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Review

Research on Carbon Emission Structure and Model in Low-Carbon Rural Areas: Bibliometric Analysis

Zejun Yu [1], Yao Wang [2,*], Bin Zhao [3], Zhixin Li [2,*] and Qingli Hao [1]

[1] School of Architecture, Tianjin University, Tianjin 300072, China; yuzejun1994@tju.edu.cn (Z.Y.); qingli_h@tju.edu.cn (Q.H.)
[2] School of Architecture, Tsinghua University, Beijing 100190, China
[3] School of Public Administration, Heilongjiang University of Science and Technology, Harbin 150006, China; zhbin202206@163.com
* Correspondence: wangyao22@mails.tsinghua.edu.cn (Y.W.); lizhixin22@mails.tsinghua.edu.cn (Z.L.)

Abstract: As the energy crisis and environmental problems are exacerbated, rural carbon emissions have gradually attracted increasing attention. Meanwhile, rural areas have the important function of ecological carbon sequestration, so the research field of carbon emissions has gradually expanded from urban to rural areas in recent years. To systematically sort out the research progress regarding low-carbon rural areas, a total of 583 papers published during 2013–2023 were acquired through the bibliometric analysis method from the "professional field of science of building technology" in the core database of Web of Science. Then, the research stage, author cooperation, institutional cooperation, national distribution, and keyword co-occurrence of "low-carbon rural areas" were analyzed via data visualization analysis software VOSviewer, and the current hot issues, such as carbon emission calculation list and elements, carbon emission measurement method/model, and energy saving and emission reduction paths, were further summarized and reviewed. The statistical analysis results show that: (1) in most of the current research on rural carbon emissions, geographical characteristics and rural carbon emissions have been rarely analyzed; (2) there is a lack of interdisciplinary research, e.g., less cooperation with geographic information or other disciplines; (3) the differences and characteristics of rural carbon emission factors in different economies and regions have rarely been analyzed. Based on the analysis, this research pointed out that future research can be comprehensively carried out in formulating rural carbon emission inventory, establishing a multi-scale and multi-regional statistical method and so on. This research also provides a comprehensive analysis and summary of the existing research on the structure and model of carbon emissions in low-carbon rural areas and also presents the problems that need to be paid attention to in the future research, pointing out the research direction for relevant scholars.

Keywords: low-carbon rural area; carbon emission structure; bibliometrics; VOSviewer

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1. Introduction

With global climate change, carbon emissions have become an increasing concern in recent years. According to the report of the International Energy Agency (IEA), global energy carbon emissions reached a record of 36.8 billion tons in 2022 [1]. Rural areas are important areas for human carbon emissions. According to the data released by the World Bank on 21 January 2023, the global rural population touched 4526.1 million in 2022, representing more than half of the world's total population [2]. Therefore, it is particularly important and necessary to study rural carbon emissions. In addition, relevant research shows that the research on carbon emission management is relatively extensive in rural areas compared to urban areas, and thus rural areas have great potential for energy conservation and emission reduction. Hence, it is necessary to explore and summarize the literature data related to rural carbon emissions in recent years.

In recent years, bibliometrics, as an important retrospective method for related research, has been widely used in various research fields. For example, Marina Figueiredo Muller used the multi-criteria decision analysis method to systematically review the literature on sustainability factors, interoperability issues, and life cycle stages of buildings. Through the screening and evaluation of a large number of documents, the author summarized the correlation between life cycle stage and sustainability, and provided the influence matrix between two fields [3]. Based on the method of artificial intelligence, Jack Ngarambe reviewed the current research aiming to improve the thermal comfort of indoor space, summarized the thermal comfort prediction models focusing on various machine learning (ML) algorithms and their deployment in building control systems to achieve the purpose of energy saving, discussed the gaps in the existing literature, and emphasized the potential research direction in the future [4]. Shameri, M.A. systematically reviewed the previous research on building double-skin facade system (DSFS), and summarized the development and future research direction of DSFS [5]. Abdelaziz, E.A. carried out a comprehensive literature review on industrial energy conservation through management, technology, and policy, and found that energy-saving technology can save a lot of electricity, emissions, and water and electricity charges [6]. Thevega, T. summarized building fireproof materials, and put forward the engineering process and tools for evaluating the applicability of coating materials to different building types [7]. Yin, X.F. explored the latest technology of OSC BIM through the bibliometric–qualitative review method, and determined the research trend and the knowledge gap that could be solved in the future research of OSC BIM. This research improved AEC practice by synthesizing the latest technology of OSC BIM and revealing the research demand in this field, thus contributing to the knowledge system [8]. It can be seen that bibliometric technology has been widely used in a large number of research fields, and its accuracy and utility have been verified. In this research, therefore, this method was adopted to systematically analyze the field of rural carbon emissions.

It is difficult to fully and clearly reveal the cooperation network, knowledge structure, and evolution trend of carbon emission structure and model research in low-carbon rural areas through the traditional literature review formed by manually reading a large amount of literature data. Therefore, VOSviewer software (Version 1.6.18) was used for analysis in this research. This investigation aims to systematically generalize and summarize the overall situation of rural carbon emissions-related research in the core collection of Web of Science in the period 2013–2022, including the comparative analysis of the number of articles published by authors, the number of articles published by institutions, the distribution of countries and regions, and the co-occurrence of keywords, and to predict the research direction and trend of rural carbon emissions. The rapid increase in the number of documents published by researchers in this field has posed a new challenge to document data mining. Therefore, it is necessary for this research to systematically review this research field by bibliometrics. In this research, the research data on the carbon emission structure and model of low-carbon rural areas were analyzed from the following five aspects: (1) knowledge map analysis of literature data; (2) analysis of research progress in several hot areas of low-carbon rural areas; (3) discussion and analysis of the research results, and identification and summarization of the research topics, research gaps, and research trends on rural carbon emissions; (4) forecasting of the research prospects on rural carbon emissions; (5) presentation of conclusions and research limitations.

2. Methodology

2.1. Bibliometric Analysis Method

Bibliometrics, which refers to a set of research methods based on literature characteristics and systems, provides an effective tool for quantitative analysis in specific research fields. Bibliometrics uses mathematical and statistical methods to explore various features of documents, including distributed architecture, collaborative relationships, and different modes. Bibliometric analysis, as one of the most effective and extensive quantitative methods, can measure the contributions of different aspects in special research topics. According to Zhou et al., [9] bibliometric analysis not only provides an effective tool to change from the micro level to the macro level but also helps scholars identify future research trends and hot topics.

2.2. Literature Screening

The research results published in the field of rural carbon emissions on the Web of Science (WoS) during 2013–2023 were summarized by using the overall research method (date of retrieval: 19 March 2023).

In this research, the core collection of WoS served as the literature data source, and retrieval was performed using topic fields under an advanced search mode: (((TS = ("Rural" OR "rural area" OR "village" OR "countryside" OR "country" OR "rural areas" OR "villages" OR "town ")) OR TS = ("village" OR "villages" OR "village distribution" OR "rural settlement" OR "traditional village" OR "settlements" OR "community" OR "rural village")) OR TS = ("farmhouse" OR "rural house" OR "house in village" OR "rural housing" OR "agricultural housing" OR "rural houses" OR "house in the countryside" OR "rural building")) AND TS = ("carbon emission" OR "carbon emissions" OR "carbon dioxide emissions" OR "carbon dioxide emission" OR "CO_2 emission" OR " CO_2 emissions" OR "carbon" OR "carbon discharge") on 19 March 2023. Specifically, the research direction was limited to construction building technology. The time span was set as 2013–2023. A total of 584 literature documents were obtained, among which 1 invalid document was excluded through data cleaning, deduplication, and preprocessing, and finally, 583 articles were acquired. The concrete steps are shown in Figure 1.

