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Bibliometric Mapping of Renewable Energy, Carbon Emissions, and Sustainable Development: Evidence from VOSviewer Analysis

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ABSTRACT

Improving renewable energy deployment, cutting carbon emissions, and ensuring sustainable development are now interdependent policy goals in energy and environmental policy. This study aims to present a bibliometric mapping of the research on the intersection of renewable energy, carbon emissions and sustainable development through the literature found in Scopus database. Analysis is drawn from 1481 journal articles and reviews that were published from 2004 to 2024. Keyword co-occurrence, country co-authorship, bibliographic coupling of documents and sources, co-citation of cited references, bibliographic influence and author-level collaboration were analyzed by VOSviewer. From the keyword co-occurrence results three thematic clusters are identified: economic growth, environmental quality, sustainability policy; renewable energy systems and energy-transition technologies; carbon emissions, greenhouse gases, climate mitigation. The country co-authorship results have been very high in the area of research activity and collaboration in Pakistan, Malaysia, Saudi Arabia, Australia, Nigeria, Bangladesh, Taiwan, Iran, Spain, Lebanon. Source-level bibliographic coupling shows that five journals namely Environmental Science and Pollution Research, Renewable Energy, Resources Policy, Journal of Environmental Management, and Journal of Cleaner Production are central journals in this field. The results from co-citation analysis reveal that the literature has a solid foundation of knowledge rooted in empirical energy-environment-growth studies and panel econometric methods. Overall, the study shows that the focus from the technology-related renewable energy and emission studies has moved toward more holistic approaches in the field of carbon systems, environmental sustainability, green finance and sustainable economic transition. The results deliver a systematic knowledge map for the scholars, policy makers and readers of journals interested in research related to energy, environment and sustainability.

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1. Introduction

The shift to low-carbon energy systems has emerged as one of the key research and policy challenges of the 21st century. Renewable energy is a topic of great discussion as a viable avenue to mitigate carbon emissions, increase energy security, and contribute to the sustainable development. The Sustainable Development Goals highlight the interconnections among affordable and clean energy, climate action, responsible consumption and production, and inclusive development as priorities (United Nations, 2015). The urgency of decarbonization is highlighted by climate science and energy-policy reports through the continued call for structural transformation of energy production and consumption, energy technologies, and environmental governance (Intergovernmental Panel on Climate Change, 2023; International Energy Agency, 2023). These developments have led to a vast multi-disciplinary body of literature on renewable energy, carbon emissions, economic growth, environmental quality and sustainability transitions.

The specific research ecosystem on Renewable Energy, Carbon Emissions, and Sustainable Development is wide since it is a cross-disciplinary domain of interest that includes engineering, environmental science, economics, finance, policy studies and sustainability science. Some studies concentrate on technical capabilities of renewable energy systems, such as solar energy, wind power, biomass, hydrogen, energy storage, and power production. Some other works focus on the impact of renewable energy consumption on carbon emissions, environmental quality or economic growth, typically relying on panel econometric techniques and country specific data. Further recent additions to the discussion suggest moving the debate towards carbon neutrality, green finance, ecological footprint, sustainable energy policy, and low carbon development. Since this field has transformed quickly, it is beneficial to analyse the bibliometric data in a systematic way to determine the structure of the field, the most influential authors, the most important journals, the collaboration patterns and emerging research themes.

Bibliometric analysis provides an objective way of analyzing large masses of scientific literature that is both transparent and replicable. It can assist researchers in detecting patterns of publication growth, knowledge clusters, collaboration networks, citation relationships and intellectual foundations (Donthu et al., 2021; Zupic & Čater, 2015). Bibliometric mapping offers quantitative and visual evidence of the organisation of a field and its evolution of themes over time, in contrast to narrative literature reviews. For this purpose, VOSviewer is particularly convenient because it is able to visualize bibliometric networks in several ways, such as co-occurrence, co-authorship, citation, bibliographic coupling, and co-citation techniques (van Eck & Waltman, 2010, 2014).

This study is a contribution to bibliometric literature, which maps the intellectual and thematic structure of research on renewable energy, carbon emissions and sustainable development. The study is based on the journal literature published in the period 2004-2024 in the online Scopus database and uses VOSviewer to create keyword, country, document, source, cited-reference, and author-level networks. The results aim to respond to four big questions: What are the prevalent research topics in this field? Who are the most influential countries, journals, documents, references and authors? What are the changes that have taken place over the years in the field? What research areas are developing for future research?

The rest of the paper will be organized as follows. The second section includes the research design, data source, search strategy and VOSviewer procedures. The bibliometric results are provided in Section 3. The intellectual and thematic implications of the findings are presented in Section 4. The paper ends with section 5 with limitations and future research directions.

2. Methodology

2.1. Research design

This study uses a bibliometric research design. Bibliometrics is the object of quantitative analysis of publications and citation patterns (Pritchard, 1969). It can be used to analyze the evolution and organization of more mature and rapidly developing research areas, as it clarifies interconnections among authors, institutions, countries, journals, documents, and keywords (Donthu et al., 2021; Zupic & Čater, 2015). In this study, the software package VOSviewer, is used for the construction and visualization of the bibliometric networks. This software is widely used for this purpose (van Eck & Waltman, 2010).

The analysis was undertaken with best practice in transparent design of search, inclusion criteria and reproducible reporting. The screening process was summarized in the search-flow in a diagram, inspired from the PRISMA process that follows the logic of transparent record identification, screening, eligibility and inclusion (Page et al., 2021).

2.2. Data source and Search Strategy

The selection of Scopus was based on the fact that Scopus is one of the largest multidisciplinary abstract and citation databases with the addition that it contains structured bibliographic fields that are necessary for analysis with VOSviewer such as authors, titles, abstracts, keywords, source titles, affiliations, citation counts, and cited references. The search was conducted the TITLE-ABS-KEY field with the central concepts of renewable energy, carbon emissions and sustainable development. First search yielded 3,617 results.

The final dataset was filtered by the following criteria: document type (Article, Review); document year (2004-2024); subject area (Energy, Environmental Science, Economics, Econometrics and Finance, Business, Management and Accounting, Social Sciences); and journal source type. The final result, after applying all the filters, is 1481 documents remaining which were then exported as a CSV file for bibliometric mapping.

