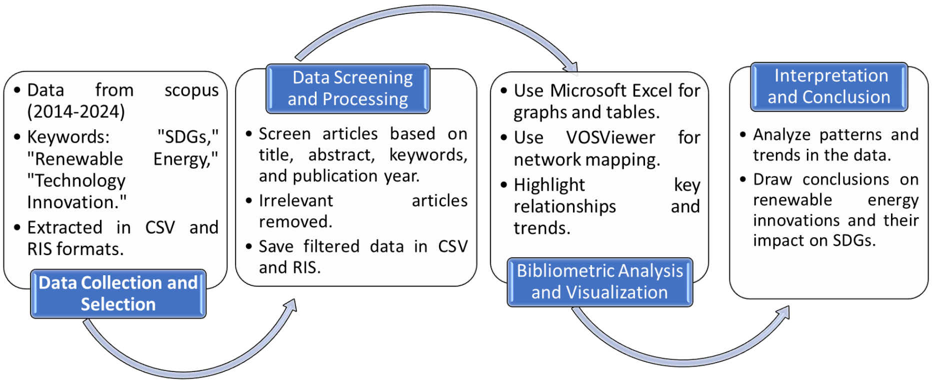

Figure 1: Flowchart diagram illustrating the bibliometric method

RESULTS AND DISCUSSION

Research Results

Publication Trends

The number of scientific publications on renewable energy and technological innovation is shown in **Figure 2**, illustrating a notable upward trend in the quantity of scientific publications on innovation in technology and sustainable energy from 2014 to 2024. This exponential growth indicates a growing interest from the scientific community and industry in the development of more sustainable alternative energy sources. This rapid increase is likely driven by the increasingly pressing issues of climatic change and restricted fossil fuel supplies. The peak of publications was recorded in 2023, indicating high research intensity in that year. This trend not only reflects the rising consciousness of the value of sustainable energy but also indicates rapid technological developments in this field. This opens up great opportunities for the development of new technologies, increasing efficiency, and attracting greater investment interest.

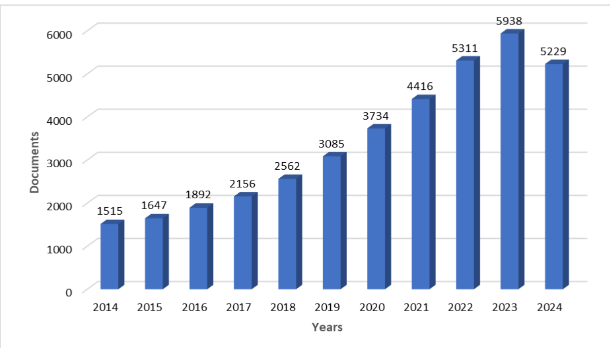

Figure 2: Development of the quantity of publications during the previous decade ten years (2014-2024)

Highly Productive Countries and Their Collaborations

Figure 3 provides a clear picture of the top 10 countries based on the number of articles published in the technical innovation and sustainability energy fields. From the graph, we can identify several key trends:

(i) China's dominance: China (N=7893) emerges as the undisputed leader in research and publications in this field, far surpassing other countries. This dominance shows that China has invested a lot of resources in renewable energy research and development, establishing itself as a global power in this field.

(ii) Presence of Western Countries: Countries such as the United States (N=4779), the United Kingdom (3089), and Germany (2334) also occupy the top positions, indicating their continued contribution to the advancement of technology for renewable energy. Moreover, there are Western countries such as Italy (N=2198), Spain (N=1941), Australia (N=1702), and Canada (N=1317).

(iii) Growing Influence of Developing Countries: India (N = 3343) and Malaysia (N = 1344), which have experienced rapid economic growth, also feature in the top 10, highlighting the increasing research activity in developing countries.

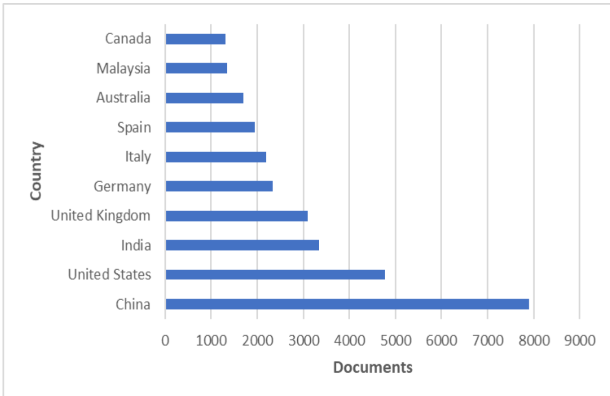

Figure 3: Top 10 countries based on the number of articles

Subject Area

Figure 4 presents ten subject areas that are often used in research on renewable energy and technology innovation to support SDGs. The circles in **Figure 4** present the percentage distribution of publications or research related to various fields of science. Each slice in the circle represents a particular field of science, and the size of the slice indicates the proportion or percentage of research focused on that field. The field of energy dominates with the highest percentage, which is 28%. This indicates that current research interests are very focused on environmental problems like pollution, climate change, and sustainability. Followed by engineering (19%), environmental science (16%), mathematics (5%), chemistry (5%), materials science (6%), chemical engineering (6%), social science (4%), computer science (3%), and physics (3%).

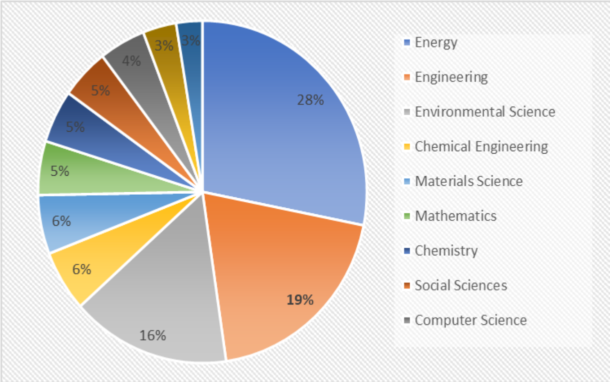

Figure 4: The ten most frequently investigated subject areas

Visualization Mapping

The VOSviewer network visualization in **Figure 5** illustrates six distinct clusters representing research topics in the area of sustainability energy, technological innovation, and their role in achieving SDGs. Each color represents a cluster of interconnected research areas:

(i) Cluster 1 (Red): This cluster predominantly focuses on technological systems and optimization. Key terms include technology, system, optimization, and energy system. These terms suggest that this cluster is largely concerned with research on optimizing energy systems, possibly related to improving efficiency, implementing energy storage solutions, and the integration of smart grid technology. It also covers challenges and strategies for system-level deployment, which ties into SDG 7 (Accessible and Sustainable Energy) by improving the efficiency of energy systems.

(ii) Cluster 2 (Green): This cluster relates heavily to renewable energy and its societal impacts, with key terms like renewable energy, role, country, and investment. This indicates that research in this cluster focuses on renewable energy's role in global development, especially in terms of country-level implementation and the financial and policy aspects surrounding it. It reflects how renewable energy is supporting the worldwide transition to sustainable practices in line with SDGs 7 (Affordable and Clean Energy) and 13 (Climate Action).

(iii) Cluster 3 (Blue): This cluster emphasizes energy transitions and technological innovation, with terms such as innovation, transition, adoption, and model. These terms suggest that research focuses on how technological innovations, particularly in renewable energy, are being adopted and integrated into broader systems. The studies in this cluster likely explore models and frameworks for transitioning to renewable energy, which ties into SDG 9 (Industry, Innovation, and Infrastructure).

(iv) Cluster 4 (Yellow): This cluster centers on energy production processes. Key terms include production, biomass, fuel, and waste. Research in this cluster may focus on alternative energy production methods, such as biofuels and waste-to-energy technologies. This promotes resource efficiency and waste reduction through the energy of renewable production techniques, which is in line with SDG 12 (Responsible Consumption and Production).

(v) Cluster 5 (Purple): This smaller cluster relates to energy storage and the role of materials. Key terms include battery, microgrid, wind, and energy storage. This indicates research on storage technologies such as batteries, which are crucial for stabilizing renewable energy sources like wind and solar. It also includes microgrid technologies, which are critical for integrating decentralized energy systems, supporting SDG 7 (Affordable and Clean Energy).

