

SYSTEMATIC LITERATURE REVIEW OF CARBON-NEUTRAL ECONOMY CONCEPT

Ihor Vakulenko,  <https://orcid.org/0000-0002-6994-833X>

PhD, Sumy State University, Ukraine

Liudmyla Saher,  <https://orcid.org/0000-0002-5628-5477>

PhD, Institute of Economic Research of the Slovak Academy of Sciences, Slovak Republic

Anastasiia Shymoshenko,  <https://orcid.org/0009-0008-1846-0781>

Student, Sumy State University, Ukraine

Corresponding author: Ihor Vakulenko, i.vakulenko@biem.sumdu.edu.ua

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Abstract: *The purpose of the article is to study trends in the development of scientific interest in the issue of implementing a carbon-neutral economy. The authors performed a bibliometric analysis of the publications indexed in the Scopus database using VOSviewer 1.6.16 software and Microsoft Excel. This analysis contributes to determining prospects for transitioning to a carbon-neutral economy and priority areas requiring special attention to accelerate this process. The obtained results of the study of the patterns of the development of the carbon-neutral economy indicate that this concept has a dynamic development, which traces the prerequisites for the formation of a powerful scientific school that investigates the influence of changes in the level of energy efficiency in the process of carbon-neutral development of the national economy. Analysis of the dynamics of publication activity demonstrates a reasonably rapid growth in the number of publications. From 1992 to March 2023, the average growth rate of published research results in the analyzed field was 28.50%. A comparison of subject areas in the study of the carbon-neutral economy shows the predominance of energy, ecology, and socio-economic studies. As a result of the bibliometric analysis of 654 publications indexed by the scientometric database Scopus during 1992-2023 on the topic of the carbon-neutral economy using the software VOSviewer v. 1.6.10, six scientific clusters were identified, which study the possibilities of building an economic system with minimal carbon emissions, taking into account the technical, technological, climatic, social and economic aspects of this issue. However, there is an urgent need to study the organizational and economic mechanisms of replacing non-renewable energy resources with renewable ones in the conditions of rapid changes in the global energy market. The study of the geographical affiliation of the authors of scientific works in this area showed that scientists from China, the USA, Great Britain, Germany, India, Canada, Italy, Japan, Switzerland, and Spain published the most significant number of publications. The share of publications by geographical affiliation to these countries is 75%. At the same time, the number of publications in the Scopus database published by domestic authors is relatively small, which once again confirmed the lack of research and timeliness of the study carried out in Ukraine.*

Keywords: carbon-neutral economy, bibliometric analysis, visualization, renewable energy, greenhouse gases, climate policy, sustainable development.

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1. Introduction

The events that have taken place in the global political arena in recent years indicate the emergence of long-term trends that will inevitably affect the world economy and the social sector. The rejection of the vast majority of EU countries from Russian energy carriers, caused by Russia's invasion of Ukraine, caused a shock in the European energy market. Experts' opinions regarding the further development of the energy sector were divided, which only increased the uncertainty regarding the prospects of the economic situation of the EU in the short and long term. Today, when the shock has partially passed, we can calmly look at the prospects for energy development, which can be realized shortly. In particular, it is about accelerating the transition to a carbon-neutral economy. A bibliometric analysis of publications on a carbon-neutral economy contributes to identifying real prospects for such a transition and priority areas that require special attention to accelerate this process.

2. Literature Review

The study of the key characteristics of CO₂ emissions (Alataş, 2020; Liu, 2022), together with the determination of carbon neutrality goals (Shao, 2021), is the first stage of forming regional or global decarbonization strategies.

Analysis of the essence, features of the implementation of decarbonization technologies (Halloran, 2007), and technologies of harmful emissions are key issues in research on the analyzed topic. Among the tools of the transition to a carbon-neutral economy, the authors propose an increase in the share of non-fossil energy (Liu, 2022), the transition from fossil fuels to renewable energy and the development of low-carbon technologies, low-carbon agriculture, changing food habits and increasing the value of food and agricultural waste (Chen, 2022), the introduction of negative emission technologies, promotion of the development of emission reduction technologies (Liu, 2022). The concept of a green economy (Yusuf Babangida Attahiru, 2019), one of the components of which is the construction of green roads and highways, can also be considered one of the decarbonization tools of the economy.

