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LOW EMISSION DEVELOPMENT STRATEGIES AND SUSTAINABLE DEVELOPMENT GOALS

Global evaluation of carbon neutrality and peak carbon dioxide emissions: current challenges and future outlook

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Abstract

With the acceleration of urbanization and industrialization, carbon neutrality and peak carbon dioxide emissions have become common sustainability goals worldwide. However, there are few literature statistics and econometric analyses targeting carbon neutrality and peak carbon dioxide emissions, especially the publication trends, geographic distribution, citation literature, and research hotspots. To conduct an in-depth analysis of existing research fields and future perspectives in this research area, 1615 publications from the Web of Science Core Collection, between 2010 and 2020, were evaluated by using three analysis tools, under the framework of the bibliometrics method. These publications are distributed between the start-up (2010–2015) and the stable development (2016–2020) phases. Cluster analysis suggests three areas of ongoing research: energy-related carbon emissions, methane emissions, and energy biomass. Overall, future trends in this field include cumulative carbon emissions, the residential building sector, methane emission measurement, nitrogen fertilization, land degradation neutrality, and sciamachy satellite methane measurement. Finally, this paper further examines the most comprehensive coverage of nitrogen fertilization and the most recent research of the residential building sector. In view of the statistical clusters from 1615 publications, this paper provides new insights and perspectives for climate-environment-related researchers and policymakers. Specifically, countries could apply nitrogen fertilizer to crops according to the conditions of different regions. Additionally, experiences from developed countries could be learned from, including optimizing the energy supply structure of buildings and increasing the use of clean energy to reduce CO_2 emissions from buildings.

Keywords Carbon neutrality · Peak carbon dioxide emissions · Bibliometric analysis · Sustainable development · Low-carbon economy · Global evaluation

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Introduction

The carbon cycle is associated with a cleaner and more sustainable society since it is the planet's largest and most important elemental cycle (Olah et al. 2011; Xu et al. 2021). With the acceleration of urbanization and industrialization, terrestrial emissions of carbon dioxide (CO_2) increase relative to the standard carbon cycle system, leading to severe global climate change and rising sea levels (Hansen et al. 2013; Liang et al. 2019a, b; Schraven et al. 2021). In 2015, the Sustainable Development Goals (SDGs) and the Paris Climate Agreement launched a global initiative, but most countries still struggle to achieve the proposed carbon neutrality target, which is the realization of a sustainable, low-carbon economy with minimum CO_2 emissions(Shao et al. 2021). As a result, the concepts of carbon neutrality and peak CO_2 emissions have become global concerns in the current decade (Rogelj et al. 2019). Carbon neutrality requires an enterprise, group, or individual to measure the total amount of greenhouse gas (GHG) emissions within a certain period, offsetting their CO_2 emissions through afforestation, energy-saving, and emission reduction simultaneously, and finally achieve "zero-emission" of CO_2 (Zuo et al. 2012). Additionally, peak CO_2 emissions are achieved when CO_2 emissions cease to grow, reaching a peak and gradually decreasing.

According to statistics, from 2009 to 2018, the average annual growth rate of global greenhouse gas emissions was 1.5%. In 2018, the total greenhouse gas emissions, including land use change, reached 55.3 billion tons, and the top four countries in terms of total greenhouse gas emissions were China, the USA, the 28 EU countries, and India. The increase in greenhouse gas emissions would lead to a series of problems such as climate warming and environmental degradation, which could endanger the ecological balance on a global scale. From the worldwide perspective of CO_2 emissions, the initial proposal for a European Climate Law aims to enshrine the legislative goals "to achieve a climate-neutral European economy and society by 2050," issued in the European Green Deal by the end of 2020 (European Union 2020). Under the United Nations Framework Convention on Climate Change (UNFCCC), China has committed to peak CO_2 emissions with a target date of 2030, announcing that it will reduce CO_2 emissions per unit of gross domestic product by 60–65% of the emission levels in 2005 (UNFCCC 2015; Ding et al. 2019). Above all, carbon neutrality and peak CO_2 emissions have received increasing attention from many countries and regions, and issues related to it are explored by researchers in various fields worldwide.

Ma et al. (2020) was the first to evaluate historical CO_2 emission reductions and use dynamic emission scenarios to simulate the energy and emission peaks, enabling the identification of a low-carbon roadmap for future residential buildings. Currently, one of the carbon cycle phases receiving the most attention is how CO_2 produced by terrestrial organisms and plants emits into the atmosphere (Xiao et al. 2019). Rogelj et al. (2019) drew on insights from the physical sciences and proposed a scenario framework to describe how society could reduce its GHG emissions and achieve temperature stabilization. This approach closely reflects the intent of the Paris Climate Agreement and translates intergenerational equity issues into clear design choices. On this basis, Van der Molen et al. (2011) also investigated the effects and relationships between soil moisture, drought, and carbon cycle interactions in terrestrial ecosystems.

Furthermore, Anav et al. (2013) assessed the ability of 18 earth system models to simulate the terrestrial and oceanic carbon cycle under the current and proposed climate, utilizing carbon cycle performance metrics to determine whether there is a consistently better set of models to reproduce the carbon cycle. On the other hand, Xie et al. (2019) examined direct emissions, spatial aggregation, and technology spillover effects, which illustrate the effect of traffic density on urban haze pollution. The acceleration of urbanization along with relative income levels has significant double-threshold effects on CO_2 emissions (Zhou et al. 2013; Dong et al. 2019). Hepburn et al. (2019) reviewed ten pathways that utilize CO_2 with limited potential to reduce CO_2 emissions, showing that each pathway could extend to more than 0.5 gigatons of CO_2 utilization per year. Borges et al. (2015) indicated that future wetland and upland cover changes might strongly influence GHG emissions in African inland waters. Moreover, anthropogenic activities might increase methane and nitrous oxide emissions, which might give rise to the consequences of climate change and GHG effects (Tian et al. 2016).

However, numerous studies in the literature generally focus on fundamental research, clean energy, and building

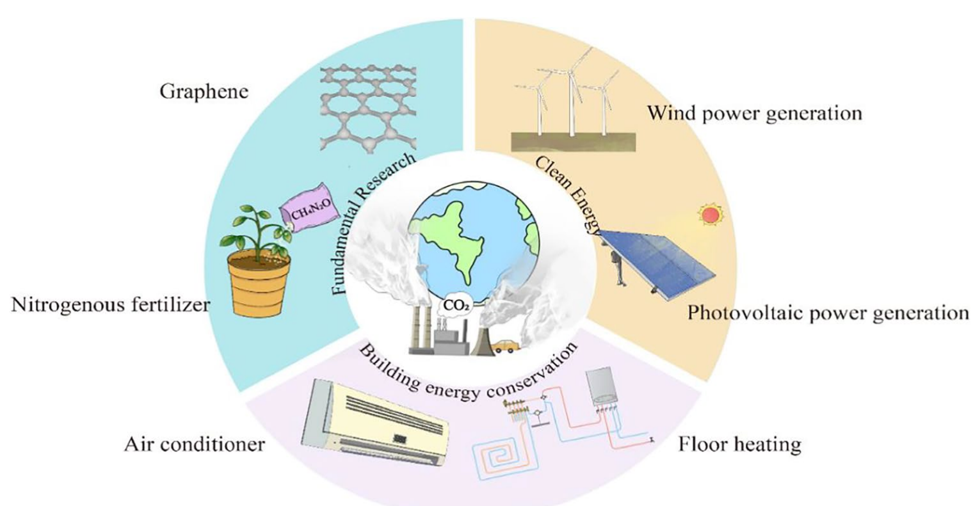


Fig. 1 Sources of CO2 emissions and areas of research on carbon neutrality and peak CO2 emissions

energy conservation, as shown in Fig. 1. This focus also typically includes an examination of the affecting factors, the improvement of carbon utilization, and the comparison of each country's carbon emissions. In the recent decade, more scholars turn their focus on the CO_2 emission data of various countries, the relationship between CO_2 emission and economic development, etc. (Feng et al. 2020; Yang et al. 2021). Muhammad's team conducted a large number of studies related to this topic, including climate (Bashir et al. 2021b), One Belt One Road policy (Bashir et al. 2021c), economic development and environmental protection (Bashir et al. 2021a), oil price and stock market (Bashir 2022), tourism, and environmental degradation (Shahbaz et al. 2021). Nevertheless, few literature statistics and econometric analyses concentrate on the publication trends, geographical distribution, citation literature, and research hotspots of carbon neutrality and peak CO_2 emissions. Given the broad scope of research on this issue, statistics and surveys in the literature can clarify existing research results, summarize research hotspots, and guide future research.

To fill the research gap, this paper employs the bibliometric analysis method to comprehensively evaluate the research field. In terms of the bibliometric analysis method of the low-carbon society, several researchers have been focusing on CO_2 reduction (Wan et al. 2012) and the supercritical CO_2 Brayton cycle (Yu et al. 2020). The relevant research fields are sustainable energy production (Arriola and Chen 2020), agricultural waste management (He et al. 2019), and the three pillars of sustainability in the wake of COVID-19 (Ranjbari et al. 2021b). In this review, we systematically analyzed 1615 publications from the Web of Science (WOS) Core Collection between 2010 and 2020 using ArcGIS, VOSviewer, and CiteSpace analysis tools. Our objective is to thoroughly investigate existing research areas and future perspectives on the research field of carbon neutrality and peak CO_2 emissions. This paper will focus on the following issues: (1) the pattern of publications, authors, countries, and institutions that are actively involved in carbon neutrality and peak CO_2 emission research; (2) the co-citation of the most important journals and references on carbon neutrality and peak CO_2 emission research; and (3) the "hot" research topics and emerging future perspectives in carbon neutrality and peak CO_2 emission research.

Around 2010, the global climate problem brought about by the increase in carbon emissions was highlighted. The most obvious problem was the appearance of a large-scale smog, which lead researchers in various fields to pay more attention to the problem of carbon emissions. This paper is the first attempt to systematically evaluate and outline publications from 2010 to 2020 on carbon neutrality and peak CO_2 emission research through employing the bibliometric analysis method. This work will provide climate-environment-related researchers with new insights about the current challenges and future research directions in this field.

Research design

The bibliometric analysis methodology has been widely adopted to evaluate joint citations from published papers (Marvuglia et al. 2020; Chen et al. 2021; Ranjbari et al. 2022). The databases used most frequently are the WOS Core Collection and Scopus databases, with a small portion of researchers using the Zephyr database (Gupta et al., 2020). This paper employs a bibliometric method to analyze carbon neutrality and peak CO_2 emission findings from 2010 to 2020, and the research framework is shown in Fig. 2 (the co-authorship analysis in the Appendix). All analytical processes follow three main principles of bibliometrics: data collection, data processing, and result extraction (Amin et al. 2019). Research data and methodology are explained in following sections.