(vi) Cluster 6 (Light Blue): The final cluster highlights specific renewable energy technologies like solar photovoltaic and carbon neutrality goals. This cluster focuses on specific types of renewable energy and their role in reaching carbon neutrality, directly supporting climate action (SDG 13) and affordable and clean energy (SDG 7). It reflects research on advancing solar technology and aligning with global carbon reduction goals.

Overall, this visualization reveals the interconnected characteristics of the study on the energy of renewable, technological innovation, and the SDGs. It highlights the various ways these areas contribute to a cleaner, more sustainable future, emphasizing both technological advances and policy implications.

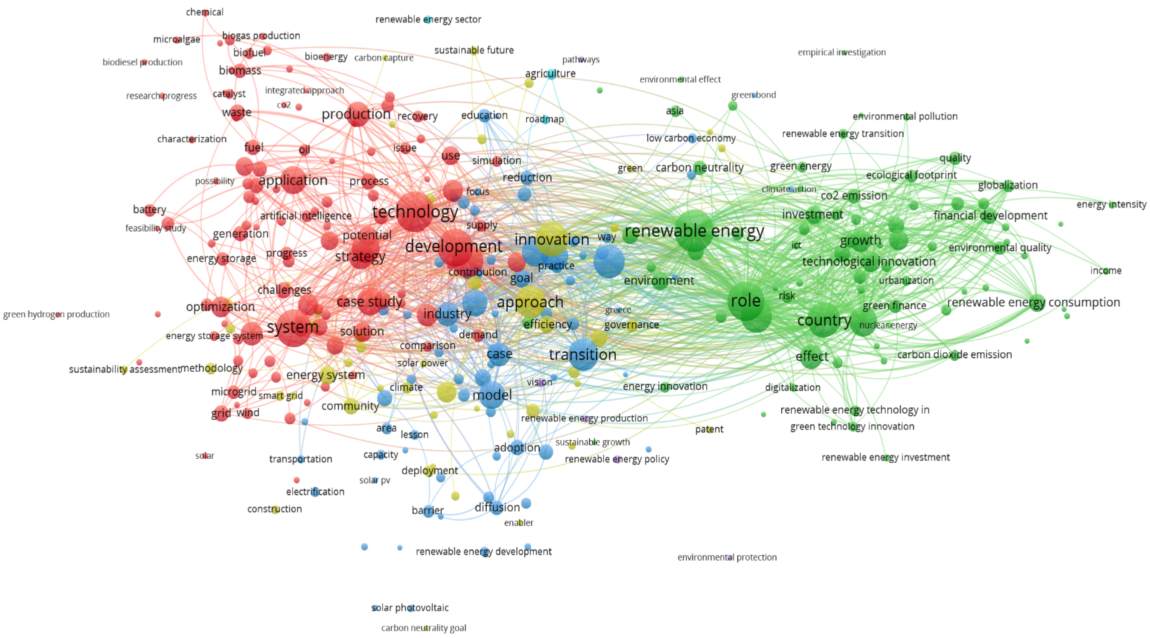

Figure 5: Network visualization

Figure 6 represents an overlay visualization of research topics related to renewable energy, technological innovation, and their connection to the goals of the SDGs. The colors in the map represent the temporal development of research topics, with darker blue indicating older topics (from around 2020), while yellow marks more recent topics (up to 2023).

(i) Key Topics from Previous Years (2020-2021, Dark Blue to Green): Topics such as system, technology, and optimization are shown in darker blue, indicating they were more prominent in earlier research. These research areas largely focus on optimizing energy systems and developing energy technologies, foundational to renewable energy. This is aligned with SDGs 7 and 9 (Affordable and Clean Energy and Industry, Innovation, and Infrastructure), respectively, which emphasize the importance of technological systems for sustainable energy management and innovation. Terms like battery, microgrid, and biomass are also visible, suggesting that energy storage, smart grid technologies, and biomass energy production were actively researched during these years. These developments are critical to the efficiency and sustainably of using renewable energy sources, playing a key role in achieving cleaner energy transitions.

(ii) Emerging Topics (2022-2023, Yellow to Light Green): The lighter green and yellow areas, including terms such as technological innovation, financial development, renewable energy consumption, and green finance, indicate newer research directions. These topics are increasingly relevant as the global focus shifts towards achieving the SDGs, particularly SDGs 12 and 13 (climate action and responsible production and consumption), respectively. Carbon neutrality and renewable energy technology are recent topics gaining more attention, reflecting growing global commitments to achieving net-zero emissions and the development of technology for renewable energy. This is highly relevant to SDG 13, as countries adopt measures to reduce carbon footprints and transition to green energy systems.

(iii) Main Nodes and Trends: Large nodes like renewable energy, innovation, and transition suggest central areas of focus in this collection of books, highlighting the critical role of innovation in advancing renewable energy transitions. These research topics support the transition to sustainable energy infrastructures, crucial for long-term sustainable growth. The connection between renewable energy and financial development is increasingly important, reflecting the financial policies and investments that are now shaping the renewable energy landscape. This emphasizes the growing role of green finance in enabling the transition to renewable energy, aligning with Partnerships for the Goals (SDG 17) and Economic Growth and Decent Work (SDG 8).

In summary, the overlay visualization captures the temporal evolution of research, with earlier work focusing on system optimization and technological solutions, while recent work has shifted towards the financial and policy aspects of implementing renewable energy solutions. This aligns with global efforts to integrate green energy into broader economic and sustainability frameworks, ensuring a holistic approach to achieving the SDGs.

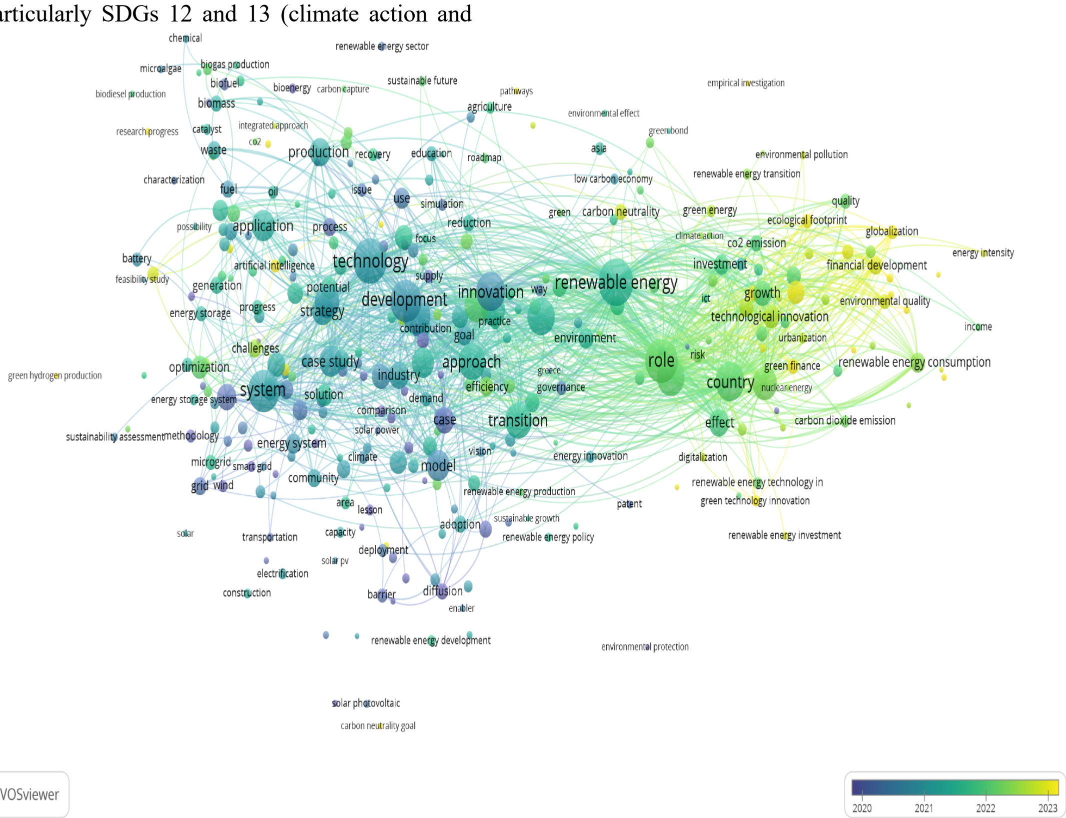

Figure 6: Overlay visualization

DISCUSSION

Support Literature with Qualitative Data Relating to Renewable Energy Definition

Renewable energy (RE) describes power sources that can be naturally renewed in a short time and will not run out if managed properly. In contrast to fossil fuels, which are finite and can harm the environment, renewable energy provides a more sustainable and eco-friendly alternative (Lund et al. 2015). This review will cover various types of renewable energy, explore technological advancements, highlight their advantages, and examine their role in achieving the SDGs. To illustrate these points, examples of energy reports are presented in **Table 1**, while a summary of previous studies using the bibliometric approach is provided in **Table 2**, demonstrating the evolution and scope of similar analyses in this field.

