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Renewable Energy Application Research Using VOSviewer software: Bibliometric Analysis

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Abstract
This study analyzes renewable energy and clean technology research trends through a bibliometric approach. The visualization results show that hydrogen and fuel topics dominate the literature, focusing on green hydrogen technology and fuel cells. Catalyst and stability topics are also frequently discussed, emphasizing the importance of developing materials to support the stability of hydrogen energy systems. In addition, biomass is a crucial concern in renewable energy research. The findings from the table reveal that energy systems and models have strong links with other topics, such as networks and supply, indicating a focus on developing integrated energy systems and smart grids. In conclusion, hydrogen technology, biomass conversion, and material innovation play a crucial role in the transition to clean and sustainable energy, although challenges related to stability and cost remain.

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1. Introduction
Renewable energy and clean technologies are increasingly becoming a significant focus in global efforts to address the climate crisis and transition towards sustainability. Conventional fossil-based energy sources are limited in quantity and contribute significantly to greenhouse gas emissions and global warming. Therefore, innovations in renewable energy technologies, such as green hydrogen, biomass, and solar energy, are becoming increasingly important. Scientific research in this field continues to grow, producing significant findings that play a role in creating solutions for cleaner and more sustainable energy. One prominent topic in renewable energy research is hydrogen, primarily green hydrogen, produced without carbon emissions (Balci & Erbay, 2024; Erdiwansyah, Mahidin, et al., 2019; Erdiwansyah, Mamat, Sani, & Sudhakar, 2019; Hassan, Al-Jiboory, et al., 2024; Hosseini & Wahid, 2016). Hydrogen has long been recognized as a potential energy source that can replace fossil fuels, especially in industrial and transportation applications. However, hydrogen production, storage, and stability remain significant challenges that must be overcome (Ahmad et al., 2024; Bade, Tomomewo, Meenakshisundaram, Ferron, & Oni, 2024; Hamlehdar, Beardsmore, & Narsilio, 2024; Irhamni, Kurnianingtyas, Muhtadin, Bahagia, & Yusop, 2025; Ishaq, Dincer, & Crawford, 2022). In this study, bibliometric visualization shows that the topics of hydrogen

and fuel are the most frequently mentioned in the literature, indicating the high attention of researchers to hydrogen-based technologies.

In addition to hydrogen, another topic widely discussed in the renewable energy literature is biomass (Cao et al., 2020; Kumar, Daw, & Milstein, 2021; Mahinpey, Abdalla, & Farooqui, 2024; Selvakumar, Gani, Xiaoxia, & Salleh, 2025). Biomass offers excellent potential as a renewable energy source due to its abundant availability and ability to be converted into energy through various conversion processes (Al-Hamamre et al., 2017; Erdiwansyah et al., 2022; Nassar et al., 2024). Research related to biomass conversion and the development of supporting materials for this conversion, such as catalysts, continues to grow. In this context, the bibliometric analysis also highlights the importance of biomass and conversion in the literature, indicating that biomass is one of the main topics in the discussion of renewable energy (Efremov & Kumarasamy, 2025; Elgarahy et al., 2021; Knapczyk, Francik, Jewiarz, Zawiślak, & Francik, 2020; Ranjbari et al., 2022). In addition to specific topics, the importance of developing integrated energy systems is also evident in the literature. The topic of energy systems and models has a robust relationship with other topics, such as networks and supply, indicating that developing efficient energy system models is essential to support integrating renewable energy into the existing energy network (Bamisile et al., 2024; Gani et al., 2023; Infield & Freris, 2020; Messini, Bourek, Ammari, & Pesyridis, 2024). This is important to ensure reliable and efficient energy distribution, especially with the increasing contribution of renewable energy such as solar and wind energy.

Although significant progress has been made in developing renewable energy technologies, there are still several challenges to overcome, primarily related to the cost and stability of these technologies. For example, green hydrogen production and fuel cell development require expensive catalysts and materials with high stability to ensure long-term efficiency (Alinejad, Parham, Tawalbeh, Al-Othman, & Almomani, 2024; Hassan, Algburi, Sameen, Salman, & Jaszczur, 2024; Hoseinpour et al., 2024). These challenges are reflected in the high frequency of topics such as catalysts and stability in the literature, indicating that developing new materials to improve the strength and lower the cost of hydrogen technologies is a research focus (Fan, Tu, & Chan, 2021; Gu, Liu, Wang, & Zheng, 2024; Li, Ikram, & Xiaoxia, 2025; Shaker et al., 2024). Overall, current research in renewable energy focuses on green hydrogen, biomass conversion, and the development of integrated and efficient energy systems. While these technologies offer great potential to reduce carbon emissions and improve sustainability, challenges related to technology stability and implementation costs remain significant obstacles to overcome. Therefore, further research and technological innovation are essential to ensuring an effective and sustainable global energy transition.

This study aims to identify critical trends and interrelationships of research topics in renewable energy and clean technologies through bibliometric analysis. This study uses keyword network visualization to reveal the most frequently discussed topics, such as green hydrogen, biomass conversion, and energy material stability. The novelty of this study lies in the in-depth analysis of the interrelationships between topics, which allows the mapping of future research directions and priority areas that require further attention, such as challenges of technology stability and cost efficiency. The results of this study provide important insights for researchers and policymakers to direct more focused investments and research efforts in supporting the global energy transition towards cleaner and more sustainable energy sources. Although previous bibliometric studies have explored renewable energy research trends, most of them focused on individual topics, such as hydrogen or biomass, without providing a comprehensive analysis of the relationships between topics and future research directions. In addition, previous studies often did not consider the technological stability and cost challenges in clean energy development. This study offers a new perspective by combining keyword network analysis using VOSviewer to map the interrelationships between key topics, such as hydrogen, biomass, material stability, and integrated energy systems. With this approach, this study not only

identifies key trends but also provides insights into areas that still need further exploration to support sustainable energy transitions more effectively.