Research on the use of alternative energy sources (Kexiang, 2021), determination of their share in the energy balance of Ukraine, and implementation of a forecast of the achievement of the set goals in providing a certain percentage of primary energy from renewable sources (Pimonenko, 2021b) demonstrate the need to determine their distribution mechanisms, given the relatively slow rates of replacement of fossil energy sources (Pimonenko, 2021a).

In part, this issue can be solved by developing a roadmap for harmonizing Ukrainian and European energy market regulation standards on the way to transition to a carbon-free economy. Part of the basis for forming this map is the definition of approaches, measures, and tools for implementing the principle of a carbon-neutral economy (Pimonenko, 2021; Halloran, 2007; Liu, 2022; Chen, 2022).

A study of approaches to reforming the economy at the level of government institutions for the transition to a carbon-neutral economy (Stern, 2022) demonstrates the need for precise coordination of the actions of governments and markets to overcome existing challenges, as well as to encourage investment (Shao, 2021) and the introduction of innovations to promote the decarbonization of the economy.

3. Methodology and research methods (for research and theoretical papers).

The Scopus database was chosen as the primary source of information. Such parameters searched for "title, abstract, keywords" by the "carbon neutral economy" keyword combination. Considering the multidisciplinary nature of the research topic, we introduced additional restrictions regarding the branches and language of publications (table 1). Accordingly, scientific works written in English on the economy, finance, management, energy, and environmental protection were selected. On this dream, 654 publications were selected from 1992 to 2023. To obtain a complete analysis, VOSviewer 1.6.16 software and Microsoft Excel were used to visualize bibliometric networks of scientific publications. All data used in this work were downloaded from publicly available databases, so ethics committee approval is not required.

Table 1. Stages of the literature search and selection process

Stage	Filters	Result
Stage 1 Data Collection		
Choice of suitable information sources	Scopus Database	
Identification of search field in the database	Title, abstract, keywords	
Identification of search keywords	“Carbon neutral economy”	944 publications
Stage 2 Data screening		
Choice of the language	English	895 publications
Choice of the field of publication	Energy; Environmental Science; Social Sciences; Business, Management, and Accounting; Economics, Econometrics, and Finance; Decision Sciences; Earth and Planetary Sciences; Multidisciplinary	654 publications
Identification of the publication's time limits	since the beginning of the start of the articles' publication on the subject in journals referenced by the databases	654 publications
Stage 3 Bibliometric analysis		
Tools	VOSviewer 1.6.16, Microsoft Excel	Visualization maps, charts, tables

Source: developed by the authors.

4. Results

Figure 1 shows the growth dynamics of the publications' number into the essence and parameters of the carbon-neutral economy. From 1992 to March 2023, the average growth rate of published research results in the analyzed field was 28.50%. Until 2008, the average annual number of publications indexed in the Scopus database did not exceed 20 units. Accordingly, for further analysis, we chose the period from 2008 to 2023. The highest number of citations per publication occurred in 2015, 2018, and 2023 (35, 36, and 33 citations per publication, respectively). There is a positive trend of increasing the number of publications and the number of citations, which generally characterizes the relevance of the research being carried out.

