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Drivers and influencing mechanisms of agricultural carbon emissions in rural China: A systematic literature review and meta-analysis

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Abstract

This research compares the findings of previous papers on agricultural carbon emission in rural China and analyzes the potential driving factors and influencing factors and mechanisms in a meta-analysis. In this paper, we also derive and elaborate on common economic, technological, policy, and social factors that affect agricultural carbon emissions based on a synthesis of published articles in refereed journals from 2000 to 2023. A total of 1,971 documents concerning agricultural carbon emissions in rural China were discovered using keyword searches in the Scopus and CNKI databases. The findings show a constant growth in research production, indicating rising worldwide interest in agricultural carbon emissions in China. We identify influential keywords, authors, and nations that shape the research landscape, emphasizing current worldwide collaboration networks and developing research hotspots. Citation networks highlight the importance of distributing scientific results, particularly significant papers from various years. The study examines the factors influencing agricultural carbon emissions in rural China, providing valuable insights for policymakers and researchers aiming to develop sustainable practices and manage climate change in agriculture.

Keywords: Carbon emission, Agriculture, China, Keyword, Database

1. Introduction

Agriculture is considered a critical sector in the Chinese economy since it provides employment opportunities to about 40% of the population as well as enhancing food security in the country [1]. Thus, having become the world's largest agricultural producer, China has significant problems associated with environmental sustainability, and the most urgent of them is GHG emissions [2]. Sources of emissions in agriculture include inputs particular to farming, including crops, livestock, forest conversion, and synthetic fertilizers and pesticides [3]. Depending on the scope of farming in China, these emissions are very large and add to the total carbon footprint in China [4]. Over the last few years, China has begun to invest vigorously to shift toward a low-carbon economy [5]. The nation has developed and put in place policies that relate to efforts of curbing the emission of carbon, improving energy conservation as well as sustainable utilization of fertilization in agricultural production [6]. Despite these efforts, the agriculture sector is still among the leading contributors to the emission of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (NO_2), all of which are known greenhouse gases with huge global warming indicators [7]. It is, hence, important to establish the factors and mechanisms that drive agricultural carbon emissions in rural China to come up with effective measures towards addressing this scourge towards the realization of the country's environmental and climate change goals [8]. Carbon emissions in agriculture are not only an environmental problem but are one of the most essential study subjects within the context of climate change [9]. In this respect, agriculture has both direct and indirect bearing on causative factors and consequences of climate change [10]. On one side, farming practices lead to the emission of GHs into the atmosphere, hence escalating global warming [11]. However, the sector of agriculture is rather sensitive to climate change since it has impacts on the yield and productivity of crops and livestock and, thereby, food security [12]. This double position of agriculture – as a participant in climate change effects and a source of carbon emission increase – proves the significance of the factors affecting agricultural emissions.

In this research, the focus is rural China, where agriculture has been the dominant sector for many years, and millions of people still rely on it for their living [13]. Rural areas of China can be classified into traditional agricultural regions of traditional farming as well as advanced industrialized farming regions [14]. Their carbon footprints also vary widely, with some of these activities emitting more greenhouse gases than others [15]. The socio-economic conditions in rural China, including population growth, income, and agricultural technology application, significantly impact agricultural activities and emissions [16]. In the last few decades, China experienced rapid changes in the rural economy, which affected the farming practices, the technologies applied in agriculture, as well as the socio-economic context of the sector [17]. They have brought significant shifts in the emission level of the carbon footprint of the sector [18]. A great number of research works have investigated different features of agricultural carbon emissions in China, yet no systematic review of such research outcomes has been elaborated, which prevents us from stating general conclusions and generating practical recommendations.

In the last ten years, numerous publications have been published in the field of environmental influences on agriculture with a general stress on carbon footprint [19][20]. Several research has investigated the origin and extent of GHG emissions in various agriculture practices, ways and measures for reducing emissions, and the effect of policies on emissions [21][22][23]. However, most of these studies are scattered, with the majority of them being carried out on a regional crop-specific or practice-specific basis, thereby continuing the deficiency of effective synthesized knowledge regarding the causes, nature, levels, patterns, and trends of agricultural carbon emissions in rural China.