2. Methodology

This study uses bibliometric methods to analyze trends and relationships among topics in renewable energy and clean technology research. The analysis was conducted using VOSviewer software, which allows the visualization of keyword networks based on data from the latest scientific publications. The data used includes literature from various scientific journals related to renewable energy topics, such as hydrogen, biomass, alternative fuels, and supporting materials for energy technology. The first step in this study is data collection through relevant scientific databases. Keywords related to renewable energy, green technology, and energy material development are used to extract relevant publications. After data collection, keywords are extracted from each article to identify frequently discussed topics. The next step is keyword network analysis using VOSviewer. Each keyword in the publication is mapped as a node, while the connecting lines between nodes indicate the relationship between the topics.

The strength of the relationship is calculated based on the frequency of co-occurrence of the keywords in the same publication. Nodes with strong and frequently occurring relationships are grouped into clusters that indicate similar research focuses. This visualization provides a better understanding of the most discussed research topics and their relationships. In addition, a temporal analysis is performed to see how research trends evolve, using the colors of the nodes to reflect the period of their appearance in the literature. This study also analyses quantitatively by calculating links, total link strength, and occurrences for each keyword. Links represent the number of relationships between a topic and other topics. Total link strength indicates the strength of the relationship between the topic and other topics. In contrast, occurrences indicate the frequency of occurrence of a topic in the dataset. Through this approach, the study identified essential topics in the spotlight and areas requiring further research.

In this study, bibliometric data were collected from the Scopus and Web of Science databases, which were selected for their extensive coverage of reputable scientific publications. The time span analyzed spans from 2015 to 2024, to capture the latest trends in renewable energy research. Articles included in the analysis were selected based on a combination of keywords such as "renewable energy", "hydrogen technology", "biomass conversion", and "energy system modeling". To ensure relevance, only journal articles and conference papers published in English and with complete abstracts and metadata were included. Studies focusing on non-technical aspects, such as policy or socioeconomics without direct relevance to energy technology development, were excluded. The screening process was carried out in two stages: first, automatic screening based on keywords and journal categories, followed by manual review to ensure the topic's suitability to the scope of this study. With these criteria, this study ensures a more focused and reproducible analysis by other researchers in the future.

3. Result & Discussion

Fig. 1 is a visualization of a thematic map network based on keywords generated by VOSviewer, a software often used for bibliometric analysis. This visualization illustrates the relationship between topics or keywords related to each other in a data corpus, such as scientific publications. Each node (circle) in this map represents a specific keyword or term. In contrast, the connecting lines between nodes indicate the relationship or connection between the topics based on the level of coexistence in the documents analyzed. The main clusters in this figure are each represented by a different colour. The green cluster seems more related to energy and models, with terms such as energy system, model, supply, network, and solar photovoltaic.

This shows a lot of research or discussion in the analysed dataset related to energy systems and models. The green cluster also includes related words such as security, government, and internet, indicating that security and policy issues may be often discussed in the context of this energy system.

The red cluster focuses more on hydrogen, fuel, and device topics. Other terms such as fuel cell, stability, catalyst, and green hydrogen production indicate that this area is related to research and technology related to hydrogen fuel and related devices such as fuel cells. The emphasis on stability and catalysts demonstrates that research on materials and catalysts for hydrogen technology is a significant topic in this area. The blue cluster focuses more on biomass and properties, with words such as biopolymer, feedstock, polymer, and oil. This suggests that topics related to biomass, feedstock, and polymer material properties are also interesting. This cluster may be related to research on biomass conversion into fuels or industrial raw materials through chemical or biological processes, with words such as modification and conversion appearing concerning materials or resources. The figures illustrate a diverse but interrelated range of research topics in energy, fuels, biomass, and related technological devices. The strong relationship between issues such as hydrogen, energy systems, and biomass reflects the synergy between research on renewable energy technologies, fuel conversion, and the development of new materials that have the potential to support future energy sustainability.

Fig. 2 visualizes the thematic map based on the bibliometric analysis with an added temporal dimension generated by VOSviewer. The color of each node (circle) reflects the time of occurrence of the most frequently discussed keywords in the analyzed literature based on the color scale at the bottom of the figure. The blue represents the topics more regularly discussed at the beginning of the defined time (around 2022.1), while the yellow represents the more recent topics (around 2022.4). This visualization shows that such issues as energy systems, models, and smart grids in the green and blue areas on the left side of the graph tend to be more frequently discussed at the beginning of 2022. This reflects the early focus on energy systems, smart grids, and energy models researchers are interested in. These topics often relate to developing renewable energy infrastructure and efficient grid technologies to support the energy transition. On the other hand, the yellow areas on the right side of the figure, especially around terms such as hydrogen, fuel cell, green hydrogen production, and electrocatalyst, show topics that became more frequently discussed towards the end of the analyzed period (2022.4). This indicates increasing interest in green hydrogen and fuel cell technologies and research into developing electrochemical catalysts that support hydrogen-based clean energy production processes.

From the bibliometric results using VOSviewer, it can be seen that the main clusters that emerged in this study consist of hydrogen and fuel technology, biomass and energy conversion, and energy systems and networks. The hydrogen cluster has the highest link strength, indicating that this topic has a strong relationship with various other renewable energy studies, especially related to fuel stability and catalyst material development. The biomass cluster, although having a lower number of links than hydrogen, still shows significance because it plays an alternative role in the clean energy transition. Meanwhile, the energy system cluster has a close connection with the topic of supply chain and smart grid, indicating that the integration of renewable energy into a wider system is still a major challenge. The density variation in the bibliometric map also shows the evolution of research interests—for example, green hydrogen production has become an increasingly discussed topic in recent years, while biomass conversion remains a stable research area but is developing in a more specific direction, such as waste-to-energy processing. This interpretation highlights that current research trends focus not only on technology development, but also on the implementation challenges and economic

sustainability of renewable energy, which are major factors in determining future research directions.