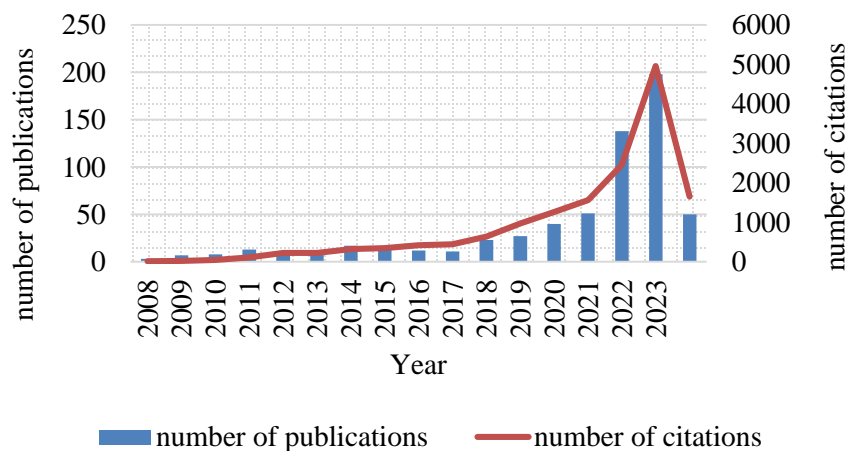


Figure 1. The publication activity dynamics of scientists regarding the carbon-neutral economy

Source: authors' analysis at Scopus Database.

A comparison of the subject areas in the study of the carbon-neutral economy (Fig. 2) shows the predominance of energy, ecology, and socio-economic research, which is entirely predictable, taking into account the need to study the economic and social effects of any technological solutions in the field of energy and the importance of solving the issue to reduce the negative impact of the energy industry on the environment.

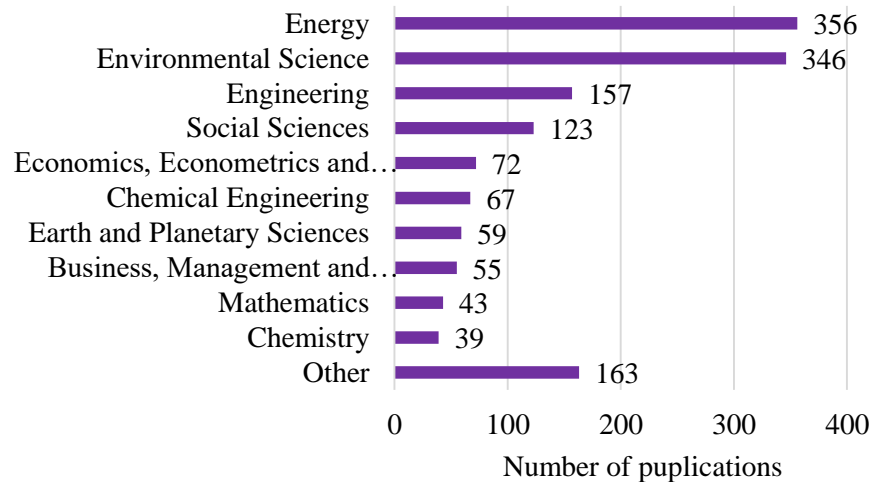


Figure 2. Publications on the carbon-neutral economy, selected by research areas

Source: authors’ analysis at Scopus Database.

The ten most cited publications in carbon-neutral economy research indexed by the Scopus database are shown in Table 2. All articles are cited more than 200 times. It indicates that the world scientific community highly values these publications. A scientific discussion is held, which emphasizes the relevance of the research topic. All articles are published in highly-ranked journals and included in the Q1 quartile.