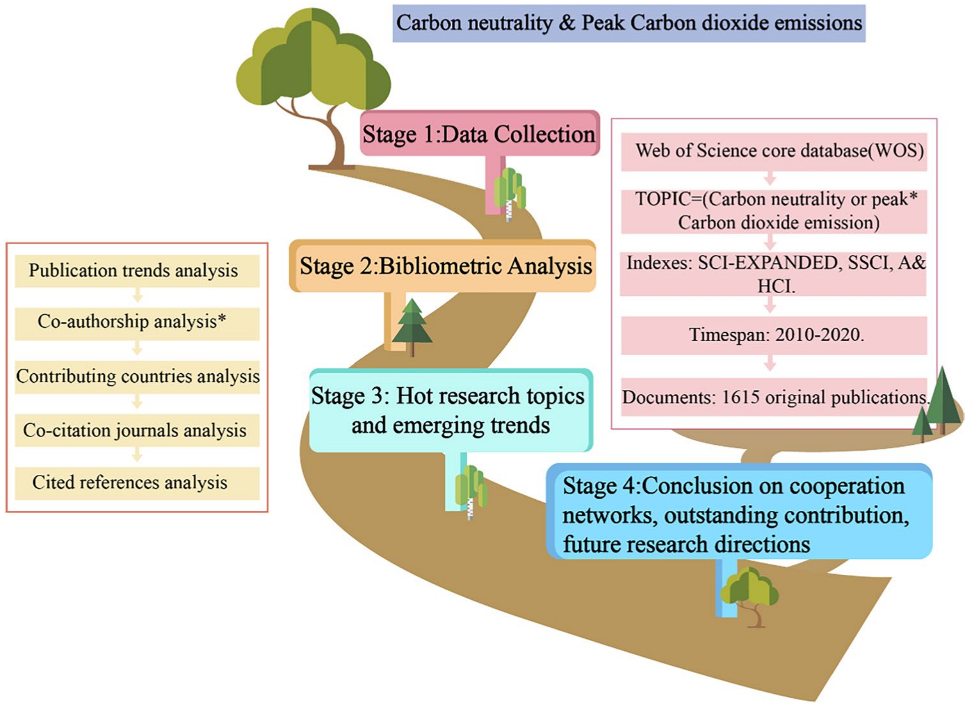
Data collection

Data from this research is also collected from the WOS Core Collection with the following main query filters: topic (carbon neutrality or peak* carbon dioxide emission), language (English) and document types (Article), timespan (2010–2020), indexes (SCI-EXPANDED, SSCI, A&HCI), and retrieved time (August 12, 2021). If the type of documentation (including article, corrections, retractions, editorial materials, and letters) is not specified, we found 1693 publications in total. We then specify such documentation following previous bibliometric method, with 1615 articles classified as this research dataset. These 1615 publications originate from 105 countries/regions and 2060 organizations, which are distributed over 130 categories in the WOS Core Collection and were written by 6816 authors. Other specific findings will be detailed in the results section.

Data analysis

To further contextualize the approach, this paper employs three practical analytical tools to develop the future research results, including VOSviewer, ArcGIS, CiteSpace. ArcGIS, a geographic information system, is adopted to allocate organizations globally and geocode the number of countries, with the objectives of creating the GIS map (Sweileh et al. 2017). VOSviewer is mainly employed to analyze joint citations across countries, journal collaboration, and quoting frequency of highly cited papers (Van

Fig. 2 Research approaches for this paper



Eck and Waltman 2010). Additionally, the functionality of the VOSviewer is especially useful for displaying large bibliometric maps in an easy-to-interpret way (Van Eck and Waltman 2010). Lastly, we use the CiteSpace analysis tool to predict and observe potential research perspectives through keywords and cluster analyses, since this tool can detect and visualize emerging trends and transient patterns in the scientific literature (Chen 2006). In addition, CiteSpace is able to identify co-citation clusters of cited references and track trends in research through co-citation network analysis based on spectral clustering and feature selection algorithms (Chen et al. 2009).

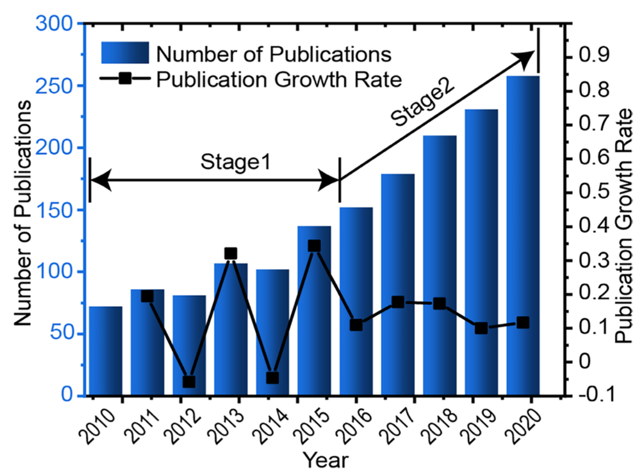


Fig. 3 Changes in the publications and growth rate of literature publications from 2010 to 2020

Results and discussion

Quantitative analysis of publication trends

The research on carbon neutrality and peak CO_2 emissions could be divided into two stages. The first stage is the start-up phase (2010–2015), with 72 papers published in 2010, 137 articles published in 2015, and an average of 97.5 papers published per year, which reflects the frequency of activity for this research domain. The number of publications and publication growth rates from 2010 to 2020 are shown in Fig. 3. In terms of the first stage, this analysis finds that the publication growth rate during these 6 years has a fluctuating trend. In fact, the number of publications in 2012 and 2014 even showed negative growth, with – 5.81% in 2012 and – 4.67% in 2014.

The second stage of the research is the stable development stage (2016–2020), consisting of 152 papers published in 2016, and nearly doubling in 2020 to 258 publications. Additionally, the publication growth rate in these 5 years is greater than zero. It fluctuates slightly around 15%, indicating that this research field has been getting more and more attention from global scholars since 2016, becoming a hot research issue. Interestingly, a 34.3% increase in the number of publications in 2015 compared to 2014 closely corresponded with SDGs, which started in 2015. This timing also effectively demonstrates the beginning of the stable development phase described earlier.

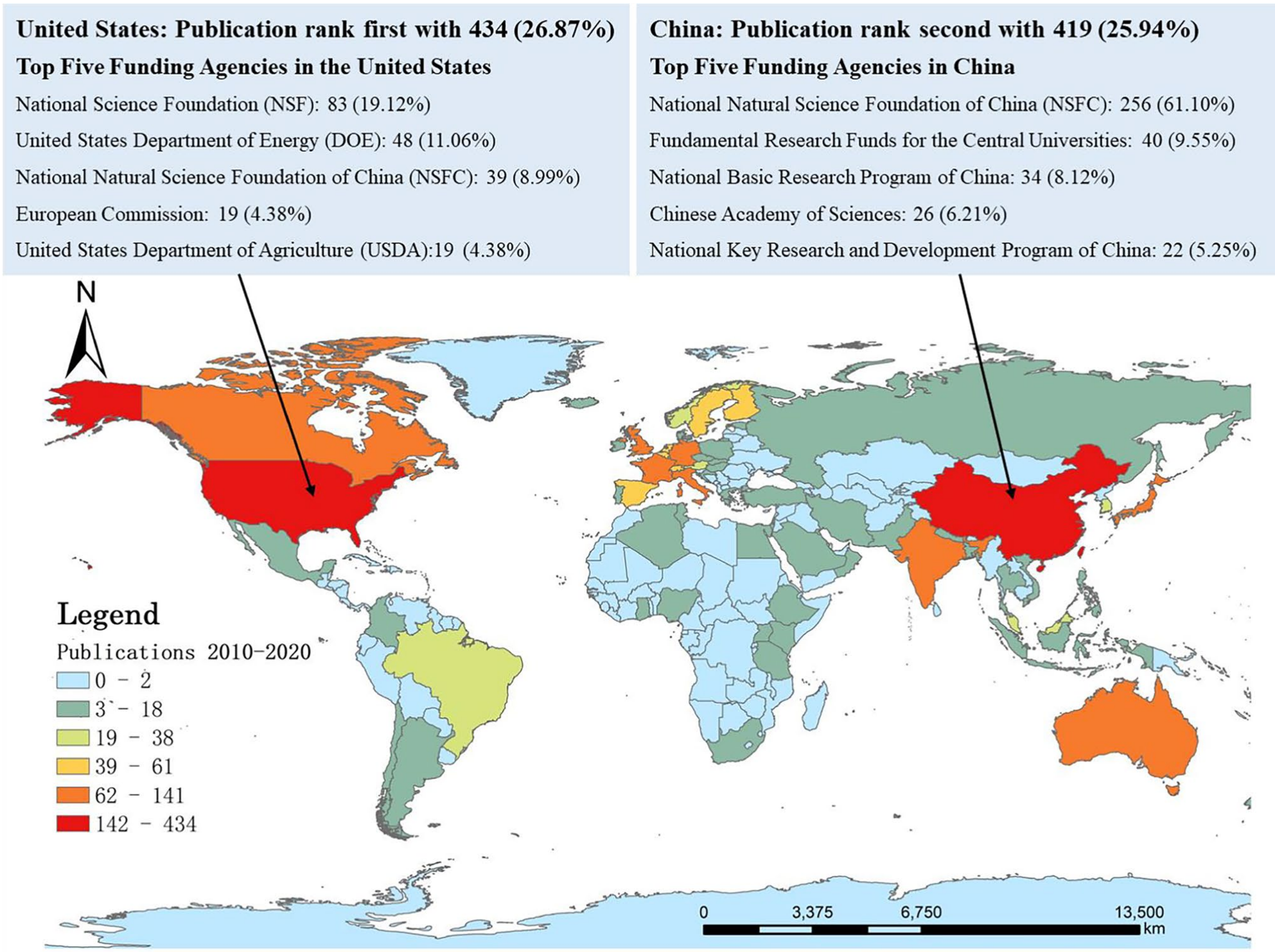


Fig. 4 Spatial distribution of global publication volume (2010–2020) and funding for specific research institutions in the USA and China

Quantitative analysis of contributing countries/regions

The geographical locations of the 1615 publications in our dataset are analyzed through ArcGIS, which are shown in Fig. 4. From 2010 to 2020, the USA and China are the top two countries in the publication of literature in this field, with 434 (26.87%) and 419 (25.94%) papers respectively. The top five funding agencies from the USA are NSF, DOE, NSFC, EC, and USDA (the full name of each funding agency can be seen in Fig. 4), and the top five funding agencies from China are NSFC, FRFCU, NBRPC, CAS, and NKRDPC. Notably, the structure of funding sources in the two countries is very different: the funding sources in the USA mainly come from research institutions, while China's funding sources are mostly from universities. In addition, Canada, Australia, India, and some countries in Europe rank after the USA and China in terms of the number of publications, which indicates that scholars in these countries are also gradually becoming more interested in this research field.

The co-citation knowledge domains of the 50 most published countries/regions were analyzed by VOSviewer (Fig. 5). These countries are broadly divided into five categories. The blue citation cluster is led by the USA and China, followed by South Korea, India, and Egypt. The red citation cluster is guided by France, followed by European countries such as Finland and Iceland. The UK leads the orange citation cluster, with Poland as a transition. The green citation cluster is led by Spain, followed by Switzerland and Sweden. The yellow citation cluster is dominated by Australia, followed by Singapore and Ireland. Lastly, Japan, Germany, and Nepal constitute the purple citation cluster.

Quantitative analysis of the geographical distribution

It is practical to understand the research differences between different organizations in terms of carbon neutrality and peak CO_2 emissions, especially regarding the organization's geographical distribution analysis. Table 1 demonstrates the