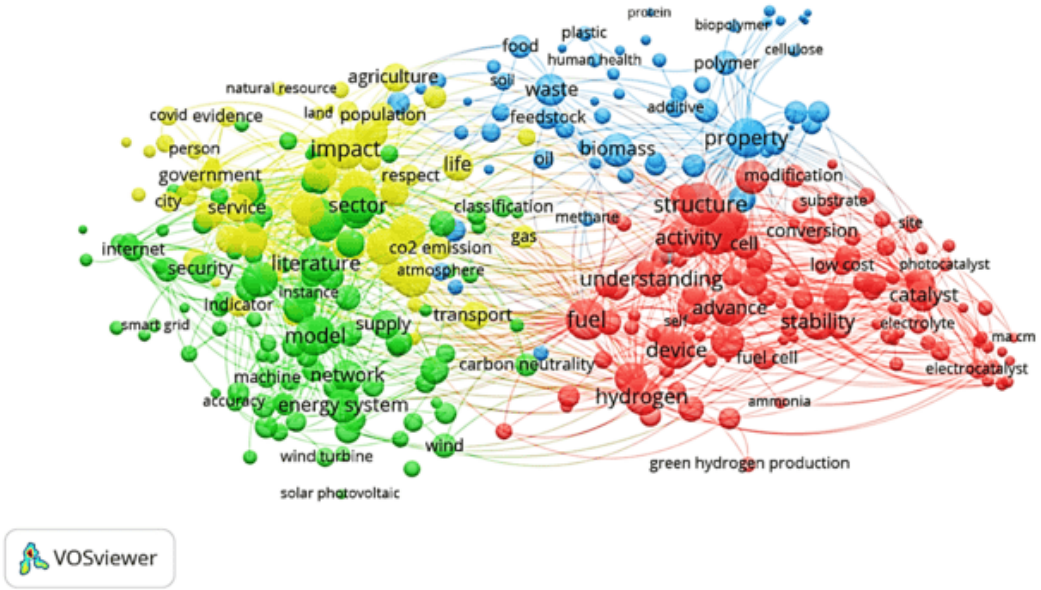

Fig. 1. Keyword-based thematic map network visualization

In addition, the cluster located in the middle with terms such as biomass, property, structure, and waste shown in green to yellow indicates a transition in research on biomass conversion and new material development from the middle to the end of the period. Research in this area appears to be growing and attracting attention as the focus on sustainable energy and material solutions increases. Overall, this map illustrates the evolution of energy research topics from the beginning to the end of 2022, with more attention being paid to the development of energy models and systems at the start of the year, while in the latter half of the year, researchers' interest shifted towards green hydrogen technologies, fuel cells, and new materials for clean energy.

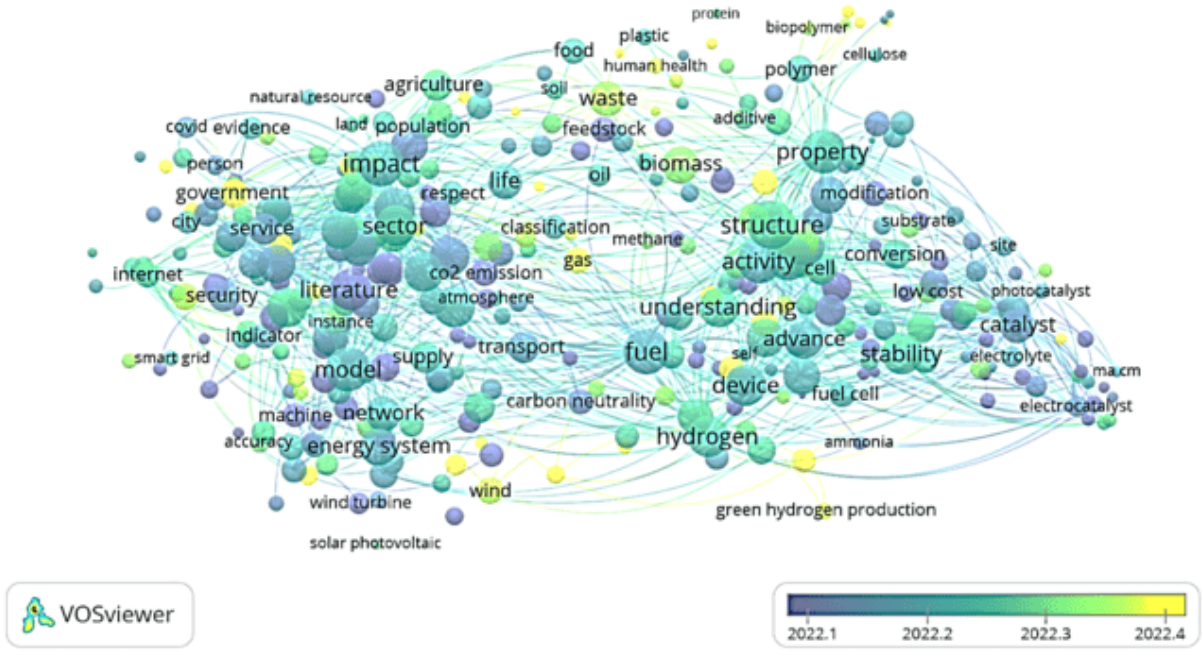

Fig. 2. Network visualization map based on keywords

Fig. 3 is a visualization of research topic density using VOSviewer, where the colour and light intensity depict the frequency or popularity of a keyword in the analyzed dataset. Yellow indicates areas with high density, meaning the topic appears frequently or is frequently discussed in the analyzed literature. In contrast, blue or purple indicates low-density regions, meaning the topic is less often discussed. On the left side of the figure, the yellower areas include topics such as impact, sector, literature, model, and energy system. This indicates that these topics are highly discussed in the research literature. The focus on energy systems and models indicates a great deal of attention to developing models that support integrating renewable energy or energy efficiency in the context of the broader energy system. In addition, terms such as literature and sector indicate that many studies focus on literature analysis or studies related to the energy sector. The middle to the right side of the figure shows topics related to hydrogen, fuel, devices, catalysts, and stability, which also have a high density (in yellow). This indicates that hydrogen technology, fuel cells, and the development of catalysts for fuel stability are trendy and growing areas in the latest scientific literature. This aligns with global trends encouraging further research into green hydrogen and the development of efficient, clean fuel technologies for decarbonizing the energy industry.

