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REVIEW ARTICLE

A review contribution to emission trading schemes and low carbon growth

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Abstract
In this study, the researchers focus on policy instruments that employ a market-based strategy to promote emission reduction, find the key spots and recent changing aspects in the field of Eemission Trading Systems (ETS) and Low Carbon Growth, and make suggestions for future studies. Making use of the bibliometric analysis, the researchers examine a sample of 1,390 research from the ISI Web of Science database to find research activity on ETS and low carbon growth between 2005 and 2022. Also, the researchers visualized the knowledge domains in this field using software like CiteSpace and R-Biblioshiny. The research unravels the most influential published articles and authors on their citations and publications and their location and significance within the network. The researchers further examined the recent themes, identified the barriers to developing literature in this field, and made recommendations for future research. Research on ETS and low carbon growth globally lack cross-border collaborations between emerging and developed economies. The researchers concluded the study by recommending three future research directions.

Keywords Emission trading systems · Emission reduction · Low carbon growth · Bibliometrics

Introduction

Anthropogenic climate change remains one of the shackles hanging around the neck of our global society today (Palmer and Stevens 2019). Although there have been several attempts to decline or possibly mitigate the impact of humans on global warming, these attempts are evident in the Kyoto Protocol, highlighting the target standards for Greenhouse Gas (GHGs) emissions in technologically advanced countries (Wegener 2020). The rising climate change can impede development. A report issued by the Intergovernmental Panel on Climate Change (IPCC) indicates that since the 1950's, our globe has faced severe weather conditions, including heavy precipitation, heat currents, surges, and droughts (Hou and Wang 2021; Tollefson 2018). Researchers opine that these challenges seem endless. The intensity and the amount of rainfall will increase exponentially globally, while some other areas will also face drought, among other severe uncertainties (Byers et al. 2017; Peel 2015; Savaresi 2016). In both developed and developing economies, a certain level of national development thrives on a differing level of fossil-fuel energy, which is also a high source of carbon dioxide emissions. Hence, if there are attempts to reduce such emissions, it implies that fossil-fuel energy consumption must be controlled.

Consequently, this will affect various countries' production and economic development (Lelieveld et al. 2019; Muttitt and Kartha 2020). For various countries to have a

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"win-win" situation and, thus, maximize potential economic gains and development while controlling emissions, there should be good coordination of various policies, conservation and low-carbon structures, and technological innovation (Zhang et al. 2021). ETS have surfaced as one of the popular and applicable approaches adopted to help curb GHGs emissions and facilitate the transition to a low carbon economy. ETS promotes cleaner manufacturing and allows firms to reduce emissions at a cost-effective rate (Al et al. 2021; Hasan et al. 2021). Currently, China emerges as a key emitter of GHG and an important location for global emission mitigation (Liu and Wu 2017; Yu et al. 2019) due to industrialization leading to excessive fossil fuel energy consumption. More so, America and some European countries follow close as locations emitting more CO_2 (Cohen et al. 2019; Syed and Ullah 2021) (see Fig. 1). As part of the efforts of various countries to respond to climate change issues, many of these countries have agreed to contribute to climate change mitigation by reducing CO_2 emissions. Juxtaposing 2020 and 2005, the Chinese government at the 2009 Copenhagen Summit pledged to reduce CO_2 emissions by 40–45% significantly.

In 2011, the Chinese government commenced the pilot model of the ETS in two provinces, Guangdong and Hubei. Since this implementation, various scholars and policymakers have been interested in assessing the impact of ETS on carbon reduction. By implication, a Cap-and-Trade scheme will ensure emission reductions once the cap is set close-fitting enough and controlled emitters are not in gross abuse of the system (Chen et al. 2020). In other circumstances where there is an emission-decreasing cap, the obvious decrease in carbon emissions cannot be directly associated with ETS since it is possible that other factors or policies can also cause carbon emissions declines. In the case of China, policies are implemented concurrently to promote low-carbon emissions (Chen et al. 2013;

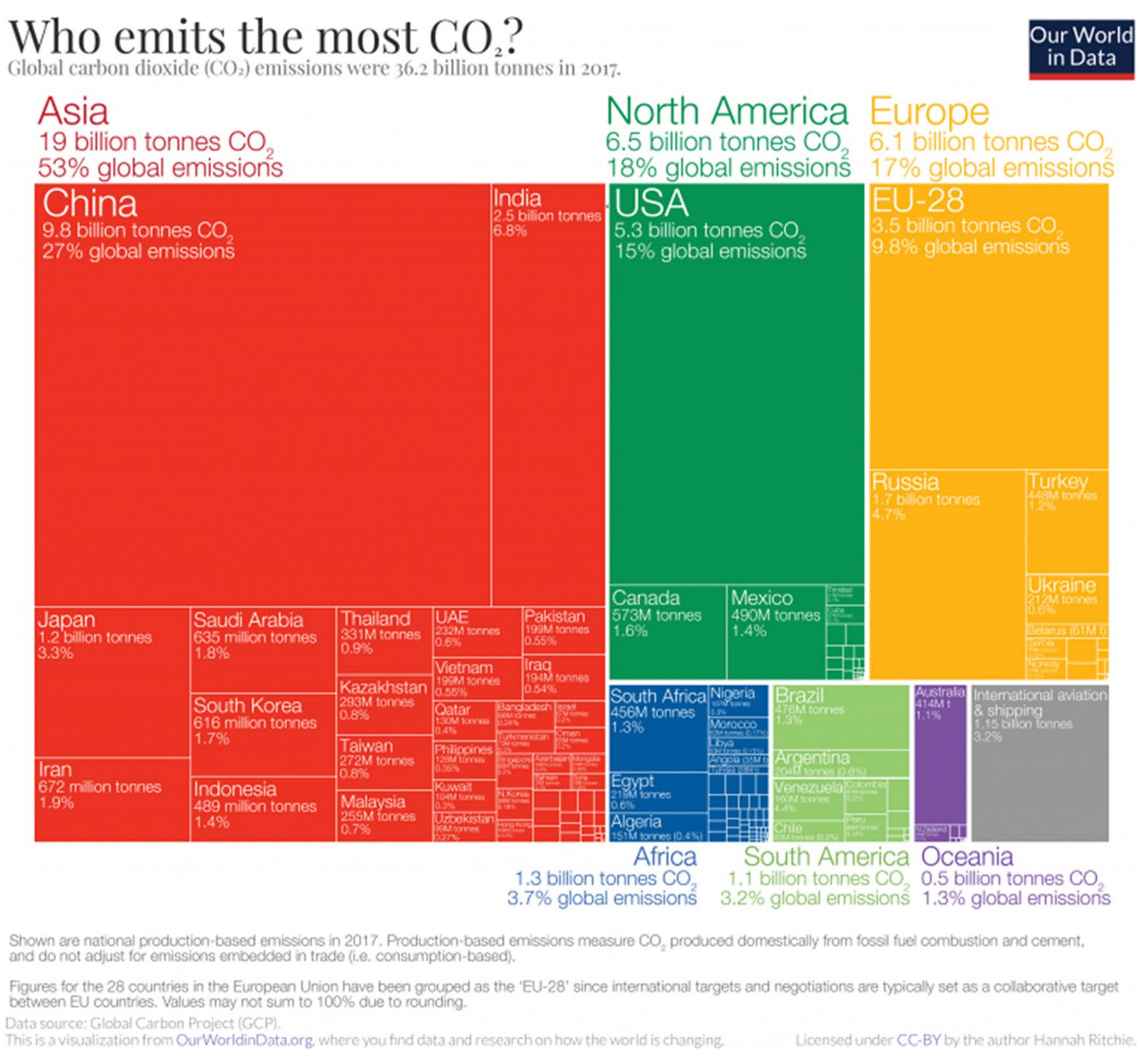


Fig. 1 Who emits more CO_2? lhttps://ourworldindata.org (Assessed on 22.11.2022)

Mi et al. 2019; Zhang and Liang 2020a, b). In 2005, the European Union (EU) enacted the EU ETS with the Kyoto Protocol's targets in perspective (Bayer and Aklin 2020). The aim was that by 2020, GHGs will decline by 20% compared to 1990.

Several increasing research is adding to ETS literature to promote mitigating carbon emissions. Adopting the computable general equilibrium (CGE) models, several researchers have explored from a quantitative perspective (Bassi and Costantini 2021; Li et al. 2019; Pang et al. 2018; Tang et al. 2020). From a theoretical point of view, other scholars have explored plausible mitigation mechanism designs (Luo et al. 2021; Ma et al. 2022). Other scholars have compared carbon emission concentration in different areas and industries, especially concerning the China pilot ETS (Zhang and Duan 2020; Zhou et al. 2020). Focusing on the EU ETS, some researchers have used panel data to explore the fundamental effect of ETS on mitigating carbon emissions (Fremstad et al. 2021; Heiaas 2021; Koch and Basse 2019; Muttitt and Kartha 2020). From a review perspective, some scholars have conducted critical reviews, systematic reviews, and empirical reviews to evaluate the performance of cap-and-trade systems, explore the future position for three design inventions, and expound on the impacts of the EU ETS on low carbon technological change (Leining et al. 2019; Narassimhan et al. 2018; Tang et al. 2020).

However, limited research adopts the bibliometric approach to visualize and map the various knowledge fields of ETS that focus on implementing ETS in various jurisdictions and their contribution to low carbon emissions. Although Zheng et al. (2022) conducted a bibliometric analysis on low carbon growth, their study was "A bibliometric review on carbon accounting in social science during 1997–2020." From a social science perspective, the researchers explored how carbon accounting is essential to determine the appropriate allocation of reduction responsibility; thus, contributing to addressing the climate crisis. The researchers purposely skewed their subject categories to the field of Social Science. In this same study, the researchers used articles and review papers and found that international trade has spurred considerable scholarly interest in responsibility allocation from a consumption perspective. Also, this research unraveled that IO (input–output) analysis used to derive embodied emissions in trade has become the most popular method in this domain. It also revealed that few publications had addressed the quantification of emissions at the organizational level. Every bibliometric analysis is unique with the keyword search. The researchers in this study used keywords like *carbon accounting*, *bibliometric review*, *input–output analysis*, *and international trade*. Based on these choices of keywords, the researchers explored carbon accounting from a social science perspective to measure and report emissions to help organizations.