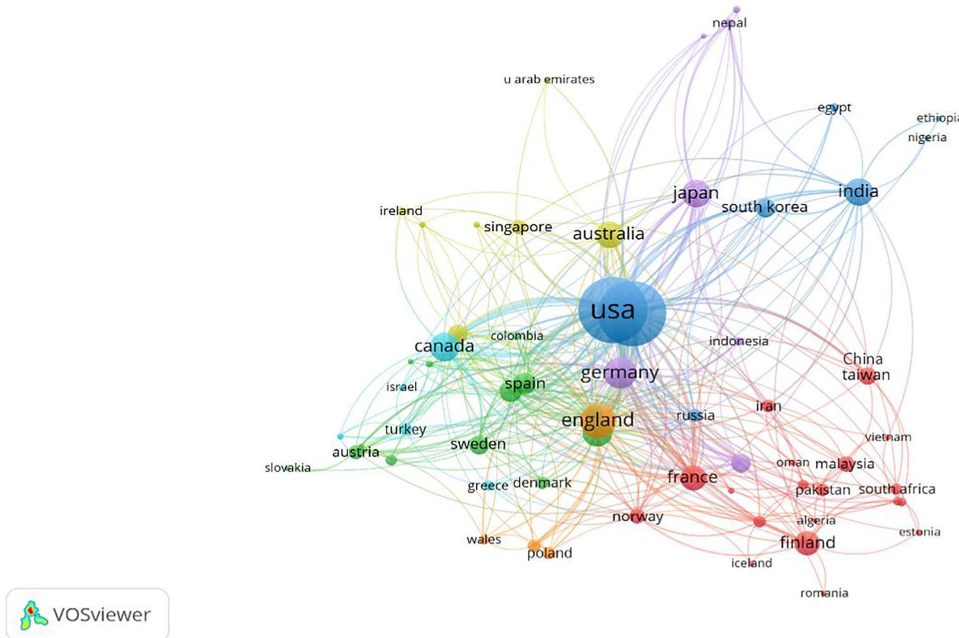


Fig. 5 Mapping knowledge field of co-citation from main countries/region

Table 1 Top 15 organizations ordered by publications from 2010 to 2020

Rank	Organization	Country	TPs	Pr(%)	H-index	CPO	TC	ACPY
1	Chinese Academy of Sciences	China	105	6.50	24	24.71	2597	236.09
2	Centre National de la Recherche Scientifique	France	49	3.03	20	37.22	1824	165.82
3	University of Chinese Academy of Sciences	China	45	2.79	16	17.89	805	73.18
4	University of California System	USA	42	2.60	19	39.19	1646	149.64
5	United States Department of Energy	USA	38	2.35	21	34.92	1327	120.64
6	Tsinghua University	China	33	2.04	15	18.61	614	55.82
7	United States Department of Agriculture	USA	29	1.80	12	18.14	526	47.82
8	University of Helsinki	Finland	26	1.61	13	23.50	611	55.55
9	Helmholtz Association	Germany	22	1.36	14	29.05	639	58.09
10	Lawrence Berkeley National Laboratory	USA	21	1.30	14	40.76	856	77.82
11	North China Electric Power University	China	21	1.30	9	19.38	407	37.00
12	Universite Paris Saclay	France	21	1.30	13	24.76	520	47.27
13	University of London	England	20	1.24	14	39.35	787	71.55
14	University of Oxford	England	20	1.24	14	38.35	767	69.73
15	Wageningen University Research	Netherlands	20	1.24	11	33.65	673	61.18

TPs, total publications; *Pr(%)*, proportion; *CPO*, citation per organization; *TC*, total citation; *ACPY*, average citation per year

worldwide ranking of the top 15 organizations researching in this field, according to the volume of publications and their respective parameters. Among the top 15 organizations, four are from the USA and four are from China, accounting for the highest percentage of research publications. This confirms that both the USA and China supported the highest volume of publications, aligning with the information highlighted in the "Quantitative analysis of contributing countries/regions" section.

Furthermore, the geographical distribution of the organizations worldwide is presented in Fig. 6. The major research organizations identified in our analyses are centralized in the USA, Europe, India, and China. Interestingly, as the countries with the most research publications, the USA and China show an uneven distribution of submission organizations. The USA's publications are mainly concentrated in the south, with the organizations significantly greater and more concentrated in the east than in the west. The uneven distribution is more evident in China, with the publications mainly concentrated in the east due to the developed economy and increased funding to support universities' research development. At the same time, the western part of China,

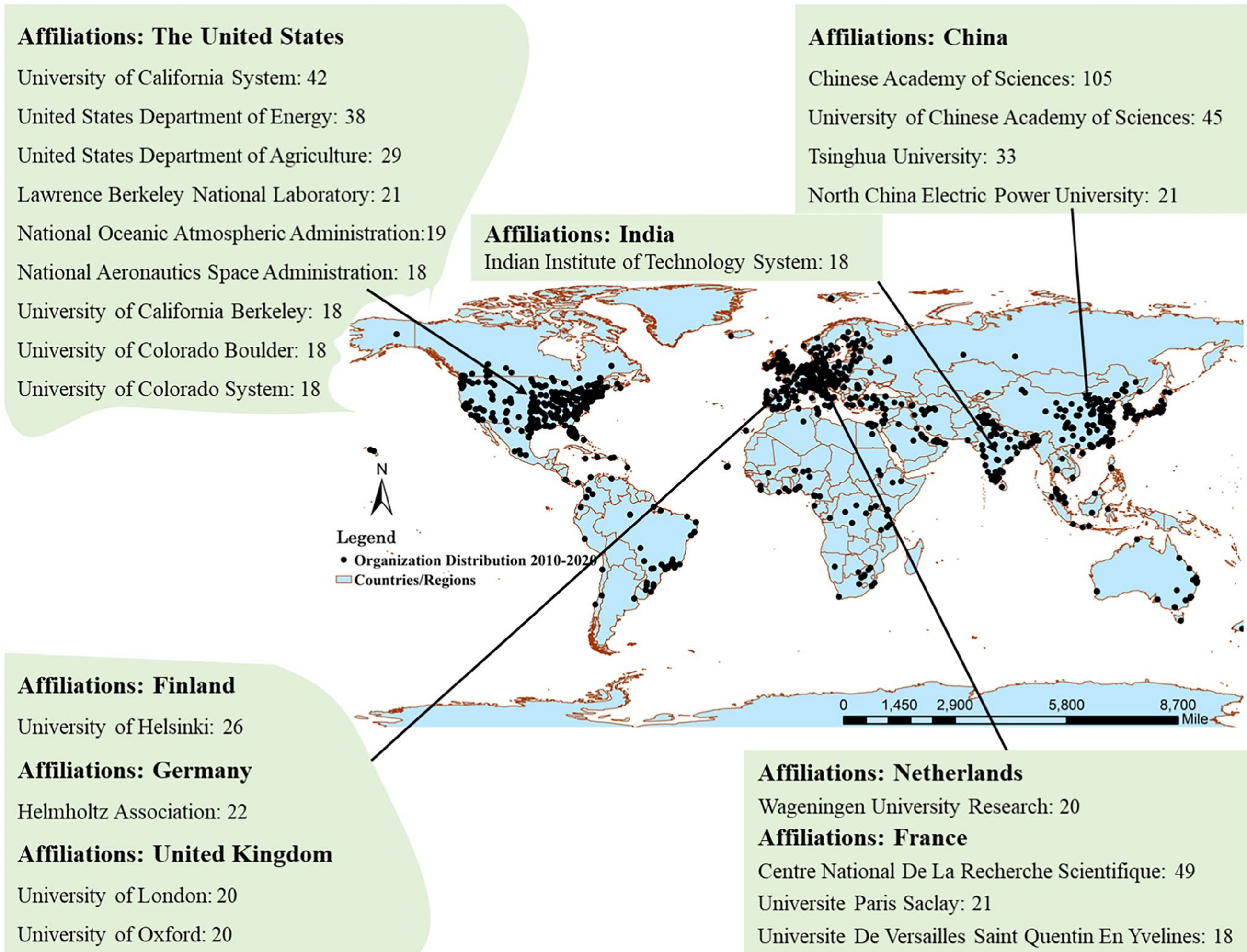


Fig. 6 Global spatial distribution of research institutions (2010–2020) and specific presentation of the top 22 organizations

especially the northwest, has complex geographical conditions and slow economic growth. Accordingly, the concentration of Chinese research institutions in the western portion of the country is not as high as in the east.

In contrast to distributions in the USA and China, there is also a greater distribution of published organizations in Europe and India. Europe has a high density of organizations. The number of organizations in India is not as plentiful as in Europe, but the distribution is consistent from north to south. Among these 22 worldwide organizations, the highest-ranked is the Chinese Academy of Sciences, with a total citation quantity of 2597 and an average citation of 236.09, followed by France, with a total citation count of 1824 and an average citation of 165.82.

Quantitative analysis of co-citation journals

The use of citations is an essential tool for scientific research, and cited journal sources provide researchers with a quick overview of new innovative research outcomes. The top 15 highly cited journal sources from 2010 to 2020 were analyzed using the WOS Core Collection, as demonstrated in Table 2.

Regarding the number of publications, the *Journal of Cleaner Production* ranks first among 15 journals, with 55 articles, 22 H-indexes, 1392 total citations, and 126.55 average annual citations. Moreover, the *Journal of Cleaner Production*, *Science of the Total Environment*, and *Atmospheric Chemistry and Physics* are the top three vital journal sources in this research field. It is worth noting that although *Energy* is the sixth most published journal, it has more than 1000 citations, and similar journals, such as *Fuel*, are also listed in Table 2. A density map of co-cited journals is demonstrated in Fig. 7.

Quantitative analysis of cited references

The quantity of citations is also an indicator of the importance of the literature. Table 3 lists the 15 most-cited

Table 2 Top 15 mainstream journal in carbon neutrality and peak carbon dioxide emission research from 2010 to 2020

Rank	Journal title	TPs	Pr(%)	H-index	CPJ	TC	ACPY	TLS
1	*Journal of Cleaner Production*	55	3.41	22	25.31	1392	126.55	51
2	*Science of the Total Environment*	48	2.97	18	17.90	859	78.09	54
3	*Atmospheric Chemistry and Physics*	41	2.54	18	33.56	1376	125.09	14
4	*Applied Energy*	40	2.48	20	33.05	1322	120.18	30
5	*Sustainability*	38	2.35	6	3.16	120	10.91	10
6	*Energy*	34	2.11	19	32.09	1091	99.18	12
7	*Energy Policy*	32	1.98	16	28.69	918	83.45	31
8	*Atmospheric Environment*	28	1.73	13	20.00	560	50.91	17
9	*Biogeosciences*	28	1.73	14	22.41	605	55.00	13
10	*Environmental Research Letters*	22	1.36	13	23.41	515	46.82	20
11	*Energies*	21	1.30	8	14.90	313	28.45	7
12	*Physical Review B*	21	1.30	11	45.86	963	87.55	0
13	*Agricultural and Forest Meteorology*	19	1.18	11	22.21	422	38.36	29
14	*Global Change Biology Bioenergy*	18	1.11	12	27.44	494	44.91	25
15	*Fuel*	16	0.99	10	67.00	1072	97.45	6

TPs, total publications; *Pr(%)*, proportion; *CPJ*, citation per journal; *TC*, total citation; *ACPY*, average citation per year; *TLS*, total link strength

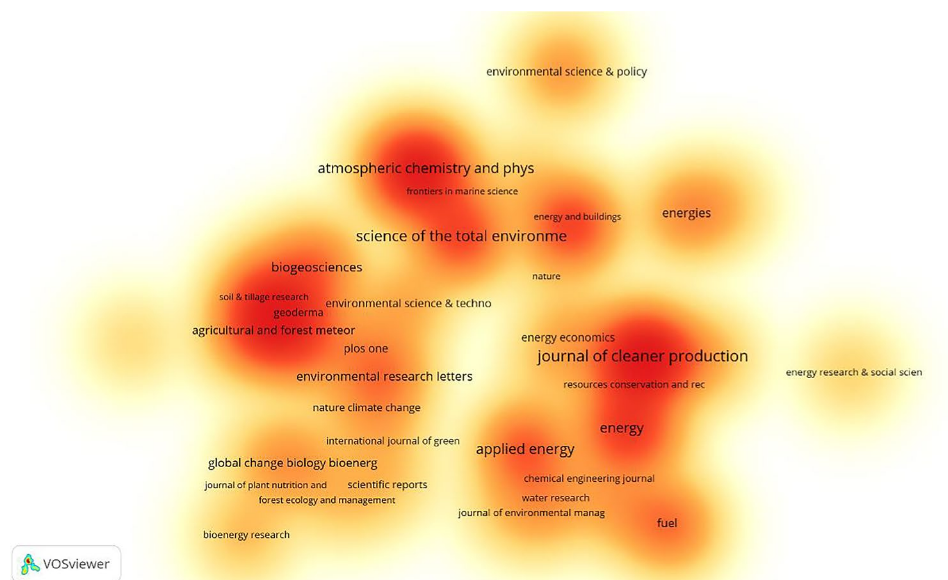


Fig. 7 Mapping knowledge domain of co-citation of journal

papers from 2010 to 2020 (Coletti et al. 2010; Riedl et al. 2010; Wang et al. 2010; Zhang et al. 2010; Elias et al. 2011; Yan et al. 2013; Hunt et al. 2013; Özener et al. 2014; Cowan et al. 2014; Ji et al. 2014; Abas et al. 2015; Omri et al. 2015; Garza et al. 2018; Keesstra et al. 2018; Le Quéré et al. 2020). We separated the list by each paper's main features, focusing on the citation, year, first author, title, source, and country.