Table 1: Previous studies on energy

No	Topic	Reference
1	Advanced green technologies toward future sustainable energy systems	Aziz (2019)
2	Air separation, refrigeration, and power generation are used to optimize the use of cold energy from LNG.	Rao et al. (2020)
3	Unbounded energy source: An analysis of the use of ocean wave energy and its effects on the environment	Satriawan et al. (2021)
4	Unbounded energy source: An analysis of the use of ocean wave energy and its effects on the environment	Satriawan et al. (2021)
6	An assessment of the rotating biological contactor's energy usage and performance in treating household wastewater.	Waqas et al. (2021)
7	Potential alternative energy of hybrid coal from co-pyrolysis of lignite with palm empty fruit bunch and the kinetic study	Jelita et al. (2023)
8	Multi-distributed activation energy model for pyrolysis of sugarcane bagasse: Modelling strategy and thermodynamic characterization	Jamilatun et al. (2023)
9	Alternative energy solutions for a Thai durian farm: trials and a feasibility analysis for combining solar photovoltaics and reused lithium-ion batteries	Wangsupphaphol et al. (2024)
10	Towards sustainable wind energy: A systematic review of airfoil and blade technologies over the past 25 years for supporting sustainable development goals (SDGs).	Krishnan et al. (2024)
11	Clean energy production from jatropha plant as renewable energy source of biodiesel.	Kareem et al. (2022)
12	Energy harvesting based on living plants for smart farming	Pechsiri and Peungsungwan (2023)
13	Electro-magnetism in battery pot plants with heating chambers for heat energy transduction	Strömberg (2023)
14	Simple micro-hydro uses water as a renewable energy source	Putri et al. (2021)
15	Geothermal: from education to a new solution for renewable energy	Fauziah et al. (2021)
16	Electrical analysis of combination of orange peel and tamarind for bio-battery application as an alternative energy	Anshar et al. (2021)
17	Steam power plant powered by wood sawdust waste: A prototype of energy crisis solution	Hidayah et al. (2021)
18	Media learning patch board in science learning energy change materials for children with intellectual disabilities	Juhanaini et al. (2022)
19	Science process skills test instruments in the new Indonesian curriculum (Merdeka): Physics subject in renewable energy topic.	Susilowati et al. (2023)
20	Design-construction of a solar cell energy water pump as a clean water source for people in Sirnajaya village, Gununghalu district	Irawan et al. (2021)
21	Improving activities and learning outcomes of elementary school students through experimental methods using lime as an alternative electrical energy source during the COVID-19 pandemic.	Octaviani et al. (2022)
22	Analyzing climate policy utilizing financial and energy industry models	Jakhongir et al. (2023)
23	Exploring diverse substrates for enhanced water splitting: tailoring energy conversion and storage through specific qualities with its limitations	Waheed et al. (2024)
24	Uncovering the full potential utilization of petroleum reserves residue for sustainable energy supply	Khan et al. (2025)
25	Harvesting cooling effect on LPG-fueled vehicles for mini cooler: A lab-scale investigation	Setiyo et al. (2019)
26	Process simulation on fast pyrolysis of palm kernel shell for production of fuel.	Nayaggy et al. (2019)
27	The properties of fuel and characterization of functional groups in biodiesel-water emulsions from waste cooking oil and its blends	Bhikuning and Senda (2020)
28	Experimental studies on in-cylinder combustion, exergy performance, and exhaust emission in a Compression Ignition engine fueled with neat biodiesels.	Kolakoti et al. (2022)
29	Learning simple pyrolysis tools for turning plastic waste into fuel	Pebrianti and Salamah (2021)
30	Study on economic, sustainable development, and fuel consumption	Maheshvari (2022)
31	Machine learning-based CO_2 hydrogenation to high-value green fuels: A comprehensive review for computational assessment	Ahmed et al. (2024)

Table 2: Previous research used bibliometric analysis

No	Topic of bibliometrics	Reference
1	Electrodes for chemically activated supercapacitors based on biomass for electrical energy storage systems	Kohnke et al. (2023)
2	Using a corncob-derived sulfonated magnetic solid catalyst as a heterogeneous catalyst in the esterification of used cooking oil	Mardina et al. (2024)

No	Topic of bibliometrics	Reference
3	Synthesis of nano metal-organic frameworks in medical science	Shidiq (2023)
4	Salicylic acid and its derivatives: historical, present, and prospective tendencies	Ruzmetov and Ibragimov (2023)
5	Producing magnetite nanoparticles	Nugraha and Nandiyanti (2022)
6	Utilizing biotechnology to advance sustainable development and education	Riandi et al. (2022)
7	Investigation into the performance of biodiesel	Setiyo et al. (2021)
8	Magnetic production of Fe3O4 nanoparticles	Nugraha and Nandiyanto (2022)
9	Energy management strategies that are optimized for electric vehicle applications:	Miah et al. (2021)
10	Using particle technology in research on computational fluid dynamics	Nandiyanto et al. (2023)
11	Utilizing technology to identify false news	Gunawan et al. (2022)
12	Applying artificial intelligence technologies to language instruction	Lubis et al. (2024)
13	Pretreatment of oil palm empty fruit bunch waste with ionic solutions based on benzotriazole to convert cellulose to glucose	Mudzakir et al. (2022)
14	Using camphor nanoparticles to improve the automobile radiator's heat transfer performance	Kolakoti et al. (2023)
15	Assessment of spatial vision skills for examining affecting factors and assessing differences	Yang et al. (2024)
16	Publishing of economic and technological education	Ragadhita and Nandiyanto (2022)
17	Learning STEM subjects with a basic spectrophotometer	Shidiq et al. (2021)
18	Photonic crystal (PHC)	Wiendartun et al. (2022)
19	Endurance-focused sports	Firdaus et al. (2023)
20	Bioenergy management	Soegoto et al. (2022)

Classifying Renewable Energy Resources

Renewable energy can be categorized according to its origin. Below are some of the primary types of renewable energy sources (Lund et al. 2015; Qazi et al. 2017):

(i) Biomass. Biomass refers to any organic material derived from plants, including algae, trees, and crops. The origins of biomass are varied, ranging from organic waste streams to agricultural and forestry residues, along with crops specifically grown for generating heat, fuels, and electricity (energy plantations)

(ii) Wind energy. Wind energy is the power produced by the movement of air in the Earth's atmosphere. Wind turbines are used to harness the power of the wind and convert it into electricity, making use of this sustainable energy source.

(iii) Hydropower. Hydropower is a type of sustainable energy produced from water movement, usually captured through turbines to change the potential energy of water into mechanical energy, which is later converted into electricity.

(iv) Solar energy. Solar energy is the energy obtained from the sun's radiation and can be utilized for activities like heating, producing electricity, and enabling chemical reactions.

(v) Ocean energy. Ocean energy involves harnessing power from various oceanic forces like waves, tides, salinity, temperature disparities in the sea, and geothermal energy. Geothermal energy is heat energy that is produced and kept underground in the Earth's crust. It is a sustainable source that can be utilized for a range of purposes, including warming buildings, producing power, and supplying heat for farming and industry.