With the recent trends and developments in the ETS research domains, there is a possibility of emerging new areas that have been overlooked in past research. This research is distinct from other research and reviews in some ways. First, this research uses subject category scope from Environmental Science and only used research articles to explore ETS and low carbon growth. The researchers make a clear distinction with their choice of keywords *emission trading systems*, *emission reduction*, *low carbon growth*, and *bibliometrics*. Based on the choice of keywords, this research focuses on the policy instrument that employs a market-based strategy to promote emission reduction. More so, this research contributes to the scarcity of bibliometric reviews in ETS and low carbon emissions through performance, empirical visualization, and mapping analysis. Consequently, the researchers explore the rational and theoretical structure of the ETS and low-carbon emission field to give researchers a general idea of the ETS and low-carbon emission and assess the evolving phases over the last 17 years.

Owing to the several advantages of adopting the bibliometric analysis that allows a researcher to succinctly analyze large data to report on emerging progress and trends (Effah et al. 2022b; Mao et al. 2015), this research adopts this approach to make an extensive review on the impacts of ETS on low carbon growth. The bibliometric approach is touted as an innovative methodology relevant to showing the emerging scope of a particular knowledge domain (Agyepong and Liang 2022). This approach helps the researchers to analyze previous literature quantitatively and qualitatively (Afrane et al. 2022a, b).

Utilizing data from the Web of Science (WoS) database, CiteSpace software, and R-Studio (Biblioshiny) for mapping and visualization, the research sought to (a) assess the suitability and quality of the subject area through the identification of leading authors, patterns, and performances of countries or institutions; (b) examine collaborations among institutions and countries that have enormously contributed to researches in the field of ETS and low-carbon emission research to unearth the research evolution between countries; and (c) to find out present hotspots in this knowledge domain based on keyword analysis which may impact and through more light on the possibilities for future research in the field. Explicitly, this research answers the outlined research questions: (1) what is the developing trend in this research field? (2) Which journals, subject categories, institutions, and regions involved in ETS and low-carbon emissions are prevalent? (3) Who are the most influential authors, and their collaborations on ETS and low-carbon emissions? (4) What are the current research's authorship output, citation, and co-citation structure? (5) What are the prevalent developing themes in ETS and low-carbon growth research and areas that need further studies? The rest of this research is outlined as follows: the "Methodology" section, which explains the methods used for the study. The "Results and Discussion" section summarizes the results centered on the subject areas, regional and authorship, and keyword analysis. The "Conclusion and Limitations of the study" section highlights the findings of the evolution of hot topics and concludes with avenues for future research and provides implications for the study and the limitations.

Overview of Emission Trading Systems (ETS)

ETS is a synthetic marketplace establishment to proscribe the total emissions of specific materials or gasses (Heiaas 2021; Lo 2016; Mi et al. 2019; Zhang et al. 2017). The major advantage of applying carbon markets among various methods to reduce GHG emissions is that they accelerate to gain emission declines where they are not expensive; hence, achieving the goals at a reduced financial and economic cost (Koch and Basse 2019; Luo et al. 2021). ETS is commonly advanced in the structure of cap-and-trade systems: the ceiling (or cap) is established totally on policy dimension and typically follows a descending trend through the years. Scholars have argued that ETS below certain situations, the externalities or inadequacies of the economic system may want to be corrected through cooperation by parties; thus, attaining the maximization of social advantages (Feng et al. 2021).

Other scholars add that in the early 1970s, Montgomery thoroughly established that the ETS is described through regulating pollutants at an economic cost; that is to say, it demands a minimal fee to attain pollution control goals (Zong et al. 2020). The numerous forms of ETS involving carbon emissions are starting to be widely released worldwide. The fundamental unit of account is 1 ton of CO_2 equal weight. At the end of every duration, contributors must "give up" the number of emissions allotted, and the devices are canceled from their accounts (Chen et al. 2020). Those who have decreased emissions more than the quantity of emission credit allocated can have an excess possibility. Those in shortage or have supplied more tons of CO_2 equivalent weight than permitted should fill in the discrepancy by applying procuring emission rights. This is how the marketplace is created. The cap guarantees that climate goals are achieved. This system's principal benefit is the climate regulations and the reduction curve are determined at the start of the cycle.

Nevertheless, this does not imply that an ETS can supply via itself the essential GHG declines required: several knowledge has indicated that with a drive to attain ETS and carbon markets and future climate targets, the reduction curves desire to be planned to work together with different policies and targets (Dong and Dai 2019). The other form of ETS is baseline and credit. In this example, there is a specific implementation or baseline, and the quantity of credits is estimated regarding the variation with the baseline. It is the type of system at the bottom of some project-based crediting systems, like the Clean Development Mechanisms of the Kyoto Protocol and the REDD+ (Doda et al. 2021). The national ETS might be running in the cap-and-trade form. The emission marketplace mechanism is an option to the greater conventional "control and manipulates" strategy, through which the public power sets restricts and then tests the conformity.

From an economic perspective, an ETS lets in to decline emissions at the lowest price for the economic system: topics with a reduction value decrease than the fee of CO_2 might be incentivized to reduce their emissions. In contrast, themes with higher reduction expenses will discover extra economics to buy credits. Consequently, from economists' perspective, if the total emission structures were to be determined or to connect the diverse national structures, emissions might be decreased with a lower usual cost.

China's new ETS

China has established a robust policy to be a leader in clean technologies, including batteries, solar, and wind power electricity. However, no nation has a latch on these still emerging markets. Many countries have shown much interest in these rapid growth potential industries; the United States (US) is notable among them. Although several opportunities exist in the US, China poses a strong challenge in this clean technologies field (Kokotsaki et al. 2018). In 2015, China declared its national ETS with a projected goal that the policy would protect a considerable portion of the country's pollutants. China's ETS has taken over the global carbon market and is projected to be thrice bigger than the European Union ETS (EU ETS).

China plans to advance to about 70% of its ETS to encapsulate industrial and manufacturing activities. This will make China's ETS the sole principal global climate change policy, covering several more emissions than the entire global carbon market (Busby et al. 2018; Yamineva and Liu 2019). Whether China's ETS will succeed or fail at a point is because China continues to lead as the world's biggest GHG emitter and, as we advance, will decide the way forward for climate change. The recent research focusing on Energy Innovation defines how China's ETS can multiply to stimulate national invention and fiscal growth and propel the nation to attain the set pledge, to sum up carbon emissions before 2030 (Heggelund 2021; Popp 2019). It is suggested that the increasing national advantages are expected to raise the drive for intensifying and reinforcing China's ETS. This is further expected to put forward aspirations for the clear-cut emission declines required to mitigate risky climate change.

China fully operationalized ETS in 2021 when the firms under the ETS policy were necessitated to deposit emission permits with the public authorities to prove a section of their 2019 and 2020 emissions (Tao et al. 2022). China's ETS policy started with controlled carbon emissions from power plants, protecting approximately 2,200 energy companies. This has been the core idea of China's ETS to reach a larger scale of manufacturing industries and emissions.

European Union ETS (EU ETS)

ETS started in the European Union in 2005 and covered a wide range of sectors noted for emitting large amounts of GHGs like energy production and energy-consuming firms such as cement and glass production. ETS in the EU covers about 11,000 firms' emissions (Basse Mama and Mandaroux 2022; Joltreau and Sommerfeld 2019). From the beginning stages of EU ETS (2005 to 2007), authorities granted GHG emissions rights without a fee. In this period, information technology and other supervisory procedures were set up to evaluate and provide an understanding of emissions of covered zones. However, from 2008 to 2012, the authorities established mandatory national goals to assist the EU in attaining its Kyoto Protocol goals. Yet, in this same period, about 90% of the emissions rights were given at no cost (Basse Mama and Mandaroux 2022; Doda et al. 2021; Hájek et al. 2019).

Generally, Article 6 of the Paris Agreement establishes the importance of ETS because carbon markets can aid in reducing emissions. Based on this, the World Bank in 2021 classified 64 Consumer Price Index (CPI). These methods collectively cover just over 20% of the world's GHG emissions (Songwe et al. 2022). Out of the world CPI, there are only 31 ETS. Figure 2 displays the progress of the world's GHG emissions reporting by the various ETS. China's ETS took the lead and was followed by the EU's regarding the negotiated volume, but the EU market has recently indicated the greatest cost signal.

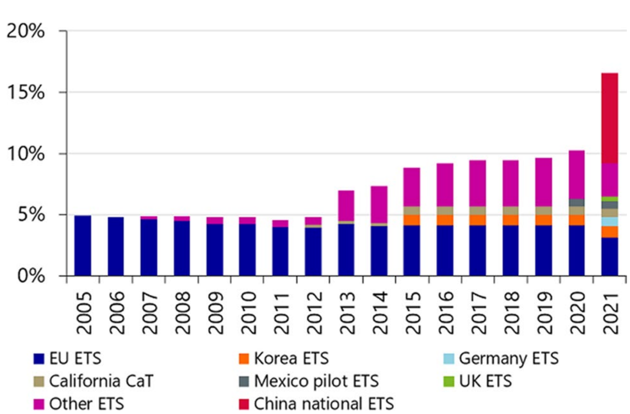


Fig. 2 Segment of world GHG emissions and various ETS | Source*: World Bank, 2022*

Over the years, several researchers have explored some models and methods to investigate the impact of ETS on low carbon growth.

In general, these models and approaches are utilized to study the effects of ETS on low-carbon growth, considering various economic, social, and environmental issues.

Methodology

Data sources

This research uses bibliometric analyses to review the literature to answer the study's research questions. Generally, the bibliometric analysis applies statistical approaches to find the traits and patterns of a document structure based on a scientific paper in a research field (Afrane et al. 2022a, b; Effah et al. 2022a, b; Ma and Ho 2016). Hou and Wang (2021) explain bibliometric analysis as a review method that intends to summarize large data sets to account for the evolving trends in a research area. The researchers gathered the data from the Web of Science (WoS) database, assembled by Thompson Reuters and kept by Clarivate Analytics. WoS is a generally adopted catalog that gives statistics on document types, language, countries, institutions and authors, journals, and subject categories. WoS allows researchers to download all records and cited references of articles published in .txt format, which can be used to generate maps and for further analysis in other software. For this review article, academic publications on ETS and low-carbon growth from 2005 to 2022 were downloaded from the WoS database using the Science Citation Index Expanded (SCI EXPANDED), Social Sciences Citation Index (SSCI), and the Arts and Humanities Citation Index (A&HCI) on the 15th of November 2022. By limiting the search to "topic," the search terms used were "Emission Trading System" (Topic) OR "ETS" (Topic) AND "Climate Change" (Topic) AND "CO_2 emission" (Topic) AND "CO_2 emission reduction" (Topic) OR "low carbon growth" (Topic) OR "CO_2 mitigation" (Topic). The search generated 1576 documents, further reduced via screening based on document type and language. Consequently, the final document used for further analysis was 1390.