Table 1
Search Strategy and Inclusion/Exclusion Criteria

Criterion	Description
Database	Scopus
Search field	TITLE-ABS-KEY
Core search terms	Renewable energy; carbon emissions; sustainable development
Initial records identified	3,617 documents
Publication period	2004-2024
Subject areas included	Energy; Environmental Science; Economics, Econometrics and Finance; Business, Management and Accounting; Social Sciences
Document types included	Article and Review
Language	English
Source type	Journals
Records excluded after applying filters	2,136 documents
Final dataset used for bibliometric analysis	1,481 documents
Software used for mapping	VOSviewer

Note: *The final dataset was exported from Scopus as a CSV file and used for VOSviewer-based bibliometric mapping.*

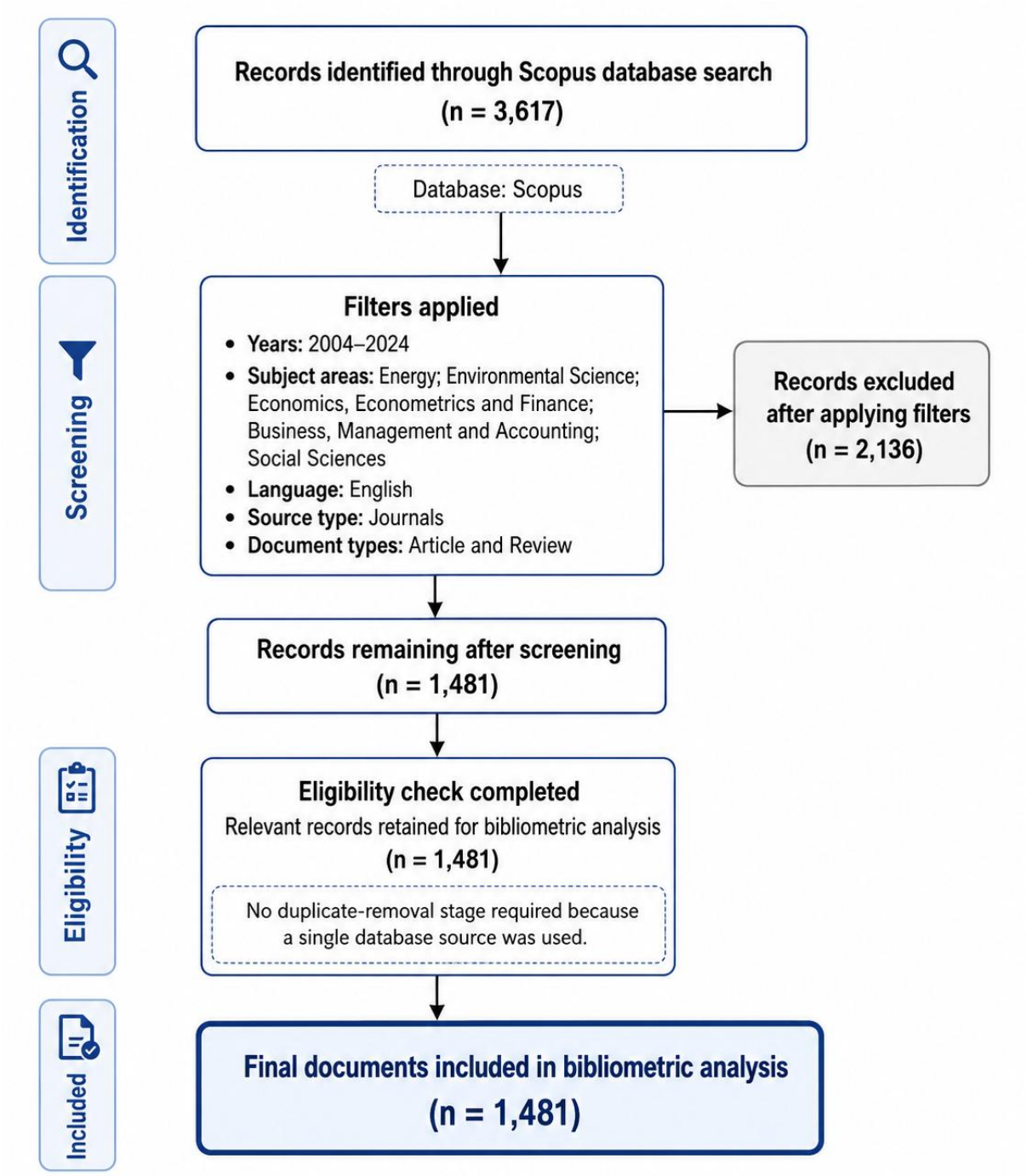

Figure 1. PRISMA/Search Flow Diagram
Note: *The diagram summarizes the identification, screening, eligibility, and inclusion process for the Scopus dataset.*

2.3. Bibliometric techniques and VOSviewer settings

This study used various bibliometric methods such as thematic structure of the field is analyzed by using keyword co-occurrence analysis. Patterns of co-authorship were explored by country and author in a co-authorship analysis. The documents and sources related to each document were identified by bibliographic coupling, based on the reasoning behind 'bibliographic coupling' as developed by Kessler (1963). Following the method of Small (1973) co-citation analysis by cited references was employed to identify foundational references which are cited together very often. Author-level citation influence was examined via citation analysis of authors. Full Counting was applied in all analyses to preserve the full contribution of each item in the network.

In the case of co-occurrence, all keywords were picked and the minimum occurrence rate set at 20. Duplicate terms were harmonized and irrelevant terms like general document labels, method-only words and non-thematic expressions were eliminated using a thesaurus file. Carbon emission/carbon emissions and renewable energy/renewable energies were combined due to similar variations. In the country co-authorship, the minimum number was determined as five documents per country. A minimum citation threshold of 150 was chosen for bibliographic coupling by documents, to retain influential documents, but to keep the map readable. A minimum of five documents was used per source for source-level bibliographic coupling. Co-citation by cited references was set at the minimum of 20 cited references per one cited reference. The final settings obtained with the VOSviewer are presented in Table 2.

Table 2
Summary of VOSviewer Analysis Settings

Analysis	Unit of Analysis	Counting Method	Threshold/Selection Criteria	Items	Clusters	Links	Total Link Strength
Keyword co-occurrence	All keywords	Full counting	Minimum keyword occurrence = 20; thesaurus applied	110	3	4,575	62,719
Co-authorship	Countries	Full counting	Minimum documents per country = 5; minimum citations = 0	53	8	340	734
Bibliographic coupling	Documents	Full counting	Minimum citations per document = 150	151	11	3,467	9,313
Bibliographic coupling	Sources/Journals	Full counting	Minimum documents per source = 5; minimum citations = 0	51	5	1,053	142,456
Co-citation	Cited references	Full counting	Minimum citations per cited reference = 20	40	3	547	1,639
Co-authorship	Authors	Full counting	Minimum documents per author = 5; minimum citations = 0	50	10	111	197
Citation analysis	Authors	Full counting	Author-level citation network	30	12	41	43

Note: *The keyword co-occurrence map was cleaned using a thesaurus file before final visualization.*

3. Results

3.1. Keyword co-occurrence and thematic structure

The conceptual structure of a research field is identified by keyword co-occurrence analysis which shows the appearance of keywords in a number of same documents. With the application of the thesaurus file and a minimum keyword occurrence of 20, the final keyword co-occurrence map had 110 items, 3 clusters, 4,575 links and a total link strength of 62,719. From Figure 2, it can be seen that the sustainable development, carbon emission, economic growth, renewable energy resources, emission reduction, environmental economics, environmental quality, and greenhouse gas are the most central and visible terms.