Technology to Convert Renewable Energy

Converting renewable energy sources into usable energy forms like electricity, heat, or mechanical power is part of renewable energy technology conversions. Technologies for various forms of renewable energy exist, each converting energy from a natural source into a usable form (Ellabban et al. 2014). Listed below are the main categories of renewable energy technology conversions:

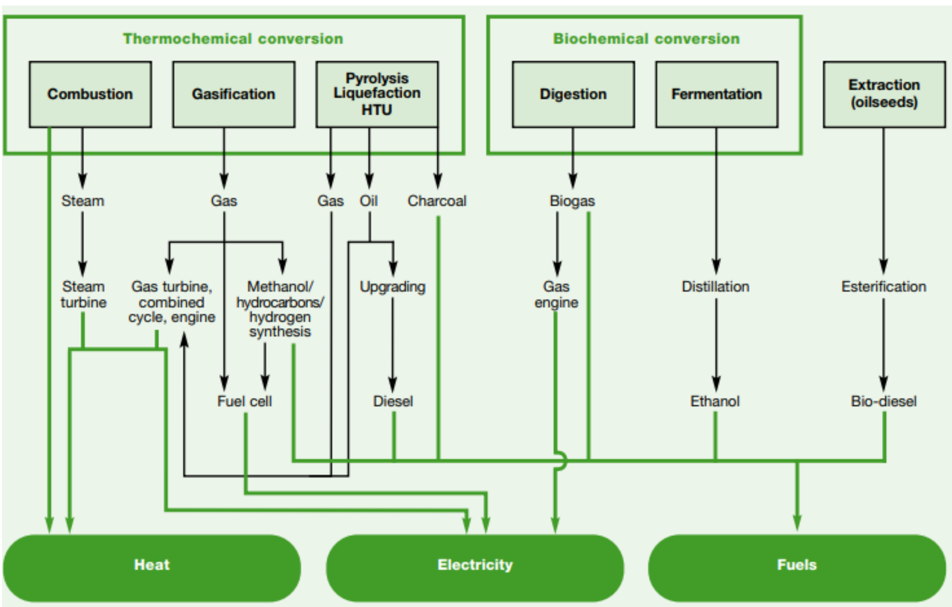

Figure 7: Key pathways for converting biomass into electricity adopted by Jha et al. (2022)

There are several methods of biomass conversion technology into energy:

(i) Conversion of Biomass Energy. Biomass energy systems produce heat, electricity, or biofuels from organic resources like wood, plants, organic waste, and agricultural residues (See **Figure 7**). Biomass combustion. Burning natural resources, such as wood, agricultural waste, or crop leftovers, to produce heat for heating or power generation is known as biomass combustion. In a boiler or furnace, biomass is burned to complete the combustion process. After that, water is heated using the generated heat to create steam. A turbine that is attached to an electric generator is then turned by the steam (Osman et al. 2023) (See **Figure 8**).

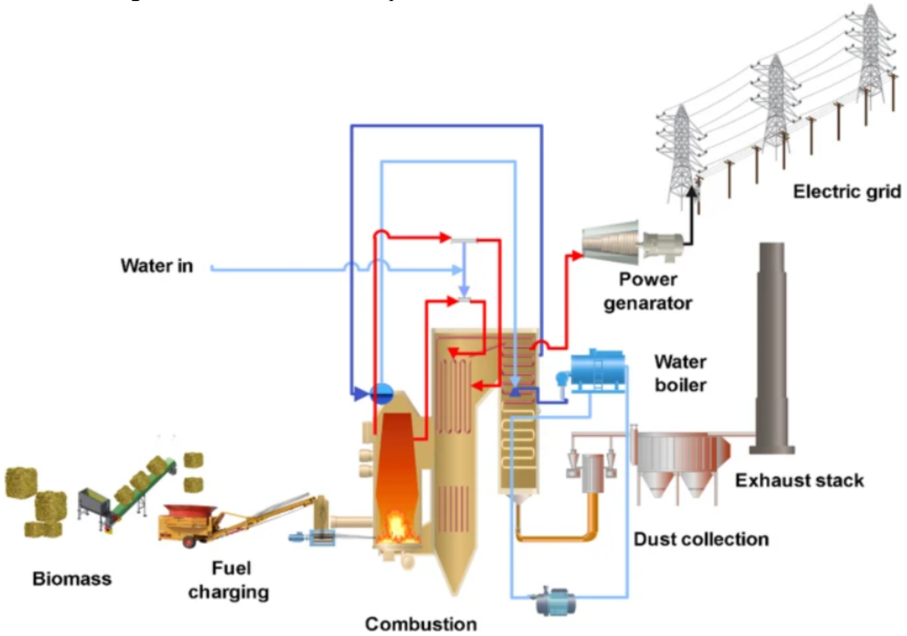

Figure 8: Biomass energy conversion using the direct combustion method adopted from Osman et al. (2023)

(ii) Biochemical. Biochemical processes are processes involving chemical reactions catalyzed by living organisms or enzymes to transform organic materials into energy that may be used, including biogas, bioethanol, and biodiesel. Biochemical processes generally utilize microorganisms or enzymes to break down biomass under certain conditions. The biochemical conversion process of biomass is carried out through the stages of enzymatic hydrolysis, fermentation, and anaerobic digestion. Carbohydrates are first broken down into simple sugars by enzymatic hydrolysis and pre-treatment of biomass. Microorganisms then convert these carbohydrates to create hydrogen (H_2), carbon dioxide (CO_2), and liquid biofuels or chemicals. Biomass can also undergo anaerobic digestion, producing biogas consisting of methane (CH_4) and CO_2, which is used as fuel. In addition, in the aerobic digestion process, biomass is further decomposed into CO_2 and organic matter that can be composted. For a variety of uses, this process generates renewable energy in the form of liquid biofuels, hydrogen, and biogas (Osman et al. 2021) (See **Figure 9**).

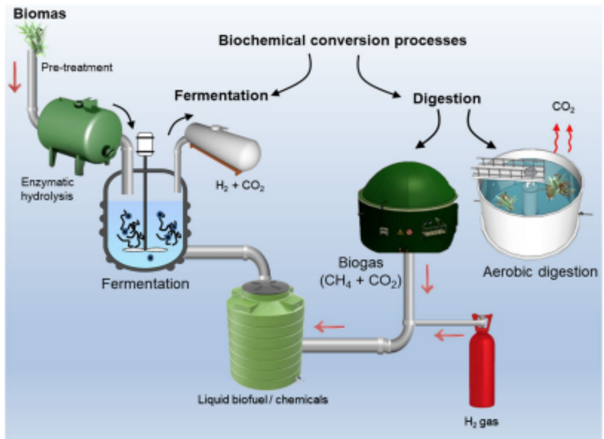

Figure 9: Biomass energy conversion using the biochemical method adopted by Osman et al. (2021)

(iii) Pyrolysis. By heating biomass or other organic materials to high temperatures without oxygen, a thermochemical process known as pyrolysis breaks them down. Pyrolysis produces three primary products: gas, liquid (bio-oil), and solid (char). The pyrolysis process is done by heating biomass at a high temperature (300–900 °C) without oxygen. Biomass is broken down into energy-rich gas, bio-oil (liquid), and biochar (charcoal). While biochar can be used as soil fertilizer or to improve soil fertility, bio-oil can be utilized as liquid fuel (Ighalo et al. 2022; Guran 2020) (See **Figure 10**).

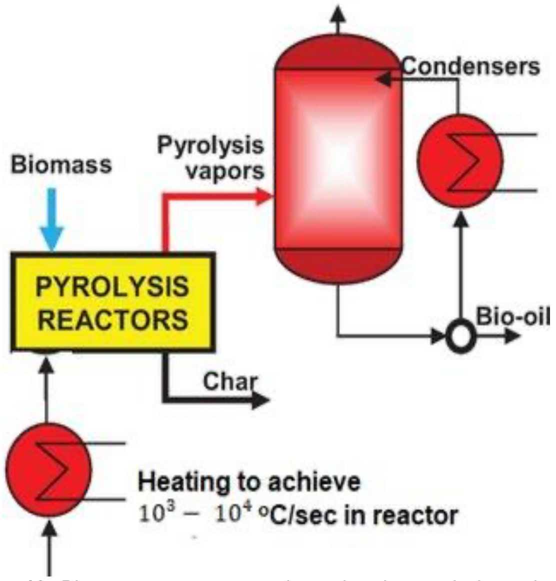

Figure 10: Biomass energy conversion using the pyrolysis method adopted by Ighalo et al. (2022)

(iv) Wind Energy Conversion. Wind energy conversion technology harnesses using wind turbines to harness the energy of the wind to create electricity. The kinetic energy of the wind that turns the turbine blades is captured by wind turbines. The generator then transforms this spin into mechanical energy, which is subsequently transformed into electrical energy. Depending on wind conditions and energy requirements, wind turbines can be positioned offshore or onshore. In **Figure 11**, a horizontal wind turbine, often known as a horizontal axis wind turbine or HAWT, from two perspectives, front and side, and its important parts. The turbine blades (rotor blades) function to capture wind energy and convert it into mechanical energy through rotation. The diameter of the rotor determines the amount of wind energy that can be captured, and the larger the diameter, the greater the energy potential. The tower (hub height) supports the rotor at a height so that it can capture stronger and more stable winds. The nacelle contains a gearbox and generator; the gearbox accelerates the rotor rotation to generate electricity. The electricity generated is channeled through underground cables to the power grid or energy storage facility (Aminzadeh et al. 2023; Rehman et al. 2023).