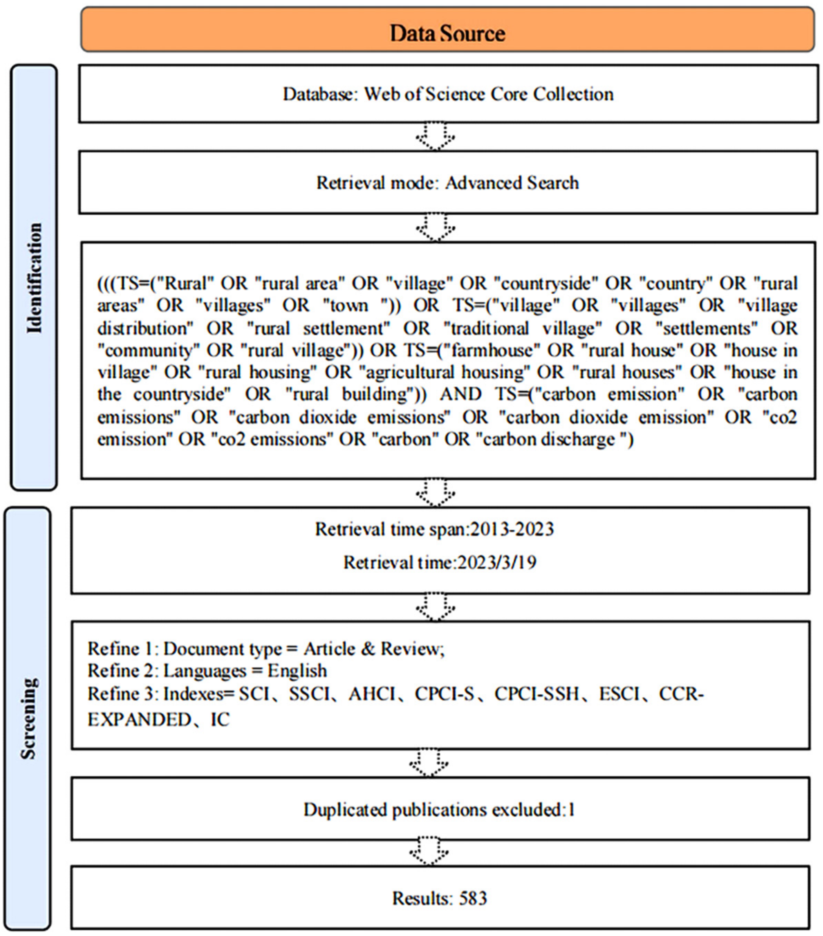

Figure 1. The procedure of the bibliometric analysis on the carbon emission structure and model in low-carbon rural areas.

2.3. Analysis Tool: VOSviewer

VOSviewer is a social network analysis (SNA) tool used to analyze and visualize complex networks. The software can be used to explore different types of knowledge networks, such as keyword co-occurrence, and cooperation network between authors and institutions. By mining potential topics and keywords, users can deeply understand the development trends and hot issues in the relevant literature fields [10]. In 2007, Leydesdorff, L. et al. used VOSviewer to analyze the data of journal papers in SCI literature library, and used the index—"node betweenness centrality"—to evaluate the interdisciplinary degree and interdisciplinary cooperation between journals [11]. In 2012, Waltman, L., et al. proposed a document classification method based on VOSviewer, establishing a journal classification system by virtue of the citation relationships between journals and displaying the interdisciplinary situation in the form of clustering heat maps [12]. In 2017, Glänzel, W. et al. analyzed the literature data in the field of astronomy by using VOSviewer combined with the LDA topic model, and improved the accuracy of literature classification and topic identification through the "core literature" strategy [13].

3. Knowledge Map Analysis via VOSviewer

Based on the bibliometrics theory, the current research situation with regard to rural carbon emissions was mainly combed from keywords, countries, institutions, authors, and time axes in this research.

3.1. Keyword Co-Occurrence Analysis

Keywords are highly summarized and generalized by researchers, which are mainly used to highlight the focus of their research content and help readers quickly understand their main research background. In this research, therefore, the keywords of authors in this research field were explored and analyzed using VOSviewer to exhibit high-frequency keywords and their co-occurrence relationship. Among the 1988 keywords, 70 ones were cited four or more times, specifically as shown in Figure 2.

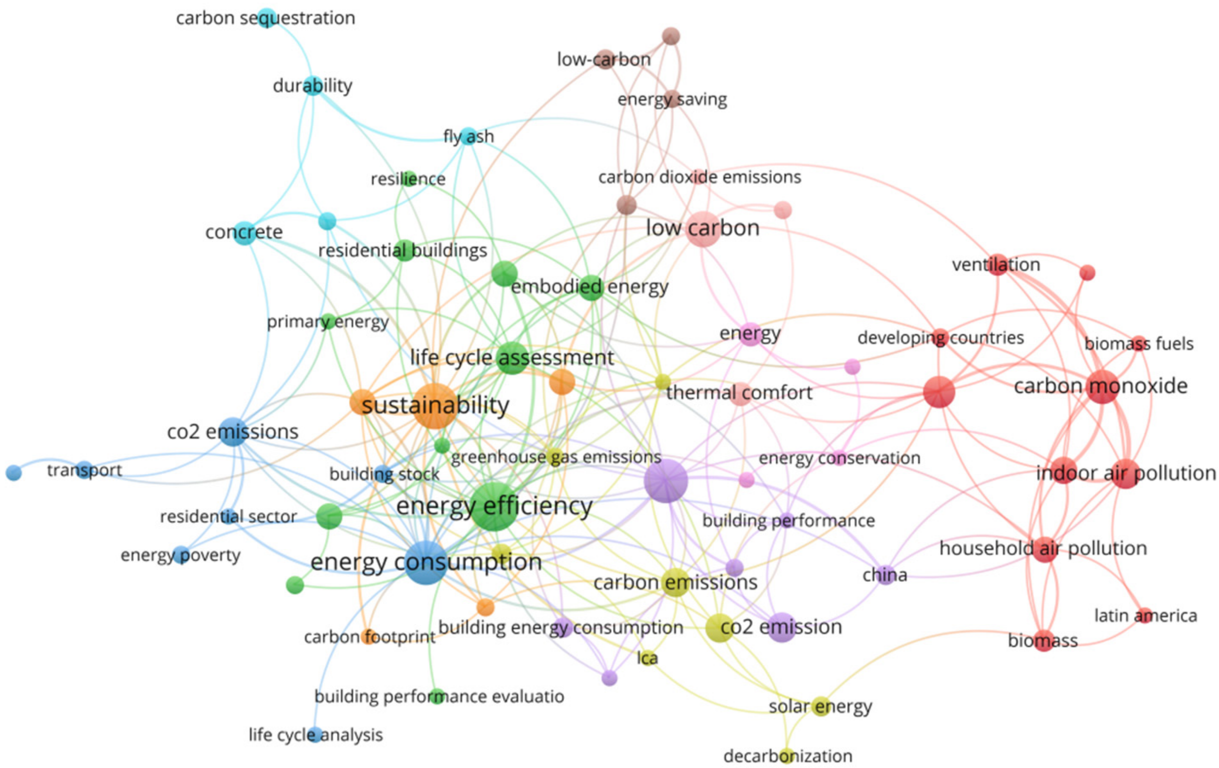

Figure 2. Keyword co-occurrence network analysis.

It can be seen from the figure that the core keyword in the literature data is energy efficiency [14,15]. Meanwhile, the research results also reveal that other several key research topics arousing widespread concern may be related to different research dimensions, such as sustainability (namely, sustainable development indexes, sustainable development) [15,16], energy consumption (namely, solar energy utilization and sustainable consumption) [17–19], climate change (namely, climate risk management) [20,21], and low carbon (namely, low-cost housing) [22,23]. The co-occurrence relationship and co-occurrence times between high-frequency keywords (the thicker the ligature, the more the co-occurrence times there were) are helpful in understanding and reflecting the research topics of rural carbon emissions in the past.

This reflects that in the past research on rural carbon emissions, energy efficiency was a core concern. Topics such as sustainable development, energy consumption, climate change, and low carbon are diverse in different research dimensions. By analyzing the co-occurrence relationship and co-occurrence times between high-frequency keywords, the theme and relationship of rural carbon emission research in the past can be understood more deeply. These results provide important reference points and guidance for the further discussion and management of rural carbon emissions. In the future research, the comprehensive solutions to sustainable development, energy consumption, climate change, and low carbon can be further explored on the basis of energy efficiency, so as to achieve the goal of reducing rural carbon emissions and achieving sustainable development.

3.2. Analysis of Research Stages

Using the time dimension to search for the whole research context of low-carbon rural areas can better understand the concerns of the entire academic community about low-carbon rural areas or the trend and direction of rural carbon emission research. In this research, the research topic trends in this field were analyzed through authors' keywords in the literature data. The time span was set to 2003–2022, the minimum frequency of words to six, and annual number of words to four.