From 2010 to 2020, the 15 highly cited papers mainly focus on the following aspects: The most interesting aspect is graphene as an electrode to improve the capacitance and other properties of capacitors, and 8 of the 15 papers are related to this. Besides, the increasingly serious smog caused by the sharp increase in CO_2 emissions is also a major concern, and 3 papers are related to this. In addition, 5 papers reported the negative impact of CO_2 emissions on global economic development and land planning, and 2 papers reported that using existing technologies, the use of biodiesel can effectively reduce CO_2 emissions.

Continuing this clarification, Table 4 lists the 11 most cited papers per year from 2010 to 2020 (Riedl et al. 2010; Elias et al. 2011; Zanchi et al. 2012; Hunt et al. 2013; Ji et al. 2014; Abas et al. 2015; Elser et al. 2016;

Table 3 Top 15 cited literatures in the carbon neutrality and peak carbon dioxide emissions from 2010 to 2020

Rank	Citation	Year	Author	Title	Source	Country
1	967	2013	Hunt, B	Massive Dirac Fermions and Hofstadter Butterfly in a van der Waals Heterostructure	*Science*	USA
2	667	2013	Yan, Y	A Survey on Smart Grid Communication Infrastructures: Motivations, Requirements and Challenges	*IEEE Communications Surveys and Tutorials*	USA
3	529	2011	Elias, DC	Dirac cones reshaped by interaction effects in suspended graphene	*Nature Physics*	Spain
4	446	2020	Le Quere, C	Temporary reduction in daily global CO_2 emissions during the COVID-19 forced confinement	*Nature Climate Change*	England
5	398	2014	Ji, HX	Capacitance of carbon-based electrical double-layer capacitors	*Nature Communications*	USA
6	347	2010	Riedl, C	Structural and electronic properties of epitaxial graphene on SiC(0001): a review of growth, characterization, transfer doping and hydrogen intercalation	*Journal of Physics D-Applied Physics*	Germany
7	325	2010	Coletti, C	Charge neutrality and bandgap tuning of epitaxial graphene on SiC by molecular doping	*Physical Review B*	Germany
8	312	2014	Ozener, O	Effects of soybean biodiesel on a DI diesel engine performance, emission and combustion characteristics	*Fuel*	Turkey
9	297	2015	Abas, N	Review of fossil fuels and future energy technologies	*Futures*	Pakistan
10	270	2018	Keesstra, S	Soil-Related Sustainable Development Goals: Four Concepts to Make Land Degradation Neutrality and Restoration Work	*Land*	Netherlands
11	247	2010	Wang, T	Air quality during the 2008 Beijing Olympics: secondary pollutants and regional impact	*Atmospheric Chemistry and Physics*	China
12	245	2015	Omri, A	Financial development, environmental quality, trade and economic growth: What causes what in MENA countries	*Energy Economics*	Tunisia
13	232	2018	Garza, AJ	Mechanism of CO_2 Reduction at Copper Surfaces: Pathways to C-2 Products	*Acs Catalysis*	USA
14	213	2010	Zhang, F	Band structure of ABC-stacked graphene trilayers	*Physical Review B*	USA
15	188	2014	Cowan, WN	The nexus of electricity consumption, economic growth and CO_2 emissions in the BRICS countries	*Energy Policy*	South Africa

Author and country referring to the first author and first country in each article

Houghton and Nassikas 2017; Keesstra et al. 2018; Le Quéré et al. 2019, 2020). These publications are also listed in the co-citation knowledge map of this paper, as shown in Fig. 8. The high density of research in this domain occurs in the USA and China, indicating that these two geographical locations have both emphasized the breadth and depth of their studies. In addition, for these two countries, seven of the most highly cited papers per year from 2010 to 2020 are among the 15 most highly cited papers counted from 2010 to 2020. Le Quéré et al. (2020) concluded that government policies during the COVID-19 pandemic significantly altered energy demand patterns worldwide, and they predicted that post-crisis government actions and economic incentives could influence global CO_2 emission pathways for decades. Providing recommendations for land policy on a global scale, Keesstra et al. (2018) examined the sustainability of land and proposed four concepts: systems thinking, connectivity, nature-based solutions, and regenerative economics. Additionally, Abas et al. (2015) explored the reduction of fossil energy storage, proposing that fossil energy sources could be used with renewable energy sources, significantly contributing to environmental sustainability.

Table 4 Top 11 cited studies per year in carbon neutrality and peak carbon dioxide emission research from 2010 to 2020

Year	Citation	Author	Title	Source	Country
2020	446	Le Quere, C	Temporary reduction in daily global CO_2 emissions during the COVID-19 forced confinement	*Nature Climate Change*	England
2019	94	Le Quere, C	Drivers of declining CO_2 emissions in 18 developed economies	*Nature Climate Change*	England
2018	270	Keesstra, S	Soil-Related Sustainable Development Goals: Four Concepts to Make Land Degradation Neutrality and Restoration Work	*Land*	Netherlands
2017	150	Houghton, RA	Global and regional fluxes of carbon from land use and land cover change 1850–2015	*Global Biogeochemical Cycles*	USA
2016	185	Elser, M	New insights into PM2.5 chemical composition and sources in two major cities in China during extreme haze events using aerosol mass spectrometry	*Atmospheric Chemistry and Physics*	Switzerland
2015	297	Abas, N	Review of fossil fuels and future energy technologies	*Futures*	Pakistan
2014	398	Ji, HX	Capacitance of carbon-based electrical double-layer capacitors	*Nature Communications*	USA
2013	967	Hunt, B	Massive Dirac Fermions and Hofstadter Butterfly in a van der Waals Heterostructure	*Science*	USA
2012	160	Zanchi, G	Is woody bioenergy carbon neutral? A comparative assessment of emissions from consumption of woody bioenergy and fossil fuel	*Global Change Biology Bioenergy*	Austria
2011	529	Elias, DC	Dirac cones reshaped by interaction effects in suspended graphene	*Nature Physics*	Spain
2010	347	Riedl, C	Structural and electronic properties of epitaxial graphene on SiC(0 0 0 1): a review of growth, characterization, transfer doping and hydrogen intercalation	*Journal of Physics D-Applied Physics*	Germany

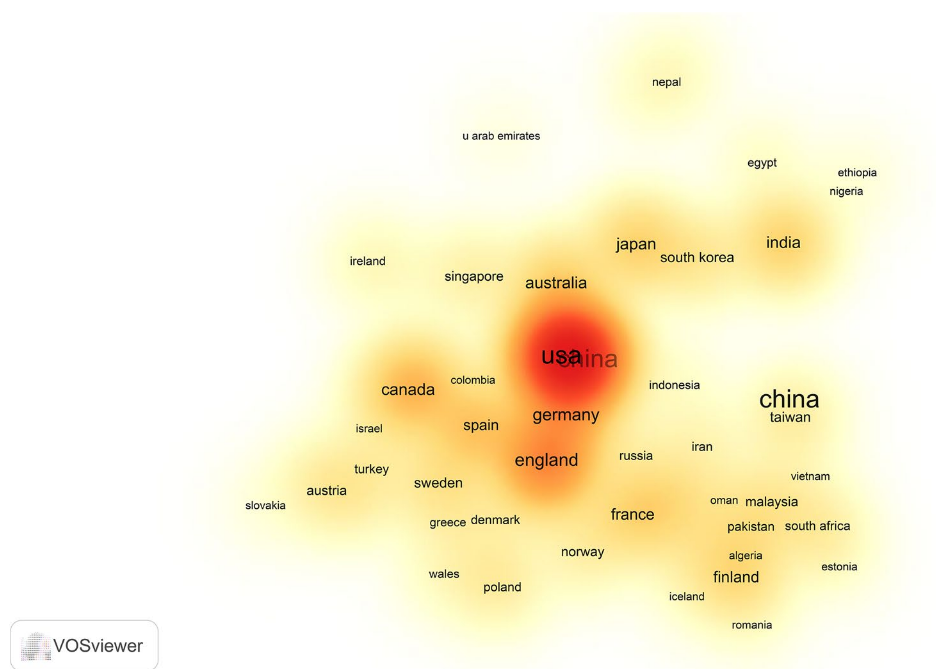


Fig. 8 Mapping knowledge domain of co-occurrence of countries

Hot research topics

Quantitative analysis of frequent keywords

Through analyzing the occurrences of keywords, scholars can better understand and grasp research developments and research hotspots. The top 30 keywords are investigated in this paper, as shown in Table 5, revealing the research hotspots from 2010 to 2020. The five keywords with the highest number of occurrences (> 100) are carbon dioxide (464), emissions (203), CO_2 emissions (202), climate change (130), and methane (116). Carbon dioxide appears the most frequently and has the most robust connection to the other keywords.

Figure 9 shows the keyword clusters in this research field on a global scale utilizing VOSviewer. The largest keyword clusters are “carbon-dioxide” and “emissions,” which have the most robust connections to other keywords, such as “fluxes” and “climate change.” The cyan cluster is dominated by “CO_2 emissions,” mainly focusing on economic growth, consumption, income, and other areas. The red and blue clusters focus on the impact of energy use on human social development, with the two main keywords being “energy” and “impact”. In addition, it is worth noting that the keyword “China” appears 76 times in the literature from 2010 to 2020, ranking 11th in terms of strength when linking with other keywords.

Research hotspots

CiteSpace analysis software was employed for cluster analysis to produce an associated knowledge map. All analysis processes are following the CiteSpace tool, which was detailed by Chen et al. (2010). Using the CiteSpace, we set Nodes Labeled in 1.0%, Modularity $Q = 0.8435$, Weighted Mean Silhouette S = 0.9466, and Harmonic Mean (Q, S) = 0.8921. Table 6 represents the visualization results by using the CiteSpace analysis tool, presenting nine co-citation clusters for the research field with the relevant parameters (Size, Silhouette, Mean (Year)), tags, and similar tags. Between 2010 and 2020, with pertinent literature emerging, this field attracted increasingly scholarly research. At the keyword level, future research directions will be more likely to concentrate on these nine clusters, with keywords, showing new trends in the research field (Fig. 10). The node sizes indicate the frequency of keyword occurrences. CiteSpace is crucial for a more comprehensive identification of research topics and research content in the study and future directions of the field.