Bibliometric analysis using CiteSpace

CiteSpace is among the commonly used tools for imagery and visualization in scientific research (Chen 2006; Chen et al. 2010). The CiteSpace software is an open-source Java application that cites and classifies information on related literature and continues to produce a graphic representation of the data generated (Chen et al. 2014a, b). Two components make up CiteSpace's visualization and mappings, thus, nodes and links. The nodes represent authors, institutions, countries, journals, keywords, subject groupings, and cited references. At the same time, links replicate the co-occurrence or co-citation association between nodes (Chen et al. 2014b). The physical characteristics of the nodes are such that they usually define the evolution and growth of a research domain. Figure 3 illustrates the general characteristics of publications on ETS and low carbon emissions from 2005 to 2022.

Furthermore, a collaboration analysis was conducted to plot the cooperation links of institutions and countries in this area. To better understand the academic structure of the research area, the researchers continued to determine the co-citation of the documents, journals, and subject categories. CiteSpace was then used to track ETS and low carbon emission research by identifying the research area and analyzing significant keywords regarding the origin, development, and current status. Gao et al. (2020) and Zhang et al. (2020) suggest that CiteSpace parameters, such as time slice, node type, and pruning, must be thoroughly checked and selected conclusively with the study's objectives. In this regard, the researchers set the study parameters to (a) time slicing = 2005 – 2022; (b) years per slice = 1; (c) node type = institution, country, keyword, cited journal, subject category; (d) network selection criteria was based on top $N = 50$; (e) link strength and scope = cosine and within slices, respectively; and (f) pruning = pathfinder and sliced network.

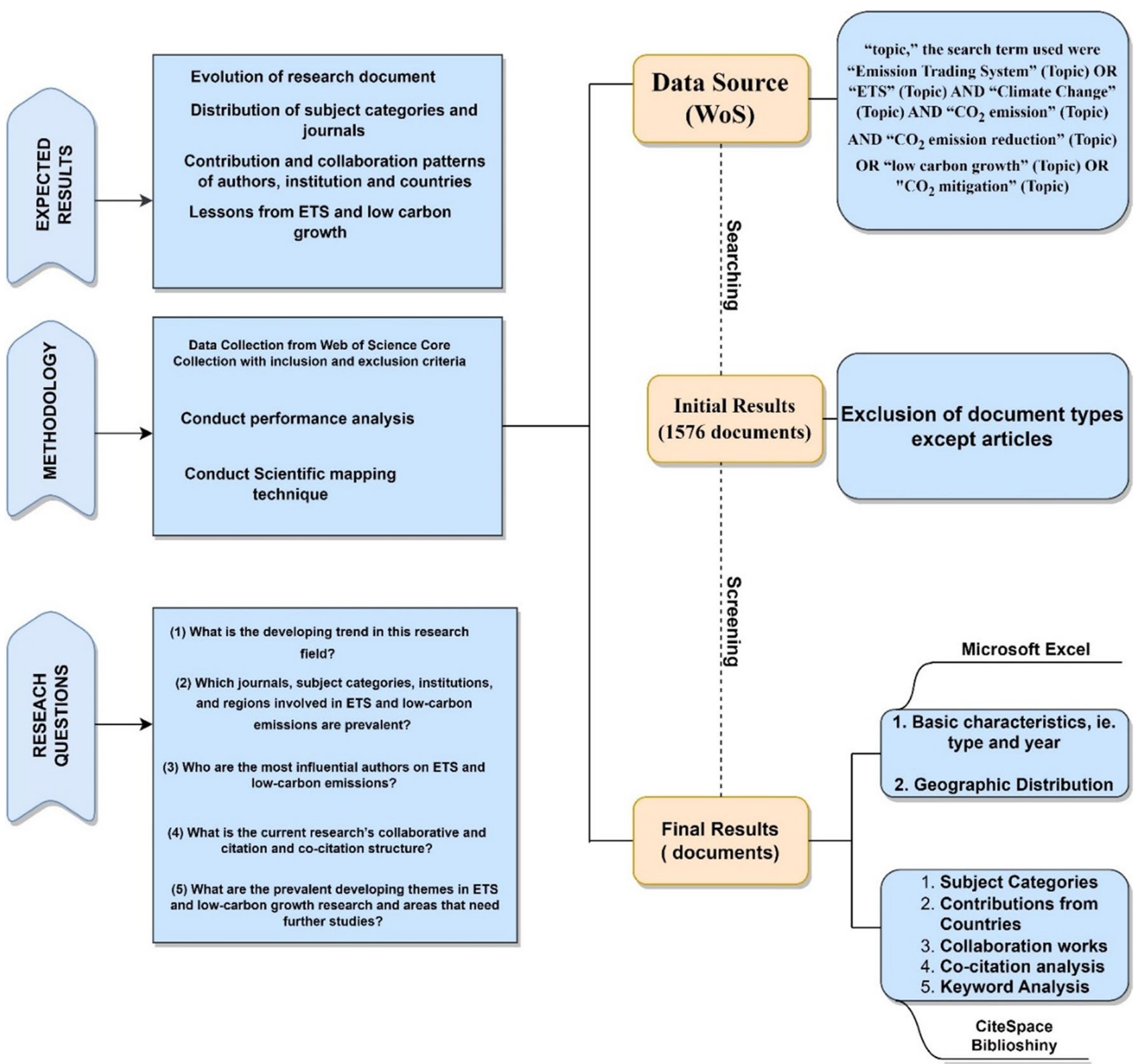


Fig. 3 Flowchart of data used for bibliometric analysis

Measure of influence: H index and impact factor

For the researchers to best measure the cumulative impact and significance of an individual's scientific output with the advantage of being unbiased, the researchers adopted the h-index as proposed by Hirsch in 2005 (Hirsch 2005). One is associated with a particular article published and may be an author, institution, country, or journal. Brandão and Soares de Mello (2019) add that the h-index links to a particular period that the h papers from an individual have been cited at least h times. Hence, the researchers utilized this index with the normal surveys of the total number of citations and publications. Impact factor (IF) is also another significant performance indicator that is widely used for journals to assess the quality of journals. The IF represents the source's mean citations of journal articles published metric over two years (Ma et al. 2018). The researchers, therefore, obtained the IF of top-performing journals from the Citation Reports (JCR) 2021 edition.

Results and discussions

Performance analysis

Development of research field

Figure 4 displays the trend in publications and citations from the WoS Core Collection from 2005 to 2022. Generally, between 2005 and 2022, there were several publications, although there were fluctuations in the number of publications. It could be realized that between 2005 and 2017, there were some fluctuations in the publication number. However, from 2018 to 2021, there was a steady rise in the publication until 2021 and 2022, when there was a quick drop in the publication number. This decline in the publication could be associated with the authors gathering the data till November 2022. The graph further illustrates the number of citations documented for publications each year. The number of citations between 2005 and 2022 steadily increased throughout the period. The year 2021 recorded the highest citation (Fig. 4). Overall, the total number of documents obtained from the WoS, which was 1390, has been cited 32,353 times (Table 1).

It was discovered that all publications from the WoS Core Collection were covered under 82 subject categories. Table 2 displays the distribution of the top ten subject categories with their corresponding number of publications. *Energy Fuels* emerged as the most influential subject in this area, with 525 (37.770%) publications, followed by *Environmental Sciences* with 454 (32.662%) publications. As earlier expounded in the introduction, ETS and low carbon research concern energy, economics, environment, mitigation, and adaptation subjects. The top ten (10) subject categories in the table confirm that researchers in the field of ETS and low carbon growth research focus on these areas.

Distribution of output in journals

Productive journals

The 1390 documents retrieved from WoS were published in 424 journals. The top 20 journals, 44.673% of the total productive journals, contained ten or more (≥10) articles. Table 3 displays the performance of the top 20 productive journals. The contributions of the *Journal of Cleaner Production* in this direction cannot be overlooked. The *Journal of Cleaner Production* is the 2nd most productive journal, with 88 articles published (6.331%) but ranks 4th regarding H-index. Bioresource Technology was the most productive journal with the highest IF, with ten (≥10) articles published. *Energy policy* again emerged as the most influential journal with the highest citation (4,575 citations). The position of these journals based on publication frequency, citations, and