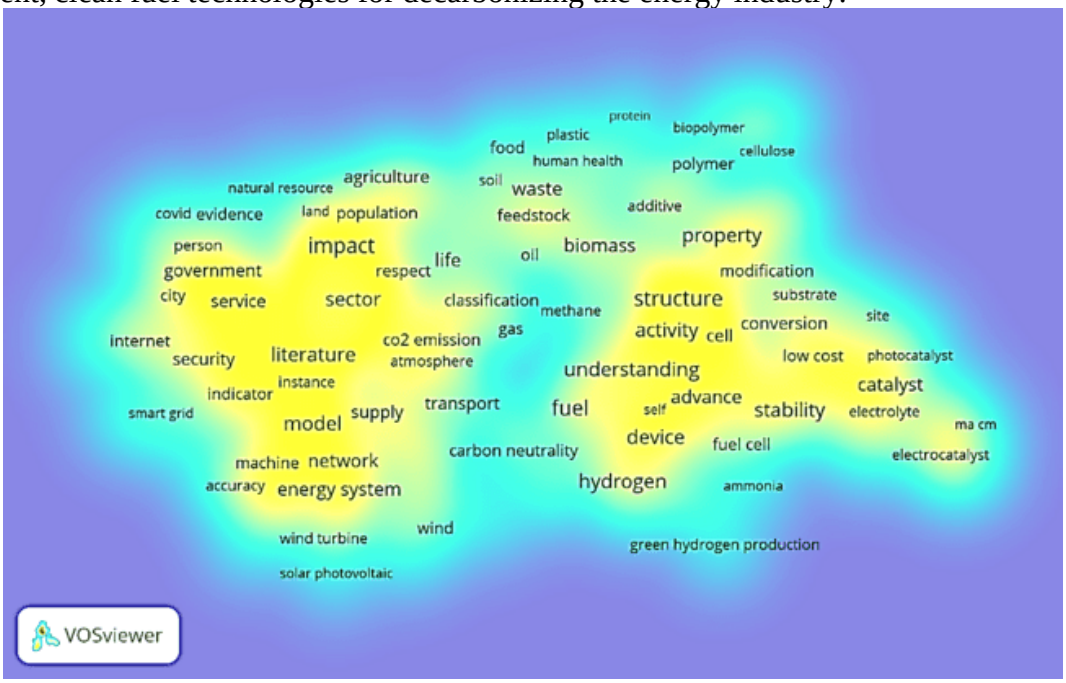

Fig. 3. Research density based on keywords

The upper right has a lighter area covering terms such as biomass, waste, property, and structure. These topics reflect the high interest in research related to biomass conversion, waste management, and material properties. This indicates the pursuit of sustainable energy solutions using biomass and waste resources and the development of materials supporting clean energy systems. Overall, this density map shows that the most frequently discussed topics in renewable energy research today include developing more efficient energy systems, hydrogen and fuel cell technologies, and using biomass and new materials to support the clean energy transition. The density of these topics reflects the importance of these technologies in supporting the sustainability and decarbonization of the energy sector in the future.

Table 1 contains parameters related to research topics grouped into several clusters. Each cluster has a value of links, total link strength, and occurrences, which reflect how often a topic appears and how strong its relationship is with other topics in the analyzed research dataset. For example, the term hydrogen in the table is in cluster 1 with 278 links, indicating that this topic has many relationships with other terms. The total link strength for hydrogen is 1,362,

which means that its relationship or connectivity with other topics is relatively high. This term also has 108 occurrences, indicating that the topic of hydrogen often appears in the analyzed literature, showing that research on hydrogen as a clean energy source is a prevalent topic. Another exciting term in cluster 1 is fuel, with 305 links and 1,574 total link strength, which is higher than the term hydrogen. This shows that the topic of fuel has more connections and is more strongly related to other topics. The fact that it occurred 131 times confirms that fuels, including clean and alternative fuels like hydrogen, are a crucial research topic in this literature.

Table 1
Relevance of energy and clean technology research topics based on the number of links, total strength of links, and frequency of occurrence

Parameter	Cluster	Links	Total link strength	Occurrences
Access	2	156	228	19
Account	2	148	213	15
Accuracy	2	136	296	23
Achievement	1	175	276	24
Action	2	159	272	24
Active site	1	102	243	19
Activity	1	298	1220	106
Additive	3	144	247	23
Adoption	2	162	329	28
Adsorption	1	147	346	33
Advance	1	262	815	74
Agriculture	4	209	575	39
Algorithm	2	171	548	48
Ammonia	1	98	166	14
Anode	1	108	251	26
Applicability	2	112	165	16
Architecture	2	202	441	36
Artificial intelligence	2	187	601	49
Atmosphere	3	141	206	13
Author	2	151	227	16
Automation	2	139	247	19
Average	2	121	176	13
Battery	1	251	881	87
Big data	2	109	186	12
Bio	3	107	178	16
Biochar	3	115	212	16
Biocompatibility	3	81	162	14
Biodegradability	3	86	202	18
Biofuel	3	148	266	21
Biomass	3	247	724	62
Biomedical application	3	58	114	11
Biopolymer	3	103	188	15
Blockchain	2	102	208	19
Blockchain technology	2	75	131	12
Bottleneck	1	145	244	22
Building	2	192	371	31