Generally, the keywords in a document are highly related to the content of the document, through which the main aspects of the research topic in this research field can be judged [24]. Although high-frequency keywords are displayed in the co-occurrence of keywords, the evolution trend of rural carbon emissions-related research topics for many years can be further understood by analyzing the keyword topic trend. Figure 3 shows research scholars' focus on the research topics regarding rural carbon emissions in different years. These topics are related to the research field of rural carbon emissions in many aspects. For example, in 2017, energy efficiency was the most discussed topic and also an important research field of rural carbon emissions. In 2018, meanwhile, climate change was the main research topic, which was one of the key factors leading to rural carbon emissions. In 2019, sustainability ranked first, which also formed another key area of rural carbon emissions. In this analysis, solar energy was found to be a hot topic in 2021. Thus, it can be seen that the current research status has gradually shifted from "reducing sources" to "opening sinks"; that is, reducing carbon sources and increasing carbon sink types to improve the optimization efficiency of carbon emissions. It is revealed that the current research on reducing carbon emission sources has entered a bottleneck, and new technologies and methodologies are needed to break such shackles.

To better analyze the evolution process of this field, we divided the low-carbon development into different stages combining the time and content of the relevant literature. Specifically, it was generally divided into three stages—budding stage, developmental stage, and deepening stage—according to the timeline.

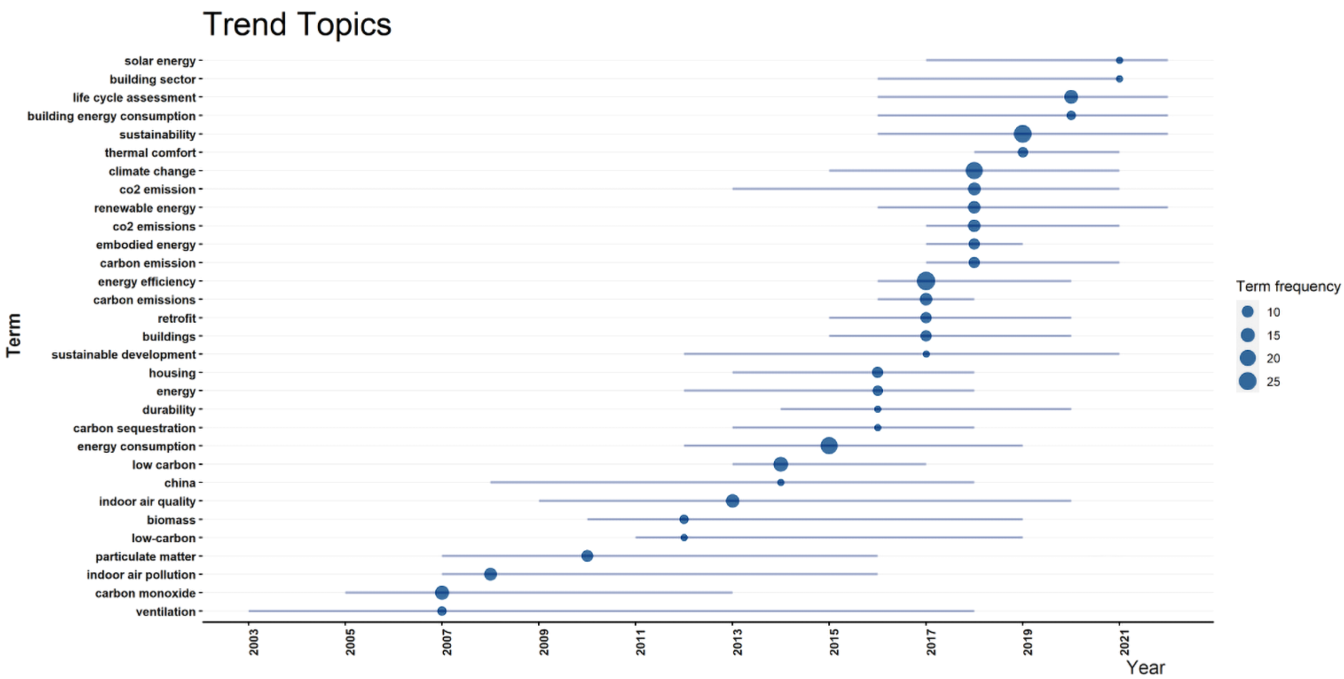

Figure 3. Keyword topic trend chart.

3.2.1. Budding Stage

The years 2003–2010 comprise the budding stage of low-carbon rural research, during which the application of the low-carbon concept in rural production and life was preliminarily explored with the keywords of low carbon, indoor air quality [25,26], and carbon monomer [27,28]. The concepts of low carbon and energy saving and emission reduction were popular in rural areas, and the research at this stage was mainly qualitative research. In addition, more attention was paid to the low carbon concept and low carbon behavior and lifestyle. The research areas were mainly traditional developed countries, such as Sweden, Germany, Denmark, Finland, and Britain. For example, Burford, N. and Neil, T. discussed four strategies for the new sustainable development of low-energy houses in traditional villages in rural Scotland. Anchoring, Court, Street, and Croft summarized these principles into four new models to design more sustainable housing in rural. Burford, N. discussed the role of landscape aesthetics and sustainability in the prototype development of new rural housing in response to local landscape quality, mixed land use, urban density, and local renewable energy production. These results provide a semi-quantifiable prototype of spatial development, and these requirements are integrated into the general conceptual framework of rural sustainable life, providing an alternative method for solving Scottish policy legislation [29]. Burford, N. explored the new spatial form of self-sufficient housing in rural land owned by Scottish National Trust in Coton, Perth, predicted that the demand for new housing in nearby rural areas would increase by 33%, put forward suggestions on substitutive theoretical model and spatial concept for affordable and low-energy regional responsive housing development, and solved the wider requirements of the Scottish environment in terms of sustainability, low energy use, low-carbon material resources, and competitive market [30].

3.2.2. Developmental Stage

The years 2011–2018 comprise the developmental stage, in which the technical means and implementation approaches of low-carbon rural areas were further perfected, trying to introduce low-carbon planning into different rural types with research keywords of energy consumption, carbon sequestration [31,32], and energy efficiency. Quantitative research gradually replaced qualitative research. Urban carbon emission research and methods were gradually introduced into rural areas, and the measurement and management of rural carbon emissions became the norm. At this stage, traditional developed countries were still the main research focus, but many developing countries were also concerned about carbon emissions at this stage. For example, Ge, J. used the data of carbon emissions and carbon sequestration of villages and the management functions of grass-roots governments to select four factors influencing the carbon emissions of these villages, including natural ecology, economic industry, residential development, and infrastructure, prepared a carbon emission inventory for these villages, and collected the data on emission activity level and emission factors. Finally, a method for evaluating village carbon emissions was developed. Meanwhile, four landforms (mountains, hills, plains, and islands) and eight villages with different industrial types were selected for case study and evaluation of carbon emissions. According to the evaluation results, the carbon emissions of villages were divided into four types [33]. Wu, G. focused on the regional household energy consumption and related carbon dioxide (CO_2) emissions, and found that family size, income, and education level are the main factors that affect carbon dioxide emissions [34]. Li, X.C. investigated the energy consumption of rural households from the aspects of energy (coal, biogas, straw gas, liquefied petroleum gas, electricity, and firewood), utilization, selection, cost, and system. The results show that coal is still the main energy source for heating in winter, accounting for the largest part of household energy consumption [35]. With the development of renewable energy, cooking with coal, liquefied petroleum gas, and firewood has been replaced by renewable energy such as biogas and straw gas, which have higher calorific value and lower prices. The research also shows that the energy consumption structure of rural households is changing from the traditional inefficient biomass energy to the comprehensive consumption of traditional energy and renewable energy. Renewable energy not only solves the problem of rural energy shortages but also helps to save fossil resources and protect the environment.

Siudek, Aleksandra mentioned that the use of renewable energy (RE) in newly built and renovated single-family houses in rural Poland will improve energy efficiency and reduce carbon dioxide emissions. Replacing coal with environmentally friendly renewable energy can reduce carbon dioxide emissions by approximately 90% every year [36].

3.2.3. Deepening Stage

From 2019 to now is the deepening stage, in which the main research direction of low-carbon rural areas was more inclined to “reducing sources and opening sinks” and various means were adopted to reduce carbon emissions. According to the keyword analysis of the retrieved literature, it could be concluded that the main current research direction of low-carbon rural areas lies in “reducing sources and opening sinks”, in which reducing sources refers to reducing carbon emissions and opening sinks means expanding the access channels and energy efficiency of new and renewable energy. With the advancement of research, the effect of reducing rural carbon emissions is becoming lower and lower, so the research direction and proportion are gradually inclined toward the development and use of clean energy. To solve the energy shortage in rural areas and improve energy efficiency, Chen, X.P. proposed a hybrid distributed power generation (DG) system including wind energy, hydrogen energy, and fuel cells to supplement the main power grid. Mura, P. proposed a demonstration project in a village in Sardinia, which consists of photovoltaic collectors connected to the network to provide electricity for households and hydrogen for transportation [37]. Yang, T.R. discussed the influence of residential community types on the building energy consumption and solar energy trade-off, aiming to achieve the best conditions of zero non-renewable energy communities, identified six typical Chongming community types, i.e., farmhouse, linear village, core village, townhouse, flat slab house, and high-rise building, and estimated the influence of increasing solar panel installation through Monte Carlo simulation [38]. Skowronski, P. discussed the economic and market potential of solar energy to prepare hot water in rural areas. According to estimates, the solar energy system could meet 30–45% of the energy demand of warm-water power generation in rural areas at a reasonable cost, and correspondingly, reduce CO_2 emissions.