Table 2. List of the most cited publications in carbon-neutral economy research

No	Author(s)	The article’s title	Citation	Journal/year of publication/quartile
1	Sivula K., Van De Krol R.	Semiconducting materials for photoelectrochemical energy conversion	974	Nature Reviews Materials, 2016 (Q1)
2	Song Q.-W., Zhou Z.-H., He L.-N.	Efficient, selective and sustainable catalysis of carbon dioxide	702	Green Chemistry, 2017 (Q1)
3	Muradov N.Z., Veziroğlu T.N.	"Green" path from fossil-based to hydrogen economy: An overview of carbon-neutral technologies	671	International Journal of Hydrogen Energy, 2008 (Q1)
4	Lee D.S., Pitari G., Grewe V., Gierens K.; Penner J.E.; Petzold A.; Prather M.J.; Schumann U.; Bais A.; Bernsten T.; Iachetti D.; Lim L.L.	Transport impacts on atmosphere and climate: Aviation	499	Atmospheric Environment, 2010 (Q1)
5	Khan S.A., Rashmi Hussain M.Z., Prasad S., Banerjee U.C.	Prospects of biodiesel production from microalgae in India	423	Renewable and Sustainable Energy Reviews, 2009 (Q1)
6	Barth M., Boriboonsomsin K.	Energy and emissions impacts of a freeway-based dynamic eco-driving system	420	Transportation Research Part D: Transport and Environment, 2009 (Q1)
7	Abbasi T., Abbasi S.A.	Biomass energy and the environmental impacts associated with its production and utilization	399	Renewable and Sustainable Energy Reviews, 2010 (Q1)
8	Singh D., Sharma D., Soni S.L., Sharma S., Kumar Sharma P., Jhalani A.	A review on feedstocks, production processes, and yield for different generations of biodiesel	396	Fuel, 2020 (Q1)
9	Chen C., Khosrowabadi Kotyk J.F., Sheehan S.W.	Progress toward Commercial Application of Electrochemical Carbon Dioxide Reduction	297	Chem, 2018 (Q1)
10	Yue M., Lambert H., Pahon E., Roche R., Jemei S., Hissel D.	Hydrogen energy systems: A critical review of technologies, applications, trends, and challenges	277	Renewable and Sustainable Energy Reviews, 2021 (Q1)

Source: authors’ analysis at Scopus Database.

The thematic focus of the analyzed publications can be tentatively divided into three areas:

- 1) Research of alternative energy sources;
- 2) Strategic approaches to reducing CO2 emissions;
- 3) Technical and other features of CO2 conversion.

An important place among the studies is the analysis of the potential of using alternative fuel/energy (Abbasi, 2010; Khan, 2009; Singh, 2020; Yue, 2021).

Scientists pay attention to the issues of determining the potential of different biomass sources as raw materials for energy production (Abbasi, 2010) and investigate the impact of using different energy options obtained from biomass on the environment. Evaluation of various raw materials for the production of biodiesel, determination of their advantages and disadvantages, and potential and economic feasibility of application (Singh, 2020; Khan, 2009) allows for reducing the time before the transition of the automotive industry to alternative solutions, which is biodiesel, which due to its renewable, non-toxic and ecological to nature is a good solution on the way to transition to a carbon neutral economy. In the paper (Muradov & Veziroğlu, 2008), a review and assessment of modern technologies' commercial potential for producing carbon-free energy carriers and transport fuel is carried out. The authors determined that without changes in the infrastructure and/or a technological breakthrough in several industries, it is impossible to achieve the goal of producing the required amount of energy.

In addition to the use of alternative fuels with neutral carbon emissions, several strategies allow reducing fuel consumption and CO2 emissions (Barth, 2009; Lee, 2010), including not only the use of fuel-efficient vehicles but also the very approaches to driving (eco-driving), using the results of assessment and modeling of the impact of aviation on the climate for a clearer understanding of the possibilities of negative implications. Research on methods of storing sunlight energy as a chemical fuel (Sivula, 2016) and features of efficient CO2 conversion (Song, 2017) are also elements of the transition to a carbon-neutral energy economy (Chen, 2018). The researchers who have made the most significant contributions to this area are listed in Table 3 (as determined by the number of their publications on the selected topic). The most productive authors in this field are Ahmad M., Capros P., Murshed M., who respectively represent China, Greece, and Bangladesh. In addition to a relatively high rate of citations per publication, these researchers have high h-index values. It confirms the high scientific level and relevance of their research. According to the Scopus database, most of the most cited scientists represent Europe, the USA, and China.