Fig. 4 Yearly distribution of publications and citations

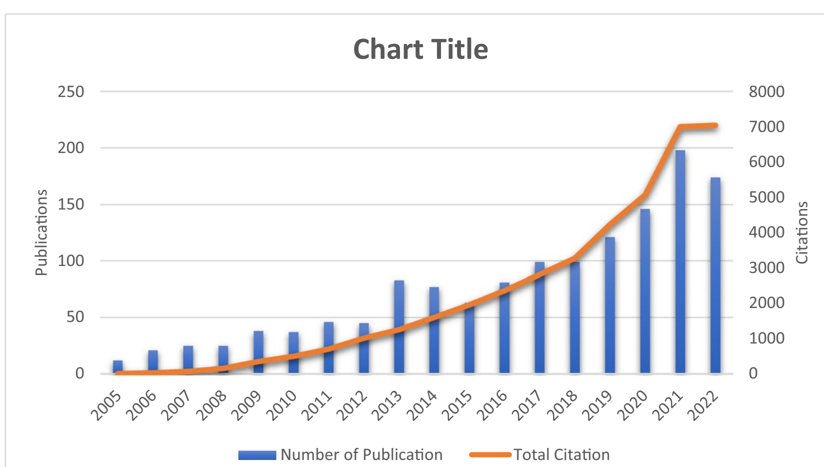


Table 1 Models and methods on the impact of carbon trading on low-carbon growth

Model/method	Aim/purpose	Authors
General equilibrium models (GEMs)	GEMs are used extensively to investigate the effects of ETS on the macroeconomy. These models show the interactions that occur between various economic sectors and markets by taking into account shifts in relative pricing, changes in trade flows, and decisions about investments. Research on carbon trading frequently makes use of GEMs such as the computable general equilibrium (CGE) model and the integrated assessment model (IAM).	Li et al. 2019; Tang et al. 2020; Zhang and Liang 2020a, b; Fragkos et al. 2021; Mercure et al. 2018; Pindyck 2013
Partial equilibrium models (PEMs)	PEMs concentrate on certain industries or marketplaces influenced by carbon trading regimes. The analysis of the effects on energy markets, such as the generation of electricity, the use of renewable energy, and the production of fossil fuels, frequently use these models. Research on ETS frequently makes use of probabilistic economic models (PEMs), such as the electricity market model (EMM), the energy modeling forum (EMF) model, and the oil market simulation (OMS) model.	Farmer et al. 2015; Pan et al. 2020
Input-output models (IOM)	These models may be used to examine the effects of carbon trading policies on industries or the economy as a whole. In ETS research, the environmental input-output (EIO) model and the social accounting matrix (SAM) are examples of input-output models.	Hawkins and Hunt, 2019; Koo et al. 2019; Liu and Wu 2017
Agent-based models (ABMs)	ABMs model the behavior of individual actors, such as households, corporations, and governments, and their interactions within a dynamic system. These models are utilized to examine the effects of ETS on the behavior of various agents and their responses to policy modifications. Energy-environment-economy (E3) and multi-agent system (MAS) models are examples of ABMs utilized in ETS.	Castro et al. 2020; Niamir et al. 2020
Difference-in-differences (DID)	DID model is used to assess the impact of ETS on low carbon growth by evaluating the emissions and economic performance of controlled entities before and after the implementation of the policy. By limiting for additional circumstances that possibly will influence emissions and economic growth. For example, changes in energy prices. Thus, DID helps to separate the contributing effect of the ETS on low carbon growth. If the DID analysis reveals a considerable reduction in emissions and/or a favorable economic impact, the adoption of the ETS can be demonstrated beneficial in supporting low carbon growth. This evidence can be used to support the effectiveness of the policy.	Lyu et al. 2020; Zhang and Zhang 2019

Table 1 (continued)

Model/method	Aim/purpose	Authors
Game model	Carbon trade can be analyzed using a game model. Sellers and buyers play the game (or consumers). The supplier sets the unit sale price and manufacturing volume, while the consumer chooses the quantity. These factors contribute to create this game model: (a) Carbon trading policy: this policy prices carbon emissions and lets companies trade carbon credits. Emission reduction programs and carbon credits can help companies cut emissions. (b) Price and production: the seller sets the unit retail price and manufacturing volume, while the customer sets the product quantity. (c) Consumer surplus: the difference between the utmost price a consumer is prepared to pay and the actual amount they pay is consumer surplus. It reflects product value. (d) Sales profit: sales profit is the difference between product revenue and production cost. A game model can help examine the effects of carbon trading on unit retail price, sales volume, sales profit, and consumer surplus. This model can help policymakers and businesses understand carbon trading and optimize its benefits.	Wang et al. 2018; Xiao et al. 2021; Zhang et al. 2019

Table 2 Top 10 subject categories

Rank	Subject categories	Number	% of 1390
1	Energy fuels	525	37.770
2	Environmental sciences	454	32.662
3	Green sustainable science technology	245	17.626
4	Environmental studies	234	16.835
5	Engineering chemical	200	14.388
6	Economics	186	13.381
7	Engineering environmental	182	13.094
8	Thermodynamics	97	6.978
9	Biotechnology applied microbiology	83	5.971
10	Multidisciplinary sciences	44	3.165

IF depicts the quality of papers published over the period. This is propelled by the nature of journal articles, the value researchers attach to them, and their citation frequencies.

Journal co-citation

The same article can be cited in two journals simultaneously, referred to as journal co-citation (Afrane et al. 2022a, b). Figure 5 displays the co-citation network of the most productive journals. There were 172 nodes and 549 links with a density of 0.0373, indicating a relatively robust network structure and the relationship between journals. Based on the threshold set for the analysis, minor journals did not show in the network. As demonstrated in Fig. 4, the network of the most leading and productive journals with node centrality is signified by the purple rings around the nodes. *Energy Policy*, *Energy* and *Applied Energy* emerged as the top three (3) most-co-cited journals with frequencies of 657, 625, and 577, respectively. However, *Science* had the highest centrality (0.20), followed by *Applied Energy* (0.19) before *Climatic Change* (0.19). These centrality results show the importance of these journals in linking the other nodes in the network.

Highly cited documents

Table 4 reveals the ten highly cited articles within the study period. The least cited article receiving a citation of 290 in less than ten (10) years of publication depicts the consideration given to low-carbon growth research over the years. Most articles in the top ten highly cited journals explored CO_2 mitigation. Griscom et al. (2017) adopted the "natural climate solutions" to access the improvement in carbon storage and declining GHGs globally, especially in the agriculture sector. Chiu et al. (2008) used the microalgal photobioreactor as a CO_2 mitigation scheme to assess the eradication of waste gas from CO_2 emission while further exploring the effects of cell concentration and CO_2 concentration on the development of Chlorella sp. Bin and Dowlatabadi (2005) suggested an alternate model, the Consumer Lifestyle Approach (CLA), to investigate the correlation between consumer activities and environmental impacts in the US. The researchers projected that more than 80% of the energy and CO_2 produced in the

Table 3 Most productive journals

Rank	Journal	Number	% of 1390	H-index	Total citation	Impact factor
1	Energy Policy	97	6.978	41	4,575	7.576
2	Journal of Cleaner Production	88	6.331	28	2,476	11.072
3	Applied Energy	70	5.036	33	3,101	11.446
4	Energy	61	4.388	30	2,307	8.857
5	Environmental Science and Pollution Research	32	2.302	10	302	5.190
6	Energies	31	2.230	10	264	3.252
7	Sustainability	30	2.158	7	158	3.889
8	Energy Economics	27	1.942	16	1,075	9.252
9	Bioresource Technology	24	1.727	17	2,029	11.889
10	International Journal of Greenhouse Gas Control	17	1.223	10	351	4.400
11	International Journal of Hydrogen Energy	17	1.223	14	494	7.139
12	Renewable Energy	16	1.151	11	450	8.634
13	Science of the Total Environment	16	1.151	11	629	10.754
14	Environmental Science Technology	15	1.079	11	471	-
15	Journal of Environmental Management	15	1.079	11	378	8.910
16	Climate Policy	14	1.007	6	294	6.056
17	Energy Conversion and Management	13	0.935	10	723	11.533
18	Solar Energy	13	0.935	10	452	7.188
19	Sustainable Energy Technologies and Assessments	13	0.935	6	121	7.632
20	Industrial Engineering Chemistry Research	12	0.863	7	268	

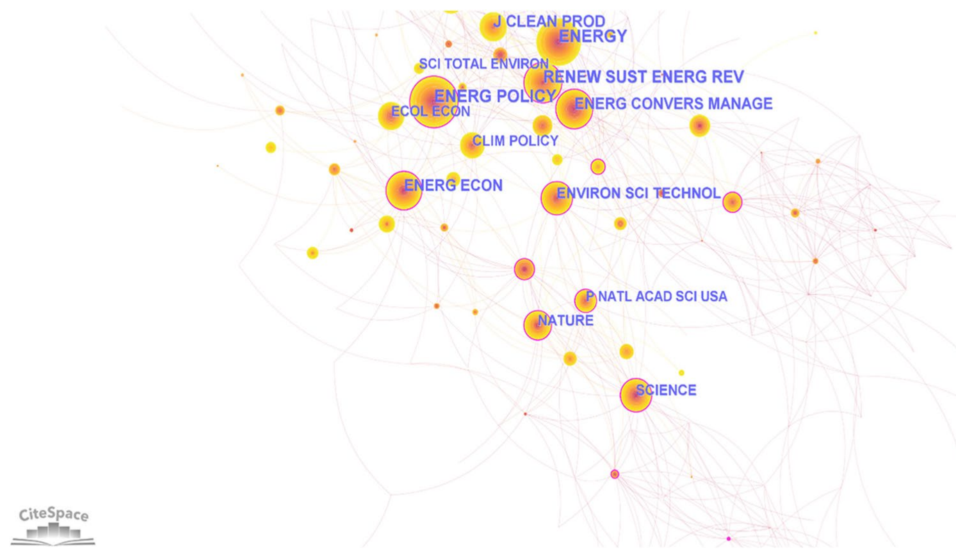


Fig. 5 Journal co-citation

US result from consumer demands and economic actions. Wang et al. (2016a, b) proposed a complete thermodynamic and kinetic assessment of the appropriateness of cerium oxide (ceria) for thermochemical fuel production.

Analysis of institutions, countries, and authors

Productive institution

The top twenty (20) institutions are displayed in Table 5. These institutions have 507 articles published, constituting 36.476% of the 1390 documents. It was shown that *Tsinghua University* in China contributed 58 articles, followed by the *Chinese Academy of Sciences*, also located in China. The *Indian Institute of Technology System Iit System* in India also contributed 48 and 35 articles, respectively. Out of the top twenty (20) institutions, China contributed to 214 publications constituting 15.396%. This is not surprising as several researchers in the area of ETS and low carbon growth have been affiliated with China.

The researchers examined the corresponding authors to conclude ETS and low carbon growth in different countries.