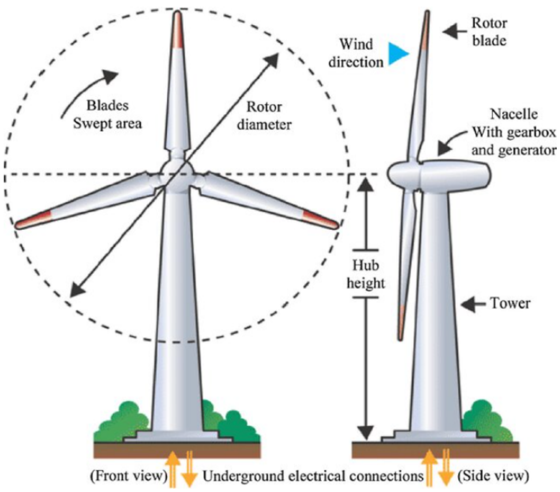

Figure 11: Wind energy conversion using a turbine adopted from Aminzadeh et al. (2023)

(v) Hydropower Conversion. Harvesting energy from falling water (from a higher height to a lower elevation) when it passes through an energy conversion equipment, like a water turbine or water wheel, is known as hydropower. After being transformed into mechanical energy by the water turbine, the mechanical energy is frequently transformed into electrical energy by a generator. Alternatively, by placing appropriate devices directly in the river, hydropower can also be generated from river currents. The equipment utilized in this instance is commonly referred to as "zero head" turbines or river or water current turbines (see **Figure 12**) (Reigstad and Uhien 2019).

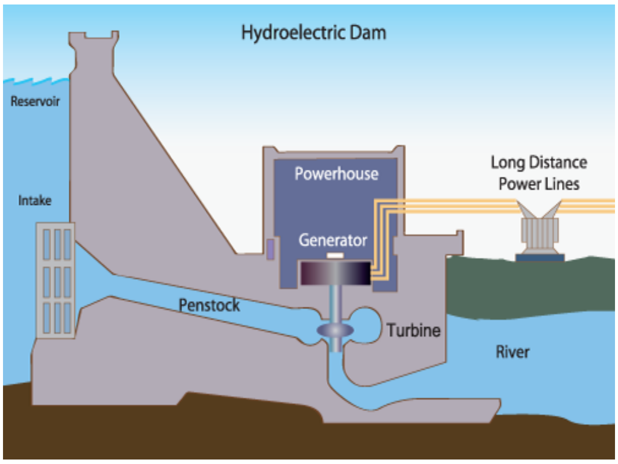

Figure 12: Hydropower conversion was adopted by Reigstad and Uhien (2019)

(vi) Solar Energy Conversion. Solar energy technologies transform sunlight into thermal energy or electrical energy. Two primary categories of solar conversion technologies (Aslam et al. 2022; Amuzuvi and Effah 2014): Solar thermal energy and photovoltaic (PV) power. Relating to PV solar power, Solar cells, often known as photovoltaic panels, transform sunlight directly into electricity through the photovoltaic effect, where light excites electrons in the material, generating an electric current (**Figure 13**). Relating to solar thermal energy, such as solar water heaters or CSP stands for concentrated solar power systems, it converts sunlight into heat. Through the use of mirrors or lenses, CSP directs sunlight into a tiny area, creating high temperatures that can be converted into steam for the production of electricity (**Figure 14**) (Amuzuvi and Effah 2014).

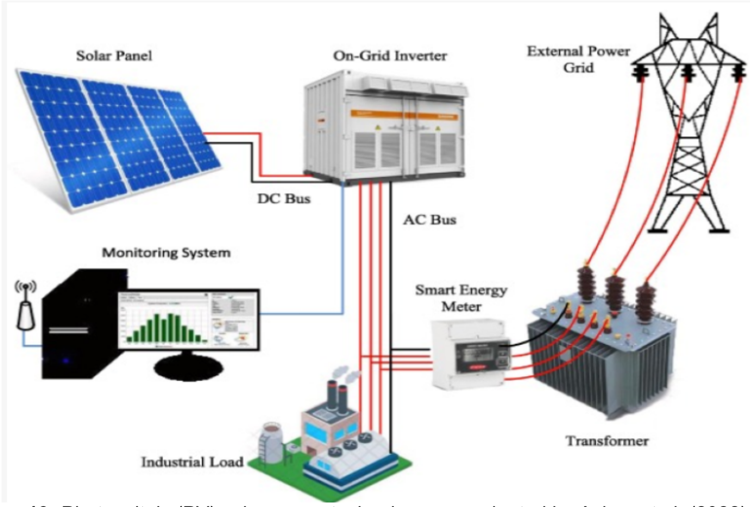

Figure 13: Photovoltaic (PV) solar power technology was adopted by Aslam et al. (2022)

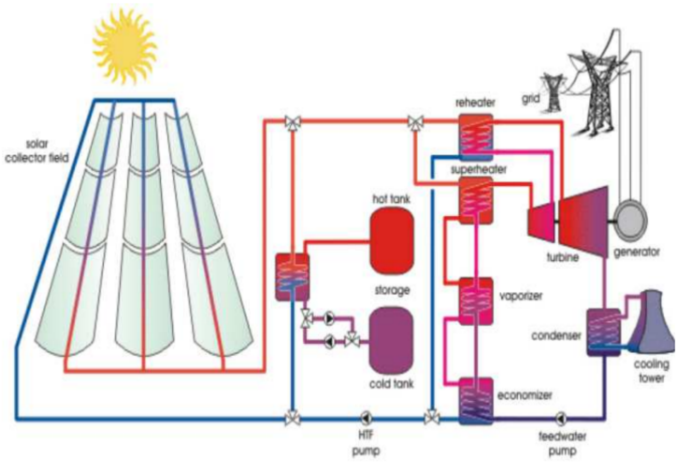

Figure 14: Photovoltaic (PV) solar power technology adopted from Amuzuvi and Effah (2014)

(vii) Ocean Energy Conversion. Ocean energy technologies convert the power of ocean waves, tides, and thermal gradients into electricity or other forms of usable energy. There are generally two types of ocean energy conversion technologies (See **Figure 15**) (Sheng 2019; Faizal and Rafiuddin Ahmed 2011)

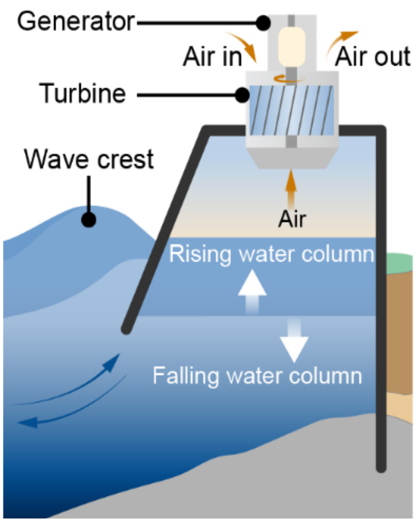

Figure 15: Wave energy conversion was adopted by Sheng (2019)

(viii)Ocean Thermal Energy Conversion (OTEC) and Wave Energy. Ocean surface waves' kinetic energy is captured using wave energy converters. Attenuators, oscillating water columns, and point absorbers are some of the devices that transform this energy into electricity (Sheng 2019) (see Figure 9). With regard to OTEC, systems use the temperature differential between the ocean's warm surface water and cold deep water to produce power. A working fluid is vaporized by this temperature differential, powering a turbine that is attached to a generator (See **Figure 16**) (Faizal and Rafiuddin Ahmed 2011).