The first cluster is linked with the economic growth, environmental quality, environmental economics, economics, trade, globalization, finance, green economy, green finance, innovation, environmental policy, pollution and natural resources. This cluster is a reflection of the economic and policy aspect of the literature. It demonstrates that there are numerous studies investigating the relationship between renewable energy, carbon emissions and economic growth, trade openness, environmental quality, financial development and green innovation.

The second cluster is of renewable energy systems and energy transition technologies. It includes renewable energy resources, power generation, energy conservation, energy planning, energy storage, hydrogen production, clean energy, electricity and energy system.

This cluster encompasses the technology and energy-system aspects of the literature, and indicates that the issue of renewable energy deployment, energy planning, and power-system transformation continues to be a central theme of research.

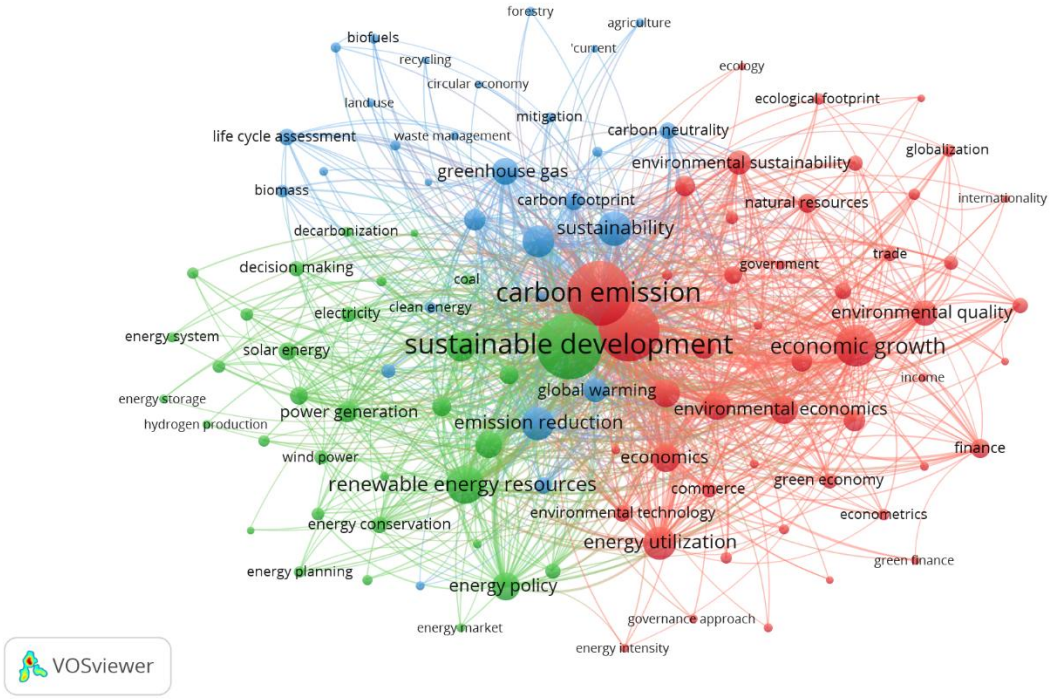

Figure 2. Keyword Co-occurrence Network Visualization
Note: *Unit of analysis: all keywords; counting method: full counting; minimum keyword occurrence: 20; thesaurus applied. Items = 110, clusters = 3, links = 4,575, total link strength = 62,719.*

The third cluster is focused on carbon emission, greenhouse gas, greenhouse gas emissions, carbon neutrality, carbon capture, biofuels, biomass, circular economy, life cycle assessment, mitigation, recycling, land use and ecological footprint. This cluster is for research on carbon-reduction and climate-mitigation. It signals research that is more and more linking carbon emissions to carbon neutrality, lifecycle assessment and circular economy and to other mitigation measures.

The overlay visualization in Figure 3 shows the temporal evolution of keywords. Earlier themes are represented with darker colors and are related to renewable energy resources, power generation, energy policy, energy conservation, biofuels, life cycle assessment, electricity and greenhouse gas. New themes, presented in green and yellow color, are related to environmental sustainability, environmental quality, economic growth, green economy, green finance, globalization and trade, natural resources, ecological footprint, carbon neutrality and finance. The transition indicates that the field has transitioned from technology-centric renewable energy research into multidisciplinary research on sustainability, finance, policy and carbon neutrality.

The density visualization in Figure 4 shows that the themes of sustainable development and carbon emission are most concentrated in the literature. The highest density is found surrounding sustainable development, carbon emission, economic growth, environmental economics, renewable energy resources, emission reduction and environmental quality. This outcome indicates that the connection between the reduction of carbon emissions and sustainable development goals, deployment of renewable energy and economic-environmental transition dominates the field.