Table 4 Top 10 most cited article

Articles	Journal	Total citation	References
Natural climate solutions	Proceedings of the National Academy of Sciences of the United States of America	946	Griscom et al. 2017
Biofuels from microalgae	Biotechnology progress	706	Dubois et al. 2008
The effect of renewable energy consumption on economic growth: evidence from top 38 countries	Applied Energy	667	Bhattacharya et al. 2016
Reduction of CO_2 by a high-density culture of Chlorella sp in a semicontinuous photobioreactor	Bioresource Technology	443	Chiu et al. 2008
Consumer lifestyle approach to US energy use and the related CO_2 emissions	Energy Policy	409	Bin and Dowlatabadi 2005
A thermochemical study of ceria: exploiting an old material for new modes of energy conversion and CO_2 mitigation	Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences	350	Chueh and Haile 2010
The relationship between economic growth, energy consumption, and CO_2 emissions: empirical evidence from China	Science of the Total Environment	330	Wang et al. 2016a, b
Utilization of flue gas for cultivation of microalgae (Chlorella sp.) in an outdoor open thin-layer photobioreactor	Journal of Applied Phycology	307	Doucha et al. 2005
Emission budgets and pathways consistent with limiting warming to 1.5 degrees C	Nature Geoscience	303	Millar et al. 2017
Power-to-what?—environmental assessment of energy storage systems	Energy and Environmental Science	290	Sternberg and Bardow 2015

Table 5 Top 20 institutions in the field of ETS and low carbon growth

Rank	Institution	Number	% of 1390	Location
1	Tsinghua University	58	4.173	China
2	Chinese Academy of Sciences	48	3.453	China
3	Indian Institute of Technology System Iit System	35	2.518	India
4	Swiss Federal Institutes of Technology Domain	31	2.230	Switzerland
5	International Institute for Applied Systems Analysis Iiasa	30	2.158	Austria
6	North China Electric Power University	28	2.014	China
7	Udice French Research Universities	26	1.871	France
8	University of California System	24	1.727	US
9	Xiamen University	24	1.727	China
10	United States Department of Energy Doe	22	1.583	US
11	Beijing Normal University	20	1.439	China
12	Thammasat University	20	1.439	Thailand
13	Centre National De La Recherche Scientifique Cnrs	19	1.367	France
14	Eth Zurich	19	1.367	Switzerland
15	Indian Institute of Technology Iit Delhi	19	1.367	India
16	University Of Chinese Academy of Sciences Cas	19	1.367	China
17	Beijing Institute of Technology	17	1.223	China
18	Helmholtz Association	16	1.151	Germany
19	Universite Paris Saclay	16	1.151	France
20	Utrecht University	16	1.151	Netherlands

The Single-Country Publication (SCP) number is the total number of articles published by authors in each country. At the same time, Multiple-Country Publication (MCP) represents the total number of articles completed through country cooperation. Figure 6 and Table 6 highlight the number of articles published to analyze Single-Country

Publications (SCP) and Multi-Country Publications (MCP). China recorded the maximum number of published articles of 404 and had 276 SCP and 128 MCP with a 0.317 MCP ratio. Although countries like the US, India, Germany and England recorded relatively higher MCP ratios, their number of MCP was somewhat lower.

Figure 7 displays the collaboration network of countries with ≥30 publications based on corresponding author addresses. The network comprised 75 nodes with 274 links, with a density of 0.0987, signifying a relatively close link among the countries. Evidently, the countries with the most published articles have a relatively closer connection. US, Spain, and Canada were essential nodes linking various groups to large nodes because they recorded higher centralities of 0.29, 0.25, and 0.20, respectively.

Authors' performance

In Table 7, the number of articles published is recorded as output. The number of citations is recorded as the influence of the top contributing authors in ETS and low carbon growth research. Limmeechokchai B (20), Lin BQ (14), Li Y (12), Liu Y (11), and Huang GH (10) were the five most productive authors. Out of these top ten productive authors, seven are Chinese. Regarding article influence, the leading author with regard to output recorded 253, but the 3rd

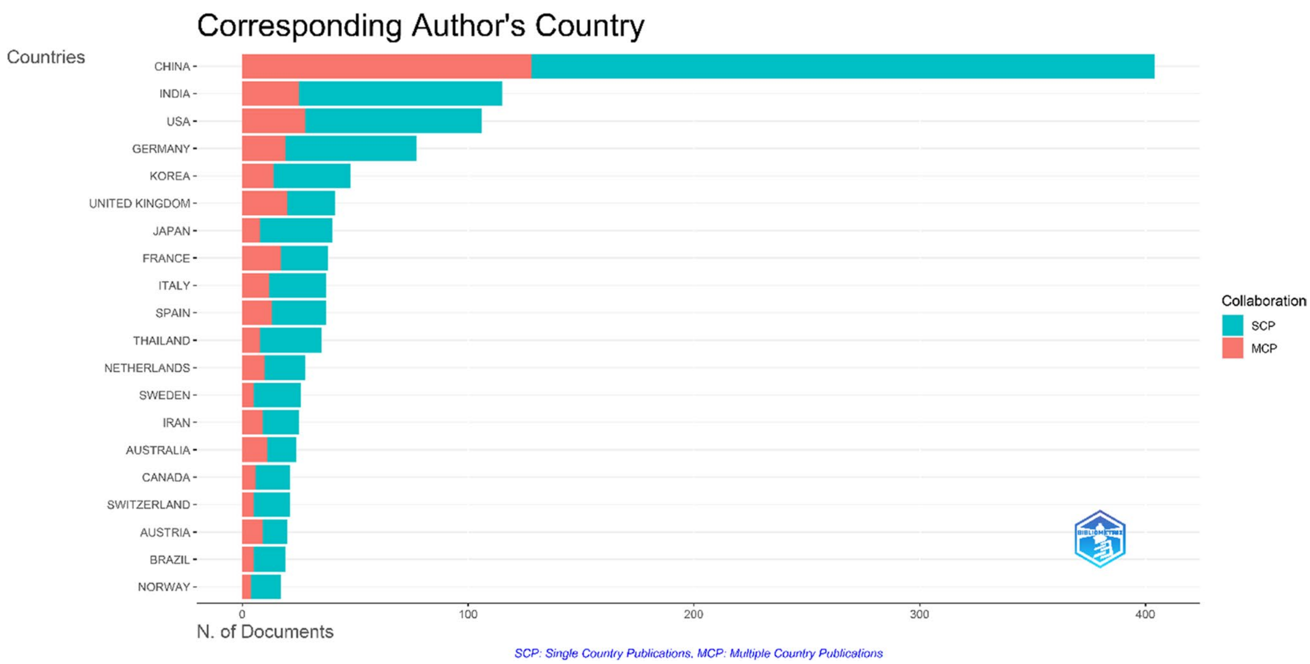


Fig. 6 Top 10 corresponding authors' countries concerning ETS and low carbon growth

Table 6 Top 10 corresponding authors' countries concerning ETS and low carbon growth

Rank	Country	Articles	SCP	MCP	Freq	MCP_ratio
1	People's Republic of China	404	276	128	0.291	0.317
2	USA	115	90	25	0.083	0.217
3	India	106	78	28	0.076	0.264
4	Germany	77	58	19	0.055	0.247
5	England	48	34	14	0.035	0.292
6	Japan	41	21	20	0.029	0.488
7	Australia	40	32	8	0.029	0.2
8	South Korea	38	21	17	0.027	0.447
9	France	37	25	12	0.027	0.324
10	Canada	37	24	13	0.027	0.351

SCP indicates a Single-Country Publication, and MCP indicates a Multiple-Country Publication

Fig. 7 Collaboration network of countries

Table 7 Author's output over time

Rank	Authors	Output	% of 3190	H-index	Total citation/influences
1	Limmeechokchai B	20	1.439	8	253
2	Lin BQ	14	1.007	12	510
3	Li Y	12	0.863	5	852
4	Liu Y	11	0.791	6	132
5	Huang GH	10	0.719	9	229
6	Kumar A	10	0.719	5	145
7	Tiwari GN	10	0.719	8	407
8	Wang C	10	0.719	8	336
9	Chen WY	9	0.647	8	426
10	Li YP	9	0.647	9	212

leading author has the leading influence in this direction with 852 citations.

Figure 8 displays the top 10 author's production over the period. The leading author, Limmeechokchai B started his contribution in this field in 2011 but was productive in 2015 and 2016. The author contributed to "*Energy security of three selected Asian countries*" and "*Co$_2$ mitigation in Thailand's low-carbon society: the potential of renewable energy*" in 2016 (Selvakkumaran and Limmeechokchai 2016; Winyuchakrit et al. 2016). These researchers explore the development of Thailand's low-carbon society in 2030. They adopt the Asia-Pacific Integrated Model/Extended SnapShot model to investigate GHGs mitigation through renewable energy (RE) use. Although Limmeechokchai B is leading in terms of article influences, the author's production has not been dominant in the current year, 2022. Authors like Li Y and Liu Y have been productive in 2022. They have contributed to articles like "*Exploring volatility of carbon price in European Union due to COVID-19 pandemic* (Dong et al. 2022)." The researchers chose the EU carbon allowance as a research aim. Using the Johansen cointegration, they utilized the Bai–Perron structural break test to explore the various dynamics that affect carbon price variations technique. Tan et al. (2022) researched "*The effect of carbon emission trading scheme on energy efficiency: Evidence from China.*" These researchers expounded on the impact of ETS pilots on energy effectiveness by the DID model.

Figure 9, a three-field plot, is created with the top 10 authors on the left, the top 10 journals on the right, and the top 10 keywords in the middle. Based on the figure, it can be realized that the top 5 keywords from these 10 authors are the same as the occurring keywords. This validates the notion that these authors have contributed significantly to this research direction. However, the size of the keywords like *biomass*, *climate change*, and *carbon dioxide* are keywords that the authors have relatively used in finding the impact of ETS on low carbon.

Author collaboration

When authors collaborate, it is seen as the proper way of scholarly association in a scientific investigation (Mao et al. 2015). Especially when there is a global collaboration link between authors, it permits emerging economies in the particular knowledge field to create a knowledge process that is conventionally led by developed nations (De Noni et al. 2018). When two scholarly views meet, there is the development and maturity of concepts and theories. As such, the quality of the paper is better developed and improved (Snyder 2019). The researchers evaluated the extent of recent