The survey of the previous studies reveals that the major sources of carbon emissions in agriculture are the conversion of land for agricultural purposes, the increase in the area of cultivated land, the utilization of chemicals in farming, livestock production, and the harnessing of technologies. The transformation of land use from forest or grassland to agricultural land is a significant source of emissions since the carbon dioxide is released from the stock in vegetation and the soil [24]. Another factor that leads to higher emissions is agricultural intensification, whereby there is greater application of fertilizers and pesticides together with the use of machinery also in the high input system [25]. The livestock sector, particularly cattle and sheep, contributes significantly to methane emissions, a greenhouse gas with a higher Global Warming Potential than CO_2 [26]. Nitrous oxide is another potent greenhouse gas that is released when synthetic fertilizers and insecticides are used [27]. At the same time, new technologies, which are regarded to be efficient for decreasing emissions, may cause an increase in emissions in case of their ineffective implementation [28].

The relationship between economic development in rural China and agricultural carbon emissions is complex and interconnected, with factors such as regulatory measures, market influences, and farmers' behavioral patterns influencing this relationship [29]. However, there is a lack of comprehensive methods to understand the processes underlying agricultural carbon emissions in rural China. This systematic literature review and meta-analysis aims to identify contributing factors and influencing mechanisms of agricultural carbon emissions in rural China. The review will compile the results of several studies and provide extensive information on factors leading to carbon emissions in different agricultural environments. The study will also analyze the interactions between various drivers to identify key leverage points for reducing emissions. The implications of this study are that its findings may be useful for policymakers and practitioners to use for future decision-making and program development. The implication of the findings will be useful to policymakers in developing better and more targeted ways of reducing carbon emissions in the agricultural sector in rural China. Understanding the impact of land use changes on emissions can guide the promotion of sustainable land management practices like agroforestry or conservation agriculture [30]. Understanding the effects of intensifying agriculture can guide strategies toward promoting sustainable and efficient practices, which are currently lacking. Furthermore, the study will also assist in the global debate pertaining to sustainable agriculture and tackling climate change.

The study aims to understand the unique characteristics of the Chinese environment at both institutional and market levels, providing valuable insights for other countries facing similar challenges. The implications of the findings will also exist for the attainment of global climate targets, such as the Paris Agreement that recognizes emission cuts across sectors, including agriculture.

This present study intends to fulfill this research gap by adopting a systematic literature review and meta-analysis approach of the current literature on agricultural carbon emission in rural China from January 2000 to December 2023. Our research objectives are:

- To systematically recognize trends and patterns of carbon emission involved in agricultural activities throughout rural China within the systematic literature review.
- This study aims to visualize the conceptual structure of the key drivers influencing carbon emission levels through the application of advanced bibliometric techniques, including country of production and keyword co-occurrence analysis.
- To analyze the driver's effect sizes using meta-analysis in order to compare the amount of influence that various drivers have.
- To summarize the state of the art and determine potential further research directions.

Achieving these goals will offer a comprehensive perspective on the factors that shape agricultural carbon emissions in rural China, enabling the development of effective strategies to reduce emissions while preserving agricultural productivity and supporting rural communities.

2. Literature review

The country, as a result of its swift economic development and intensification of agricultural practices, has come to worry about carbon emissions in agriculture [31]. Rural China is the largest agricultural producer on earth, hence accounting for a good percentage of global carbon emissions [32]. The research aims to comprehensively examine the drivers and influencing mechanisms of rural Chinese farm carbon emissions through a systematic review of various studies and meta-analyses.