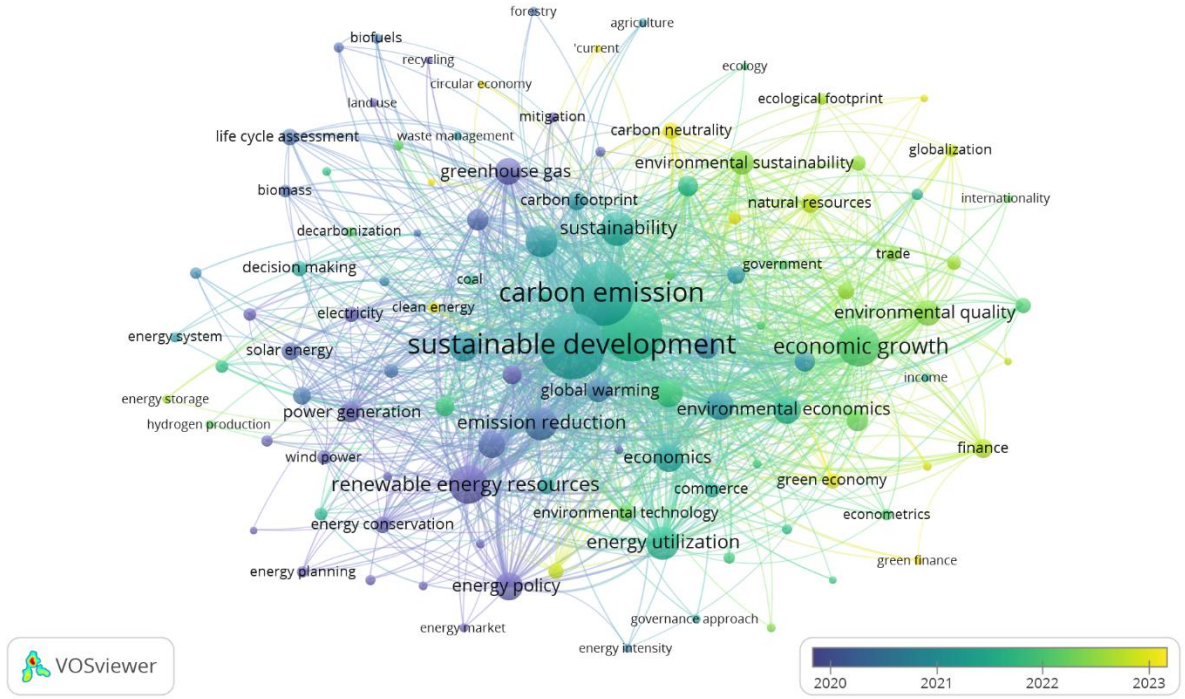

Figure 3. Keyword Overlay Visualization
Note: *The overlay color scale shows the average publication year of keyword occurrence, with earlier themes in darker colors and recent themes in green/yellow tones.*

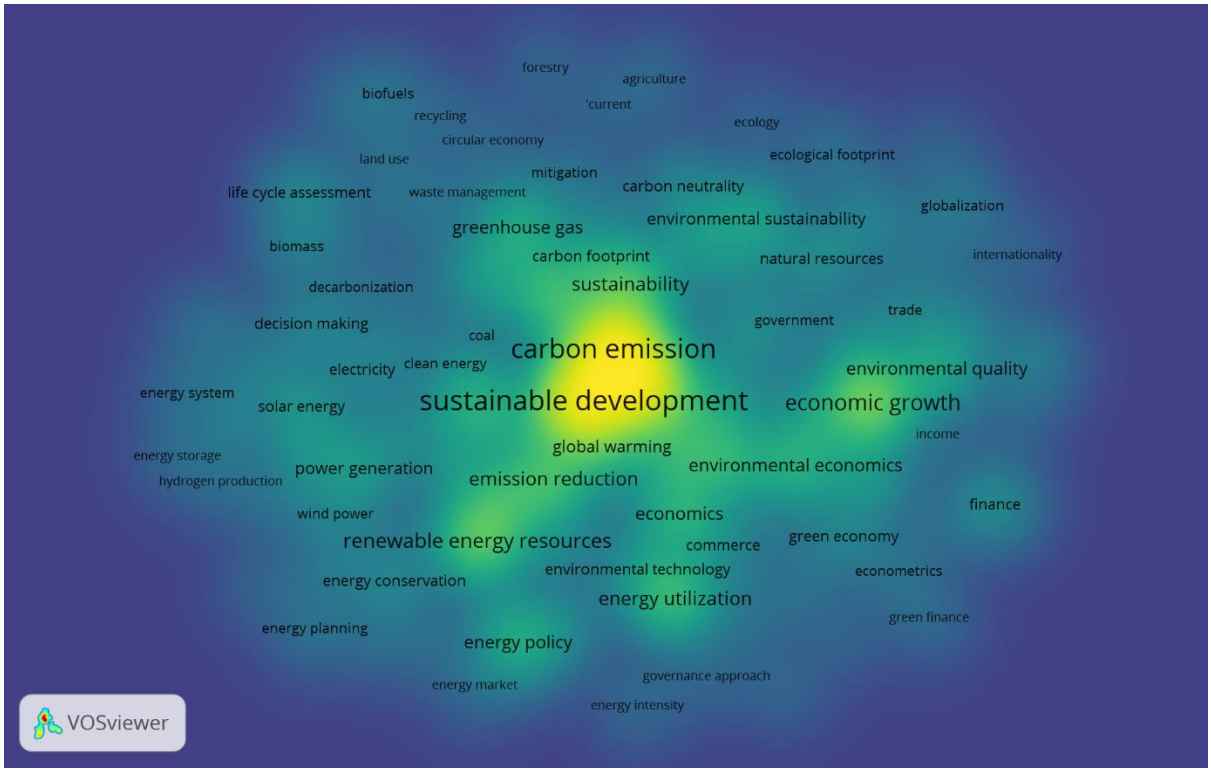

Figure 4. Keyword Density Visualization
Note: *Yellow areas represent stronger density and higher concentration of keyword co-occurrence.*

3.2. Country co-authorship and international collaboration

The country co-authorship analysis identifies the geographical distribution of the collaboration in the field. A minimum threshold of five documents per country was set, resulting in 53 countries being included in the map. The network had eight clusters, 340 links and a total link strength of 734. As illustrated in Figure 5, international collaboration is spread across multiple regional and cross-regional groups. The visible output of VOSviewer shows that the most productive countries are Pakistan, Malaysia, Saudi Arabia, Australia, Nigeria, Bangladesh, Taiwan, Iran, Spain and Lebanon.

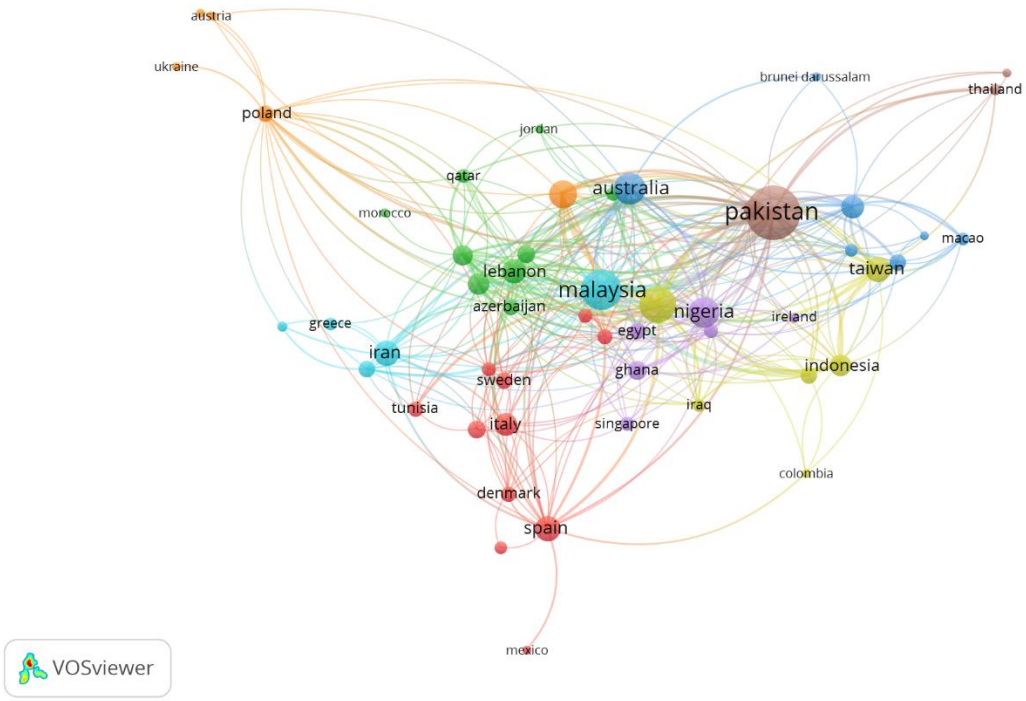

Figure 5. Country Co-authorship Network Visualization
Note: *Unit of analysis: countries; minimum documents per country = 5; items = 53, clusters = 8, links = 340, total link strength = 734.*