Constant research fields

Cluster #0: Energy-related carbon emissions

Energy consumption is closely related to CO_2 emissions, especially fossil energy, which causes GHG effects and

Table 5 Quantitative analysis of 30 frequently used keywords in carbon neutrality and peak carbon dioxide emission research

Rank	Keyword	Occurrences	TLS	Rank	Keyword	Occurrences	TLS
1	Carbon-Dioxide	464	3231	16	Carbon Neutrality	58	349
2	Emissions	203	1326	17	Nitrous-Oxide Emissions	57	494
3	CO_2 Emissions	202	1607	18	Transport	55	284
4	Methane	116	934	19	Renewable Energy	54	349
5	Energy	95	631	20	Nitrous Oxide	53	509
6	Temperature	93	639	21	Denitrification	49	437
7	Performance	91	537	22	CH4	49	427
8	Model	88	589	23	Dynamics	49	385
9	Fluxes	81	638	24	Water	49	372
10	Impact	77	538	25	Soil	47	367
11	China	76	595	26	Management	47	354
12	Greenhouse-Gas Emissions	68	534	27	Biomass	47	315
13	Carbon	66	392	28	Methane Emissions	46	369
14	Climate-Change	130	877	29	Reduction	46	335
15	Energy-Consumption	63	511	30	Economic-Growth	44	371

Carbon-Dioxide including co2 (99,697) and carbon dioxide (95,713); CO_2 Emissions including carbon-dioxide emissions (68.547); Climate-Change including climate change (65,414); *TLS*, total link strength

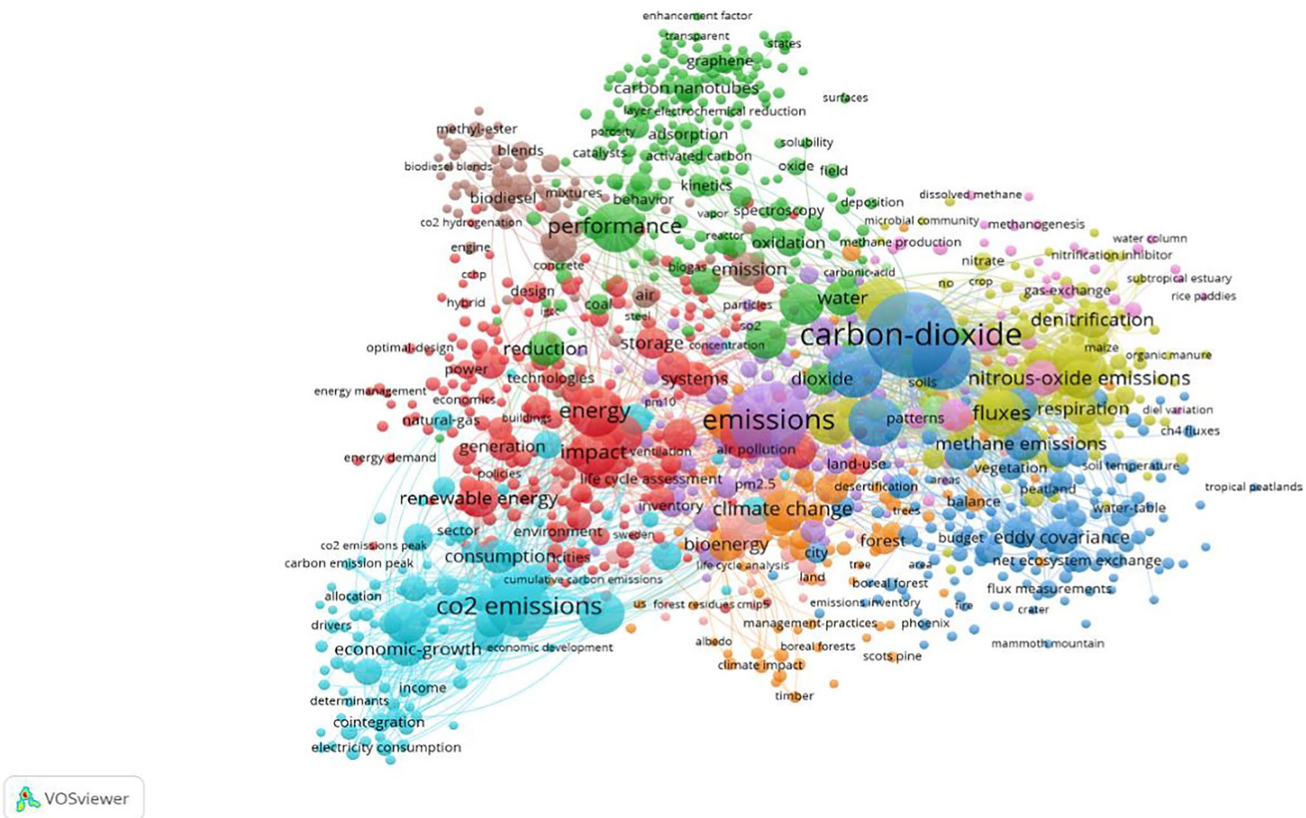


Fig. 9 Mapping of the co-occurrence of this research keywords

Table 6 Top nine co-citation clusters of carbon neutrality and peak carbon dioxide emission research

Cluster ID	Size	Silhouette	Mean (year)	Label (LLR)	Alternative label
#0	72	0.943	2016	Energy-Related Carbon Emission	Scenario Analysis; Case Study; Reduction Potential; Carbon Intensity Target
#1	64	0.855	2014	Methane Emission	Carbon Dioxide; Abandoned Boreal Peatland Pasture; Near-Zero Methane Emission
#2	54	0.982	2011	Energy Biomass	Stable Age-Class Distribution; Forest Biomass Production; Boreal Forest
#3	39	0.958	2012	Cumulative Carbon Emission	Global Warming; Using Earth System Model; Reducing Carbon Dioxide Emission
#4	38	0.883	2018	Residential Building Sector	Human Development Index; Mapping Carbon Emission; Southwest China; Carbon Dioxide Intensity
#5	37	0.969	2011	Measuring Methane Flux	Irrigated Rice Field; Eddy Covariance Method; Using Open-Path Gas Analyzer
#6	28	0.987	2008	Nitrogen Fertilization	Cropping Sequence; Dryland Soil Greenhouse Gas; Soil Greenhouse Gas Emission
#7	26	0.981	2017	Land Degradation Neutrality	Sustainable Development Goal; National Baseline; Trend Analysis; Near-Term Mitigation
#8	25	0.955	2007	Sciamachy Satellite Methane Measurement	Regional Studies; Eastern Mediterranean; Organic Broiler; Grassy Outdoor Run

Due to the CiteSpace analysis system, #6 is the same meaning with the #7 content listing in Fig. 10, following by the #7, and #8. *LLR*, log-likelihood ratio

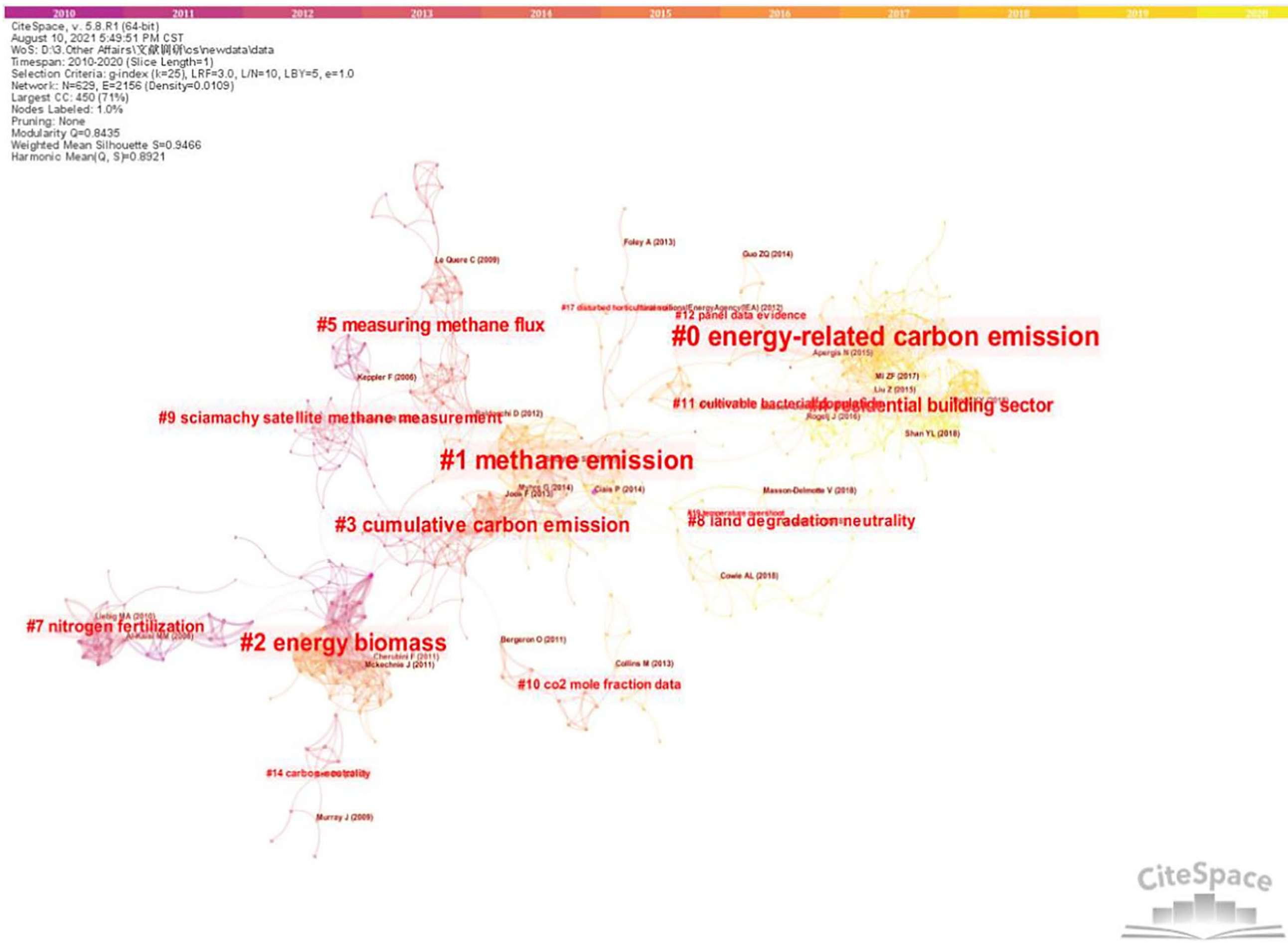


Fig. 10 Diagram of the main research clusters

severe environmental damage. Zhang and Da (2015) indicated that, as the main driver of carbon emissions, economic growth has increased in the past decades in China, while the decrease in energy intensity and the cleaning of final energy consumption structures have played significant roles in curbing carbon emissions. To effectively achieve green growth and sustainable development, more stringent environmental and energy-related regulations are needed. Adedoyin et al. (2020) evaluated global warming by considering the interactions between economic growth, pollutant emissions, coal rents, and the motivation of other covariates like regulatory quality.

Cluster #1: Methane emissions

Compared to coal and oil, natural gas is one of the most common fossil energy sources, and its main component is methane. Saunois et al. (2020) quantified the global methane budget, which is critical for assessing realistic ways to mitigate climate change. They proposed five measures to improve methane emissions accordingly. Sellar et al. (2019) documented the development of the first version of the UK Earth System Model (UKESM1), which provided a guide to methane extraction and geo-environmental simulations, coupled with carbon and nitrogen cycles. The Sellar model has been developed with a stable pre-industrial state and with good agreement with observations from later stages of historical simulations.

Cluster #2: Energy biomass

Biomass is a renewable and clean energy source that can effectively reduce CO_2 emissions, and fundamental research on biomass has increased in recent years. Bi et al. (2019) summarized that recently reported biomass-derived carbon materials with three-dimensional structures had applications as carbon-based electrode materials for supercapacitors. They highlight current challenges and prospects of carbon-based electrode material supercapacitor performance. Acar and Dincer (2019) showed that biomass, geothermal, hydroelectric, nuclear, solar, and wind are the selected sources of hydrogen production. Biological, thermal, photonic, and electrical are the chosen methods of hydrogen production. Liao et al. (2020) invented an integrated biorefinery that converts 78% birchwood into xylose chemicals. Reductive catalytic fractionation of the wood produces a carbohydrate pulp and lignin oil suitable for bioethanol production, using technical analysis to further investigate, revealing that life cycle assessment predicts low CO_2 emissions.

Emerging trends

Cluster #3: Cumulative carbon emissions

Cumulative carbon emissions have the means and methods to count and collect CO_2 emissions. Rogelj et al. (2016) summarized approaches that estimate cumulative carbon emissions to keep global warming below a given temperature. Allen et al. (2018) suggested that temperatures in future decades will be strongly influenced by short-term climate pollutants, thus complicating the estimation of cumulative emission budgets for ambitious reduction targets. Also, in terms of global warming potential, expressing the impact of mitigation measures on cumulative future emissions will directly relate to future warming, better informed responsibility-sharing discussions, and long-term policies and standards to achieve global temperature targets (Allen et al. 2018).

Cluster #4: Residential building sector

As the world's population grows and the number of buildings increases, the amount of CO_2 emitted from human habitation will gradually increase. Ma et al. (2020) suggested that rapidly increasing carbon emissions from the residential building sector are barriers to the Chinese 2030 emission peak target. To identify a low-carbon roadmap for future residential buildings, they assessed historical carbon emission reductions for the first time and modeled energy and emission peaks in the Chinese residential building sector using dynamic emission scenarios.