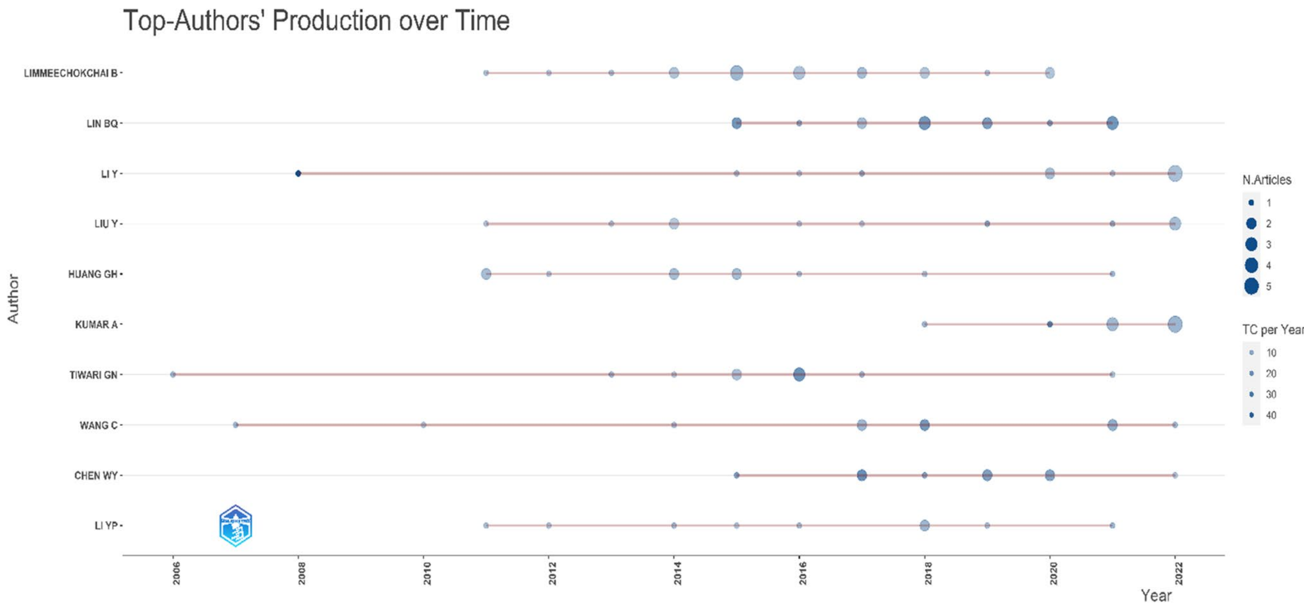


Fig. 8 Researcher's output over time

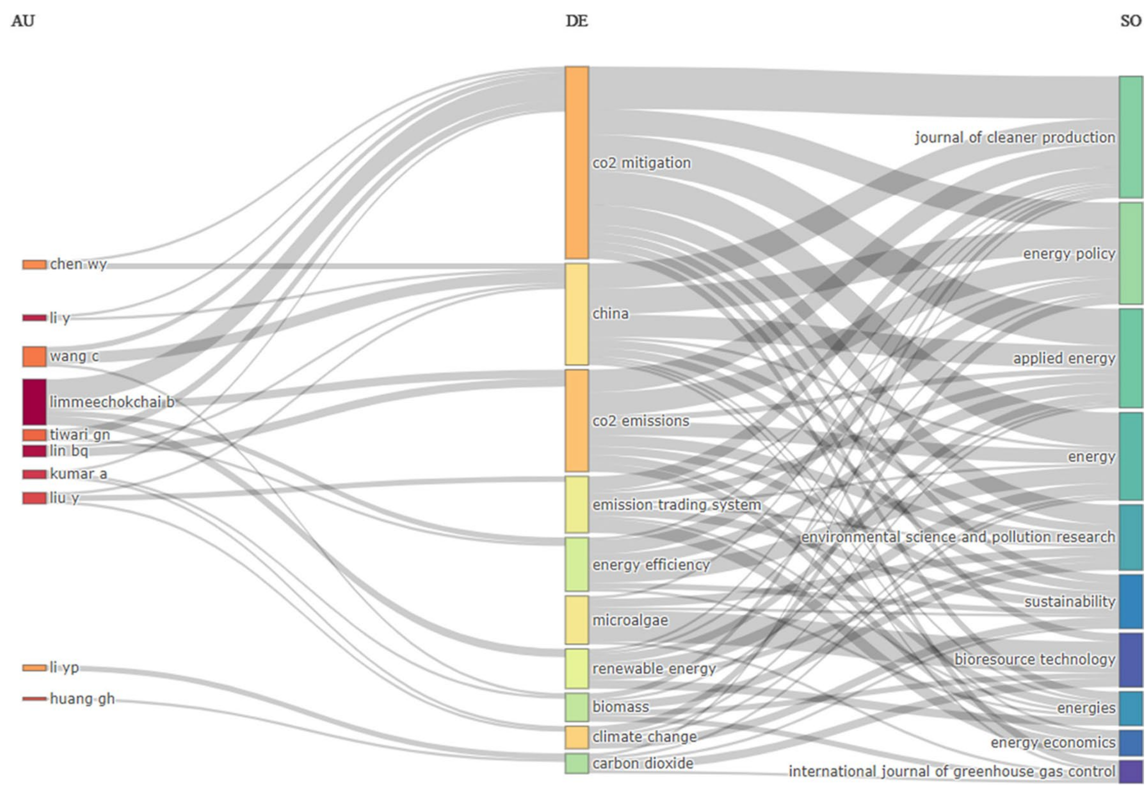


Fig. 9 Three plot field of author keywords and journals (AU, author; DE, keywords; SO, journals)

author collaborations. As Fig. 10 displays, the dominant authors with regard to collaborative efforts are Limmeechokchai B, Huang GH, Wang C, Lin BQ, and Li YP. Most of these author collaborations are based in China. They form a consistent connection of authors in which collaborative works are restricted to authors in their affiliated countries. The links indicate that the research focuses on a few authors, and the nodes show a particular form of a link of two and

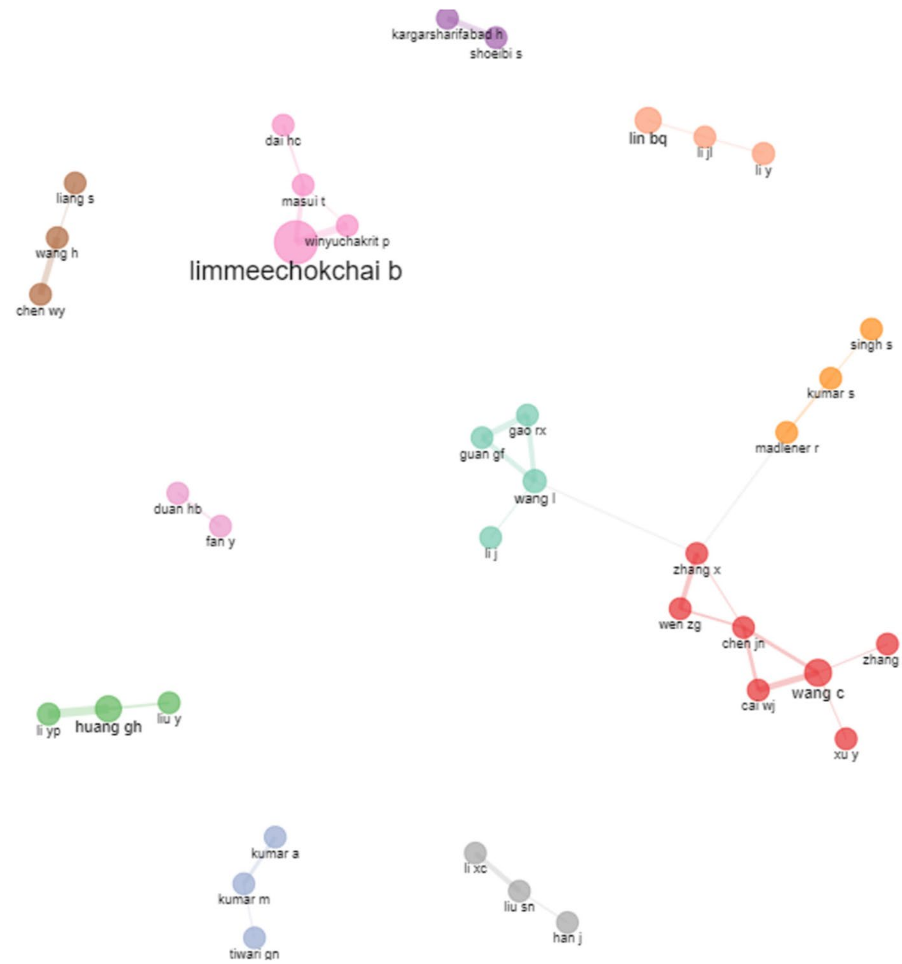


Fig. 10 Collaborations between dominant authors

three. Consequently, the co-authorship connection is realized as a set of smaller connections that are relatively closed and display a few connections among themselves. Collaboration among researchers is essential to improve an area, and, hence, more cross-country collaborations are required.

Keyword analysis

Distribution of hotspot keywords

Research keywords are important because they portray important research content with several words. Figure 10 displays the keyword growth in this research from 2005 to 2022. The keyword growth has progressed gradually from 2005 to 2022. From 2005 to 2022, the growth of these keywords *biomass*, *China*, *carbon dioxide*, *energy efficiency*, *renewable energy*, and *climate change* has been most explored. These keywords have gained much attention, but *CO_2 mitigation* has developed much attention in this field and research direction. It suggests that several researchers are still interested in ETS and low carbon growth. China has become a hotspot keyword after implementing several regulations to protect the environment, of which ETS and CO_2 emissions have been explored. Chu et al. (2023) unraveled that ETS implementation reduces CO_2 by 22.8% of the energy consumption in China (Fig. 11).

Keyword co-occurrence

Researchers typically utilize co-occurrence to understand the approach and management areas. More so, scientific researchers use this approach to assess the performance and the level of inventions and data flows (Kastrin and Hristovski 2021). The researchers explored the dominant themes of keywords in the ETS and low carbon growth by conducting keyword co-occurrence analyses. As displayed in Fig. 12, the keywords have been grouped into three bigger nodes and further linked. The three bigger nodes are *growth*, *energy*, and *CO_2 mitigation* to demonstrate their importance to the area of ETS and low carbon growth. Figure 13 shows that CO_2 mitigation, CO_2 emissions, and ETS co-occur often. These keywords indicate that the researchers have placed more emphasis on the ETS and low carbon emission, which is understandable because it forms the core of this study.