Table 3 shows the top productive Countries based on the VOSviewer country co-authorship output. In Pakistan, there were 187 documents, 17679 citations and overall link strength of 157. Malaysia had 106 documents, 9,489 citations and a total link strength of 134, while Saudi Arabia had 85 documents, 5,986 citations and a total link strength of 141. The findings show that the countries in South Asia, Middle East and Southeast Asia contributed a lot in this field of research. Other major contributors include Australia, Nigeria, Bangladesh, Taiwan, Iran, Spain and Lebanon, demonstrating the international collaboration among research community.

Table 3
Top Productive Countries in the Dataset

Country	Documents	Citations	Total Link Strength
Pakistan	187	17,679	157
Malaysia	106	9,489	134
Saudi Arabia	85	5,986	141
Australia	65	5,161	56
Nigeria	57	3,752	56
Bangladesh	48	3,141	64
Taiwan	42	2,755	45
Iran	41	3,488	28
Spain	40	3,840	43
Lebanon	37	1,426	57

Note: *Countries are reported from the VOSviewer co-authorship by countries output. Total link strength represents the strength of co-authorship links with other countries.*

3.3. Bibliographic Coupling by Documents

The intellectual structure of influential papers was explored using bibliographic coupling by documents. With a minimum of citations of 150, a total 151 documents were included in the network. There were 11 clusters, 3,467 links and 9,313 link strength on the map. The figure 6 reveals that the highly cited documents tend to form a dense core of interconnected documents and are related to each other and linked to other research streams within the field of renewable energy, carbon emissions, economic growth and sustainability.

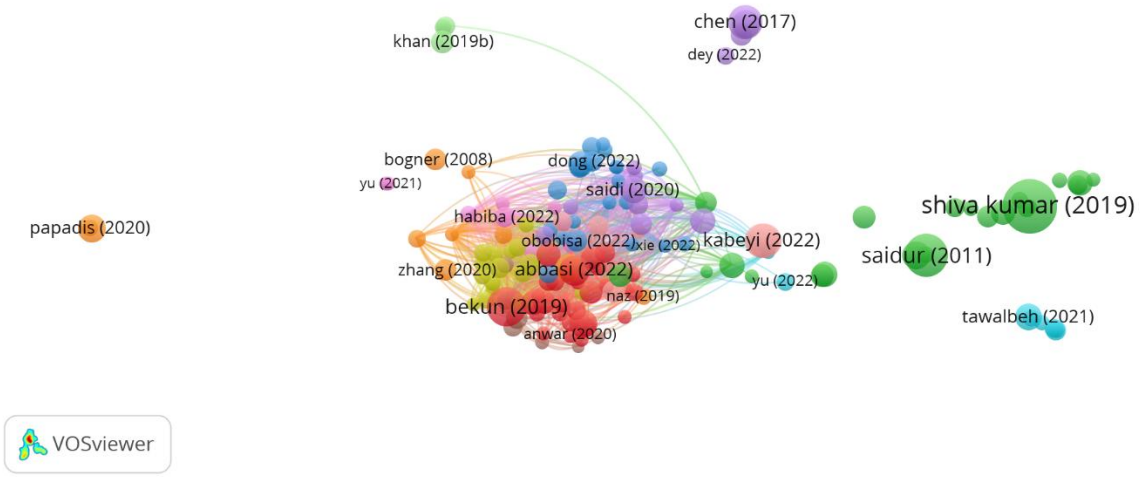

Figure 6. Bibliographic Coupling by Documents Network Visualization
Note: *Unit of analysis: documents; minimum citations per document = 150; items = 151, clusters = 11, links = 3,467, total link strength = 9,313.*

The central part of the document-level bibliographic coupling map includes studies such as (Bekun et al., 2019), (Abbasi et al., 2022), (Habiba et al., 2022), (Obobisa et al., 2022), (Saidi & Omri, 2020), (Dong et al., 2022), (Kabeyi & Olanrewaju, 2022), (Xie & Jamaani, 2022), and (Zhang et al., 2020). The documents are grouped together due to their similar references and thematic linkage. Smaller clusters like (Shiva Kumar & Himabindu, 2019), (Saidur et al., 2011), (Khan et al., 2021), (Chen & Wang, 2017), (Dey et al., 2022), (Khan et al., 2019) and (Papadis & Tsatsaronis, 2020) propose more focused areas such as energy-system analysis (ESA) with a focus on technology, clean energy applications, or specific approaches to sustainability assessment. The map shows that the field is diverse, with several non-contiguous research streams, which suggests that the field is intellectually diverse.

3.4. Bibliographic Coupling by Sources and Journals

The source-level bibliographic coupling method was employed to find journals which have publications with the same reference structure. Five documents minimum were used, and a total of 51 sources, five clusters, 1053 links and a total link strength of 142,456 were used. The structure of the sources level is focused on journals related to environmental science, renewable energy, sustainability, energy economics and energy policy studies (Figure 7).