Parameter	Cluster	Links	Total link strength	Occurrences
Business	2	108	184	16
Carbon	1	257	739	64
Carbon dioxide	1	192	446	35
Carbon emission	4	198	500	38
Carbon neutrality	2	175	392	29
Carbon sequestration	3	93	149	10
Case	2	195	432	37
Case study	2	168	339	27
Catalyst	1	232	1167	106
Catalytic activity	1	115	262	18
Cell	1	217	463	43
Cellulose	3	95	181	17
Characterization	1	140	249	22
Chemical	3	198	481	45
Chemical energy	1	71	103	10
China	2	168	399	27
Chitosan	3	77	140	12
Circular economy	3	174	383	35
City	4	154	399	24
Class	3	113	180	17
Classification	2	163	245	19
Climate	4	165	495	32
Climate change	4	250	939	74
Co2	1	178	427	39
Co2 emission	4	182	401	35
Collaboration	2	115	180	15
Combustion	3	114	191	15
Commercialization	1	149	255	24
Company	2	147	248	22
Complexity	2	137	221	17
Composite	3	164	388	39
Composition	3	200	403	35
Consumer	2	152	266	22
Contrast	1	105	140	11
Contribution	4	193	395	35
Conversion	1	203	601	55
Correlation	1	170	307	22
Country	4	262	1122	81
Covid	4	148	414	24
Current challenge	1	155	252	21
Current density	1	103	295	26
Current trend	3	71	83	10
Data	2	273	1216	109
Day	2	138	223	17
Decision maker	4	107	224	13
Deep learning	2	131	238	16

Parameter	Cluster	Links	Total link strength	Occurrences
Definition	2	135	184	18
Degradation	1	201	392	34
Device	1	277	1052	99
Digital transformation	4	83	192	10
Digital twin	2	76	143	13
Dimension	4	130	275	17
Disadvantage	2	120	188	18
Discovery	1	126	169	17
Domain	2	168	296	27
Drug delivery	3	63	133	11
Durability	1	107	190	19
Economic growth	4	106	210	17
Economy	4	276	1188	85
Ecosystem	4	152	281	26
Electric vehicle	2	150	306	27
Electrical energy	1	96	131	14
Electrification	2	111	187	13
Electrocatalysis	1	117	237	19
Electrocatalyst	1	146	680	56
Electrochemical performance	1	106	217	18
Electrode	1	151	352	35
Electrode material	1	89	130	13
Electrolyte	1	146	418	42
Electronic structure	1	81	155	13
Emission	4	267	1137	92
Energy conversion	1	141	307	28
Energy crisis	1	172	309	21
Energy sector	2	146	265	20
Energy storage	1	239	704	64
Energy storage system	1	165	335	33
Energy supply	4	156	359	24
Energy system	2	249	818	64
Energy transition	2	155	310	23
Engineering	1	261	660	53
Environmental performance	4	85	131	11
Environmental pollution	1	153	274	21
Environmental sustainability	4	150	293	25
Evidence	4	161	451	36
Evolution	1	198	432	42
Fabrication	1	126	232	21
Feedstock	3	172	405	35
First time	1	118	152	13
Food	3	178	427	38
Food industry	3	79	110	10
Formation	1	168	438	41
Fuel	1	305	1574	131

Parameter	Cluster	Links	Total link strength	Occurrences
Fuel cell	1	185	430	32
Functionality	3	163	270	25
Fundamental	1	129	184	16
Fundamental understanding	1	94	146	11
Future development	1	182	328	29
Future perspective	1	208	399	31
Prospect	1	151	215	17
Future trend	2	103	129	11
Gas	4	179	396	24
Gasification	3	103	197	14
Ghg	4	96	162	13
Goal	4	274	918	72
Governance	4	95	165	15
Government	4	193	492	31
Great potential	1	93	116	13
Green hydrogen	1	128	264	21
Green hydrogen production	1	115	204	16
Greenhouse gas	4	110	201	17
Greenhouse gas emission	3	175	400	34
Greenhouse gase	3	112	191	16
Grid	2	199	512	42
Guidance	1	139	194	17
Health	4	166	317	29
Heavy metal	3	70	114	10
Her	1	100	288	18
Heterostructure	1	80	153	15
High cost	1	103	147	12
High efficiency	1	87	116	10
High energy density	1	115	156	12
High performance	1	94	157	15
High power density	1	56	94	10
Highlight	1	200	393	32
History	2	119	168	15
Human	3	127	214	21
Human health	3	110	187	19
Hydrogen	1	278	1362	108
Hydrogen energy	1	139	227	17
Hydrogen evolution reaction	1	123	422	31
Hydrogen production	1	195	519	44
Hydrogen storage	1	141	290	24
Iii	2	90	122	11
Impact	4	313	1914	169
Implementation	2	240	651	61
Implication	4	200	567	49
India	2	123	197	11
Indicator	4	178	429	29

Parameter	Cluster	Links	Total link strength	Occurrences
Industrial application	1	131	212	18
Industrialization	4	136	237	18
Infrastructure	4	202	558	38
Innovation	2	244	732	66
Instance	2	143	209	11
Interface	1	152	301	30
Internet	2	174	565	41
Investment	4	170	382	33
IoT	2	132	388	28
Key challenge	1	123	157	13
Kinetic	1	160	403	35
Land	4	109	180	15
Life	4	233	647	46
Life cycle assessment	3	135	217	20
Lignocellulosic biomass	3	91	140	13
Literature	2	279	988	84
Literature review	2	141	229	20
Lithium-ion battery	2	109	192	20
Load	2	167	349	29
Long term	2	137	201	14
Lot	2	101	119	12
Low cost	1	168	407	39
Ma cm	1	81	215	20
Machine	2	169	402	36
Machine learning	2	169	417	36
Major challenge	1	86	106	10
Manufacturing	2	199	455	41
Market	2	242	733	52
Measure	4	163	448	35
Mechanical property	3	47	69	12
Mechanism	1	313	1293	121
Medicine	3	83	136	13
Membrane	1	115	190	19
Metal	1	191	491	45
Metal-organic framework	1	78	109	10
Methane	3	121	233	19
Methanol	1	80	127	11
Microgrid	2	79	131	13
Microorganism	3	131	215	18
Model	2	295	1560	142
Modification	1	172	341	33
Morphology	1	129	228	21
Nanomaterial	3	152	341	29
Nanoparticle	3	177	411	38
Nanotechnology	3	97	158	14
Natural gas	3	116	212	14