A number of studies have shown that there are increasing trends in agricultural carbon emissions in rural China over the last several decades. For instance, Zhang et al. [33] noted that China's agricultural greenhouse gas emissions increased by 47% between 1990 and 2015. Various reasons, like the use of more chemical fertilizers, expansion of animal husbandry, and mechanization of farming, are responsible for this change [34]. Also, various scholars have explored the spatial distribution pattern of rural Chinese agricultural GHG emissions [35]. Another researcher found significant differences, which showed the highest level in east coastal parts and North China plain regions [36]. These regional discrepancies arise due to differences in the intensity of agriculture, level of economic development, and local environmental policies [37]. As many studies confirm, agricultural intensification is a major factor contributing to carbon emissions from rural China. Chen et al. [38] conducted an extensive analysis of all the provinces in mainland China and came up with the results showing that intensive crop production, especially coupled with increased use of chemicals, was positively associated with carbon emissions. In addition, Liu et al. [19] noted that replacement by high-yield crop varieties and intensive farming systems have led to higher releases from soils and farm machinery for carbon emissions. Another key driver of agricultural CO_2 emissions has been found to be the rapid expansion of the livestock sector in China [39]. He et al. [26] found that livestock activities, including enteric fermentation and manure management, contribute about 30% of total CO2 emissions from agriculture in rural China. Notably, it was also observed that there is an increasing trend towards more greenhouse gas emissions coming from this sector as influenced by meat demand growth and movement toward bigger-scale factory farm setups [40].

Land use changes, in particular the transformation of natural ecosystems into agricultural lands, have been shown to be a major cause of carbon emissions. Li et al. [36] found in a comprehensive analysis involving 50 papers that land use changes, including deforestation and wetland draining for agriculture in rural China, caused significant losses of carbon in soil and biomass. The increased mechanization and electrification of agriculture in rural China have led to higher energy-related carbon emissions [41]. Wang et al. [31] concluded that energy consumption by agriculture was responsible for over half of the total carbon emissions in these regions, primarily due to the consumption of fossil fuels for machinery and irrigation systems. This assertion was based on data from 31 provinces [42].

The digital economy has a social impact that shows how agriculture has been transformed by increasing efficiency and sustainability. Several researchers have claimed that the availability of technologies like precision agriculture, smart farming, and e-commerce has resulted in the lowering of agricultural carbon footprint by minimizing resource utilization and supply chain [43]. Digital platforms improve the tracking of emissions and promote behavior change for low carbon, but challenges regarding e-waste and energy consumption exist [44]. Industrial concentration also plays a role in the agricultural carbon footprint. Exposure to industrial areas increases emissions because of the high energy consumption. However, concentration brings about technology transfer, which in turn reduces emissions since organizations get updated information on sustainable innovation [45]. Annually, economies of scale for firms located in affected regions add to the optimization of the use of resources and reduced emissions [46]. In this context, technology plays a vital role, especially in terms of adopting green technologies, in the quest to keep the carbon footprint of agriculture at bay. Technologically advanced practices, like integrating clean energy, conservation agriculture, and environment-friendly machinery, reduce emissions by increasing energy utilization efficiency and decreasing the usage of chemicals [47]. Nevertheless, the adoption of such technologies depends on policies, funding, and the digital ecosystem, which has been discussed [48]. Altogether, these aspects determine the course of carbon emissions in the agricultural industry.

The development and modernization of agriculture are two crucial factors that explain the levels of carbon emissions in rural China. According to Zhang et al. [49], rural per capita income has a positive impact on agricultural carbon emissions. The authors hypothesized that higher income generates higher demand for carbon-intensive agricultural products and investment in carbon-intensive farming technology. This research established that government policies and institutional arrangements significantly impact agricultural processes and carbon emissions. Du et al. [50] conducted a systematic review of 40 studies that showed that agricultural subsidies, especially those targeting chemical fertilizers, increase carbon emissions. However, policies that promote sustainable agricultural production and carbon storage in the context of agriculture play a moderating role in emissions [51]. The results suggest that technological progress in agriculture has led to somewhat contradictory levels of carbon emissions in rural China. There are various technologies, some of which have facilitated higher emissions through intensification, while others have mitigation possibilities [52]. According to Wu et al. [53], the optimal use of smart inputs, including variable-rate fertilizer application and smart irrigation systems, can achieve a 10-15% effective reduction in agricultural carbon emissions compared to traditional farming practices. Climate change and variability have been established as predictors of agricultural carbon emissions in rural China [54]. A comprehensive examination of pertinent literature and a meta-analysis were undertaken to provide an inclusive perspective on the factors and mechanisms that contribute to the release of agricultural carbon emissions in rural China. The results of this research indicate that the emission patterns are impacted by agricultural intensification, economic growth, policy-related matters, and environmental changes. Although there has been a notable progression towards acknowledging the intricacy of these interactions, there is still much to be learned about them in order to implement effective measures for mitigation and promote sustainable agriculture in rural China.