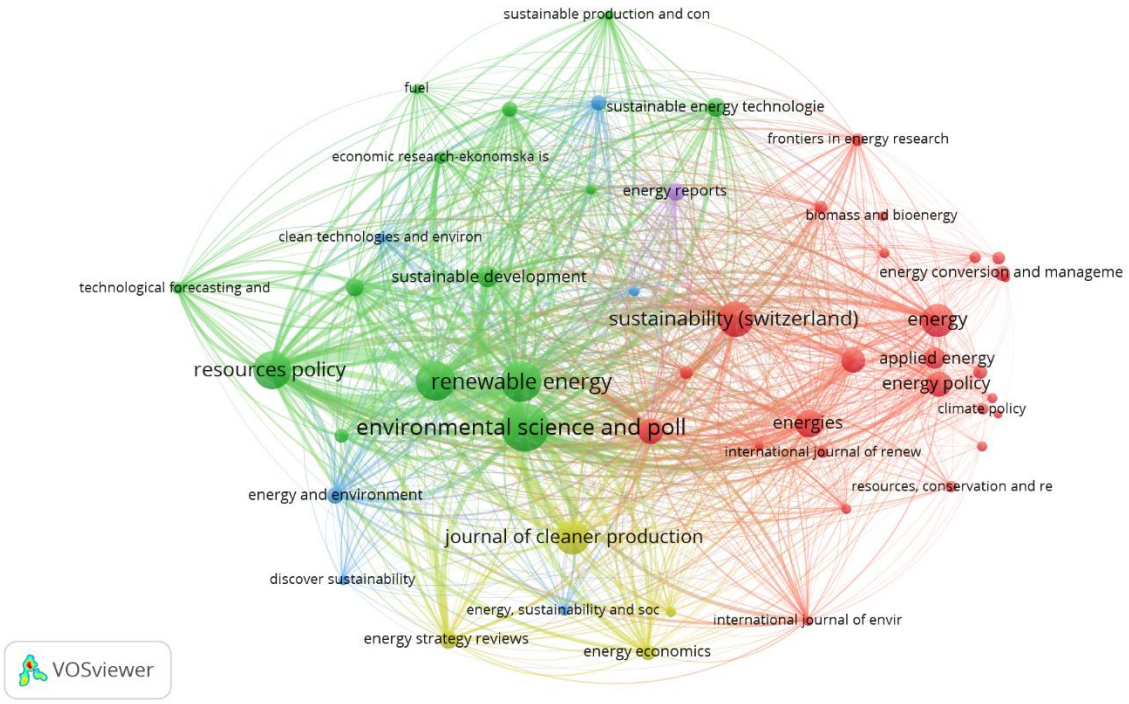

Figure 7. Bibliographic Coupling by Sources/Journals Network Visualization
Note: *Unit of analysis: sources; minimum documents per source = 5; items = 51, clusters = 5, links = 1,053, total link strength = 142,456.*

Table 4
Top Sources/Journals by Bibliographic Coupling Strength

Source/Journal	Documents	Citations	Total Link Strength
Environmental Science and Pollution Research	128	6,254	51,316
Resources Policy	79	3,518	32,899
Renewable Energy	90	10,158	31,447
Journal of Environmental Management	84	7,655	27,533
Journal of Cleaner Production	64	5,715	13,294
Science of the Total Environment	35	7,411	11,154
Sustainable Development	28	2,504	11,101
Sustainability (Switzerland)	70	1,618	9,354
Environment, Development and Sustainability	17	828	7,424
Energy	59	6,180	5,689
Energies	43	1,169	5,627
Energy Economics	14	1,464	5,574
Energy Strategy Reviews	18	903	5,565
Energy and Environment	16	478	5,021
Frontiers in Environmental Science	13	325	4,937
Renewable and Sustainable Energy Reviews	32	6,543	4,767
Economic Research-Ekonomska Istraživanja	9	306	4,469
Sustainable Energy Technologies and Assessments	20	990	4,272
Technological Forecasting and Social Change	8	1,544	4,005
International Journal of Energy Economics and Policy	13	468	3,640

Note: *Sources are ranked according to total link strength in bibliographic coupling by sources/journals.*

The top sources are listed by total link strength in Table 4. In the total link strength, Environmental Science and Pollution Research is the strongest with 128 documents, 6,254 citations, and a total link strength of 51,316. With 10,158 citations and a total link strength of 31,447, Renewable Energy is the most cited visible source. Other central sources are Resources Policy, Journal of Environmental Management, Journal of Cleaner Production, Journal of Environmental Science and Technology, Science of the Total Environment, Sustainability (Switzerland), Energy, and Renewable and Sustainable Energy Reviews. This

shows that environmental science, energy systems, sustainability, and policy-oriented journals are representatives of a wide range of fields of science.

3.5. Co-citation by Cited References

Co-citation analysis reveals the intellectual bases of the field, since the references that are cited together form the bases. The co-citation analysis (CCA) used 40 cited references that were cited at least 20 times. There were three clusters in the map, with 547 links and a total link strength of 1639. The basic literature is presented around methodological references and substantive energy-environment-growth studies as depicted in Figure 8.

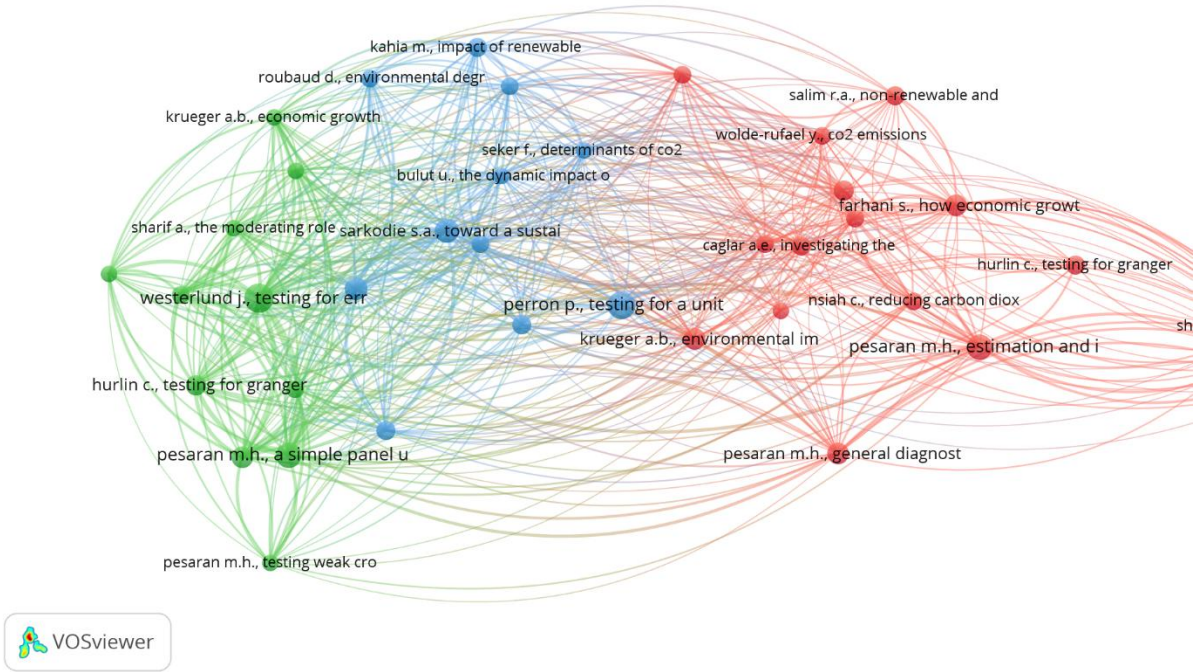

Figure 8. Co-citation by Cited References Network Visualization
Note: *Unit of analysis: cited references; minimum citations per cited reference = 20; items = 40, clusters = 3, links = 547, total link strength = 1,639.*

The most highly co-cited authors are Westerlund (error correction approach in panel data), Pesaran (panel unit-root and large heterogeneous panels), Yamagata (slope homogeneity), Hurlin (heterogeneous-panel causality), and Pedroni (panel cointegration). They are repeatedly cited together, demonstrating the methodological foundation in the field of panel-data econometrics. The empirical energy-environment-growth literature can be found in other basic sources such as Sarkodie, Farhani, Paramati, Seker, Kahia, Bulut and Zhong. This is because the presence of Krueker confirms that Environmental Kuznets Curve (EKC) is still a relevant theoretical foundation in the field.