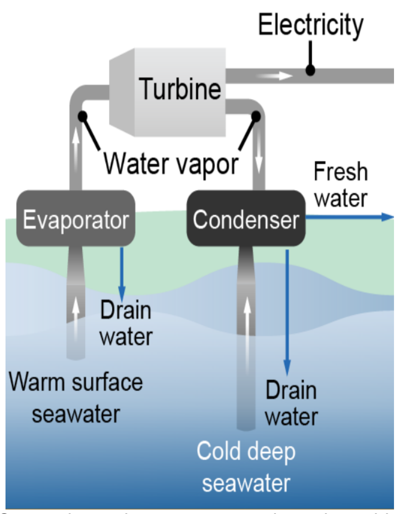

Figure 16: Ocean thermal energy conversion adopted by Faizal and Rafiuddin Ahmed (2011)

(ix) Conversion of Geothermal Energy. Utilizing heat from the earth, geothermal energy technology transforms it into thermal energy or electricity. Heat from subterranean hot water or steam reservoirs is used in geothermal power plants. To generate energy, the steam powers a turbine that is connected to a generator (**Figures 17(a-c)**) (Kumar et al. 2020; Anderson and Rezale 2019).

A summary of the different kinds of sustainable energy technology conversions, lengthy with their processes and energy sources, has been systematically compiled and presented in **Table 3**, including information on each technology, such as the conversion mechanism, the resources used, and the benefits generated, thus facilitating understanding and comparison between technologies**.**

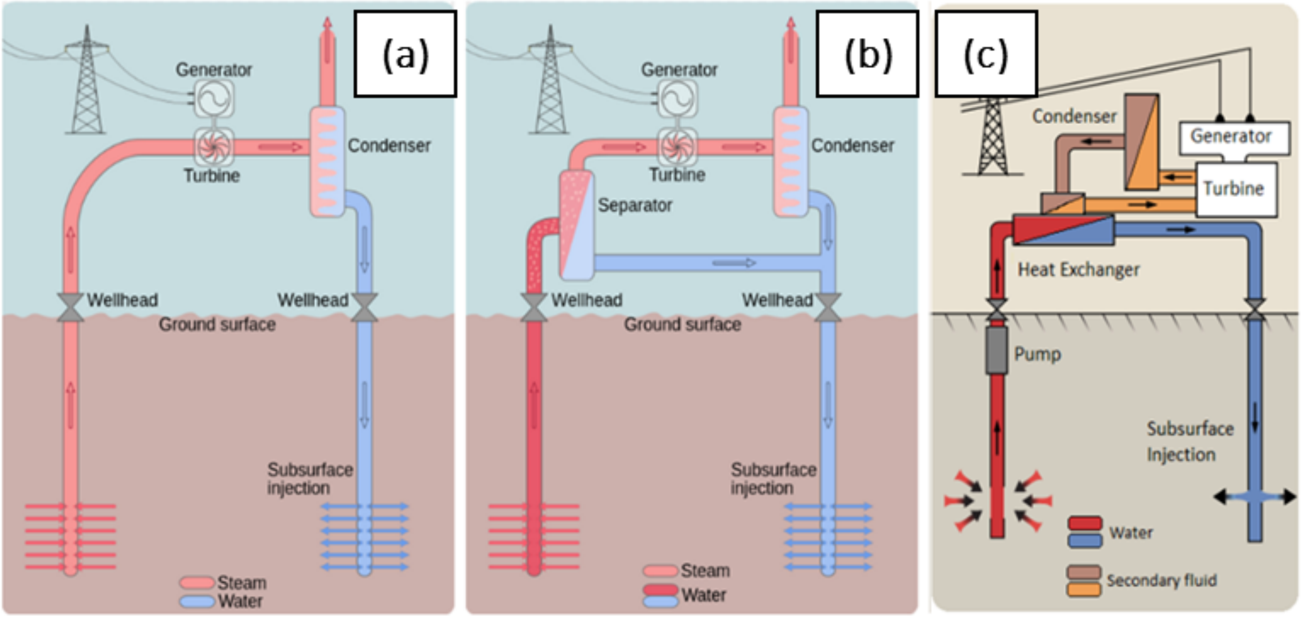

Figure 17: Types of geothermal energy conversion include the dry steam cycle (a), the flash steam cycle (b), and the binary cycle (c) adopted by Kumar et al. (2020)

Table 3: Conversion types for renewable energy technologies

Technology	Energy Product	Application
Biomass • Domestic scale combustion on an industrial scale, combustion • Gasification and power generation • Gasification and the creation of fuel both fermentation and hydrolysis • The process of pyrolysis and liquid fuel production	• Heat (for cooking and space heating) • Heat (CHP), steam, electricity, and processes. • Methanol, hydrocarbons, H_2 ethanol, and bio-oils • Charcoal	• Broadly used; enhanced technology accessible; broad use; room for advancement • Development phase • Commercially used for starch and sugar crops; wood production is being developed phase of pilot; • A few technical obstacles are broadly used; a variety of efficiency • Commercially applied; applied; reasonably priced
Wind energy • Battery charging and water pumping; • Onshore and offshore wind turbines	• Power electricity motion	• The development and demonstration phase; small wind machines; broad commercial use;
Solar energy • Photovoltaic conversion of solar energy • Thermal power from the sun • Use of solar energy at low temperatures. Use of passive solar energy: Man-made photosynthesis	• Energy sources include electricity, heat, and steam. • Heating (water and space heating, cooking, drying) and cooling, Heating, cooling, lighting, and ventilation • H_2 or hydrogen-rich fuels.	• Widely applied; rather expensive; further development needed • Demonstrated; further development needed • Solar collectors are commercially applied; solar cookers are widely applied in some regions; solar drying is demonstrated and applied
Hydropower		

Technology	Energy Product	Application
	• Electricity, Energy, and Power	• Small- and large-scale commercial applications
Geothermal energy	• Steam, heat, and electricity	• Used in a commercial setting
Ocean energy • Wave energy, tidal energy, and current energy • Conversion of ocean thermal energy • The gradient of salinity and osmotic energy • Production of marine biomass	• Energy, Heat, and Fuels	• Applied; comparatively costly • Phases of research and development, as well as demonstration • Option in theory, Investigation, and advancement

Benefits of Renewable Energy and Technology Innovation

Renewable energy and technological innovation offer many benefits across various elements, such as technological, environmental, economic, and social, as well as in education and public awareness. Here is a complete discussion of the benefits of renewable energy and technology from various perspectives (Raihan et al. 2024): environmental, economic, social, technological, as well as education and public awareness aspects. Relating to environmental aspects, they include:

(i) Renewable energy provides many benefits to the environment in a sustainable manner, reducing the negative impacts usually caused by fossil-based energy sources.

(ii) Lower greenhouse gas emissions using solar and other renewable energy methods, wind, and hydropower do not produce carbon emissions during energy production, reducing their contribution to global warming and climate change.

(iii) Reduce Air Pollution: Renewable energy does not release air contaminants like fine particulate matter, nitrogen oxides, and sulfur dioxide (SO_2) (PM2.5), which are often the main causes of health and environmental problems.

(iv) Conserve Water Resources: Renewable energy technologies, especially wind and solar, do not require the use of large amounts of water, thus helping to conserve precious water resources.

(v) Reduce Waste: Technologies such as biomass and biogas allow the application of organic waste for energy production, reducing the accumulation of waste that pollutes the environment.

(vi) Protect biodiversity: Renewable energy does not require large-scale extraction such as fossil fuel mining, which often destroys endangered biodiversity and natural habitat.

Regarding the financial side of things, using renewable energy brings advantages in the short and long terms, such as:

(i) Creating New Jobs: The renewable energy sector creates many jobs in areas such as manufacturing, installation, maintenance, and research and development. For example, solar and wind power are sectors with rapid job growth.

(ii) Reducing Fossil fuel dependency: Countries can lessen their reliance on importing fossil fuels by using renewable energy, thereby reducing the risk of volatile energy prices and energy crises.

(iii) Long-Term Cost Savings: After the initial investment, the operating Generally speaking, renewable technologies are less expensive than fossil fuels, because they do not require continuous fuel.

(iv) Economic Diversification: By developing renewable energy, countries can diversify their economies and reduce the risk of dependence on a single energy source or industry.

(v) Technological Innovation: The advancement of technologies for renewable energy spurs innovation, which can create new products and services and strengthen global economic competitiveness.

Relating to social aspects, renewable energy technologies have positive impacts on society from a variety of social perspectives, including health and energy access including:

(i) Improvement of Health Public: By lowering air pollution, renewable energy contributes to a decrease in the prevalence of pollution-related respiratory and cardiovascular disorders.