3. Methodology

In order to identify and review previous studies on the factors driving and the mechanisms through which agricultural carbon emissions occur in rural China, we used the systematic literature review accompanied by meta-analysis. This approach can help systematize evidence from previous studies and quantify the significance of different factors.

3.1. Systematic literature review (SLR)

3.1.1. Research strategy and databases

The present study adopted a systematic review approach to survey scholarly production in agricultural carbon emissions, mapping out research trends and progressing themes, as well as identifying prolific authors, institutions, and countries. Such techniques for patterns of scholarly publications like research articles, chapters, and books are used to visualize the trends of the publications. Also, it offers a scientific map of authors, countries, organizations, and collaborations involved in the production of scientific literature globally. The nature of the research means that the systematic literature review coupled with meta-analysis is used to identify and analyze the current literature on agricultural carbon emissions in rural China. All identified articles for the SLR are retrieved based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow diagram. By means of meta-analysis, it is possible to use a quantitative approach to analyze the relationships between the drivers and the agricultural carbon emission, providing a statistically grounded view of the actual processes. The research design of this study is selected because it ensures that it gathers, assesses, and integrates all the available knowledge within a coordinated approach, hence offering an efficient way of studying the subject. Integration of both SLR and meta-analysis means that it is possible to detect certain patterns and trends in the literature, obtain information about the gaps in the knowledge of certain drives of agricultural carbon emissions, as well as ascertain the overall impact size of agricultural carbon emissions. We conducted a systematic search of peer-reviewed literature using the following electronic databases: Scopus and China National Knowledge Infrastructure (CNKI).

As for the academic research databases, Scopus has some advantages compared to WoS in terms of comprehensive and worldwide coverage [55]. CNKI also extends this global approach by providing the richest coverage of Chinese sources that have been traditionally omitted from the WoS [56]. Because of its extensive coverage of Chinese research, it offers a valuable collection for researchers seeking Asian academic content, discovering original and subtle research works that may otherwise remain excluded from international academic discussions.

The arch was done with the use of some keywords combining agricultural carbon emissions, rural China, and other possible factors. The search string used was: TITLE-ABS-KEY (agricultural AND carbon AND emission AND China) OR (agricultural AND greenhouse gas AND emissions) AND (rural China OR Chinese agriculture) AND (driver OR factor)

3.1.2. Inclusion and exclusion criteria

Studies were included in the review if they met the following criteria:

1. Journal articles that are accessible in English and have been published between the years of January 2000 and December 2023. This is framed so as to cover academic publications in the Twenty-First Century.
2. Concentrating on the effects of carbon in the farming sector of rural China
3. Primary field research papers that included the evaluation of antecedent driver or influencing factor measures

4. Scholarly publications such as scientific journals or conference papers

Studies were excluded if it is:

1. It is a work that is focused only on urban agriculture.
2. Failed to include statistical information regarding the drivers as well as the influences.

Table 1. Inclusion criteria for the systematic literature review

Search string	TITLE-ABS-KEY (agricultural AND carbon AND emission AND China) OR (agricultural AND greenhouse gas AND emissions) AND (rural China OR Chinese agriculture) AND (driver OR factor)
Database	Scopus and China National Knowledge Infrastructure (CNKI)
Document type	Article, conference paper, book chapter, review
Time frame	January 2000 to December 2023
Language	English

3.2. Data extraction

The first search resulted in about 2922 articles to be reviewed for possible inclusion in the study. The articles included in this review underwent two screenings. First, only the titles and abstracts of the articles were read to make an initial concern of their relevance or not according to the inclusion and exclusion criteria. After that, articles published between January 2000 and December 2023 are included (Table 1). Thereafter, authors limited articles published in the English language in this period. This stage left the researcher with about 2074 articles in which the full text would have to be reviewed. In the second stage of the selection process, the authors included articles, conference papers, book chapters, and review work. A few articles found duplicates that failed to satisfy the criteria for inclusion were also eliminated. From this stage, 1971 articles were selected to be included in the systematic review and meta-analysis. Any research that did not meet the aforementioned criteria has been excluded and not further considered in the analysis. However, those articles in languages other than English or articles that the readers could not access were also excluded. Thus, grey literature, like reports, blog posts, online newspapers, theses, etc., were not included in this study.