Cluster #5: Methane flux

Since natural gas is an important component of fossil energy, measuring the emission flux of its main ingredient, methane, is becoming more critical. The measurement of fluctuations and eddies has attracted the attention of many scholars. For example, Baldocchi (2014) discussed the advantages and disadvantages of using vorticity covariance methods, relative to other methods used, to measure trace gas exchanges between ecosystems and the atmosphere, discussing how eddy covariance methods have evolved simultaneously. Tian et al. (2016) used both bottom-up and top-down approaches to quantify the global net biogenic GHG balance between 1981 and 2010 from anthropogenic activities and their contribution to climate change.

Cluster #6: Nitrogen fertilization

Lawrence et al. (2019) described the model development included in the Community Land Model 5 (CLM5), which assesses simulations against a range of indicators according to the International Land Model benchmark, including prescribed and predicted vegetation states and multiple forcing datasets, such as CLM4, CLM4.5, and CLM5, which are instructive for nitrogen fertilizer development and use. Walker et al. (2021) synthesized theoretical and broad multidisciplinary evidence regarding the impact of increased CO_2 on global terrestrial carbon sinks.

Cluster #7: Land degradation neutrality

Gann et al. (2019) analyzed the second edition of the International Principles and Standards for Ecological Restoration Practice, which provides a robust framework for restoration projects to achieve desired goals, addresses challenges, including effective design and implementation, and considers complex ecosystem dynamics. Novara et al. (2021) quantitatively highlighted the role of cover crops in vineyards and olive groves in runoff reduction and soil moisture status in low vigor vineyards, low fertility soils, and dry soils environments. Cover crops positively contribute to agricultural sustainability, although Mediterranean ecosystems should be aware of their impact on the availability of water. Water competition should be correctly monitored to avoid adverse effects on grape yields.

Cluster #8: Sciamachy satellite methane measurements

Hu et al. (2018) monitored air quality and climate and compared the results with methane products obtained from the GHG Observing Satellite. Despite using different spectral ranges and inversion methods, they found excellent agreement between the methane products obtained from the two satellites. Wunch et al. (2011) established a global network of ground-based Fourier transform spectrometers to remotely measure column abundances of CO_2, CO, CH_4, N_2O, and other NIR-absorbing molecules. These measurements can be directly compared with total NIR column measurements from space-based instruments, developing datasets for scientific research on the carbon cycle and drawing links between satellite measurements and extensive ground-based in situ networks simultaneously. Veefkind et al. (2012) described science and mission objectives, tasks and instruments, and data products, providing information on air quality, climate, and the ozone layer.

Two additional insights

The research hotspots were obtained from the statistics in the literature using CiteSpace software and are shown in Table 6. Moreover, the results of the literature derived from the WOS Core Collection alone are somewhat limited and are supplemented by the following.

The first additional issue relates to the most extensive cluster, *Cluster #6*, whose main label is nitrogen fertilization. Cluster #6 has a silhouette of 0.987, which indicates that it requires attention from the literature in this area. The emission of CO_2 affects the organic matter in the soil (Chen et al. 2020; Hamann et al. 2021), so it is very important to fix the organic matter in the soil to be absorbed by the crops through the application of nitrogen fertilizer (Lavallee et al. 2020). Lassaletta et al. (2014) clarified the importance of nitrogen fertilization and concluded that countries that use a higher proportion of nitrogen inputs from symbiotic nitrogen fixation rather than synthetic fertilizers have better nitrogen efficiency. Guerrini et al. (2020) investigated whether agronomic treatments could improve flour processing in three old wheat varieties. They indicated that only nitrogen fertilization affects bread characteristics, and it can be enhanced by designing agronomic treatments to obtain higher quality wheat bread. In addition, the study of Ali et al. (2021) showed that applying nitrogen fertilizer can improve potato yield. In order to quantify the effect of nitrogen fertilizer on mitigating CO_2 emissions on soil quality, Du et al. (2020) proposed a series of indicators to evaluate the quality of nitrogen fertilizer.

The second additional issue is linked to *Cluster #4*, which is the cluster whose average date is closest to the present (mean (year) of 2018). The primary label for this cluster is the Residential Building Sector. In different seasons, indoor heating or cooling often consumes a lot of energy (Nejat et al. 2015; Ürge-Vorsatz et al. 2015), which will aggravate CO_2 emissions and have a great impact on human health (Giles-Corti et al. 2016). Hu et al. (2017) conducted an online survey in 2015 to examine urban dwellers' energy and usage behaviors and found that electricity use would continue to grow as household electronics become more prevalent and the demand for a higher quality of life increases. The key to energy efficiency in urban residential buildings is to maintain traditional behaviors and lifestyles, promoting energy-efficient policies and technology systems to improve indoor environments and comfort. Liang et al. (2019a, b) investigated the gap in decoupling CO_2 concentration from income level in the residential building sector, and they made an important contribution to the analysis of peak CO_2 emissions in the residential building sector in China. In addition, Pacheco et al. (2012) gave some policy suggestions for reducing CO_2 emissions through the utilization of building waste heat. Foucquier et al. (2013) proposed three different building energy consumption prediction methods based on different mathematical models.

Based on the software data and our analysis results, especially additional insights, we found that Residential Building Sector have a greater impact on CO_2 emissions. However, a series of studies have shown that the acceleration of urbanization can help reduce CO_2 emissions, with the feature more obvious in developed countries (Nangini et al. 2019; Crippa et al. 2021). This will lead to new thinking: how to learn from developed countries and regions as the global population increases, and how to balance the relationship between urbanization and environmental protection, which could be the focus of further research.

Conclusions and policy recommendations

Conclusions

This paper is the first attempt to evaluate the research field of carbon neutrality and peak CO_2 emissions through employing the bibliometric analysis method. 1615 publications from the WOS Core Collection between 2010 and 2020 are analyzed by employing ArcGIS, VOSviewer, and CiteSpace. The following conclusions are obtained from the literature's data and statistics.

First, the literature published from 2010 to 2020 is divided into two phases. The first is from 2010 to 2015, defined as the start-up phase, as evidenced by the unstable fluctuation in the growth rate of published literature. The second phase is 2015–2020, defined as the stable development phase due to less fluctuation in the growth rate. Second, the USA and China have more funding institutions for scientific research than other countries, resulting in that these two countries have the most significant publication numbers. Third, by counting the journals where this literature exists, the most published journals in this field are the *Journal of Cleaner Production*, *Science of the Total Environment*, and *Atmospheric Chemistry*.

Additionally, the cluster analysis of different publications in this field demonstrates that the three constant research areas are energy-related carbon emission, methane emission, and energy biomass, and the remaining frontier of "hot" research areas are cumulative carbon emission, residential building sector, measuring methane flux, nitrogen fertilization, land degradation neutrality, and sciamachy satellite methane measurement. In addition, two augmented insights are nitrogen fertilization and the residential building sector. Following the UN's increased attention to the greenhouse effect and global warming in the last century, the UN has proposed SDGs in this century. Each country has proposed corresponding carbon peaks and carbon–neutral targets accordingly. In the field of scientific research, scholars around the world have made various efforts. This paper intends to help provide direct and efficient assistance to researchers in their respective academic fields with regard to carbon neutrality and peak CO_2 emissions.

There are three limitations despite all the relative publications about the research field have been evaluated in this study. First, the data was only collected from the WOS Core Collection, and there may be an issue regarding incomplete publications in the other databases. Future research can utilize WOS and Scopus as research databases to ensure adequate coverage of published papers (Mongeon and Paul-Hus 2016; Ranjbari et al. 2021b). Second, other informative analysis tools could be considered to conduct an in-depth analysis of this research dataset in the future. Eventually, the bibliometrics analysis methods could be extended to text mining and content analysis, which may make the analysis more comprehensive (Ranjbari et al. 2021a).

Policy recommendations

Given the above original insights, we further summarize several targeted policies to overcome the potential issues behind nitrogen fertilization and the residential building sector. A mature indicator system has been proposed and widely applied in resource and environmental academic fields (Anderson et al. 2015).

For the issue of nitrogen fertilization, MRTN (Maximum Return to N) was established with the objective of recommending the most appropriate amount of regional nitrogen to local governments. MRTN is an effective ecological method to solve the variation in nitrogen fertilizing levels caused by climate and is worth popularizing on a larger scale (Sawyer et al. 2006). In addition, the life cycle assessment method has been applied in many developed states and has seen outstanding achievements in carbon reduction and economic efficiency, which boost agriculture efficiency and sustainability (Brentrup et al. 2004).

Concerning the residential building sector, ecological policies have been proposed in the literature, and a dynamic system model has been introduced to analyze the mutual relationships between different stakeholders included in the industrial carbon reduction process. This method was applied to find the main drivers hindering the application of carbon reduction technologies (Lai et al. 2017). Additionally, governments could implement robust fiscal and financial policies, providing positive incentives for enterprises to achieve carbon reduction and solving the externality effect in the residential building sectors (Kim et al. 2013).

Finally, some scholars have explored potential factors affecting carbon trading schemes from the perspective of building owners based on game theory, which demonstrated that the fear of reputation loss could alter the behavior of households to a large extent (Jalali Naini et al. 2011; Liang et al. 2016). A multiple-target optimal path has been modeled simultaneously, which leads to a minimal incremental cost to achieve the required carbon emission reduction (Song et al. 2018).

Appendix

Quantitative analysis of co-authorship

Chinese scholars are very active in researching carbon neutrality, and peak carbon dioxide emissions and publications are significantly higher than scholars from other countries. Statistics on the number of publications by scholars can help deepen the field's understanding by providing a better experience of the active authors in the area and tracking the state-of-the-art research results of their teams. Table 7 lists the 15 scholars with the highest number of publications from 2010 to 2020 and their literature-related parameters, including total publications (TPs), percentage (Pr (%)), total citations (TC), H-index, and per-page citations (CPP). The statistical results reveal that scholars that published most literature are Zhang Y from China with 15 publications from 2010 to 2020 (TC: 284, CPP: 18.93), followed by Wang Y from China with 11 publications (TC: 322, CPP: 29.27). Additionally, Chen H, also from China, with 10 publications (TC: 147, CPP: 14.70), among the top 15 authors in terms of publication volume, Huang Y has the highest citation volume (TC: 380, CPP: 54.29). However, he is ranked 11th in terms of publication volume (Table 7).

Table 7 Characteristics by top 15 active contributing authors from 2010 to 2020

Rank	Author	Organization	Country	TPs	Pr(%)	TC	H-index	CPP
1	Zhang Y	Fudan Univ et al.	China	15	0.93	284	10	18.93
2	Wang Y	Guangzhou Inst Geog et al.	China	11	0.68	322	6	29.27
3	Chen H	Tsinghua Univ et al.	China	10	0.62	147	7	14.70
4	Li J	Sun Yat Sen Univ et al.	China	9	0.56	166	7	18.44
5	Li W	North China Electric Power Univ et al.	China	9	0.56	125	5	13.89
6	Wang J	Chinese Academy of Sciences et al.	China	9	0.56	93	6	10.36
7	Zhang Q	Univ Sci and Technol China et al.	China	9	0.56	132	6	14.67
8	Li Y	Shandong Univ et al.	China	8	0.50	289	6	36.13
9	Vesala T	Univ Helsinki	Finland	8	0.50	225	5	28.13
10	Zhang X	Shanghai Jiao Tong Univ et al.	China	8	0.50	230	5	28.75
11	Huang Y	Chinese Acad Sci et al.	China	7	0.43	380	6	54.29
12	Kellomaki S	Univ Eastern Finland	Finland	7	0.43	106	6	15.14
13	Sainju UM	ARS, USDA	USA	7	0.43	163	7	23.29
14	Allen MR	Univ Oxford	England	6	0.37	297	6	49.50
15	Joos F	Univ Bern	Switzerland	6	0.37	216	5	36.00

Note: *TPs*, total publications; *Pr(%)*, proportion; *TC*, total citation; *CPP*, citation per paper. Top 15 active authors based on WOS Core Collection; multiple organizations from one author using et al

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Author contribution SY: conceptualization, methodology, data curation, writing—original draft, writing—review and editing, replying-to-reviewers and thesis-polishing. DY: data curation, writing—review and editing. WS: data curation, writing—review and editing. CD: writing—original draft, writing—review and editing, replying-to-reviewers and thesis-polishing. CC: conceptualization, methodology, data curation, writing—review and editing, supervision, funding. SF: writing—review and editing.