(ii) Improve Quality of Life: Renewable energy helps create a cleaner and healthier environment, which has a favorable effect on people's quality of life, particularly in crowded cities.

(iii) Provide Energy Access in Remote Areas: In remote locations, renewable energy sources like solar and wind can be installed that are not covered by the conventional electricity grid, providing electricity access to communities that previously did not have access.

(iv) Promote Energy Equity: With more widely accessible technologies and lower energy costs in the long term, renewable energy can help close the energy gap between developed and developing countries.

(v) Improve local energy resilience: Local energy production with renewable technologies can reduce communities' vulnerability to energy supply disruptions and natural disasters.

Relating to technological aspects, sustainable energy is a major factor in the advancement of more environmentally friendly and efficient technologies, including:

(i) Driving Innovation in Energy Storage: The advancement of sustainable energy has driven research in the energy storage field, like batteries made of lithium-ion and hydrogen-based energy storage systems, which allow renewable energy to be used during times of low production (for example, at night for solar power).

(ii) Smart Grid Technology: Renewable energy is driving the development of smart grid technology, which allows for more efficient energy distribution, reduces waste, and increases the reliability of electricity supply.

(iii) Green Building Technology Development: Renewable energy, especially solar power, can be combined with environmentally friendly building design to create a more energy-independent system, reducing the need for external energy.

Relating to the education and public awareness aspect, renewable energy also has a positive impact on public education and environmental awareness, including:

(i) Increasing Environmental Awareness: Utilizing renewable energy raises public understanding of the value of environmental preservation and lessens the harmful effects of using fossil fuels for energy.

(ii) Inspiring the Younger Generation: STEM (science, technology, engineering, and mathematics) education opportunities made possible by renewable energy technologies can inspire the future generation to pursue careers in the clean energy and green technology industries.

Sustainability Development Goals (SDGs)

SDGs are a group of 17 worldwide targets agreed upon by the United Nations (UN) in 2015. The SDGs are an integral part of the 2030 Agenda, which aims to encourage the development of sustainable development. These objectives are designed to address pressing global challenges with a comprehensive approach, integrating economic, social, environmental, and institutional dimensions (Maryanti et al. 2022; Allen et al. 2018). Specifically, the SDGs goals include (See **Figure 18):**

(i) End Poverty: Reduce the number of people living in poverty worldwide, with a focus on inclusive economic and social empowerment.

(ii) End Hunger: Improve global food security and nutrition, ensuring adequate access to wholesome, safe food.

(iii) Promoting health and well-being includes lowering maternal and infant mortality, increasing access to high-quality healthcare, and improving people's health.

(iv) High-quality education: provide inclusive, equitable, and high-quality education and encourage opportunities for lifelong learning for everyone.

(v) Equality of Gender: Address prejudice and injustice based on gender to empower all women and girls.

(vi) Accessible and sustainable sources of clean water and proper sanitation should be made available to everyone.

(vii) Access to clean, affordable, and dependable energy should be expanded, and the switch to renewable energy should be encouraged.

(viii) Fair Employment and Economic Development: Encourage equitable and sustainable economic development and establish fair employment for all.

(ix) Infrastructure, Industry, and Innovation: Describe sustainable infrastructure, encourage innovation, and strengthen industrial capacity to promote equitable growth.

(x) Less Inequality: Strengthen social and economic inclusion for all people and lessen inequality both within and between nations.

(xi) Sustainable Urban Areas and Human Communities: Construct safe, welcoming, and sustainable cities and human settlements, paying particular emphasis to quality of life and infrastructure.

(xii) Conscientious Consumption and Production: Encourage resource efficiency, lessen environmental effects, and advocate for sustainable patterns of consumption and production.

(xiii) Climate Action: Take measures to mitigate the effects of climate change, such as cutting greenhouse gas emissions and boosting climate change resistance.

(xiv) Life Below Water: Protect marine ecosystems and aquatic resources by safeguarding biodiversity and combating marine pollution.

(xv) Terrestrial Life: To sustain life on Earth, preserve and rebuild terrestrial ecosystems, and manage natural resources responsibly.

(xvi) Sturdy Institutions, Justice, and Peace: Establish inclusive, peaceful societies, guarantee justice, and fortify efficient, answerable, and open institutions.

(xvii) Partnership for the Goals: Strengthen the global partnership for SDGs, support international cooperation in achieving the SDGs, and mobilize resources.

Many reports relating to SDGs have been well-documented (see **Table 4**). Through the achievement of these goals, a more equitable, sustainable, and wealthy world is what the SDGs want to achieve. Cooperation between nations, the private sector, civil society, and individuals is essential to realize this global vision and address the challenges of the contemporary era.

Figure 18: 17 items of the SDG mission

Table 4: Previous studies relating to SDGs

No	Title	Ref
1	Low-carbon food consumption for solving climate change mitigation: Literature review with bibliometric and simple calculation application for cultivating sustainability consciousness in facing sustainable development goals (SDGs)	Nurramadhani et al. (2024)
2	Towards sustainable wind energy: A systematic review of airfoil and blade technologies over the past 25 years for supporting sustainable development goals (SDGs).	Krishnan et al. (2024)
3	Assessment of student awareness and application of eco-friendly curriculum and technologies in Indonesian higher education for supporting sustainable development goals (SDGs): A case study on environmental challenges	Djirong et al. (2024)
4	Effect of substrate and water on cultivation of Sumba seaworm (nyale) and experimental practicum design for improving critical and creative thinking skills of prospective science teacher in biology and supporting sustainable development goals (SDGs)	Kerans et al. (2024)
5	Smart learning as transformative impact of technology: A paradigm for accomplishing sustainable development goals (SDGs) in education	Makinde et al. (2024)
6	The relationship of vocational education skills in agribusiness processing agricultural products in achieving sustainable development goals (SDGs)	Gemil et al. (2024)
7	The influence of environmentally friendly packaging on consumer interest in implementing zero waste in the food industry to meet sustainable development goals (SDGs) needs	Haq et al. (2024)
8	Sustainable packaging: Bioplastics as a low-carbon future step for the sustainable development goals (SDGs)	Basnur et al. (2024)
9	Implementation of Sustainable Development Goals (SDGs) No. 12: Responsible production and consumption by optimizing lemon commodities and community empowerment to reduce household waste	Maulana et al. (2023)
10	Analysis of the application of Mediterranean diet patterns on sustainability to support the achievement of sustainable development goals (SDGs): Zero hunger, good health and well beings, responsible consumption, and production	Nurnabila et al. (2023)
11	Efforts to improve sustainable development goals (SDGs) through education on diversification of food using infographic: Animal and vegetable protein	Awalussillmi et al. (2023)
12	Safe food treatment technology: The key to realizing the Sustainable Development Goals (SDGs) zero hunger and optimal health	Rahmah et al. (2024)
13	Analysis of student's awareness of sustainable diet in reducing carbon footprint to support Sustainable Development Goals (SDGs) 2030	Keisyafa et al. (2024)
14	Sustainable development goals (SDGs) in science education: Definition, literature review, and bibliometric analysis	Maryanti et al. (2022)

Alignment of Renewable Energy and Technologies with SDGs

Alignment with the goals for SDGs is critical to ensuring that renewable energy and technology aid in the accomplishment of global objectives set by the United Nations. Renewable energy and technology support SDG 7, "Clean and Inexpensive Energy," by providing environmentally friendly and sustainable sources of energy and reducing dependence on polluting fossil fuels. In addition, innovation in renewable technologies contributes to SDG 9, "Industry, Innovation, and Infrastructure," by driving progress in energy efficiency and infrastructure development that supports industrial sustainability (Hernandez et al. 2020). These efforts are also aligned with SDG 13, "Addressing Climate Change," as renewable energy helps lessen the harmful effects of climate change and greenhouse gas emissions. On the other hand, the application of renewable energy technologies supports SDG 11, "Sustainable Cities and Human Settlements," by providing environmentally friendly energy solutions for urban infrastructure and buildings, and helps achieve "Responsible Consumption and Production," SDG 12, by encouraging more effective and sustainable consumption and production patterns. By ensuring that projects and policies related to renewable energy and technology are aligned with these SDGs, we can maximize benefits for people and the environment and help achieve a more inclusive and sustainable future (Esiri et al. 2024).