3.6. Author Collaboration and Citation Influence

The main paper presents results for the 8 core figures, but authors-level results are also presented in tables to provide the reader with summary information on collaboration and citation influence without additional network maps. A minimum threshold of five documents per author was used for the co-authorship analysis of the authors. Finally, there were 50 authors, 10 clusters, 111 links, and a total link strength of 197. Table 6 reveals that among the authors with higher level of co-authorship strength are Adebayo, Awosusi, Bekun, Gyamfi, Khan, Murshed, Alola, and Sharif, Kuppumedu, and Kirikkaleli.

Table 5
Top Co-cited References

Cited Reference	Citations	Total Link Strength
Westerlund (2007) Testing for error correction in panel data.	58	235
Pesaran (2007) A simple panel unit root test in the presence of cross-section dependence.	44	194
Pesaran and Yamagata (2008) Testing slope homogeneity in large panels	34	158
Dumitrescu and Hurlin (2012) Testing for Granger non-causality in heterogeneous panels	28	129
Bekun et al. (2019) Toward a sustainable environment	41	120
Farhani and Shahbaz (2014) What role of renewable and non-renewable electricity consumption	35	118
Pedroni (2004) Panel cointegration	21	107
Pesaran (2006) Estimation and inference in large heterogeneous panels	43	102
Baloch et al. (2019) Effect of natural resources, renewable energy and economic development	23	100
Bhattacharya et al. (2017) The dynamic impact of renewable energy and institutions	21	96
Im et al. (2003) Testing for unit roots in heterogeneous panels	22	94
Grossman and Krueger (1995) Economic growth and the environment	20	82
Anwar et al. (2021) The moderating role of renewable and non-renewable energy	20	82
Dogan and Seker (2016) Determinants of CO2 emissions in the European Union	20	80
Shen et al. (2021) Does green investment, financial development and natural resources rent limit carbon emissions?	26	78

Note: *Co-cited references are ranked by total link strength. Reference titles are shortened for readability, while complete bibliographic details are provided in the reference list.*

Table 6
Top Authors by Co-authorship Strength

Author	Documents	Citations	Total Link Strength
Adebayo, Tomiwa Sunday	22	2,392	32
Kirikkaleli, Dervis	18	1,891	23
Murshed, Muntasir	14	1,496	20
Alola, Andrew Adewale	23	3,378	18
Bekun, Festus Victor	15	2,983	16
Awosusi, Abraham Ayobamiji	7	443	12
Gyamfi, Bright Akwasi	9	713	12
Shahbaz, Muhammad	14	2,645	12
Khan, Syed Abdul Rehman	11	1,666	11
Sharif, Arshian	13	2,104	11
Anser, Muhammad Khalid	8	656	10
Onifade, Stephen Taiwo	7	550	9
Rjoub, Husam	5	149	9
Sinha, Avik	10	1,757	9
Udemba, Edmund Ntom	14	467	9
Yu, Zhang	9	988	9
Agyekum, Ephraim Bonah	5	237	8
Balsalobre-Lorente, Daniel	8	1,698	8
Irfan, Muhammad	8	1,335	8
Mahmood, Haider	8	781	8

Note: *Authors are ranked according to total link strength in the co-authorship analysis.*

The citation network of authors yielded a smaller and more diffuse network of citations, with 30 authors, 12 clusters, 41 links, and a total link strength of 43. Table 6 shows that Pata, Mehmood, Bekun, Balsalobre-Lorente, Agyekum, Murshed, Adebayo, Kirikkaleli, Raihan, Mahmood, and Alola are important authors in the citation-impact structure. Pata has the highest author-level total link strength, and high citations across the field for Alola, Bekun, Adebayo and Kirikkaleli.

Table 7
Top Authors by Citation Influence

Author	Documents	Citations	Total Link Strength
Pata, Ugur Korkut	7	1,677	22
Mehmood, Usman	8	413	9
Bekun, Festus Victor	15	2,983	7
Balsalobre-Lorente, Daniel	8	1,698	6
Agyekum, Ephraim Bonah	5	237	3
Murshed, Muntasir	14	1,496	3
Adebayo, Tomiwa Sunday	22	2,392	2
Destek, Mehmet Akif	5	308	2
Emir, Firat	6	185	2
Hossain, Mohammad Razib	6	495	2
Khan, Uzma	6	375	2
Kirikkaleli, Dervis	18	1,891	2
Li, Rongrong	7	722	2
Mahmood, Haider	8	781	2
Onifade, Stephen Taiwo	7	550	2
Raihan, Asif	10	1,284	2
Udemba, Edmund Ntom	14	467	2
Wang, Qiang	7	722	2
Ali, Sajid	6	669	1
Alola, Andrew Adewale	23	3,378	1

Note: *Authors are reported from the citation analysis by authors. Total link strength indicates author-level citation connectivity in VOSviewer.*

4. Discussion

The results indicate that there are three interrelated knowledge fields in the literature on renewable energy, carbon emissions, and sustainable development. The first domain is related to economic growth, environmental quality and sustainable policy. It is evidence of the ongoing significance of the energy-environment-growth nexus and the issue of how renewable energy can lower carbon emissions while not stifling economic growth. Economic growth, environmental economics, trade, finance, green economy and environmental quality have a high presence in the field, indicating that there are strong ties with development economics and environmental policy.

The second domain relates to renewable energy systems and technologies for energy transition. The term technology deployment is evident in the presence of renewable energy resources, solar energy, wind power, power generation, energy storage, clean energy, hydrogen production, and energy policy. This is in line with sustainability transition literature that highlights the importance of technological innovation, infrastructure development and energy-system transformation for low-carbon development (Geels, 2002; Markard et al., 2012).

The third domain is related to carbon emissions, greenhouse gases, carbon neutrality, carbon capture, circular economy, life cycle assessment, ecological footprint and mitigation. The number of documents that link renewable energy and climate-policy targets and carbon-neutrality strategies grew during this cluster. The overlay results also indicate a shift in the focus of new research to environmental sustainability, green finance, ecological footprint, natural resources, carbon neutrality and finance. This is a sign that the field is increasingly policy-driven and finance-driven and that institutional, investment and governance structures are increasingly recognized as playing a supporting role in low-carbon transition.