Table 3. List of authors with the largest number of publications in carbon-neutral economy research

Author Name	Total publications (on the research topic)	h-index	Affiliation
Ahmad, M.	4	44	Ningbo University of Finance & Economics, Ningbo, China
Capros, P.	4	24	National Technical University of Athens, Athens, Greece
Murshed, M.	4	42	North South University, Dhaka-1229, Bangladesh
Alola, A.A.	3	34	Inland Norway University of Applied Science, Elverum, Norway
Bracmort, K.	3	43	Agricultural Conservation and Natural Resources Policy, United States
Fragkos, P.	3	20	National Technical University of Athens, Athens, Greece
Goepfert, A.	3	37	University of Southern California, Los Angeles, United States
Klemeš, J.J.	3	73	Brno University of Technology, Brno, Czech Republic
Mahmood, H.	3	27	Prince Sattam Bin Abdulaziz University, Al Kharj, Saudi Arabia
Prakash, G.K.S.	3	84	University of Southern California, Los Angeles, United States
Rehman, A.	3	37	Henan Agricultural University, Zhengzhou, China
Van de Voorde, M.	3	9	Delft University of Technology, Delft, Netherlands

Source: authors' analysis at Scopus Database.

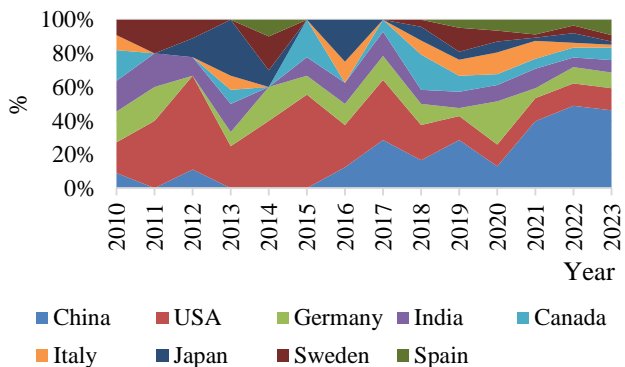
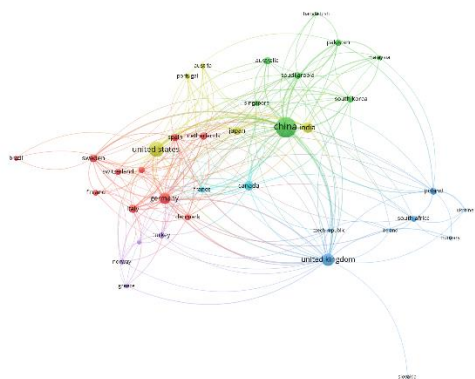
The analysis of the sources of scientific publications also confirms the relevance of the research topic. These journals have high SNIP. 60% of magazines are included in Q1, 40% - in Q2. The largest works were published in Energies (30) and Sustainability (27). However, the largest number of citations per 1 publication is in the journals Renewable and Sustainable Energy Reviews (92.21 per article) and Energy Policy (50.07 per article).

Table 4. Top 10 Scopus sources by publications on the carbon-neutral economy in 1992-2023

Source Title	Q	SNIP	Number of published articles	Number of citations	Citations per 1 publication
Energies (Switzerland)	Q2	1,10	30	229	7,63
Sustainability (Switzerland)	Q2	1,31	27	275	10,19
Renewable And Sustainable Energy Reviews (United Kingdom)	Q1	4,53	19	1752	92,21
Journal Of Cleaner Production (United Kingdom)	Q1	2,44	17	303	17,82
Energy Policy (United Kingdom)	Q1	2,03	15	751	50,07
Bioresource Technology (United Kingdom)	Q1	2,06	12	320	26,67
Environmental Science And Pollution Research (Germany)	Q2	1,15	12	170	14,17
International Journal Of Environmental Research And Public Health (Switzerland)	Q2	1,44	12	103	8,58
Journal Of Environmental Management (United States)	Q1	0,82	11	428	38,91
Applied Energy (United Kingdom)	Q1	2,56	10	337	33,70

Source: authors' analysis at Scopus Database

Among the leaders of publishing activity in a geographical section (Fig. 3) are China, the USA, and European countries: China - 172 publications (16.9%); USA – 96 (11.35%); Great Britain – 64 (8.53%); Germany – 52 (7.58%); India – 45 (7.10%); Canada – 35 (5.94%); Italy – 28 (5.05%); Japan – 26 (4.94%); Sweden – 26 (5.20%); Spain – 25 (5.27%). Data from 10 countries account for over 75% of the total publications in carbon-neutral economy research published from 1992 to 2023 in journals reviewed by the Scopus database. It should be noted that the number of publications in the Scopus database by Ukrainian authors is relatively small - 6 publications. At the same time, they were published within the last three years, which indicates insufficient research and timeliness of study in Ukraine.