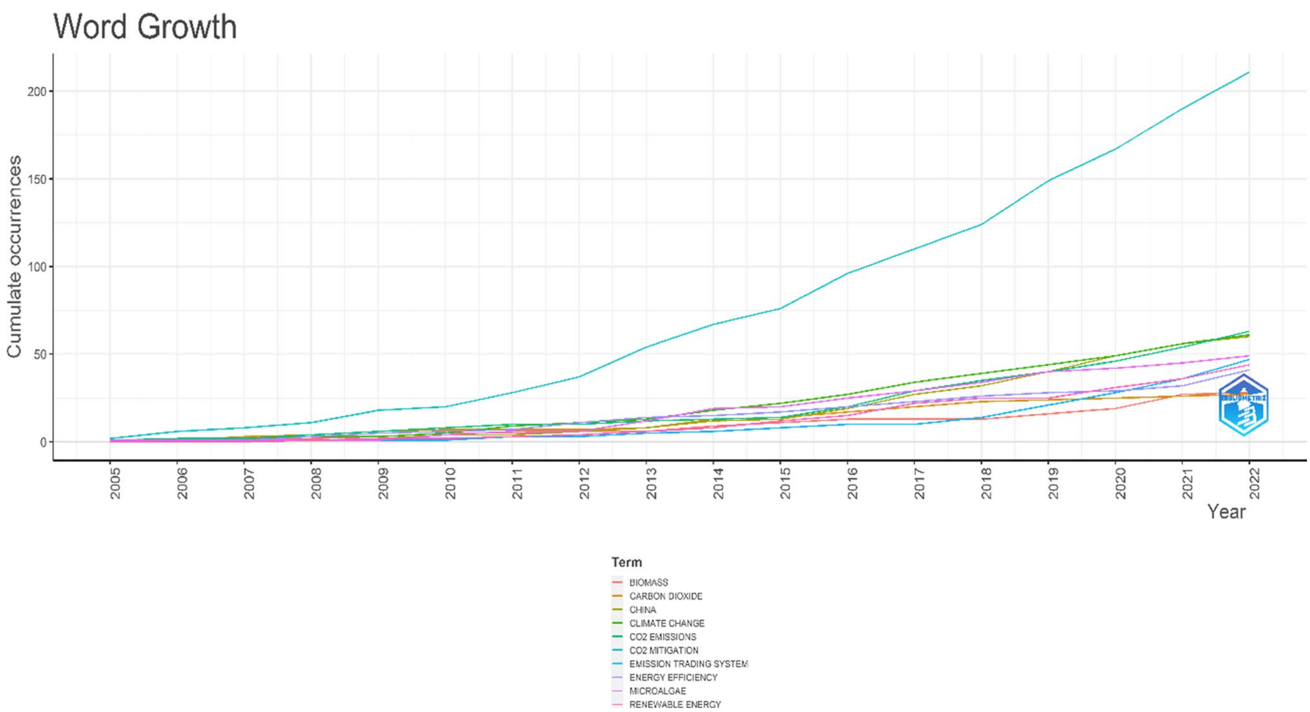


Fig. 11 Keyword development in this research from 2005 to 2022

Fig. 12 Keyword co-occurrence

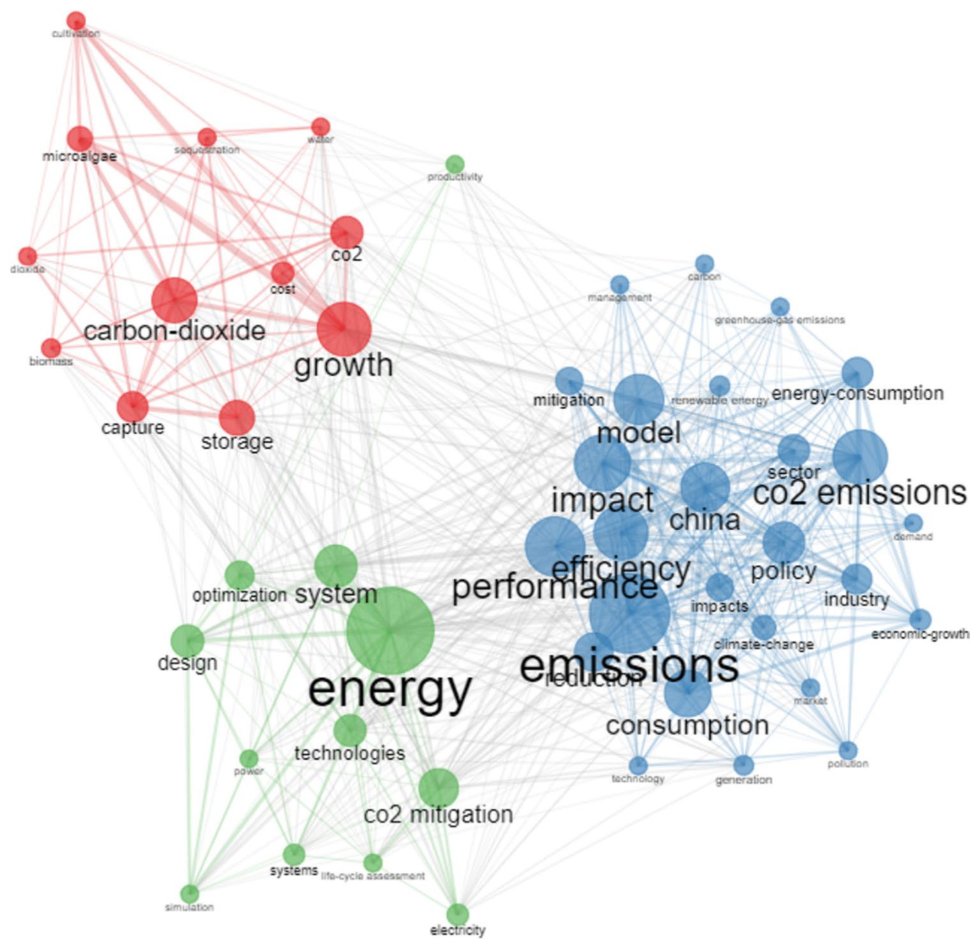


Figure 13 displays the frequently occurring author keywords. In no systematic order, for author keyword analysis, *CO_2 mitigation*, *CO_2 emission*, *emission trading systems*, *energy efficiency*, and *China* have gained much prominence. Keywords displayed in small sizes like a *solar still*, *CO_2 utilization*, *solar energy*, *carbon tax energy*, and *Paris Agreement* are evolving keywords that still need to be explored in the ETS and low carbon emission field. *Solar still* and *solar energy* are new area and requires more exploration. These areas are vital technical and energy efficient, so various governments could pay much attention to them and formulate policies to reduce carbon growth. Governments have set carbon emission caps and prices in China and Europe. This indicates that governments and other stakeholders should involve in low carbon technologies (Rissman et al. 2020; Zhang and Andrews-speed 2020). With regard to the utilization of the ETS and low carbon emissions, Paris Agreement is also an emerging area. It does not recommend the modes, especially on how energy efficiency should be attained, thereby declining CO_2 emissions.

Thematic map

Figure 14 displays the intensity of ETS and low carbon growth in a thematic map. In this figure, a dotted line divides the map into four parts using density (development degree) and centrality (relevance degree). The circle sizes displayed are defined by the number of articles in which the keyword emerged. The first part is the *motor themes* on the top right corner, which have a high density and centrality. This suggests that the well-used themes have strong inner and peripheral connections. The second part, *niche themes* on the top left corner, has a theme with high density but low centrality. They are described by well-developed inner connections and slightly substantial peripheral connections. On the down, left corner is the *emerging/declining themes*. In this quadrant, keywords have low density and centrality, which indicates the weakness of their inner and peripheral connections. The basic themes are in the final part, in the right, down corner. Keywords in this quadrant have low density and high centrality. More so, keywords demonstrate well-developed peripheral connections and irrelevant inner connections. As shown in the map, the impactful themes have high total citations and include the following keywords: *CO_2 mitigation*, *climate change*, and *China*.

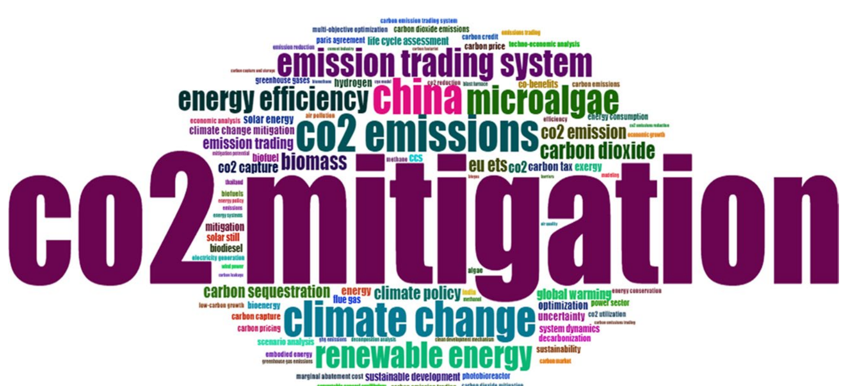
Trending topics

Figure 15 displays the trending topics in this research field from 2005 to 2022. From 2006 to 2010 and further impact felt till 2014, topics like *carbon capture and storage* and *clean development mechanism* started to trend with search terms of frequency 100 and below. CO_2 mitigation had a great trend after 2016, with a search term frequency of 200 and above. This can be associated with the fact that the Paris Agreement had been concluded in the preceding year, and several researchers were exploring it. Currently, *carbon emission trading*, *thermal efficiency*, *solar still*, *energy*, *decarbonization*, and *ETS* are trending topics in this study. Hence, more research should be conducted on these topics to explore their contributions to current discussions on ETS and low carbon growth. The trending topics from 2005 to 2022 suggest the importance researchers have attached to ETS and low carbon growth research. From 2015 to 2021, researchers (Doda et al. 2021; Feng et al. 2021; Hájek et al. 2019; Zhang 2015) asserted that these trending keywords had been explored to unravel several findings like the ETS policy has promoted energy and conservation; thus, reducing the emissions of CO_2 in China even at the pilot stages and Europe at large.