Parameter	Cluster	Links	Total link strength	Occurrences
Natural resource	4	112	207	19
Network	2	241	717	62
New insight	4	123	233	13
New material	1	85	103	10
New technology	2	132	193	11
Oer	1	95	269	18
Oil	3	161	315	26
Optimization	2	209	549	49
Organization	2	140	233	21
Oxygen evolution reaction	1	96	294	21
Pandemic	4	137	294	20
Period	2	183	358	27
Person	4	138	343	26
Petroleum	3	105	167	16
Photocatalysis	1	99	215	21
Photocatalyst	1	113	302	31
Photovoltaic	1	101	157	15
Physicochemical property	3	96	146	16
Place	4	130	258	15
Plastic	3	114	246	24
Policy	4	213	772	60
Policymaker	2	141	253	24
Polymer	3	183	502	48
Popularity	3	85	110	10
Population	4	186	366	33
Potential application	3	178	332	33
Power generation	2	150	258	18
Power system	2	155	311	24
Practical application	1	185	425	37
Practice	2	197	496	41
Prediction	2	170	422	33
Preparation	3	168	331	30
Presence	1	125	200	20
Present study	4	103	140	11
Pressure	4	213	584	39
Privacy	2	103	197	16
Promising candidate	1	125	190	15
Property	3	300	1581	147
Protein	3	75	123	14
Publication	2	131	194	18
Pyrolysis	3	127	260	22
Quality	4	254	753	56
Rational design	1	101	220	18
Raw material	3	119	191	17
Reaction	1	211	847	75
Reaction mechanism	1	107	228	18

Parameter	Cluster	Links	Total link strength	Occurrences
Reader	2	97	122	11
Recent advance	1	259	729	65
Recent development	3	207	404	35
Recent progress	1	195	473	41
Recommendation	2	195	413	34
Recovery	4	176	431	36
Recycling	3	151	241	21
Region	4	191	440	31
Release	3	124	190	19
Reliability	2	168	330	29
Reliance	2	114	163	14
Renewable	2	152	272	20
Renewable energy generation	2	93	128	12
Renewable energy system	2	130	248	21
Renewable resource	3	131	207	20
Renewable source	3	120	210	18
Report	4	165	360	27
Research gap	2	101	133	12
Research progress	1	131	207	17
Respect	4	163	342	23
Rise	4	155	266	21
Risk	2	189	370	36
Robustness	2	133	235	17
Scope	2	170	267	23
Sector	2	282	1181	100
Security	2	213	610	44
Selectivity	1	130	295	32
Self	1	109	153	13
Sensor	2	144	272	26
Service	4	217	596	38
Set	4	176	407	25
Share	2	182	328	24
Simulation	2	164	313	24
Site	1	133	332	32
Sluggish kinetic	1	79	152	11
Smart city	2	120	218	16
Smart grid	2	112	172	13
Society	4	250	718	51
Soil	3	137	232	19
Solar cell	1	115	197	23
Solar photovoltaic	2	76	114	10
Space	4	165	329	27
Stability	1	281	1251	121
Stakeholder	2	138	234	19
Standard	4	181	383	23
Structure	1	329	1529	139

Parameter	Cluster	Links	Total link strength	Occurrences
Substrate	1	127	195	18
Supercapacitor	1	117	252	24
Supply	2	212	447	34
Supply chain	2	154	298	23
Surface	1	216	491	45
Survey	2	191	428	34
Sustainable development	2	209	373	32
Sustainable development goal	4	125	216	19
Synergistic effect	1	86	149	11
Synergy	1	117	146	11
Synthesis	1	250	709	68
Synthesis method	1	101	181	14
Systematic literature review	2	100	175	17
Systematic review	2	142	238	23
Task	2	165	299	23
Theory	1	189	362	33
Thing	2	141	435	32
Tissue engineering	3	62	132	10
Trade	4	81	132	14
Transition	4	278	928	72
Transport	4	213	532	35
Treatment	3	189	408	40
Uncertainty	2	174	424	36
Understanding	1	275	779	68
Urbanization	4	97	149	12
User	2	113	183	17
Valorization	3	75	110	11
Vehicle	2	127	205	17
Volatility	2	119	184	13
Waste	3	244	788	71
Wastewater	3	126	213	20
Wastewater treatment	3	100	132	12
Water electrolysis	1	167	369	29
Water purification	1	80	125	11
Water splitting	1	145	406	33
Web	2	99	139	11
Wind	2	182	441	37
Wind energy	2	127	183	11
Wind power	2	109	195	13
Wind turbine	2	144	287	19

On the other hand, in cluster 3, the topic biomass has 247 links and a total link strength of 724, with 62 occurrences. This shows that biomass, although quite frequently discussed, has a lower relatedness level than hydrogen and fuels. This may reflect that biomass-related research is more focused on a specific segment or less connected to broader topics in the analyzed literature. Furthermore, the term structure in cluster 1 has 329 links with a total link strength of 1,529, indicating that this term is highly related to various other topics. With 139

occurrences, this topic is frequently discussed, which may reflect the great interest in developing new material structures used in clean energy technologies, such as catalysts or fuel cell materials. This table illustrates some prominent topics in clean energy and technology research, such as hydrogen, fuels, material structures, and biomass. The relationships and link strengths between topics indicate a growing research trend, especially regarding alternative fuels and materials development to support renewable energy technologies.

Hydrogen technologies, especially green hydrogen, are increasingly gaining attention in global energy policies as part of industrial and transport decarbonization strategies. Countries such as Germany, Japan, and the United States have developed policies to subsidize and invest in hydrogen infrastructure to accelerate its adoption in manufacturing and fuel cell vehicles. Biomass research also plays a key role in supporting the circular economy, especially in the conversion of waste into cleaner energy sources, such as biofuels and biogas, which are being adopted by the energy and agricultural industries. In addition, developments in energy systems and smart grid integration are increasingly supporting the implementation of renewable energy at scale, enabling more efficient and stable energy load management. This study provides insights into how the integration of multiple renewable energy sources can help create a more resilient electricity grid, a key focus of energy transition policies in many countries. In doing so, this study not only identifies academic trends but also provides insights into technological innovations and policies that support sustainable energy transformation globally.