This research adheres to the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) Statement to report systematic review [57]. The PRISMA framework would help scholars to report clearly the rationale for the conduct of the review study, the activities conducted, and the findings made, particularly for a systematic review study. PRISMA flow diagram of the literature review process adopted in this study is shown in Figure 1. From each included study, we extracted the following information: study characteristics (authors, publication year, location, duration), sample size and characteristics, drivers and influencing factors examined, and research methods utilized. Thematic content analysis was conducted using both qualitative and quantitative methods within the dataset. First the first step was to identify thematic clusters with the help of VOSviewer, a literature review analysis tool that enables the determination of primary themes considering the connection frequency of specific words. After that, there is the application of the deductive analysis approach, which involves reducing the context and extracting the text portions based on the mentioned themes in the datasets [58].

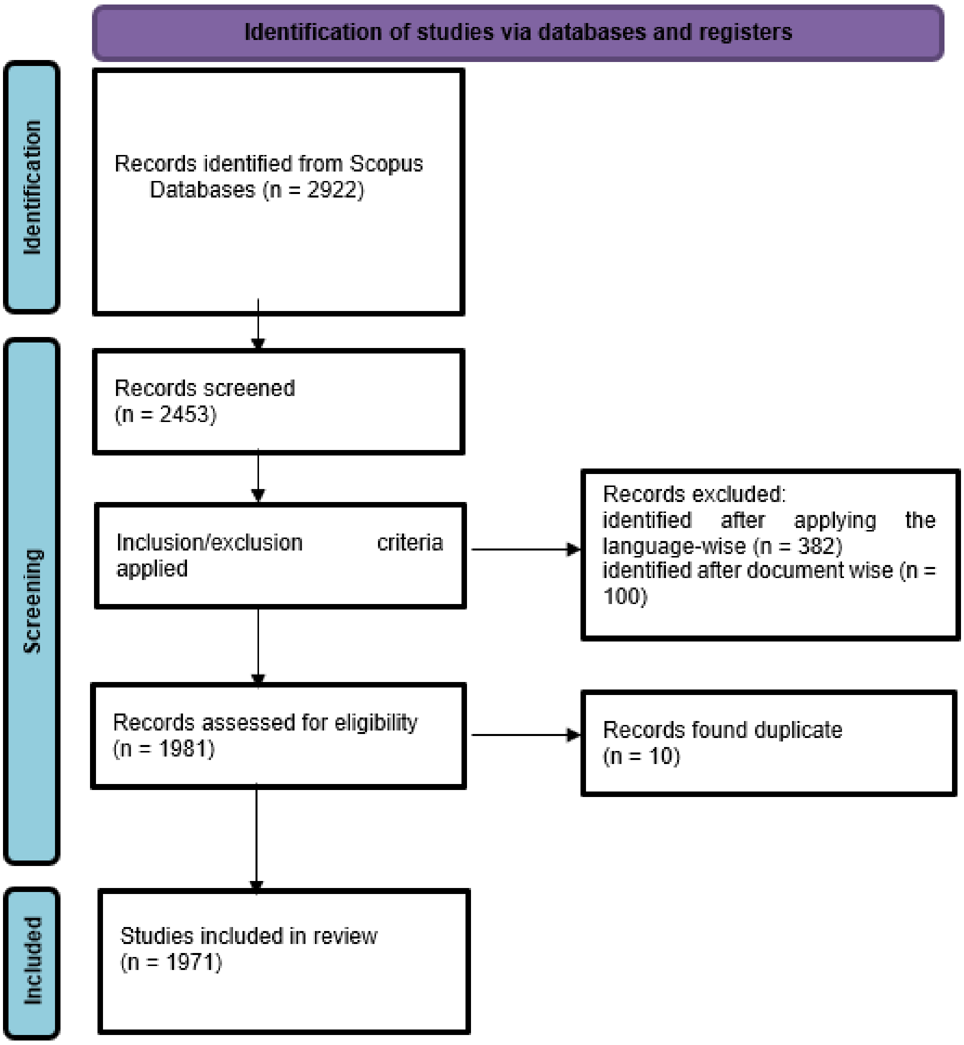

Figure 1. PRISMA flow diagram representing the systematic literature review selection