The realization rate of the economic potential of solar water heaters depends on the subsidy for equipment installation [39]. There is a large space for research on low-carbon rural areas. At the same time, the rural energy structure and the comparative regional differences also remain to be further explored.

3.3. Research Countries, Authors, and Groups

Through the comprehensive analysis of authors and their literature fields, the current key academic focus in rural carbon emissions can be figured out, which can better clarify the research gaps and new research objectives.

3.3.1. Analysis of Countries

By analyzing the number of papers published in different countries, the current research investments and the region and scope of the current research results can be revealed, which can facilitate the better analysis of application prospects and future trends.

The world distribution map of papers released in different countries is as shown in Figure 4. Although rural carbon emissions have always been a global concern, the research intensity may vary from region to region. Therefore, it is very important to prove the global distribution of rural carbon emissions research by analyzing papers published in different countries and regions. A total of 89 countries participated in the research, among which over nine papers were published in more than 22 countries, and China ranked first in the number of papers published (170). The time-dependent changes in carbon emissions from urban and rural houses were investigated from the aspect of terminal use; in particular, the comprehensive emission factor of electricity and heating power in time series was considered. Then, it was found that the carbon emissions from private transportation grew fastest, and the carbon emissions produced by space heating and cooling were approximately 40% and 30% [40].

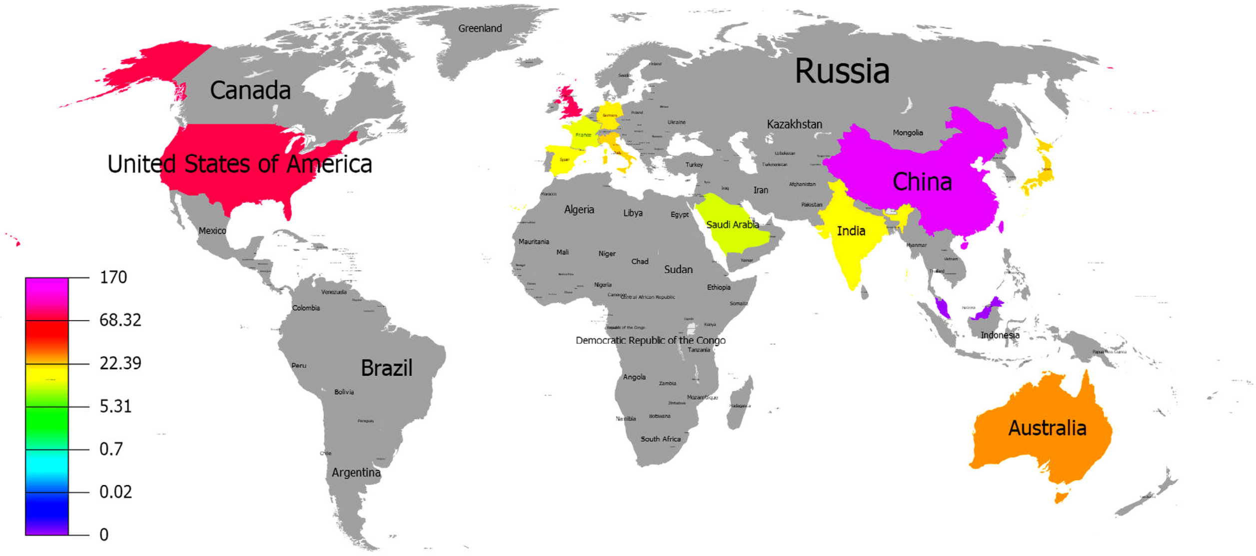

Figure 4. Distribution map of papers published in different countries.

Secondly, the United States (77 papers) pointed out that the construction industry was the emitter of the majority of thr greenhouse gas carbon dioxide (CO_2) partly because of the operation scale and a great variety of equipment [41]. Kaya, Y. proposed in 1993 that building carbon emissions can be calculated using the Kaya formula used to measure the effects of economic growth, population growth, energy efficiency, and energy structure on greenhouse gas emissions, specifically CO_2 emissions = population $\times$ per capita energy consumption $\times$ energy intensity $\times$ CO_2 emission coefficient. Usually, the calculation boundary of building carbon emissions includes the manufacturing, transportation, and installation of construction materials, energy consumption during the use of buildings, and maintenance and demolition of buildings. The calculation method of building carbon emissions based on the Kaya formula can provide guidance and support for the sustainable development of the construction industry. In addition, this method can identify and quantify the source and influencing factors of building carbon emissions so as to formulate the corresponding emission reduction measures and reduce building carbon emissions. Meanwhile, this method can provide a scientific basis for the environmental protection policy making of the construction industry and boost its sustainable development and green transformation [42].

Thirdly, the United Kingdom (69 articles) described the application of the data-driven localized geographic information system (GIS) in Oxford, England, to model, draw, and manage household energy use and carbon emissions at the residential and community levels [43]. It has been discovered that the neighborhood energy model helps to summarize the demand for cost-effective energy action measures. It is estimated that the energy consumption will be reduced by 44% and the energy cost will be reduced by 38% after the comprehensive transformation of surveying and mapping areas. If actions are taken, energy use can be reduced and the fuel shortage in neighboring areas can be mitigated [44]. Based on the interconnection between different countries, it is shown that in recent years, with the increasingly severe global climate change and the gradual improvement of carbon emission reduction targets, developed countries have carried out a lot of research work in the field of carbon emissions [36]. With the implementation of relevant policies and the advancement of technological progress, however, some developed countries seem to be paying less attention to carbon emissions, which may be ascribed to some progress in carbon emission reduction in such countries.

In addition, the research in the fields of green energy, climate adaptation, and carbon capture in developed countries has also received more attention. Secondly, China and other developing countries continue to exert their efforts in the field of rural low-carbon research. With the rapid economic development and accelerated urbanization in China, carbon emission has become a problem to be solved urgently. Rural areas are also an important source of carbon emissions. Therefore, it is very significant for China to make continuous efforts in the field of rural low-carbon research. In recent years, China has achieved some progress in the field of rural low-carbon research, such as developing green agriculture, improving rural ecological environment protection, and popularizing clean energy. In addition, China is also exploring policies and technologies for carbon emission reduction in rural areas, including carbon trading, carbon sequestration, and biomass energy.

As revealed by the literature analysis, the emphasis on rural carbon emissions varies with the rural developmental stage and resource endowment in different countries. Developed countries are characterized by a high degree of rural mechanization and a large number of equipment activities. More emphasis is on scientific research and development to reduce carbon emissions from construction and agricultural equipment operation. Developing countries should explore more policies and technologies for carbon emission reduction in rural areas, including carbon trading, carbon sequestration, and biomass energy, and increase the generation of clean energy. Generally speaking, carbon emission is a global environmental problem, which breaks through the past pure concern about the emission reduction responsibility of developed countries and highlights the important role played by developing countries in emission reduction and climate change. It calls on the international community to implement a global carbon emission reduction plan to ensure that all countries work together and cooperate to reduce carbon emissions. Such global cooperation and efforts will ensure the fairness and effectiveness of carbon emission reduction measures and lay the foundation for achieving global climate goals. At the same time, this also means that carbon emission reduction is not only the responsibility of developed countries but also needs to be shared by all countries in the world. Developing countries should strengthen their own research and exploration, seek emission reduction schemes suitable for their own national conditions, and promote the implementation of these schemes within the framework of sustainable development. This will help to balance global emission reduction efforts and promote sustainable economic growth and social development in developing countries.

3.3.2. Analysis of Research Authors

By analyzing the authors of the 583 articles on rural carbon emissions, the authors publishing most papers were determined, including their cooperative relationships and cooperation network. In a new research field, the number of papers published by an author could represent their research contribution and professional level in this field. In this research, the minimum number of papers published was set to two, and 111 authors met the standard. The authors publishing the largest number of papers were Gupta, Rajat, and Zhang, Y. who each published five articles on rural carbon emissions, followed by Shan M., Smith, K.R., and Yang X.D. who each published four papers.