4. Conclusion

This article reveals the rapidly growing research trends in renewable energy and clean technologies, focusing on critical topics such as hydrogen, alternative fuels, biomass, and new material development. Based on the bibliometric analysis shown through various keyword network visualizations, it is clear that the topics hydrogen and fuel dominate the literature, indicating that hydrogen-based technologies, such as green hydrogen production and fuel cells, have been the focus of research in recent years. The interrelationships between these topics and other terms, such as catalyst and stability, underscore the importance of developing materials supporting hydrogen-based energy systems' stability and efficiency. In addition, the topic of biomass also emerged as an essential area, reflecting the research focus on renewable energy sources that can support a clean and sustainable energy transition. Topics such as conversion and property in the context of biomass emphasize the importance of developing biomass conversion technologies and new materials to support greener energy production. From the table analysis, other influential findings include the high frequency of topics such as energy systems and models, indicating the need for a systematic approach and accurate models in integrating renewable energy into current energy systems. The strong linkage between energy systems and topics such as networks and supply also suggests that developing energy infrastructure that supports intelligent grids and efficient energy distribution remains a top priority. Overall, renewable energy research is moving toward hydrogen technology, biomass conversion, and material innovation that can accelerate the transition to cleaner, more sustainable energy. The challenge ahead is to ensure technological stability and overcome cost constraints in implementing these technologies globally.

References

Ahmad, S., Ullah, A., Samreen, A., Qasim, M., Nawaz, K., Ahmad, W., … Egilmez, M. (2024). Hydrogen production, storage, transportation and utilization for energy sector: A current status review. *Journal of Energy Storage*, 101, 113733. Retrieved from https://doi.org/https://doi.org/10.1016/j.est.2024.113733

Al-Hamamre, Z., Saidan, M., Hararah, M., Rawajfeh, K., Alkhasawneh, H. E., & Al-Shannag, M. (2017). Wastes and biomass materials as sustainable-renewable energy resources for Jordan. *Renewable and Sustainable Energy Reviews*, 67, 295–314. Retrieved from

https://doi.org/https://doi.org/10.1016/j.rser.2016.09.035
Alinejad, Z., Parham, N., Tawalbeh, M., Al-Othman, A., & Almomani, F. (2024). Progress in green hydrogen production and innovative materials for fuel cells: A pathway towards sustainable energy solutions. *International Journal of Hydrogen Energy*. Retrieved from https://doi.org/https://doi.org/10.1016/j.ijhydene.2024.09.153
Bade, S. O., Tomomewo, O. S., Meenakshisundaram, A., Ferron, P., & Oni, B. A. (2024). Economic, social, and regulatory challenges of green hydrogen production and utilization in the US: A review. *International Journal of Hydrogen Energy*, 49, 314–335. Retrieved from https://doi.org/https://doi.org/10.1016/j.ijhydene.2023.08.157
Balci, Y., & Erbay, C. (2024). Harnessing solar energy for sustainable green hydrogen production in Türkiye: Opportunities, and economic viability. *International Journal of Hydrogen Energy*, 87, 985–996. Retrieved from https://doi.org/https://doi.org/10.1016/j.ijhydene.2024.09.098
Bamisile, O., Cai, D., Adun, H., Dagbasi, M., Ukwuoma, C. C., Huang, Q., … Bamisile, O. (2024). Towards renewables development: Review of optimization techniques for energy storage and hybrid renewable energy systems. *Heliyon*, 10(19), e37482. Retrieved from https://doi.org/https://doi.org/10.1016/j.heliyon.2024.e37482
Cao, L., Yu, I. K. M., Xiong, X., Tsang, D. C. W., Zhang, S., Clark, J. H., … Ok, Y. S. (2020). Biorenewable hydrogen production through biomass gasification: A review and future prospects. *Environmental Research*, 186, 109547. Retrieved from https://doi.org/https://doi.org/10.1016/j.envres.2020.109547
Efremov, C., & Kumarasamy, S. (2025). Optimisation of Microgrid by HOMER Pro Software Design: Innovative Approach and Performance Evaluation. *International Journal of Engineering and Technology (IJET)*, 1(1), 120–130.
Elgarahy, A. M., Hammad, A., El-Sherif, D. M., Abouzid, M., Gaballah, M. S., & Elwakeel, K. Z. (2021). Thermochemical conversion strategies of biomass to biofuels, techno-economic and bibliometric analysis: A conceptual review. *Journal of Environmental Chemical Engineering*, 9(6), 106503. Retrieved from https://doi.org/https://doi.org/10.1016/j.jece.2021.106503
Erdiwansyah, E., Gani, A., Mamat, R., Mahidin, M., Sudhakar, K., Rosdi, S. M., & Husin, H. (2022). Biomass and wind energy as sources of renewable energy for a more sustainable environment in Indonesia: A review. *Archives of Environmental Protection*, 48(3), 57–69. Retrieved from https://doi.org/10.24425/aep.2022.142690
Erdiwansyah, Mahidin, Mamat, R., Sani, M. S. M., Khoerunnisa, F., & Kadarohman, A. (2019). Target and demand for renewable energy across 10 ASEAN countries by 2040. *The Electricity Journal*, 32(10), 106670. Retrieved from https://doi.org/10.1016/J.TEJ.2019.106670
Erdiwansyah, Mamat, R., Sani, M. S. M., & Sudhakar, K. (2019). Renewable energy in Southeast Asia: Policies and recommendations. *Science of The Total Environment*. Retrieved from https://doi.org/https://doi.org/10.1016/j.scitotenv.2019.03.273
Fan, L., Tu, Z., & Chan, S. H. (2021). Recent development of hydrogen and fuel cell technologies: A review. *Energy Reports*, 7, 8421–8446. Retrieved from https://doi.org/https://doi.org/10.1016/j.egyr.2021.08.003
Gani, A., Erdiwansyah, Munawar, E., Mahidin, Mamat, R., & Rosdi, S. M. (2023). Investigation of the potential biomass waste source for biocoke production in Indonesia: A review. *Energy Reports*, 10, 2417–2438. Retrieved from https://doi.org/https://doi.org/10.1016/j.egyr.2023.09.065
Gu, W., Liu, X., Wang, Z., & Zheng, H. (2024). Applications of PLIF in fundamental research on turbulent combustion of hydrogen and hydrogen hybrid fuels: A brief review. *International Journal of Hydrogen Energy*, 78, 1240–1274. Retrieved from https://doi.org/https://doi.org/10.1016/j.ijhydene.2024.06.350
Hamlehdar, M., Beardsmore, G., & Narsilio, G. A. (2024). Hydrogen production from low-temperature geothermal energy – A review of opportunities, challenges, and mitigating solutions. *International Journal of Hydrogen Energy*, 77, 742–768. Retrieved from https://doi.org/https://doi.org/10.1016/j.ijhydene.2024.06.104
Hassan, Q., Al-Jiboory, A. K., Sameen, A. Z., Barakat, M., Abdalrahman, K. Y. M., & Algburi, S. (2024). Transitioning to Sustainable Economic Resilience through Renewable Energy and Green Hydrogen: The case of Iraq. *Unconventional Resources*, 100124. Retrieved from https://doi.org/https://doi.org/10.1016/j.uncres.2024.100124