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Data availability The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

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Consent to participate Not applicable.

Consent for publication Not applicable.

Competing interests The authors declare no competing interests.

References

Abas N, Kalair A, Khan N (2015) Review of fossil fuels and future energy technologies. Futures 69:31–49. https://doi.org/10.1016/j.futures.2015.03.003

Acar C, Dincer I (2019) Review and evaluation of hydrogen production options for better environment. J Clean Prod 218:835–849. https://doi.org/10.1016/j.jclepro.2019.02.046

Adedoyin FF, Gumede MI, Bekun FV et al (2020) Modelling coal rent, economic growth and CO2 emissions: Does regulatory quality matter in BRICS economies? Sci Total Environ 710:136284. https://doi.org/10.1016/j.scitotenv.2019.136284

Ali AM, Awad MYM, Hegab SA et al (2021) Effect of potassium solubilizing bacteria (Bacillus cereus) on growth and yield of potato. J Plant Nutr 44:411–420. https://doi.org/10.1080/01904167.2020.1822399

Allen MR, Shine KP, Fuglestvedt JS, et al (2018) A solution to the misrepresentations of CO2-equivalent emissions of short-lived climate pollutants under ambitious mitigation. npj Clim Atmos Sci 1:1–8. https://doi.org/10.1038/s41612-018-0026-8

Amin MT, Khan F, Amyotte P (2019) A bibliometric review of process safety and risk analysis. Process Saf Environ Prot 126:366–381. https://doi.org/10.1016/j.psep.2019.04.015

Anav A, Friedlingstein P, Kidston M et al (2013) Evaluating the land and ocean components of the global carbon cycle in the CMIP5 earth system models. J Clim 26:6801–6843. https://doi.org/10.1175/JCLI-D-12-00417.1

Anderson JL, Anderson CM, Chu J et al (2015) The fishery performance indicators: A management tool for triple bottom line outcomes. PLoS ONE 10:1–20. https://doi.org/10.1371/journal.pone.0122809

Arriola ER, Chen W (2020) A bibliometric review on the application of fuzzy optimization to sustainable energy technologies. Int J energy Res 1–22. https://doi.org/10.1002/er.5729

Baldocchi D (2014) Measuring fluxes of trace gases and energy between ecosystems and the atmosphere - the state and future of the eddy covariance method. Glob Chang Biol 20:3600–3609. https://doi.org/10.1111/gcb.12649

Bashir MF (2022) Oil price shocks, stock market returns, and volatility spillovers: a bibliometric analysis and its implications. Environ Sci Pollut Res. https://doi.org/10.1007/s11356-021-18314-4

Bashir MF, Ma B, Bashir MA et al (2021a) Scientific data-driven evaluation of academic publications on environmental Kuznets curve. Environ Sci Pollut Res 28:16982–16999. https://doi.org/10.1007/s11356-021-13110-6

Bashir MF, Ma B, Bilal, et al (2021b) Analysis of environmental taxes publications: a bibliometric and systematic literature review. Environ Sci Pollut Res 28:20700–20716. https://doi.org/10.1007/s11356-020-12123-x

Bashir MF, Ma B, Qin Y, Bashir MA (2021c) Evaluation of One Belt One Road publications: a bibliometric and literature review analysis. Environ Sci Pollut Res 28:37016–37030. https://doi.org/10.1007/s11356-021-14621-y

Bi Z, Kong Q, Cao Y et al (2019) Biomass-derived porous carbon materials with different dimensions for supercapacitor electrodes: a review. J Mater Chem A 7:16028–16045. https://doi.org/10.1039/c9ta04436a

Borges AV, Darchambeau F, Teodoru CR et al (2015) Globally significant greenhouse-gas emissions from African inland waters. Nat Geosci 8:637–642. https://doi.org/10.1038/ngeo2486

Brentrup F, Küsters J, Kuhlmann H, Lammel J (2004) Environmental impact assessment of agricultural production systems using the life cycle assessment methodology: I. Theoretical concept of a LCA method tailored to crop production. Eur J Agron 20:247–264. https://doi.org/10.1016/S1161-0301(03)00024-8

Chen C (2006) CiteSpace II: detecting and visualizing emerging trends and transient patterns in scientific literature. J Am Soc Inf Sci Technol 57:359–377. https://doi.org/10.1002/asi.20317

Chen C, Chitose A, Kusadokoro M et al (2021) Sustainability and challenges in biodiesel production from waste cooking oil: an advanced bibliometric analysis. Energy Rep 7:4022–4034. https://doi.org/10.1016/j.egyr.2021.06.084

Chen C, Ibekwe-SanJuan F, Hou J (2010) The structure and dynamics of cocitation clusters: a multiple-perspective cocitation analysis. J Am Soc Inf Technol 61:1386–1409. https://doi.org/10.1002/asi.21309

Chen C, Zhang J, Vogeley MS (2009) Visual analysis of scientific discoveries and knowledge diffusion. 12th Int Conf Sci Inf ISSI 2009 2875:874–885.

Chen QL, Ding J, Zhu D et al (2020) Rare microbial taxa as the major drivers of ecosystem multifunctionality in long-term fertilized soils. Soil Biol Biochem 141:107686. https://doi.org/10.1016/j.soilbio.2019.107686

Coletti C, Riedl C, Lee DS et al (2010) Charge neutrality and band-gap tuning of epitaxial graphene on SiC by molecular doping. Phys Rev B - Condens Matter Mater Phys 81:1–8. https://doi.org/10.1103/PhysRevB.81.235401

Cowan WN, Chang T, Inglesi-Lotz R, Gupta R (2014) The nexus of electricity consumption, economic growth and CO2 emissions in the BRICS countries. Energy Policy 66:359–368. https://doi.org/10.1016/j.enpol.2013.10.081

Crippa M, Guizzardi D, Pisoni E et al (2021) Global anthropogenic emissions in urban areas: Patterns, trends, and challenges. Environ Res Lett 16: https://doi.org/10.1088/1748-9326/ac00e2

Ding S, Zhang M, Song Y (2019) Exploring China's carbon emissions peak for different carbon tax scenarios. Energy Policy 129:1245–1252. https://doi.org/10.1016/j.enpol.2019.03.037

Dong F, Wang Y, Su B et al (2019) The process of peak CO2 emissions in developed economies: A perspective of industrialization and urbanization. Resour Conserv Recycl 141:61–75. https://doi.org/10.1016/j.resconrec.2018.10.010

Du E, Terrer C, Pellegrini AFA et al (2020) Global patterns of terrestrial nitrogen and phosphorus limitation. Nat Geosci 13:221–226. https://doi.org/10.1038/s41561-019-0530-4

Elias DC, Gorbachev RV, Mayorov AS et al (2011) Dirac cones reshaped by interaction effects in suspended graphene. Nat Phys 7:701–704. https://doi.org/10.1038/nphys2049

Elser M, Huang RJ, Wolf R et al (2016) New insights into PM2.5 chemical composition and sources in two major cities in China during extreme haze events using aerosol mass spectrometry. Atmos Chem Phys 16:3207–3225. https://doi.org/10.5194/acp-16-3207-2016

Feng C, Zheng CJ, Shan ML (2020) The clarification for the features, temporal variations, and potential factors of global carbon dioxide emissions. J Clean Prod 255:120250. https://doi.org/10.1016/j.jclepro.2020.120250

Foucquier A, Robert S, Suard F et al (2013) State of the art in building modelling and energy performances prediction: a review. Renew Sustain Energy Rev 23:272–288. https://doi.org/10.1016/j.rser.2013.03.004

Gann GD, McDonald T, Walder B et al (2019) International principles and standards for the practice of ecological restoration. Second Edition Restor Ecol 27:S1–S46. https://doi.org/10.1111/rec.13035

Garza AJ, Bell AT, Head-Gordon M (2018) Mechanism of CO2 Reduction at Copper Surfaces: Pathways to C2 Products. ACS Catal 8:1490–1499. https://doi.org/10.1021/acscatal.7b03477

Giles-Corti B, Vernez-Moudon A, Reis R et al (2016) City planning and population health: a global challenge. Lancet 388:2912–2924. https://doi.org/10.1016/S0140-6736(16)30066-6

Guerrini L, Napoli M, Mancini M et al (2020) Wheat grain composition, dough rheology and bread quality as affected by nitrogen and sulfur fertilization and seeding density. Agronomy 10. https://doi.org/10.3390/agronomy10020233

Gupta R, Mejia C, Gianchandani Y, Kajikawa Y (2020) Analysis on formation of emerging business ecosystems from deals activities of global electric vehicles hub firms. Energy Policy 145:111532. https://doi.org/10.1016/j.enpol.2020.111532

Hamann E, Blevins C, Franks SJ et al (2021) Climate change alters plant–herbivore interactions. New Phytol 229:1894–1910. https://doi.org/10.1111/nph.17036

Hansen J, Sato M, Russell G, Hansen J (2013) Climate sensitivity, sea level and atmospheric carbon dioxide Author for correspondence. Phil Trans R Soc A 371:20120294. https://doi.org/10.1098/rsta.2012.0294

He K, Zhang J, Zeng Y (2019) Science of the Total Environment Knowledge domain and emerging trends of agricultural waste management in the fi eld of social science: a scientometric review. Sci Total Environ 670:236–244. https://doi.org/10.1016/j.scitotenv.2019.03.184

Hepburn C, Adlen E, Beddington J et al (2019) The technological and economic prospects for CO2 utilization and removal. Nature 575:87–97. https://doi.org/10.1038/s41586-019-1681-6

Houghton RA, Nassikas AA (2017) Global and regional fluxes of carbon from land use and land cover change 1850–2015. Global Biogeochem Cycles 31:456–472. https://doi.org/10.1002/2016GB005546

Hu H, Landgraf J, Detmers R et al (2018) Toward global mapping of methane with TROPOMI: first results and intersatellite comparison to GOSAT. Geophys Res Lett 45:3682–3689. https://doi.org/10.1002/2018GL077259

Hu S, Yan D, Guo S et al (2017) A survey on energy consumption and energy usage behavior of households and residential building in urban China. Energy Build 148:366–378. https://doi.org/10.1016/j.enbuild.2017.03.064

Hunt B, Taniguchi T, Moon P et al (2013) Massive Dirac fermions and. Science (80-) 340:1427–1431. https://doi.org/10.1594/PANGAEA.808834

JalaliNaini SG, Aliahmadi AR, Jafari-Eskandari M (2011) Designing a mixed performance measurement system for environmental supply chain management using evolutionary game theory and balanced scorecard: a case study of an auto industry supply chain. Resour Conserv Recycl 55:593–603. https://doi.org/10.1016/j.resconrec.2010.10.008

Ji H, Zhao X, Qiao Z et al (2014) Capacitance of carbon-based electrical double-layer capacitors. Nat Commun 5. https://doi.org/10.1038/ncomms4317

Keesstra S, Mol G, de Leeuw J et al (2018) Soil-related sustainable development goals: Four concepts to make land degradation neutrality and restoration work. Land 7. https://doi.org/10.3390/land7040133

Kim MJ, Oh MW, Kim JT (2013) A method for evaluating the performance of green buildings with a focus on user experience. Energy Build 66:203–210. https://doi.org/10.1016/j.enbuild.2013.07.049

Lai X, Liu J, Shi Q et al (2017) Driving forces for low carbon technology innovation in the building industry: A critical review. Renew Sustain Energy Rev 74:299–315. https://doi.org/10.1016/j.rser.2017.02.044

Lassaletta L, Billen G, Grizzetti B et al (2014) 50 year trends in nitrogen use efficiency of world cropping systems: The relationship between yield and nitrogen input to cropland. Environ Res Lett 9. https://doi.org/10.1088/1748-9326/9/10/105011

Lavallee JM, Soong JL, Cotrufo MF (2020) Conceptualizing soil organic matter into particulate and mineral-associated forms to address global change in the 21st century. Glob Chang Biol 26:261–273. https://doi.org/10.1111/gcb.14859