Findings, implications of the study, and future perspectives

In this section, the researchers put forward their findings, the study's implications, and future research directions for this field. Thus, what are the issues that obstruct

Fig. 13 Frequently occurring author keywords



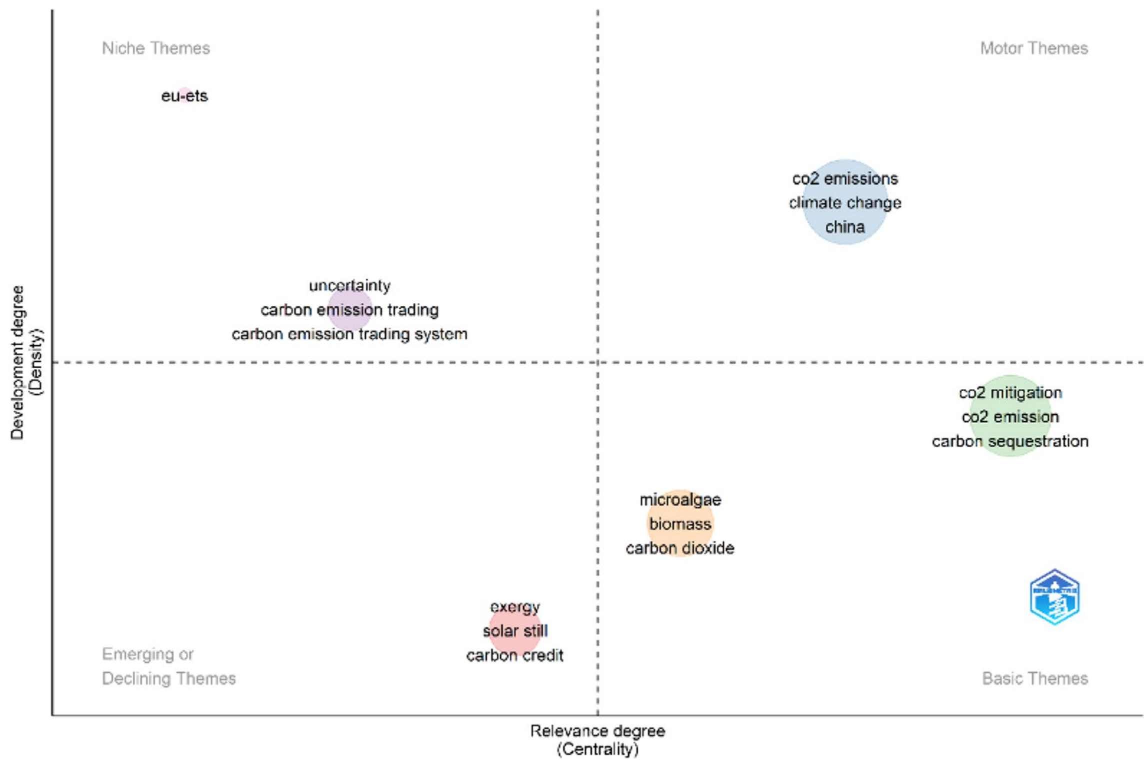


Fig. 14 The intensity of ETS and low carbon growth in a thematic map

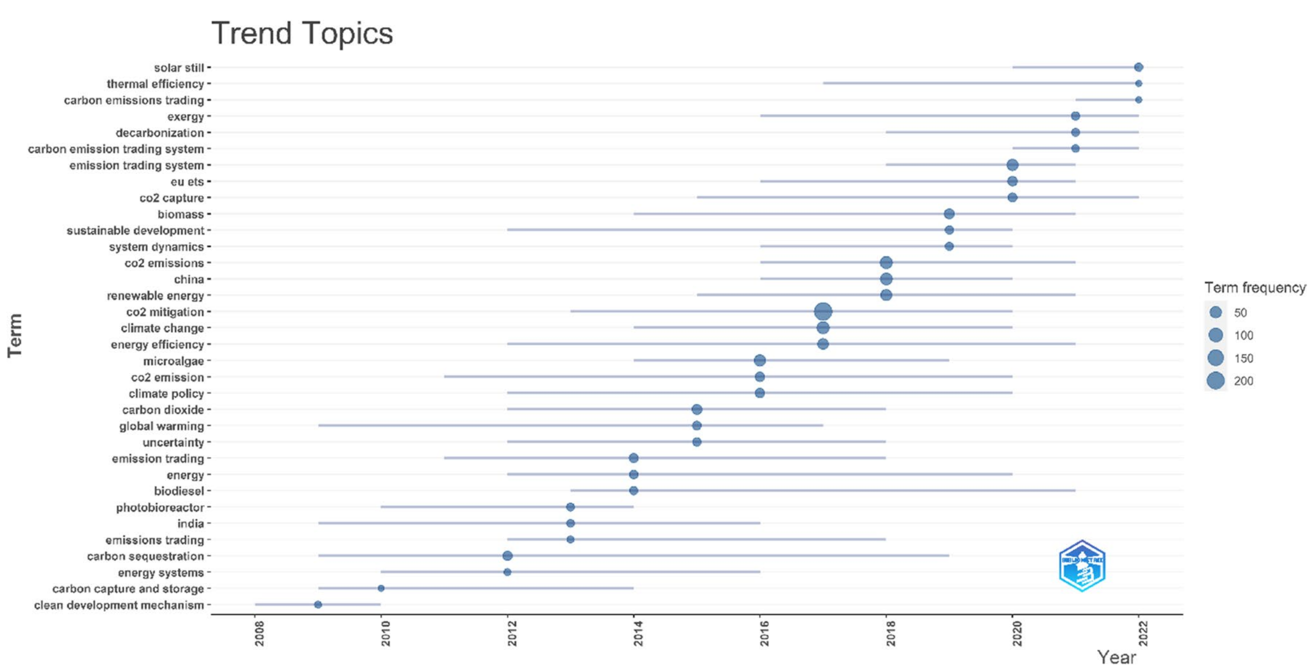


Fig. 15 Trending topics in this research field from 2005 to 2022

research on ETS and low carbon growth and what areas involving ETS and low carbon growth need further study? The researchers in Research Questions 1 and 2 (RQ1&2) identified the developing trends in this field. The explanatory analysis explains the current trend of research on ETS and low carbon growth. The research expounds that most research in this field has been published since 2015. This may be partly propelled by the new understanding of the CO_2 agreements ratified, like the Paris Agreement, which called for a collective effort to reduce CO_2 emissions. The Paris Agreement did not suggest ETS as a mechanism to reduce CO_2 emissions. Since the Paris Agreement looked at innovative ways to reduce CO_2, China and the European Union saw ETS as an innovative means to help reduce CO_2 emissions (Daggash and Mac Dowell 2019; Diniz Oliveira et al. 2019; Michaelowa et al. 2019). Much research on ETS and low carbon growth focus on China because China started a pilot ETS study and gradually improved it, calling for more exploration. The US gained the highest degree of centrality and policy contributions toward carbon emissions mitigation. The research also unravels that although authors from China are mostly associated with the research field, there are contributions from other authors and organizations globally who have contributed to the ETS and low carbon growth research (Daggash and Mac Dowell 2021; Markard and Rosenbloom 2020). On RQ3, Limmeechokchai B has contributed more papers in this field. However, there is a big discrepancy when assessing influential authors using the influence of their contributions. The contributions of Li Y have had the most influence in terms of citation in this field.

Chinese authors have yielded much influence in tandem with the number of institutions available in China that have contributed much to this field. The results from the author's output show that at least every author has contributed to this field for four years despite having a relatively low number of article contributions. Keywords and co-occurrence analysis recommend prevalent themes in ETS and low carbon emission (RQ5). We realized that CO_2 mitigation is the dominant keyword in this field and discussion. Based on our findings, most research focuses on how ETS has affected the mitigation of CO_2 emissions. This finding is rational because the issue of ETS and low carbon growth emerges from the need for countries and stakeholders to contribute collaboratively to CO_2 emission reduction. Themes such as *solar still*, *thermal energy*, and *carbon trading system* emerge as growing and trending words that are innovative means to reduce CO2 emissions drastically.

Several implications can be drawn from this review article for analyzing the scientific productivity of ETS and low carbon growth. This discussion presented data and significant information that will make it easy for future researchers, policymakers, government officials, and other related stakeholders to comprehend and appreciate the roles of countries, authors and ETS and low carbon growth research themes. Thus, this research explained the influence of each country's research productivity and prominent authors associated with ETS and low carbon growth. The literature presents extensive evidence on existing themes and points of view for further research by identifying highly impactful research hotspots.

Notwithstanding the extent of this research, other areas require further exploration. (i) As previously explored, a strong research structure for ETS and low carbon growth is required. Although some conceptual research has been conducted (Bae and Cho 2020; Schenuit et al. 2021; Wang et al. 2020; Zhou et al. 2020), more research is needed to expound the impacts of ETS on low carbon growth and build a robust conceptual framework. Past theoretical contributions like that of Zheng et al. (2022) could only address just a part of the ETS and low carbon growth issues; as such more research is required, (ii) most of the research on ETS and low carbon growth are based on a single country. More research is encouraged to be conducted in a multi-country context which is likely to encourage more author collaboration and help introduce a more robust framework for exploring and expounding ETS and low carbon growth; (iii) based on the keyword hotspot analysis, the future of ETS and low carbon growth hinges on trending topics like *solar still*, *thermal efficiency*, and *emission trading systems* with a strong emphasis on energy and CO_2 emissions mitigation. Figure 13 showed in its 4th quadrant that microalgae, biomass, and carbon dioxide are basic themes and need more study. Few researchers have explored the relationship of microalgae, biomass, CO_2, and their possible impact on low carbon growth from the perspective of ETS (Dubois et al. 2008).

Conclusion and limitations of the study

In this research, the researchers explored and analyzed the impacts of ETS implementation and low carbon growth while identifying the directions for a possible future. The researchers have highlighted the major findings in this literature domain till now, utilized the bibliometric analysis to unravel the major trending literature, and emphasized certain practical issues that can constrain the functionality and interpretation of research findings in this research field. Several calls have been made for more innovative means to help mitigate carbon emissions (Cui et al. 2018). ETS has been identified as an innovative policy to help salvage carbon emissions issues.

The study has heightened that since the implementation of this policy, there have been some positive contributions toward CO_2 mitigation. It is worth acknowledging that the present study is not without limitations. This bibliometric analysis review was exclusively conducted by concentrating on ETS and low carbon growth and compare with other approaches toward CO_2 mitigation. Hence, there is a chance for other scholars to make a comprehensive comparative study of other approaches geared toward CO_2 mitigation.

The subscription database where the data was retrieved started from the last decade (2005–2022), explaining why the authors' started the study in 2005. More so, the search phrases were used at the authors' decision to reduce extreme contamination in the database as much as possible. The bibliometric approach adopted for this study usually centers on the research outputs rather than content; however, the researchers were able to capture contents as part of the discussions for this study.

Additionally, selection bias is possible since the study documents were fundamentally based on the WoS Core Collection. Although the WoS is broad and reliable, more sources like Scopus and Google Scholar could present a more thorough concept and ideas. Nevertheless, if these limitations are solved, we do not expect a substantial difference from the findings of the current review.

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Author contributions Conceptualization: Emmanuel Mensah Aboagye and Chen Zeng; formal analysis: Emmanuel Mensah Aboagye, Gabriel Owusu, and Selina Annah Brenyah; methodology: Sandylove Afrane and Felix Mensah; software: Emmanuel Mensah Aboagye, Sandylove Afrane, and Jeffrey Dankwa Ampah; proof reading: equal contribution; supervision: Emmanuel Mensah Aboagye.

Data availability Not applicable.

Declarations

Ethics approval Not applicable

Consent to participate All authors agreed to contribute to this study

Consent for publication All authors agreed.

Competing interests The authors declare no competing interests.

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