Ranking	Countries	Publications, n	%	H-index	Average citations per document
1	China	172	16,90	32	19,56
2	United States	96	11,35	24	39,78
3	United Kingdom	64	8,53	17	21,27
4	Germany	52	7,58	13	40,52
5	India	45	7,10	15	39,67
6	Canada	35	5,94	12	25,54
7	Italy	28	5,05	10	29,32
8	Japan	26	4,94	11	17,38
9	Sweden	26	5,20	11	17,08
10	Spain	25	5,27	10	12,28

Figure 3. A. Visualization map of co-authored scientists according to the country specified in the affiliation; B. Top 10 most productive countries related to carbon neutral economy research; C. The annual number of publications in the top 10 prolific countries from 1992 to 2023

Most published studies on the carbon-neutral economy are increasing in most countries (except India, Italy, and Spain in 2022). The highest growth rates are in China and Germany (the number of publications on the topic in 2022 compared to 2021 has more than doubled). Average growth rates for the analyzed period (2010-2023) are highest in China, Germany, and Japan (119%, 64%, and 43%, respectively).

We used the VOSviewer 1.6.16 software for a more detailed analysis of the actual content of publications on the analyzed topic. This product allows you to explore the direction of scientific research combined with the principle of essential proximity.

From among 5824 keywords, 241 relevant ones were selected (according to the principle of thematic correspondence, avoidance of repetitions, and removal of irrelevant words "article", "research", etc.). Based on them, we created a visualization map (Fig. 4). It shows the frequency of use of the terms (the size of the circle), the closeness of the connections between them, and the different combinations of words both within and between clusters. Each node in the figure represents a particular keyword. Nodes and font size represent the number of occurrences of keywords. Keywords with close correlation are combined in one cluster of the same color. Accordingly, 6 clusters were formed.

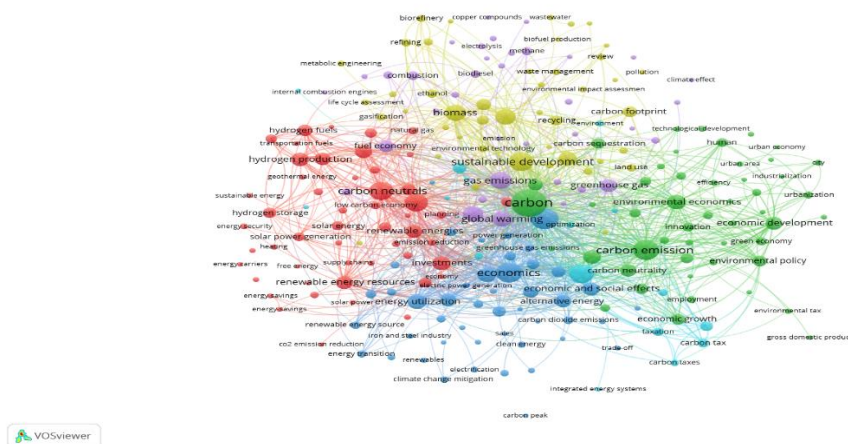


Figure 4. Visualization map of the keyword network in the carbon neutral economy sphere (based on the Scopus database using VOSviewer)

The red cluster, which contains 51 keywords, is formed around the "fossil fuels" concept. And combines the following areas: carbon naturals, renewable energy resources, investment, renewable energies, solar energy, hydrogen, hydrogen production, hydrogen fuels, energy conservations, cost-effectiveness, natural gas, and costs.