In addition, it could be clearly found from Figure 5 that 111 authors could be divided into 33 cooperation networks, and a few authors were independent researchers. Each cooperative group was named after the author publishing the largest number of papers in a cooperation network. For instance, the most influential cooperation networks were Shan, M., including authors Shan, M., Lu, F., Nie, Y.Z., Yuan, Y.P., Yang, M., Deng, M.S., and Ma, R.J. Such authors mainly summarized the use of renewable energy in buildings, and pointed out some problems and basic laws of renewable energy utilization. Through two demonstration projects in different rural areas, it has been proved that it is feasible to realize "low carbon" or "zero coal" villages by implementing different renewable energy technologies [45]. Meanwhile, it has been pointed out that the environment will be seriously polluted by combusting solid fuels in traditional heating furnaces, and the PM2.5, CO, and SO_2 emissions from biomass particle heating furnaces using wood pellets are the lowest [46,47]. The second most influential cooperation network was Gupta R. who implemented the alternative method of reducing domestic energy demands by changing the understanding and behaviors of house owners and implementing physical transformation. The results show that energy transformation is quite effective in reducing residential energy use (75% of households reduce the use of gas and/or electricity) [48,49]. It is estimated that energy consumption will be reduced by 44% and energy cost will be reduced by 38% by implementing individual and combined energy improvement measures. If actions are taken, energy use can be reduced and the fuel shortage in neighboring areas can be relieved.

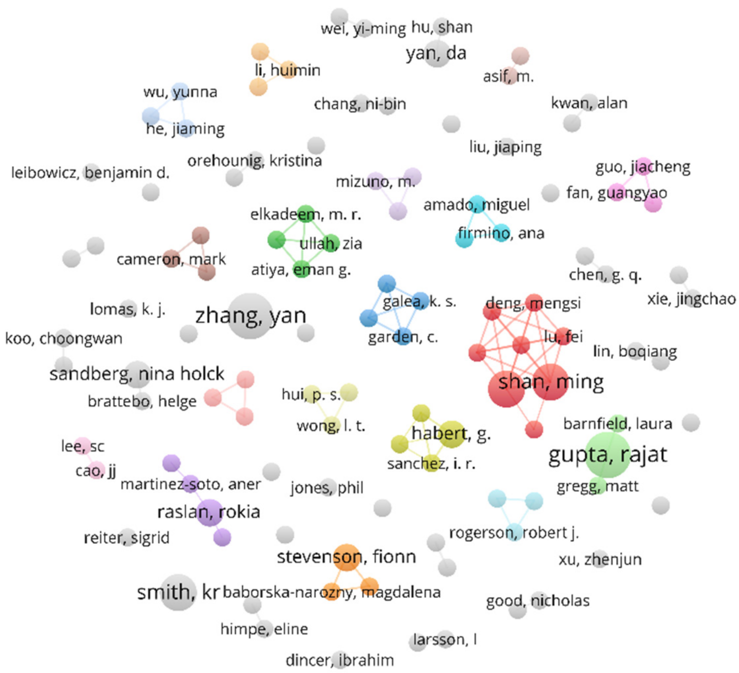

Figure 5. Cooperation network of authors.

It could be observed from Figure 5 that the cooperation networks of authors did not overlap, indicating the relative independence of rural carbon emission researchers who may differ in their concerns and research methods. This phenomenon reflects the complexity and diversity of rural carbon emission research fields. The carbon emissions in rural areas are affected by geographical, climatic, ecological, and economic factors, and great regional differences are manifested [44]. Hence, researchers need to study from multiple angles to fully understand and master the knowledge in this field. At the same time, this relative independence also brings opportunities for researchers to cooperate and communicate, through which they can share their research results and experience, thus improving the research level and quality of the whole field. However, this relative independence may also lead to information asymmetry and knowledge barriers among researchers. If there is not enough communication and cooperation between different researchers, they may miss some important research results and discoveries, and may even produce redundant and repetitive research. Therefore, researchers dedicated to the rural carbon emission research should strengthen exchanges and cooperation and establish a closer and more organic cooperation network, which can promote the sharing and dissemination of knowledge, thus improving the research level and quality of the whole field.

3.3.3. Analysis of Research Institutions

The institutional cooperation network included 94 institutions and 153 cooperative ties. As shown in Figure 6, the Harbin Institution of Technology ranked first (12 papers). Taking the cold region as the research object, this research institution analyzed the structure and mode of rural energy consumption and the main problems of rural planning and construction, put forward planning technical measures and construction schemes considering terrain selection, divided functional areas in towns and villages, encouraged the construction of townhouses, built multiple windbreaks, explored energy from rural production and household waste, and developed solar energy, biogas, wind energy, and other energy sources to adapt to the characteristics of cold climate [32,43,50], followed by Tsinghua University (11 papers). Tsinghua University mainly focused on carbon emissions. In addition, the influence of the unbalanced proportion of forest land on urban carbon emissions was also studied [51–53]. Meanwhile, it has been found that many people in cold rural areas still use coal as the main heat source, and traditional cooking and heating by burning solid fuel in rural areas in the winter has also caused serious environmental pollution [46]. It is very important to choose clean heating technology that can replace raw coal, which may be useful to other countries facing similar environmental problems [54]. The Chinese Academy of Sciences (10 papers) paid attention to the carbon emissions generated by household consumption and the impact of overall emission changes on the sustainable development of the Qinghai–Tibet Plateau with the highest altitude in the world [15,55,56], reflecting that researchers from the Chinese Academy of Sciences concern various factors in environmental protection and put efforts into solving practical problems through scientific research. Particularly, they focus on the influence of regional characteristic differences and spatial heterogeneity on carbon emissions. Significant regional differences in carbon emissions result from the differences in geographical location and climate. Therefore, taking regional characteristics into account, carbon emissions can be evaluated more accurately, so as to formulate the corresponding environmental protection policies. In addition, researchers from the Chinese Academy of Sciences also concern the carbon emissions from rural household consumption, reflecting that they lay emphasis on the environmental impact of human activities. With the improvement of people's living standards and the change in the consumption structure, the impact of rural household consumption on carbon emissions has become increasingly prominent. Therefore, investigating the influences of the carbon emission from household consumption and the overall emission changes on the sustainable development of Qinghai–Tibet Plateau can provide a more scientific basis for formulating environmental protection policies. Other institutions, including the Hong Kong Polytechnic University (eight papers) and Xi'an University of Architecture and

Technology (8 papers), analyzed the different possibilities of cost/benefit in reducing the carbon emission level [20,57,58]. In rural areas, biomass (wood and agricultural wastes, such as straws, corn vines and branches, wood firewood) is the most commonly used fuel type, which will emit a variety of air pollutants: particulate matter (PM), CO, NMHC, CH_4, high-content black carbon (BC)—a greenhouse effect aerosol, and organic carbon (OC)—a cooling effect aerosol [21]. The University of Sheffield (seven papers) deeply interviewed different British family environments (owner-occupied and leased; additional care, shelter and nursing homes; urban and rural areas) to explore how the elderly living with low-carbon thermal technology expressed thermal comfort. The survey results show that the elderly attach great importance to comfort and radiance, and achieve it in many ways that may run counter to the policy objectives. In the rural residence occupied by the owner, the wood-burning stove is reserved after the floor heating/heat pump is installed, so as to provide visible brilliance and hospitality for the guests. In nursing homes, fake fireplaces provide comfort and brilliance without affecting the concerns about risks. The research shows that the assumed emission reduction brought by implementing low-carbon heating technology may be overestimated because the equipment is supplemented in the family manufacturing practice to provide comfort and social contact [49,59,60]. Colorado State University (six papers) analyzed the total carbon (TC) and radioactive carbon (C-14) of fine particles collected from two cities, four neighboring cities, and six remote locations in the United States. It is found that in summer, the carbon concentration in urban and rural areas is similar. In winter, the carbon content in urban areas is more than twice that in neighboring areas, and the carbon content in urban fossils in both seasons is 4–20 times that in neighboring rural areas. Organic carbon (OC) and elemental carbon (EC) were obtained by TOR analysis, and these data and radioactive carbon data were used to estimate the characteristic fossils in winter and summer and the EC/TC ratio in the same period. These ratios were applied to the carbon data monitored between protected visual environmental network institutions to estimate the carbon proportion of most rural areas in the United States in the same period [61–63].