Lawrence DM, Fisher RA, Koven CD, et al (2019) The Community Land Model Version 5: description of new features, benchmarking, and impact of forcing uncertainty

Le Quéré C, Jackson RB, Jones MW et al (2020) Temporary reduction in daily global CO2 emissions during the COVID-19 forced confinement. Nat Clim Chang 10:647–653. https://doi.org/10.1038/s41558-020-0797-x

Le Quéré C, Korsbakken JI, Wilson C et al (2019) Drivers of declining CO_2 emissions in 18 developed economies. Nat Clim Chang 9:213–217. https://doi.org/10.1038/s41558-019-0419-7

Liang S, Zhao J, He S et al (2019a) Spatial econometric analysis of carbon emission intensity in Chinese provinces from the perspective of innovation-driven. Environ Sci Pollut Res 26:13878–13895. https://doi.org/10.1007/s11356-019-04131-3

Liang X, Peng Y, Shen GQ (2016) A game theory based analysis of decision making for green retrofit under different occupancy types. J Clean Prod 137:1300–1312. https://doi.org/10.1016/j.jclepro.2016.07.200

Liang Y, Cai W, Ma M (2019b) Carbon dioxide intensity and income level in the Chinese megacities' residential building sector: decomposition and decoupling analyses. Sci Total Environ 677:315–327. https://doi.org/10.1016/j.scitotenv.2019.04.289

Liao Y, Koelewijn SF, van den Bossche G et al (2020) A sustainable wood biorefinery for low-carbon footprint chemicals production. Science (80-) 367:1385–1390. https://doi.org/10.1126/science.aau1567

Ma M, Ma X, Cai W, Cai W (2020) Low carbon roadmap of residential building sector in China: Historical mitigation and prospective peak. Appl Energy 273:115247. https://doi.org/10.1016/j.apenergy.2020.115247

Marvuglia A, Havinga L, Heidrich O et al (2020) Advances and challenges in assessing urban sustainability: an advanced bibliometric review. Renew Sustain Energy Rev 124:109788. https://doi.org/10.1016/j.rser.2020.109788

Mongeon P, Paul-Hus A (2016) The journal coverage of Web of Science and Scopus: a comparative analysis. Scientometrics 106:213–228. https://doi.org/10.1007/s11192-015-1765-5

Nangini C, Peregon A, Ciais P et al (2019) A global dataset of co2 emissions and ancillary data related to emissions for 343 cities. Sci Data 6:1–29. https://doi.org/10.1038/sdata.2018.280

Nejat P, Jomehzadeh F, Taheri MM et al (2015) A global review of energy consumption, CO_2 emissions and policy in the residential sector (with an overview of the top ten CO2 emitting countries). Renew Sustain Energy Rev 43:843–862. https://doi.org/10.1016/j.rser.2014.11.066

Novara A, Cerda A, Barone E, Gristina L (2021) Cover crop management and water conservation in vineyard and olive orchards. Soil Tillage Res 208:104896. https://doi.org/10.1016/j.still.2020.104896

Olah GA, Prakash GKS, Goeppert A (2011) Anthropogenic chemical carbon cycle for a sustainable future. J Am Chem Soc 12881–12898. https://doi.org/10.1021/ja202642y

Omri A, Daly S, Rault C, Chaibi A (2015) Financial development, environmental quality, trade and economic growth: what causes what in MENA countries. Energy Econ 48:242–252. https://doi.org/10.1016/j.eneco.2015.01.008

Özener O, Yüksek L, Ergenç AT, Özkan M (2014) Effects of soybean biodiesel on a DI diesel engine performance, emission and combustion characteristics. Fuel 115:875–883. https://doi.org/10.1016/j.fuel.2012.10.081

Pacheco R, Ordóñez J, Martínez G (2012) Energy efficient design of building: a review. Renew Sustain Energy Rev 16:3559–3573. https://doi.org/10.1016/j.rser.2012.03.045

Ranjbari M, Saidani M, Shams Esfandabadi Z et al (2021a) Two decades of research on waste management in the circular economy: insights from bibliometric, text mining, and content analyses. J Clean Prod 314:128009. https://doi.org/10.1016/j.jclepro.2021.128009

Ranjbari M, Shams Esfandabadi Z, Shevchenko T et al (2022) Mapping healthcare waste management research: Past evolution, current challenges, and future perspectives towards a circular economy transition. J Hazard Mater 422:126724. https://doi.org/10.1016/j.jhazmat.2021.126724

Ranjbari M, Shams Z, Chiara M et al (2021b) Three pillars of sustainability in the wake of COVID-19: A systematic review and future research agenda for sustainable development. J Clean Prod 297:126660. https://doi.org/10.1016/j.jclepro.2021.126660

Riedl C, Coletti C, Starke U (2010) Structural and electronic properties of epitaxial Graphene on SiC(0001): A review of growth, characterization, transfer doping and hydrogen intercalation. J Phys D Appl Phys 43. https://doi.org/10.1088/0022-3727/43/37/374009

Rogelj J, Huppmann D, Krey V et al (2019) A new scenario logic for the Paris Agreement long-term temperature goal. Nature 573:357–363. https://doi.org/10.1038/s41586-019-1541-4

Rogelj J, Schaeffer M, Friedlingstein P et al (2016) Differences between carbon budget estimates unravelled. Nat Clim Chang 6:245–252. https://doi.org/10.1038/nclimate2868

Saunois M, Stavert AR, Poulter B, et al (2020) The Global Methane Budget 2000–2017. Earth Syst Sci Data 1561–1623. 10.5194/essd-12-1561-2020.

Sawyer J, Nafziger E, Randall G, et al (2006) Concepts and rationale for regional nitrogen rate guidelines for corn. Iowa State Univ Univ Ext 1–28.

Schraven D, Joss S, De JM (2021) Past, present, future: engagement with sustainable urban development through 35 city labels in the scienti fi c literature 1990 e 2019. J Clean Prod 292:125924. https://doi.org/10.1016/j.jclepro.2021.125924

Sellar AA, Jones CG, Mulcahy JP et al (2019) UKESM1: description and evaluation of the U.K. Earth System Model. J Adv Model Earth Syst 11:4513–4558. https://doi.org/10.1029/2019MS001739

Shahbaz M, Bashir MF, Bashir MA, Shahzad L (2021) A bibliometric analysis and systematic literature review of tourism-environmental degradation nexus. Environ Sci Pollut Res 28:58241–58257. https://doi.org/10.1007/s11356-021-14798-2

Shao X, Zhong Y, Liu W, Li RYM (2021) Modeling the effect of green technology innovation and renewable energy on carbon neutrality in N-11 countries? Evidence from advance panel estimations. J Environ Manage 296:113189. https://doi.org/10.1016/j.jenvman.2021.113189

Song X, Lu Y, Shen L, Shi X (2018) Will China's building sector participate in emission trading system? Insights from modelling an owner's optimal carbon reduction strategies. Energy Policy 118:232–244. https://doi.org/10.1016/j.enpol.2018.03.075

Sweileh WM, Al-Jabi SW, AbuTaha AS et al (2017) Bibliometric analysis of worldwide scientific literature in mobile - health: 2006–2016. BMC Med Inform Decis Mak 17:1–12. https://doi.org/10.1186/s12911-017-0476-7

Tian H, Lu C, Ciais P et al (2016) The terrestrial biosphere as a net source of greenhouse gases to the atmosphere. Nature 531:225–228. https://doi.org/10.1038/nature16946

UNFCCC (2015) Enhanced actions on climate change: China's intended nationally determined contributions. http://unfccc.int/focus/indc_portal/items/8766.php

Union E (2020) 2050 long-term strategy. https://ec.europa.eu/clima/policies/strategies/2050_en.

Ürge-Vorsatz D, Cabeza LF, Serrano S et al (2015) Heating and cooling energy trends and drivers in buildings. Renew Sustain Energy Rev 41:85–98. https://doi.org/10.1016/j.rser.2014.08.039

Van der Molen MK, Dolman AJ, Ciais P et al (2011) Drought and ecosystem carbon cycling. Agric for Meteorol 151:765–773. https://doi.org/10.1016/j.agrformet.2011.01.018

Van Eck NJ, Waltman L (2010) Software survey: VOSviewer, a computer program for bibliometric mapping. Scientometrics 84:523–538. https://doi.org/10.1007/s11192-009-0146-3

Veefkind JP, Aben I, McMullan K et al (2012) TROPOMI on the ESA Sentinel-5 Precursor: A GMES mission for global observations of the atmospheric composition for climate, air quality and ozone layer applications. Remote Sens Environ 120:70–83. https://doi.org/10.1016/j.rse.2011.09.027

Walker AP, De Kauwe MG, Bastos A, et al (2021) Integrating the evidence for a terrestrial carbon sink caused by increasing atmospheric CO_2.

Wan T, Shen S, Bandyopadhyay A, Shu C (2012) Bibliometric analysis of carbon dioxide reduction research trends during 1999–2009. Sep Purif Technol 94:87–91. https://doi.org/10.1016/j.seppur.2011.07.022

Wang T, Nie W, Gao J et al (2010) Air quality during the 2008 Beijing Olympics: Secondary pollutants and regional impact. Atmos Chem Phys 10:7603–7615. https://doi.org/10.5194/acp-10-7603-2010

Wunch D, Toon GC, Blavier JFL et al (2011) The total carbon column observing network. Philos Trans R Soc A Math Phys Eng Sci 369:2087–2112. https://doi.org/10.1098/rsta.2010.0240

Xiao J, Chevallier F, Gomez C et al (2019) Remote sensing of the terrestrial carbon cycle: a review of advances over 50 years. Remote Sens Environ 233:111383. https://doi.org/10.1016/j.rse.2019.111383

Xie R, Wei D, Han F et al (2019) The effect of traffic density on smog pollution: evidence from Chinese cities. Technol Forecast Soc Change 144:421–427. https://doi.org/10.1016/j.techfore.2018.04.023

Xu YC, Li XH, Ren K, Chai LH (2021) Structures of urban carbon cycle based on network indicators: Cases of typical cities in China. J Clean Prod 282:125405. https://doi.org/10.1016/j.jclepro.2020.125405

Yan Y, Qian Y, Sharif H, Tipper D (2013) A survey on smart grid communication infrastructures: Motivations, requirements and challenges. IEEE Commun Surv Tutorials 15:5–20. https://doi.org/10.1109/SURV.2012.021312.00034

Yang J, Hao Y, Feng C (2021) A race between economic growth and carbon emissions: what play important roles towards global low-carbon development? Energy Econ 100:105327. https://doi.org/10.1016/j.eneco.2021.105327

Yu A, Su W, Lin X, Zhou N (2020) Recent trends of supercritical CO_2 Brayton cycle: Bibliometric analysis and research review. Nucl Eng Technol. https://doi.org/10.1016/j.net.2020.08.005

Zanchi G, Pena N, Bird N (2012) Is woody bioenergy carbon neutral? A comparative assessment of emissions from consumption of woody bioenergy and fossil fuel. GCB Bioenergy 4:761–772. https://doi.org/10.1111/j.1757-1707.2011.01149.x

Zhang F, Sahu B, Min H, MacDonald AH (2010) Band structure of ABC-stacked graphene trilayers. Phys Rev B - Condens Matter Mater Phys 82:1–10. https://doi.org/10.1103/PhysRevB.82.035409

Zhang YJ, Da YB (2015) The decomposition of energy-related carbon emission and its decoupling with economic growth in China. Renew Sustain Energy Rev 41:1255–1266. https://doi.org/10.1016/j.rser.2014.09.021

Zhou X, Zhang J, Li J (2013) Industrial structural transformation and carbon dioxide emissions in China. Energy Policy 57:43–51. https://doi.org/10.1016/j.enpol.2012.07.017

Zuo J, Read B, Pullen S, Shi Q (2012) Achieving carbon neutrality in commercial building developments-Perceptions of the construction industry. Habitat Int 36:278–286. https://doi.org/10.1016/j.habitatint.2011.10.010