3.3. Descriptive analysis

Descriptive analysis was performed in order to provide the basic results of the included studies in terms of year of publication, geographical distribution, co-occurrence of keywords, and the different types of drivers for agricultural carbon emissions investigated. This study outlined the nature of the research and gave a general indication of the themes and patterns of the literature. Due to the concept of meta-analysis, the study aimed at providing a quantitatively integrated result of the findings of the sample of studies. In regard to the meta-analysis, the emphasis was given to the calculation of the overall effect magnitude of all the drivers affecting the agricultural carbon emissions. The suggested methodological framework presented above can be used systematically to identify the factors and processes that actualize agricultural carbon emissions in China's rural regions. This study will, therefore, aim to provide additional knowledge of the various factors influencing emissions and achieve this by incorporating the literature review with the meta-analysis approach to help in developing a policy and practice to enhance sustainable agricultural development in China. The study has employed VOSviewer software for the bibliometric analysis and ArcGIS for drawing the map.

4. Results

4.1. Agricultural carbon emission (ACM) research trends

Scholarly publication and citation on agricultural carbon emission have also increased in terms of annual publication and citation from year 2010 (Figure 1). Some of the new frontiers of research include the agricultural carbon footprint within local and global scale. New millennium research on Agricultural carbon emission

(ACM) gained momentum since there was rapid escalation of environmental pollution of villages and cities in China. Several reasons can be attributed to the increased ACM publications, such as the quest for better institution ratings, the friendly research environment, developments in research and technology, and the growing availability of data. The Chinese government has taken various steps to combating effects of climate change, especially after joining international treaties like Kyoto Protocol and the Paris Agreement. China also pledged to cut down on carbon emissions as well as enhancing environmental food safety. Further strategies and policies like encouraging low-carbon agriculture led to academic research to support these national strategies. Apart from that, improvements in technologies, including remote sensing, GIS, big data, and precision agriculture, gave the chance to the researchers to quantify and model emissions with the needed accuracy after 2010.

The analysis indicates a significant increase in both publication frequency and references subsequent to 2010, potentially attributable to China's heightened concern regarding climate change and the implementation of carbon reduction policies in agriculture. The consistent increase in the number of publications over the years, particularly from 2016 onwards, suggests that the topic of research interest, including policy research, in minimizing agricultural carbon emissions in rural China is receiving sustained attention from scholars. The decline in citations following 2018 may indicate the development of novel concepts within agricultural carbon emissions studies, and that prior work has established sufficient foundational knowledge. The number of publications in 2023 is the highest, which suggests either sustained or growing interest from the research community, potentially due to increasing policy relevance and persistent environmental challenges.