Collaborations with the country show a high geographical spread and strong representation by emerging economies in the research network. Australia, Spain, Taiwan and Lebanon are also prominently featured while Pakistan, Malaysia, Saudi Arabia, Nigeria, Bangladesh and Iran also make an appearance. This could be a reflection of the importance of renewable energy and carbon-emission issues for countries with energy-security problems, growth pressures and climate vulnerability. The results also reveal that international

partnerships are not limited to more traditional high income research economies, but the use of Asia, Middle East and developing economies is becoming more prevalent.

The source level results show that the literature comes from non-disciplinary journals and not from one disciplinary journal. Some of the key journals that feature environmental papers include Environmental Science and Pollution Research, Renewable Energy, Journal of Environmental Management, Journal of Cleaner Production, Science of the Total Environment, Resources Policy and Sustainability (Switzerland). This reinforces the fact that the field is at the nexus of environmental science, energy studies, sustainability, resource policy and applied economics.

It is important to note that the co-citation results show that the field's intellectual background is methodological. The Westerlund's, Pesaran's, Yamagata's, Hurlin's and Pedroni's econometric references are often co-cited with each other indicating that empirical research in this area often uses panel unit-root tests, panel co-integration, slope heterogeneity tests, and causality models. Concurrently, the references that were co-cited reveal that the substantive ground of the field is in energy-environment-growth nexus and the Environmental Kuznets Curve framework literature.

5. Implications

5.1. Theoretical implications

The study gives a structured overview of the relationship between renewable energy, carbon emissions and sustainable development and their scientific literature. It can be seen that the keyword clusters capture three theoretical perspectives such as the energy-transitions perspective, the energy-environment-growth perspective, and the climate-mitigation perspective. This aids future researchers to place their research in the knowledge structure. Researchers in the field of renewable energy technology can link their research to the issue of sustainability policy and economic-growth debate, and researchers in the field of macroeconomic or econometric modeling can better include the technological and carbon-neutrality aspect.

5.2. Policy implications

It is suggested that renewable energy policy should not just be considered as a technological problem. The key concepts in the literature are sustainable development, carbon emission, economic growth, environmental quality and energy policy. This suggests that coordinated energy planning, green regulation, green finance, technological innovation and international cooperation policies will play a crucial role in effective low-carbon transition. Policymakers in developing and emerging economies could benefit in particular from combining the adoption of renewables with industrial policy, trade policy, climate finance and environmental governance.

5.3. Practical implications for researchers and journals

The results are useful for researchers to find key journals, authors, countries, and references that might be helpful to them in designing research. The analysis shows that renewable energy, carbon emissions and sustainable development are a good interdisciplinary field with high relevance for energy and environmental journals. New manuscripts on this topic can improve by presenting links between the mechanisms of renewable energy and the impacts on carbon emissions, sustainable development indicators and policy implications.

6. Conclusion

To identify and map the literature from Scopus database on renewable energy, carbon emissions and sustainable development from the year 2004 to 2024, a bibliometric mapping was conducted. The study proceeded by analysing 1,481 journal articles and reviews using VOSviewer for keyword co-occurrence analysis, country co-authorship analysis, bibliographic

coupling analysis, co-citation analysis and author-level analysis. The results illustrate the following three main thematic clusters, namely: economic growth, environmental quality and sustainability policy; renewable energy systems and energy-transition technologies; and carbon emissions, greenhouse gases and climate mitigation.

In this field, the country collaboration results show that Pakistan, Malaysia, Saudi Arabia, Australia, Nigeria, Bangladesh, Taiwan, Iran, Spain and Lebanon are the top contributor. Environmental Science and Pollution Research, Resources Policy, Renewable Energy, Journal of Environmental Management, Journal of Cleaner Production, Journal of the Environment, and Sustainability (Switzerland) are important outlets for publishing in this field. Document-level bibliographic coupling demonstrates that the studies that are cited most often tend to form a few intellectual streams, and co-citation analysis indicates that the field has a basis in both panel econometric methods and empirical studies of energy-environment-growth.

In general, the study reveals a shift in research directions on renewable energy, carbon emissions and sustainable development from technical and emission-based research to the discussion of sustainable economic transition, carbon neutrality, green finance, environmental sustainability and ecological footprint. The results offer a valuable knowledge map for scholars, policy makers, and journal stakeholders who are interested in the field of energy and environmental sustainability studies.

7. Limitations and Future Research Directions

There are a number of limitations in this study. Firstly, only documents with a Scopus index were analyzed. While Scopus offers good quality bibliographic information, future work can compare Scopus to Web of Science, Dimensions, or others. Second, only articles from journals and reviews were counted, so this could overlook relevant research in other publications such as newspapers, books, or conference proceedings. Third, the bibliometric results are influenced by the search terms, database coverage and the threshold decisions. The search strategy was designed to be transparent and replicable but may have been performed with different search strings. Fourth, the VOSviewer maps give insights into the structure and relations but are not a substitute for detailed qualitative content analysis. The application of bibliometric mapping in combination with systematic literature reviews, text mining, topic modelling, or meta-analysis, could be used in future studies to explore the substantive results of the field in greater depth.

The study can be broadened to other subfields like green finance and carbon neutrality, renewable energy and ecological footprint, renewable energy and energy security, and the part of artificial intelligence in energy and environmental sustainability for future research. Comparisons of the regions may also be helpful, particularly in Asia, Africa, the Middle East and emerging economies where both renewable and carbon-emission issues are closely tied to development priorities.

Authors Contribution

Altaf Hussain: conceptualized the study, designed the bibliometric methodology, developed the search strategy, collected and refined the Scopus dataset, performed the VOSviewer analysis, interpreted the results, prepared the figures and tables, and drafted the original manuscript.
Muhammad Atif Nawaz: contributed to the refinement of the research idea, reviewed the methodological framework, supported the interpretation of bibliometric findings, and critically revised the manuscript for academic quality and coherence.
Ruqayya Ibraheem: assisted in reference management, EndNote formatting, citation checking, bibliography preparation, data organization, and final manuscript formatting.
Furrukh Bashir: contributed to the review of the literature, improvement of the discussion section, validation of the interpretation, and critical revision of the manuscript. All authors reviewed and approved the final version of the manuscript.

Conflict of Interests/Disclosures
The authors declared no potential conflicts of interest w.r.t. the research, authorship and/or publication of this article.

Data availability
The bibliographic data were retrieved from Scopus. The exported dataset and VOSviewer files can be made available from the corresponding author upon reasonable request, subject to database-use restrictions.

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