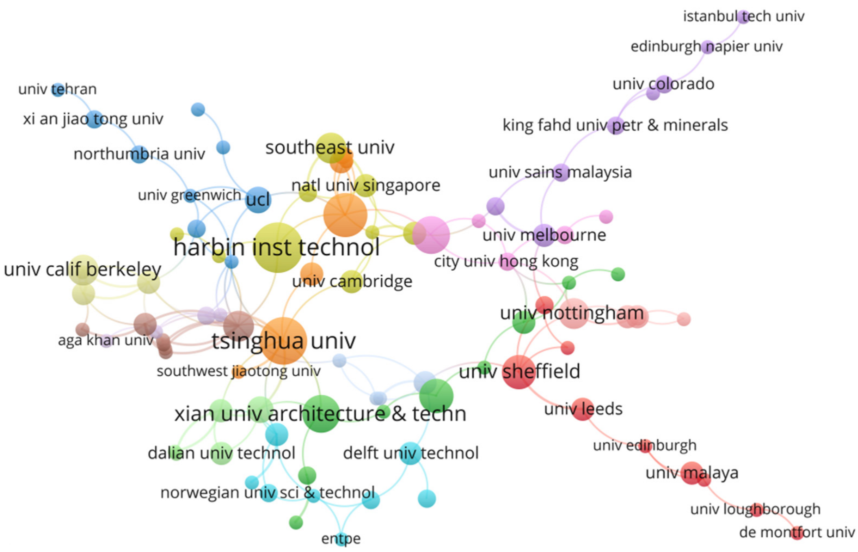

Figure 6. Cooperation network of institutions.

This analysis of institutions shows that different institutions have different research interests in rural carbon emissions. The University of Sheffield, Colorado State University, and other institutions paid more attention to the research and development of some technical models. Harbin Institution of Technology and other units focused on the influences of different behaviors and factors on rural carbon emissions, and attention was also paid to computational boundaries and methods. This reflects that in environmental protection, different research institutions turn their eyes to different regions and scenarios, and meanwhile, different calculation methods and parameters need to be considered to more accurately evaluate carbon emissions and formulate the corresponding environmental policies. To evaluate the carbon emissions in rural areas more accurately, therefore, the geographical location, climate conditions, energy structure, and production modes should be comprehensively considered.

Generally speaking, these studies provide valuable information for solving the problems of rural energy consumption and low-carbon planning and construction and can be referenced by other countries facing similar environmental challenges. In future research work, clean heating technology that can replace raw coal can be explored to reduce the air pollution caused by the use of biomass fuel in rural areas and promote the development and utilization of sustainable energy. These research results are of great significance for promoting rural sustainable development and low-carbon transformation and provide a beneficial reference for relevant policy makers, academic circles, and all walks of life.

4. Current Research Progress and Hotspots in Low-Carbon Rural Areas

4.1. Low-Carbon Rural Structure

The research on the structure of rural carbon emissions is mainly divided into two categories: carbon source and carbon sink. The inventory of rural carbon sources and carbon sinks is slightly different in different countries and different regions [15,64]. In this research, the carbon source and sink inventory in the current mainstream research on the carbon emissions in low-carbon rural areas were summarized and analyzed [15,15,65,66].

Through the analysis, the existing literature can be basically divided into the following aspects (Table 1): the first-level carbon sources refer to the source indexes of carbon emissions, under which there are two second-level indexes: domestic carbon emissions and production carbon emissions. This division method is based on the consideration that the industrial structure of rural areas in China is dominated by agriculture and labor export, the energy structure by biomass and fossil energy, and the carbon emission source by domestic carbon emission. The second-level index—domestic carbon emissions—contains four classes of third-level indexes: domestic energy carbon emissions, transportation carbon emissions, building operation carbon emissions, and domestic waste carbon emissions. The second-level indexes are adjusted according to the characteristics of the target village, and production carbon emissions mainly include three classes: production energy carbon emissions, farmland carbon emissions, and animal husbandry carbon emissions, in which farmland carbon emissions are subdivided into farmland carbon emissions and pesticide and chemical fertilizer carbon emissions. Each class of third-level indexes also contains some sub-indexes. Such sub-indexes should be accounted for appropriately to reduce errors as much as possible. When calculating the net value of carbon emissions, the current total carbon emission can be obtained by total carbon emission, i.e., carbon source index, minus carbon sink index.

Table 1. Decomposition of rural carbon source and carbon emission indexes.

First-Level Index	Second-Level Index	Third-Level Index	Concrete Content
Carbon source index	Domestic carbon emission	Domestic energy carbon emission	Daily use time and total power
		Building carbon emission	Heating and cooling
		Transportation carbon emission	Vehicle operation
		Household waste carbon emission	Household waste
	Production carbon emission	Production energy carbon emission	Planting and harvesting
		Farmland carbon emission	Seed, agricultural film, pesticide, fertilizer, and irrigation
		Animal husbandry carbon emission	Excretion
Carbon sink index	Natural carbon sink	Natural forest carbon sink	Area, and forestry category
	Artificial carbon sink	Artificial forest carbon sink	Planting area and category
		Planting carbon sink	Planting area and category

In these sectors, the most important source of rural carbon emissions is the carbon emissions generated by agricultural production and rural residents' life.

4.1.1. Agricultural Carbon Emission

In the agricultural system, agricultural production activities such as livestock breeding and crop planting are the most active. Methane can be produced by rumen microbial fermentation and animal manure treatment in animals [67]. The production and use of chemical fertilizers, pesticides, and agricultural films in the process of crop planting, the power consumption of agricultural machinery fuel and farmland irrigation [68,69], and the exposure and erosion of agricultural soil caused by ploughing will increase rural agricultural carbon emissions; regional differences will be enormously influenced by the developmental stage and agricultural habits [70].

4.1.2. Rural Residents' Life

In the life of residents, carbon emissions will be produced by energy consumption resulting from heating, cooling, and lighting needs in daily life [71]. Additionally, indirect carbon emissions will be caused by producing the commodities and services needed by basic necessities of life of rural residents. With the continuous changes in rural residents' living standard and demands, the rural indirect carbon emission structure becomes more complicated, and the carbon emission source identification in rural areas is taken as the emphasis in many case studies [72].

4.2. Calculation Model of Low-Carbon Rural Areas

The measurement method of low-carbon rural areas, which has always been an important direction of academic research, derives from urban carbon emission accounting, but because the carbon emission inventory is different from that of urban areas, the methods adopted are different, as well. The rural carbon emission effect originates from agricultural production activities and residential energy consumption. Due to the lack of unified accounting standards, the total rural carbon emissions calculated by different calculation ranges, methods, and indexes are quite different.

To understand the current quantitative method for low-carbon rural areas in a more detailed way, the followings were input into the literature retrieval page of the core collection of WoS: (TS = ("low-carbon rural area" OR "low-carbon rural areas" OR "low-carbon" OR "low-carbon rural areas" OR "low-carbon rural")) AND TS = ("carbon emission measurement" OR " measurement of carbon emissions" OR "calculation of building carbon dioxide emission" OR "carbon emissions" OR "carbon emission calculation"), while other options were the same as above. A total of 76 papers were acquired, followed by the keyword analysis, so as to obtain Figure 7. The following conclusions could be drawn from the keyword analysis (Table 2):

The rural carbon emission measurement methods are mainly divided into three main classes. The first class is the carbon dioxide emission accounting method used to support the carbon trading market, which is mainly formed according to the methodology and guideline system released by such institutions as IPCC and is generally accepted by various countries in the world [73]. The second class refers to the carbon emission estimation methods based on the input–output method and life cycle assessment method, where the latter is applied to measure the greenhouse gas emissions in each production step and the whole life cycle of products and the former is more applicable to the estimation of emissions at such levels as the national macro-level and industrial meso-level [74]. The third class is the carbon emission model measurement method based on the factor decomposition method, which analyzes the varying interactions between relevant factors and carbon emissions through modeling and performance estimation [75].