The authors of publications belonging to this cluster focus on developing technologies that are already available or will be available shortly for use in large-scale energy projects designed to increase the amount of energy generation from renewable sources.

The green cluster is the second largest (49 items) and contains the concept of "carbon" at its core.

The research results of this cluster are aimed at the formation of economic and organizational conditions for the successful implementation of projects to replace non-renewable energy with renewable energy and the alignment of energy and climate policy goals with existing economic opportunities.

Keywords are characteristic of publications of this cluster: carbon emission, Environmental economics, economic development, renewable energy, carbon neutrality, economic growth, Environmental policy, Environmental impact, human, and carbon sequestration.

Publications, the authors of which focused on various aspects of climate change, are formed into a blue cluster containing 46 items.

Most of the articles in this cluster directly or indirectly investigate the issue of climate change. Due to the multifaceted nature of the research subject, the focus of the articles is significantly different, from the technological aspects of reducing greenhouse gas emissions to the economic and social effects observed now or expected in the future due to various scenarios of greenhouse gas emissions.

Keywords are characteristic of publications of this cluster: Economics, energy utilization, energy policy, alternative energy, decarbonization, economic and social effects, carbon neutralities, carbon neutral,

The yellow cluster contains 44 items and is devoted to sustainable development issues. In this context, scientists have paid considerable attention to defining the features of the implementation of the goals of the circular economy, which is based on the principle of three R "Reduce - Reuse - Recycle": reducing the use of resources and switching to renewable materials, maximally efficient use of products and recovery of by-products and waste for further use in the economy.

Keywords are characteristic of publications of this cluster: sustainable development, circular economy, biomass, life cycle, processing, ecology, sustainability, forestry, and carbon footprint.

The purple cluster is formed based on 36 items around the issue of energy efficiency in the context of overcoming the challenges of global warming. Unlike the publications of other clusters, the authors of studies in this cluster study traditional energy technologies and renewable energy technologies that are used or may be widely implemented soon. Researchers are trying to identify technologies that are energy and cost-effective, affordable, and have a high potential to reduce greenhouse gas emissions while combating climate change.

Keywords characteristic of the publications of this cluster: energy efficiency, global warming, gas emission, fuel economy, greenhouse gas, combustion, methane, biodiesel, chemical notoriety

The blue cluster is based on the concept of "emission control." It contains publications whose authors study climate policy and emission control tools, including emission quota trading systems for setting the maximum allowable amount of greenhouse gas emissions within the country and using tax levers within the framework of climate policy implementation, including promoting sustainable production.

Keywords are characteristic of the publications of this cluster: control taxes, carbon tax, climate policy, energy, international trade, pollution tax, reduction, renewable fuels, and sustainable production.

5. Conclusions

The obtained results of the study of the patterns of development of the carbon-neutral economy indicate that this concept has a dynamic development, which traces the prerequisites for the formation of a powerful scientific school that investigates the power of the influence of changes in the level of energy efficiency in the process of carbon-neutral development of the national economy. Bibliometric analysis of publication activity on the carbon-neutral economy using VOSViewer v. software. 1.6.10 made it possible to identify and visualize six scientific clusters that study the possibilities of building an economic system with minimal carbon emissions, considering

this issue's technical, technological, climatic, social, and economic aspects. At the same time, despite a significant number of publications, it is worth noting that there is an urgent need to study the organizational and economic mechanisms of replacing non-renewable energy resources with renewable ones in the conditions of rapid changes in the global energy market.

Author Contributions: Conceptualization, I.V. and L.S.; methodology, I.V.; software, I.V., L.S.; validation, I.V., L.S.; formal analysis, L.S., A.S.; investigation, I.V.; resources, I.V., A.S.; data curation, L.S, A.S.; writing-original draft preparation, I.V., L.S.; writing-review and editing, I.V.; visualization, L.S.; supervision, I.V.; project administration, I.V.; funding acquisition, I.V.

Conflicts of Interest: Authors declare no conflict of interest.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

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