Innovation Technologies in Renewable Energy to Support SDGs

To optimize the potential of renewable energy resources (RES), technological innovations are needed that can increase efficiency, overcome energy storage challenges, and ensure fair and transparent energy distribution. Along with rapid developments in various technological fields, several significant breakthroughs have directly contributed to the use of additional efficient and reliable sustainable energy. Currently, artificial intelligence (AI) technology plays an important role in energy management by optimizing energy use in real-time through analysis of consumption patterns and prediction of energy needs. This allows for higher efficiency, especially in volatile sustainable energy sources like wind and solar power (Ahmad et al. 2021). In addition, the Internet of Things (IoT) allows devices to be connected to monitor and control energy use more effectively. IoT sensors can be placed on sustainable energy infrastructure such as solar panels or wind turbines to monitor performance and detect problems early on, thereby increasing efficiency and reducing operational disruptions. Blockchain is also one of the promising technologies in decentralized energy by offering transparency and security in energy transactions. This technology allows consumers and producers of renewable energy, such as households with solar panels, to sell and buy energy through a secure and efficient platform (Kumar et al. 2020; Casquico et al. 2021). Furthermore, energy storage technology continues to advance, with innovations such as solid-state and flow batteries offering greater storage capacity, greater durability, and improved efficiency. These storage technologies are essential to addressing the challenges of storing energy from intermittent renewable sources, such as solar power, which is only available during the day. In solar power, innovations such as perovskite-based solar cells enable higher energy conversion efficiency, allowing more energy to be generated at a lower cost (Fagiolari and Bella 2019). Meanwhile, smart wind turbines equipped with sensors and AI technology can automatically adjust blade angles to maximize energy output, making them more efficient and reliable. The potential is provided by the creation of novel materials like graphene and nanomaterials offer the potential to improve energy storage and conversion performance, extend the useful life of energy, and lower production costs (Olabi et al. 2021).

Role of Renewable Energy and Technology Innovation on SDGs

Innovation in technology and sustainable energy is essential to reaching the SDGs established by the United Nations (UN). Sustainable energy, such as solar, wind, and biomass, directly contributes to SDG 7, "Clean and Inexpensive Energy," by providing an eco-friendly energy source and lowering reliance on fossil fuels, which have detrimental effects on the environment and human health. Additionally, using renewable energy lowers greenhouse gas emissions, which advances SDG 13, "Climate Action," an international initiative to lessen the effects of climate change and halt global warming (Gielen et al. 2019). The creation and implementation of new technologies for the generation, storage, and use of renewable energy is an example of technological innovation, which advances SDG 9, "Industry, Innovation, and Infrastructure." Innovative technologies enable higher efficiency and lower costs in renewable energy production and facilitate improvements in infrastructure that support industrial and economic sustainability. In addition, new technologies also contribute to enhancing energy quality and accessibility, particularly in underprivileged areas, in keeping to achieve SDG 11, "Sustainable Cities and Human Settlements," by promoting the development of environmentally friendly and sustainable infrastructure in cities and human settlements (Dzhunushalieva and Teuber 2024).

In addition, the application of renewable technologies and innovation in resource management supports waste reduction and resource efficiency promotion, SDG 12, "Responsible Consumption and Production,". Renewable technologies also support "Decent Work and Economic Growth," SDG 8, by developing new jobs in the green energy sector and related industries. Through the application of innovative and sustainable technologies, we can achieve significant progress in various aspects of development, ensuring that economic growth and social progress do not come at the expense of the health of our planet. Thus, renewable energy and technological innovation play a critical part in making sure that the SDGs are achieved effectively and sustainably (Dantas et al. 2021).

The Impact of Renewable Energy and Technological Innovation on the SDGs

Sustainable energy and technological innovation have a profound and far-reaching impact on achieving the SDGs, which are intended to solve a variety of global concerns. Reliance on fossil fuels, which are recognized to be harmful to the environment and human health, must be reduced to use renewable energy sources like solar, wind, and hydropower. By providing a clean and environmentally friendly energy alternative, renewable energy directly contributes to SDG 7, "Clean and Affordable Energy." It makes energy more accessible to people, including in remote and less developed areas that previously lacked access to conventional energy sources. By reducing reliance on fossil fuels, renewable energy also helps reduce greenhouse gas emissions, supporting SDG 13, "Climate Action." These reduced emissions play a critical role in mitigating the impacts of climate change, slowing global warming, and creating a more wholesome environment for coming generations (Olabi et al. 2023).

Technology innovation has a big influence on SDG 9, "Industry, Innovation, and Infrastructure," especially when it comes to renewable energy." New technologies in energy storage, such as more efficient and high-capacity batteries and intelligent management systems, are improving the efficiency of renewable energy production and distribution. These advances not only reduce costs but also strengthen sustainable energy infrastructure, facilitate incorporating renewable energy sources into current electrical systems, and increase capacity to meet growing energy demand. In addition, technological innovation supports the development of smarter and more cost-effective solutions, contributing to more innovative and sustainable industrial development (Georgious et al. 2021)

At the urban level, renewable energy and innovative technologies support SDG 11, "Sustainable Cities and Human Settlements," by offering clean energy solutions that reduce air pollution and the detrimental effects on the environment of industrial and transport activities. The use of smart technologies in energy management and urban infrastructure helps reduce energy consumption and improve the quality of life, making cities greener and more efficient.

The application of environmentally friendly technologies also supports SDG 12, "Responsible Consumption and Production." By reducing waste and increasing the efficiency of resource use, renewable technologies contribute to more sustainable consumption patterns. This includes better management of resources and the adoption of production practices that reduce environmental impacts. Another positive impact is employment growth in the green energy industry, which advances SDG 8: "Decent Work and Economic Growth." Jobs generated in this industry create new economic opportunities, encourage the emergence of more prosperous communities, and support equitable and sustainable economic growth (Al-Shetwi 2022).

Challenge and Future Direction

Renewable energy development and technological innovation face several challenges that need to be addressed to achieve the SDGs effectively. The high initial cost of putting renewable energy technology like solar panels, wind turbines, and energy storage devices into place is one of the biggest obstacles. Despite lower long-term operational costs, many developing countries still face financial constraints to widely adopt these technologies. In addition, inadequate infrastructure in some areas, especially in remote or less developed areas, slows down the adoption of renewable energy technologies. Other challenges include the need for further research and development to improve technology efficiency, energy storage capacity, and the incorporation of renewable energy sources into current electrical systems. The future direction of renewable energy development and technological innovation shows very positive prospects. The development of energy storage technologies, such as more efficient and high-capacity batteries, is a major focus to ensure stable energy supply from inconsistent sources such as solar and wind. Improvements in smart grid technologies are also helping to minimize energy waste and maximize the spread of renewable energy. In addition, global collaboration on international policies and financing is needed to accelerate the transition to renewable energy, especially in countries with limited resources. Governments, the private sector, and the international community need to work together to create policies that support technological innovation, including incentives for investment in clean energy. The future direction also emphasizes the importance of educating and raising public awareness of the benefits and desirability of renewable energy. By increasing public awareness and community involvement in the use of cleaner and more efficient energy, the transition to a more sustainable energy system will be easier to achieve.

CONCLUSION

The bibliometric analysis shows that renewable energy and technological innovations play a pivotal role in achieving the SDGs, especially in the areas of climate action (SDG 13), cheap renewable energy (SDG 7), and sustainable cities (SDG 11). The analysis results demonstrate a significant increase in scientific publications from 2014 to 2023, peaking in 2023, which indicates a heightened focus on renewable energy and technological innovation. Technologies such as IoT and AI are instrumental in improving energy efficiency by enabling Monitoring, predicting, and optimizing sustainable energy systems in real time. China leads the research output, reflecting significant global interest in this field. Future efforts must focus on overcoming challenges such as high implementation costs and infrastructure limitations, while fostering international collaboration and public awareness. Advancements in energy storage, smart grids, and innovative technologies like AI and IoT are crucial to accelerating the transition to a sustainable energy system. This study lays the groundwork for next research and policy development aimed at integrating renewable energy solutions with global sustainability efforts.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

CONTRIBUTIONS OF INDIVIDUAL AUTHORS

M. Fiandini is mainly doing experiments and writing the first draft. A.B.D. Nandiyanto is the main contributor, supporting grant, and editing final manuscript. RR. Agustin are supporting and give advices for this research.

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