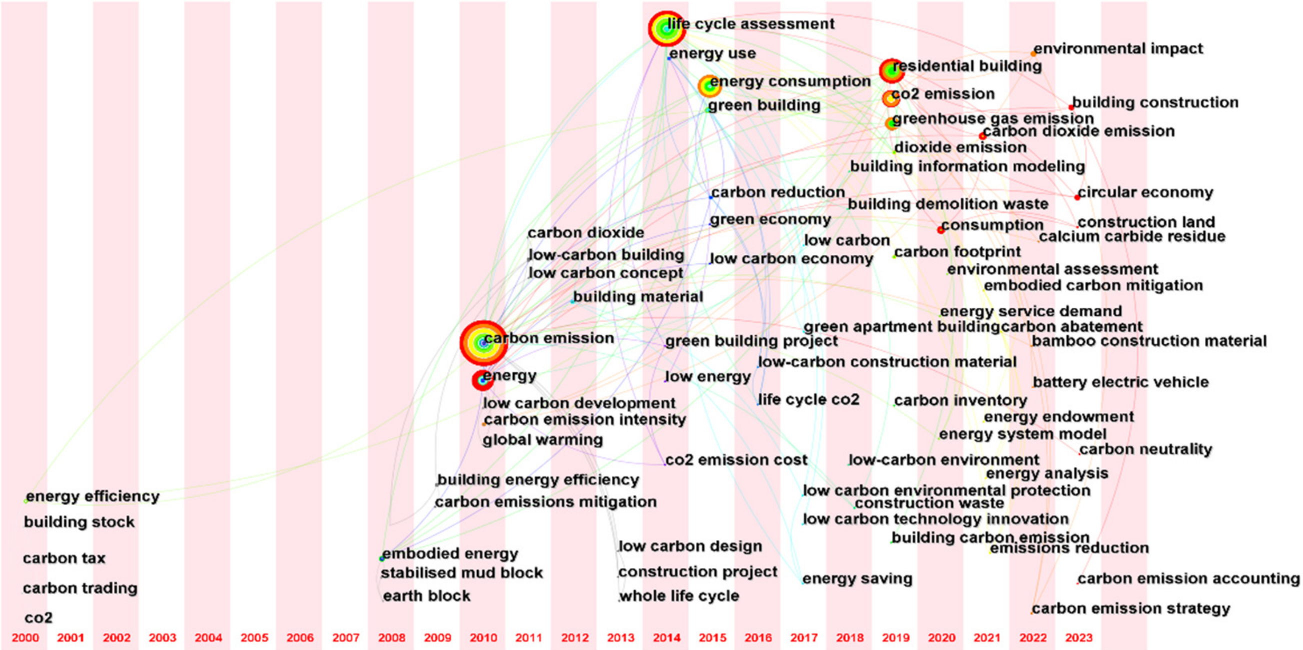

Figure 7. Retrieval content and keyword analysis results.

Table 2. Carbon emission calculation methods and characteristics.

Calculation Method	Data Source	Model	Advantage	Disadvantage	Research Method	Reference
Decomposition method	Statistical yearbooks	STIRPAT, grid model, Kaya equation	Data availability	Subjectively defined influencing factors; results unverified		[76–78]
Input–output method	Input–output tables	Relevant carbon emission models	Supply chain emission; data availability	Subjectively defined construction-related industries, without full coverage; failure to cover all production materials	From top to bottom	[79,80]
Statistical method	Statistical yearbooks and industrial statistics	Emission factor method	Simplicity, and relatively reliable data	Failure to cover all production materials		[80,81]
Simulation modeling method	Building parameters	Modeling tools integrating energy modules	Macroscopic energy evaluation	Manual insertion of parameters; data are not intuitive, remaining to be explained	From the bottom up	[41,42]
Architectural prototype method	Building attributes	Actual building projects	Accuracy, clear boundary, and comparable results	Difficulty in concrete data acquisition		[43,44]

Rural areas are vast and sparsely populated compared to rural areas, making it rather difficult to collect data. Hence, the carbon emission coefficient method is currently used to account for carbon emissions from rural agricultural production and direct carbon emissions from residents' lives, and the input–output method to account for the indirect carbon emissions from residents' lives, which has gradually predominated carbon emission accounting [82]. Different measurement methods slightly differ in the difficulty in data collection and estimation precision [83].

4.3. Rural Energy Conservation and Emission Reduction Paths

An important academic research direction at present lies in improving rural carbon emissions, reducing carbon emissions and increasing carbon sinks by various means, and creating low-carbon rural areas. To comprehend the energy conservation and carbon emission reduction paths of low-carbon rural areas more comprehensively, the following were input into the literature retrieval page in the core collection of WoS: (TS = ("Rural" OR "rural area" OR "village" OR "countryside" OR "country" OR "rural areas" OR "villages" OR "town ")) AND TS = ("energy saving and emission reduction" OR " energy conservation and emission reduction" OR "energy saving" OR "energy conservation" OR "energy conservation and emissions reduction" OR "energy-saving and emission-reducing" OR "energy-saving emission reduction" OR "energy saving and emissions reduction"), the research field was limited to construction building technology, and a total of 89 papers were retrieved, followed by the keyword analysis to obtain Figure 8. The following conclusions could be drawn from the keyword analysis:

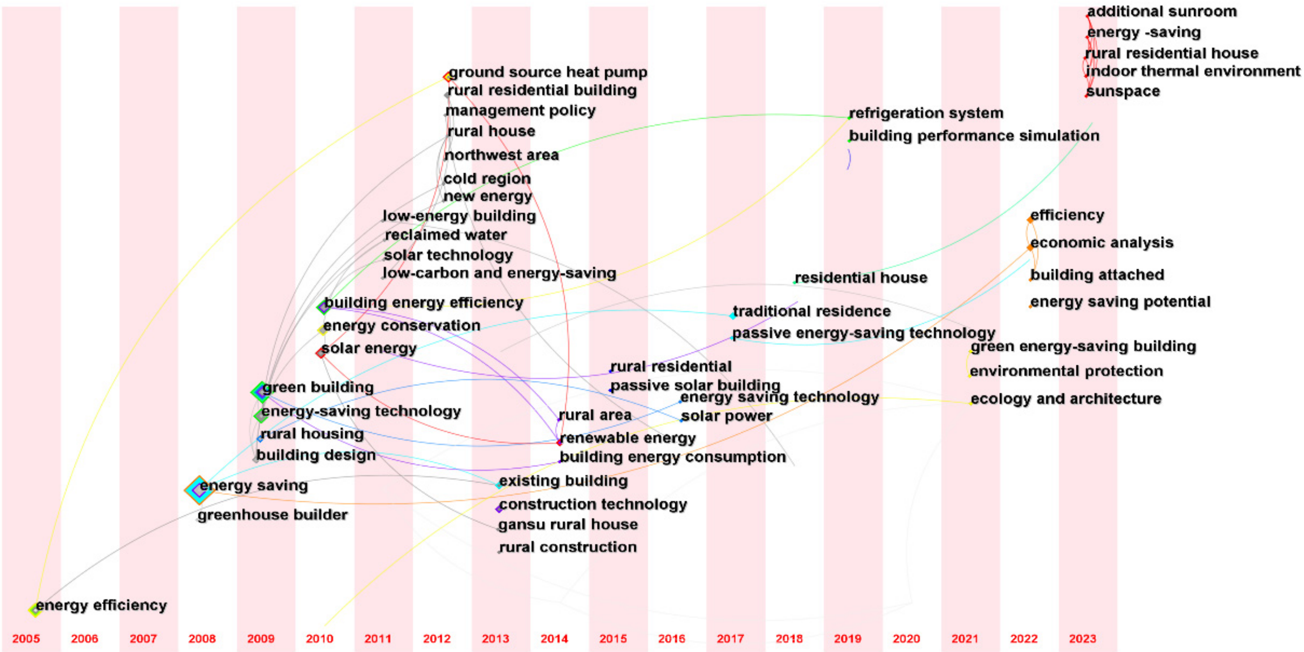

Figure 8. Keyword analysis.

Through the literature retrieval and further analysis of rural energy conservation and emission reduction pathways, low-carbon rural areas are created mainly from two aspects: source expansion and consumption reduction.

4.3.1. Source Expansion

Rural areas are vast, sparsely populated, and rich in carbon sink resources, which can balance their own carbon emissions and back-feed urban areas, with great potentials, gradually attracting attention. On the one hand, the research focus is on increasing the carbon sink of rural areas and evaluating the carbon reserves and carbon sequestration capacity of herbaceous plants, shrubs, rivers and lakes, wetlands, forest floors, mineral soils, and trees. For example, Xu, W. has proposed and formulated many innovative methods to mitigate the impact of excessive greenhouse gas emissions on global climate change. Sequestration of carbon to terrestrial ecosystems is one of the important clean development mechanisms [84].