Hassan, Q., Algburi, S., Sameen, A. Z., Salman, H. M., & Jaszczur, M. (2024). Green hydrogen: A pathway to a sustainable energy future. *International Journal of Hydrogen Energy*, 50, 310–333. Retrieved from https://doi.org/https://doi.org/10.1016/j.ijhydene.2023.08.321

Hoseinpour, M., Karami, R., Rasul, M., Aghaei, J., Hassan, N., Khan, M. M. K., & Trabelsi, M. A. (2024). Green Hydrogen as a Sustainable Future Energy: Technologies and Challenges. In M. R. B. T.-E. of R. E. Rahimpour Sustainability and the Environment (First Edition) (Ed.) (pp. 643–662). Oxford: Elsevier. Retrieved from https://doi.org/https://doi.org/10.1016/B978-0-323-93940-9.00277-2

Hosseini, S. E., & Wahid, M. A. (2016). Hydrogen production from renewable and sustainable energy resources: Promising green energy carrier for clean development. *Renewable and Sustainable Energy Reviews*, 57, 850–866. Retrieved from https://doi.org/https://doi.org/10.1016/j.rser.2015.12.112

Infield, D., & Freris, L. (2020). *Renewable energy in power systems*. John Wiley & Sons.

Irhamni, I., Kurnianingtyas, E., Muhtadin, M., Bahagia, B., & Yusop, A. F. (2025). Bibliometric Analysis of Renewable Energy Research Trends Using VOSviewer: Network Mapping and Topic Evolution. *International Journal of Engineering and Technology (IJET)*, 1(1), 75–82.

Ishaq, H., Dincer, I., & Crawford, C. (2022). A review on hydrogen production and utilization: Challenges and opportunities. *International Journal of Hydrogen Energy*, 47(62), 26238–26264. Retrieved from https://doi.org/https://doi.org/10.1016/j.ijhydene.2021.11.149

Knapczyk, A., Francik, S., Jewiarz, M., Zawiślak, A., & Francik, R. (2020). Thermal treatment of biomass: A bibliometric analysis—The torrefaction case. *Energies*, 14(1), 162.

Kumar, A., Daw, P., & Milstein, D. (2021). Homogeneous catalysis for sustainable energy: hydrogen and methanol economies, fuels from biomass, and related topics. *Chemical Reviews*, 122(1), 385–441.

Li, D., Ikram, M., & Xiaoxia, J. (2025). A brief overview of the physical layer test system: Development of an IoTbased energy storage and electrical energy distribution system. *International Journal of Engineering and Technology (IJET)*, 1(1), 131–140.

Mahinpey, N., Abdalla, A., & Farooqui, A. (2024). Chapter 9 - Biomass gasification for hydrogen production: a pathway to cleaner energy transition. In S. Nanda & A. K. B. T.-B. to B. Dalai (Eds.), *Woodhead Series in Bioenergy* (pp. 205–235). Woodhead Publishing. Retrieved from https://doi.org/https://doi.org/10.1016/B978-0-443-15377-8.00009-6

Messini, E. M. B., Bourek, Y., Ammari, C., & Pesyridis, A. (2024). The integration of solar-hydrogen hybrid renewable energy systems in oil and gas industries for energy efficiency: Optimal sizing using Fick's Law optimisation Algorithm. *Energy Conversion and Management*, 308, 118372. Retrieved from https://doi.org/https://doi.org/10.1016/j.enconman.2024.118372

Nassar, Y. F., El-Khozondar, H. J., Elnaggar, M., El-batta, F. F., El-Khozondar, R. J., & Alsadi, S. Y. (2024). Renewable energy potential in the State of Palestine: Proposals for sustainability. *Renewable Energy Focus*, 49, 100576. Retrieved from https://doi.org/https://doi.org/10.1016/j.ref.2024.100576

Ranjbari, M., Shams Esfandabadi, Z., Shevchenko, T., Scagnelli, S. D., Lam, S. S., Varjani, S., … Tabatabaei, M. (2022). An inclusive trend study of techno-economic analysis of biofuel supply chains. *Chemosphere*, 309, 136755. Retrieved from https://doi.org/https://doi.org/10.1016/j.chemosphere.2022.136755

Selvakumar, P., Gani, A., Xiaoxia, J., & Salleh, M. R. (2025). Porosity and Pore Volume Analysis of EFB Fiber: Physical Characterization and Effect of Thermal Treatment. *International Journal of Engineering and Technology (IJET)*, 1(1), 100–108.

Shaker, L. M., Mohammed, J. K., Basem, A., Halbos, R. J., Mahdi, R. R., Mohammed, S. A., … Al Lami, M. H. (2024). Comparative analysis of solar cells and hydrogen fuel: A mini-review. *Results in Engineering*, 23, 102507. Retrieved from https://doi.org/https://doi.org/10.1016/j.rineng.2024.102507