On the other hand, rural areas are a good carrier for the utilization of many new energy sources. In recent decades, the global energy demand has been increasing. As climate change is aggravated and environmental awareness is enhanced, seeking for alternative solutions to renewable energy has become the focus of common concern of governments and the international community. In this context, compared with urban areas, rural areas are rich in building roofs, water, and forest resources, serving as a good carrier of new energy, which is non-renewable. Solar energy is considered one of the best alternative energy sources for traditional energy sources. Rational use of solar energy is of great significance for alleviating energy depletion and reducing energy carbon emissions. Compared with wind power generation and hydropower generation technologies, solar power generation is the renewable energy power generation technology with the greatest potential for large-scale development and application, and it has broad market demands and good development prospects. Taking the cold regions as the research object, Xu, D.M. analyzed the structure and mode of rural energy consumption and the main problems of rural planning and construction, put forward the technical planning measures and construction schemes, designed, arranged, and divided the functional areas in towns and villages, encouraged the construction of row houses and multiple windbreaks, explored energy from rural production and domestic garbage, and developed solar energy, biogas, wind energy, and other energy sources to adapt to the characteristics of cold climate [43]. Xu Y, et al. analyzed the development trend of rural solar water heaters, solar cookers, and solar houses, predicted their development potential, and calculated the energy saving, CO_2 emission reduction, and their costs. The energy analysis results show that the utilization of solar energy resources in rural areas is increasing rapidly, with huge development potential, and the utilization efficiency needs to be improved. The three methods of solar energy utilization have exhibited remarkable energy saving and emission reduction effects. According to the EU emission trading price, the CO_2 emission reduction cost of solar houses and solar furnaces is negative. It is suggested that the government should rationally plan and utilize rural solar energy resources while increasing investments to form scale benefits [85].

4.3.2. Consumption Reduction

The related research is mostly based on the application of new carbon reduction technologies in rural areas, while advocating for innovative mechanisms and encouraging rural residents to practice the concept of low-carbon life. Hao, A.M. found that there is an "inverted U" curve relation between digital rural construction and rural carbon emissions. Agricultural planting structure and agricultural technical efficiency are important ways of reducing agricultural carbon emissions in digital village construction. The research findings also reveal that the higher the level of economic development, the stronger the carbon emission reduction effect of digital village construction [86]. Zhou, C.Y. deeply studied the envelope structure of rural houses in severe cold regions and put forward the low-carbon design principles and key technologies for the envelope structures of rural houses: shape control, utilization of natural materials, window design, and the effective utilization of solar energy. These technologies can reduce energy consumption, control greenhouse gas emissions, and relieve environmental pollution [87].

5. Discussion

The research field of rural carbon emission is a field of global concern, and all countries are carrying out related research. Generally speaking, the existing research also has some limitations, mainly manifested in the following aspects:

First, the research on carbon emissions in low-carbon rural areas still focuses on a few countries, lacking cross-regional and interdisciplinary cooperation. Due to the differences in developmental stages and energy structure, the experience and methods of relevant countries cannot be directly copied. Low-carbon rural carbon emissions is a global problem to be solved through global cooperation and efforts. Therefore, more countries and institutions are needed to join in the research on carbon emissions in low-carbon rural areas to jointly promote the development of this field.

Second, each country and region should formulate appropriate standards to deepen the research on rural carbon emissions and carbon sinks accounting based on the current conditions and economic development. On the one hand, countries and regions can carry out more in-depth and detailed research on the current measurement of rural carbon emission sources, which is not scientific and comprehensive enough, such as the large differences in the accuracy of data collection, the lagging carbon emission coefficients, the crude calculation methods, and the lack of dynamic adjustments. On the other hand, considering the unevenness of regional development and the balance between carbon emissions and economic development, basic data statistics should be carried out for the less-developed regions, and appropriate and simple carbon emission calculation methods should be established.

Thirdly, the current research on the rural comprehensive energy conservation and emission reduction path lacks comprehensive consideration and comprehensive carbon emission reduction optimization strategies based on carbon emission reduction optimization efficiency ranking, not to mention comprehensive consideration, optimization prediction, and modeling. Hence, it is necessary to divide villages into specific categories according to the influencing factors of different countries for quantitative research, such as geographical features and population structure. Therefore, multiple factors should be comprehensively considered in future research to more comprehensively evaluate rural carbon emissions and propose the corresponding solutions.

Considering the shortcomings of the existing research, future research on low-carbon rural area-related problems can be comprehensively carried out from the following perspectives:

First, a scientific and convenient rural carbon emission inventory should be formulated in accordance with the basic conditions of different regions, which can include: the chemical fertilizers, pesticides, and agricultural films input in rural crop plantation, intestinal fermentation, and fecal discharge during the growth of livestock; residential clothing, food, housing, and travel activities, and the fossil energy consumption throughout production and living activities as sources of rural carbon emissions; and the greenhouse gases to be accounted for, including CO_2, N_2O, and CH_4, and so on.

Secondly, a multi-scale and multi-regional statistical method of carbon emissions, especially the carbon emission coefficient, should be established to determine the carbon emission coefficients of different greenhouse gases, different varieties of crops and livestock, and their planting and breeding methods as well as the carbon sequestration effects of various conservation tillage measures in different regions so that the accounting results of rural carbon effects can be pertinent.

Finally, according to the geographical resource endowment conditions and rural developmental stages of different countries, the principles of rural low-carbon development should be formulated, and rural energy conservation and emission reduction paths specific to different types of villages should be scientifically determined, specifically including: reducing energy consumption, pollution and emission, and increasing carbon sinks, which aims to realize a win–win pattern of rural carbon emission reduction and economic development.

6. Conclusions

With the increasing concern around low-carbon rural carbon emissions, a comprehensive view on the low-carbon rural carbon emissions research in the recent decade was proposed in this research. This research was mainly based on the bibliometric analysis results of 583 low-carbon rural carbon emission-related papers published during 2013–2023, and the following results were found:

The analysis of high-frequency keywords shows that keywords such as sustainability, energy consumption, climate change, and low carbon have always been the focus of researchers devoted to the research on low-carbon emissions in low-carbon rural areas. The topic trend analysis of keywords can allow us to further understand the evolution trend of rural carbon emissions research topics for many years and provide effective guidance for the future research on carbon emissions in low-carbon rural areas.

According to the results of the authors' cooperation network analysis, Gupta, R. and Zhang, Y. are the main contributors to the research on carbon emissions in low-carbon rural areas, meaning that they have a major influence in this field. In addition, Shan, M., Smith, K.R., and Yang, X.D. have investigated carbon emissions in rural carbon villages too. Very obviously, scholars from developing economies will conduct more extensive research work on carbon emissions in low-carbon rural areas, since the carbon emissions in low-carbon rural areas have become one of the most critical channels for efficient energy conservation.

According to the analysis results of institutional cooperation networks, it has been discovered that Harbin Institution of Technology, Tsinghua University, the Chinese Academy of Sciences, the Hong Kong Polytechnic University, Xi'an University of Architecture and Technology, the University of Sheffield, Colorado State University, and Oxford Brookes

University are the main contributors to the research on carbon emissions in low-carbon rural areas. This indicates that the work of these institutions in the field of carbon emission research in low-carbon rural areas is very valuable and significant.

In addition, the analysis results of country and region distribution reveal that China, the United States, and the United Kingdom are the main countries making efforts into the research on carbon emissions in low-carbon rural areas. This shows that developed countries invest more into the research on carbon emissions in low-carbon rural areas on the whole and such countries have extensive influence in this field.

The development of low-carbon rural areas is of positive significance for protecting the environment, promoting sustainable development, and narrowing the gap between urban and rural areas. However, obvious differences are observed in the development of low-carbon rural areas with different geographical characteristics, which also provides a broad prospect for related research. With increasing attention being paid to climate change, countries around the world are taking action to mitigate the impact of climate change. Among them, peak carbon dioxide emissions and carbon neutrality have become one of the main ways of achieving emission reduction targets in the world. The traditional carbon emission assessment method only considers the energy consumption of enterprises and households while ignoring the influence of geographical characteristics on carbon emissions. Therefore, when evaluating the carbon emissions of low-carbon rural areas, the influence of geographical characteristics should be considered and adaptation should be made to the developmental stage, so as to better serve rural grassroots to realize energy transformation and upgrading.

Finally, the domestic and foreign literature documents on low-carbon rural optimization under different geographical characteristics were analyzed and summarized, and the related research stages, processes, and frontiers in this field were mainly presented. Meanwhile, the research limitations were also reviewed, and research prospects were noted. In addition, the connotations, research boundary, and field frontier of low-carbon rural areas were also sorted out, which will provide reference for the research on rural geography, urban–rural planning, and environmental science and probably extend the current research to more extensive special research fields. However, this research has certain limitations, since the research data mainly came from the core database of Web of Science. The research sample size was relatively small, and the relevant research content might not be deep enough. The research on low-carbon rural areas under different geographic features should be a research topic of practical guiding significance.

Despite these limitations, this research is of more theoretical significance than practical significance. Hence, it is necessary to form more valuable research content in the follow-up work by combining the specific practice of low-carbon rural optimization.

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