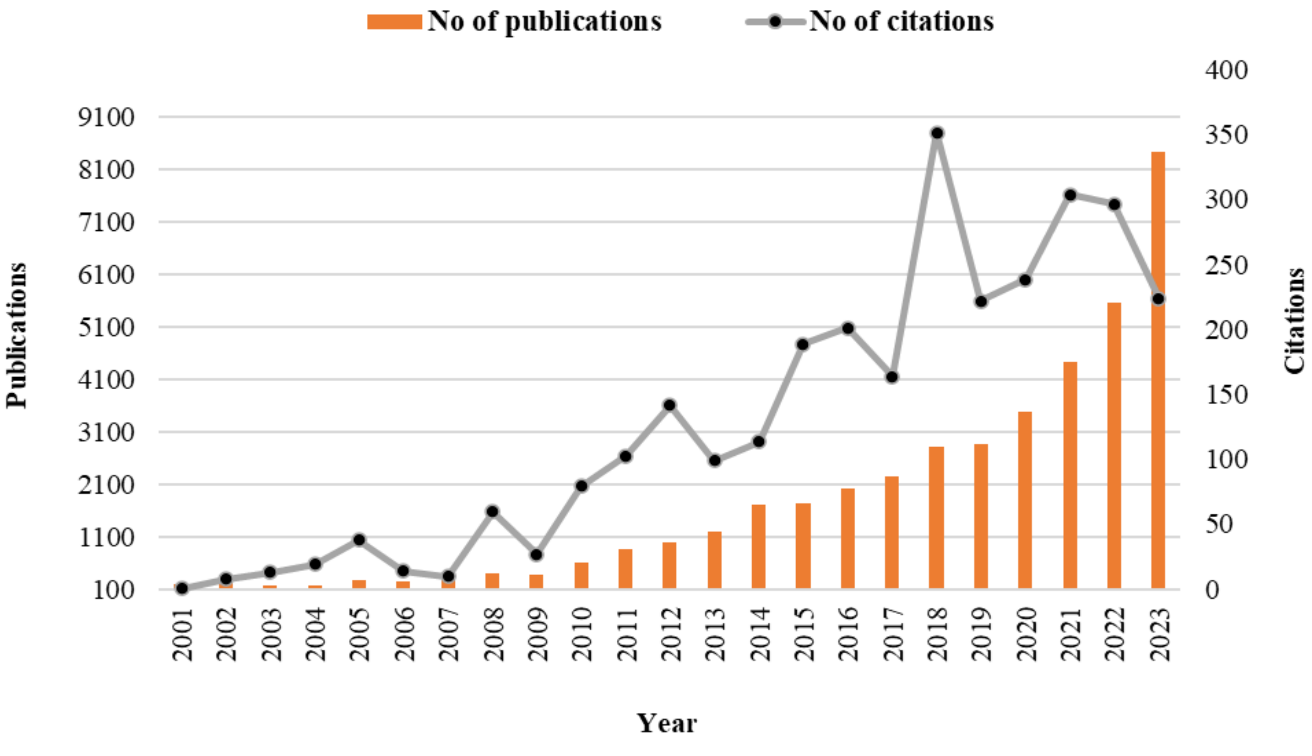

Figure 2 Agricultural carbon emission publication and citation trend

4.2. Systematic literature review analysis

In this section, we perform a systematic literature review analysis by examining the co-occurrence of keywords, country of production and citations by country. First, we describe the connections of the focused elements and the sets of themes in the dataset. Next, we analyze co-occurrence over time to identify trends in the data and new topics evolving over time. After that, this research discuss the density distribution for the thematic analysis of areas of concern and their distribution in the dataset.

4.2.1. Keywords co-ocurrence analysis

A total of 4783 keywords were compiled from the reviewed documents. This was done in VOSviewer from the aggregated metadata of the reviewed papers analyzed during the compilation of the findings. Out these, 247 that were mentioned at least five times were selected. This means that only keywords used with the frequency of five and above were used. Furthermore, an ideal thesaurus file that was generated manually was included to combine similar or synonymous keywords, optimistically reducing the chances of inconsistency. Therefore, the following eight keywords were obtained. The structure of the cluster map includes texts, nodes, and lines, and the size of the texts and nodes is proportional to the weights of the objects, with greater sizes being associated with greater weights. A large circle signifies more papers containing that keyword while a smaller circle symbolizes the fewer papers exploring concepts. The color red represents China agriculture, green represents greenhouse gas, blue represents pollution while light blue represents human and carbon emissions in the cluster (Figure 3). Furthermore, the lines connecting the points indicate the interacting partners, meaning that one keyword is usually found together with another. The major topics include China, Carbon Footprint, Carbon Emission, Greenhouse Gas Emission, Climate Change and Agriculture Carbon Emission. Of these, the term 'China' had appeared most frequently (150), followed by 'Carbon Footprint' (117), 'Carbon Emissions' (82), 'Greenhouse Gas Emissions (72), 'Climate Change' (68), 'and Agricultural Carbon Emissions. The keywords of clusters are shown in Table 2. For instance, the total link strength of "China" is 225 meaning that the keyword was linked with, or appeared jointly with other keywords in 225 publications in the dataset.

Table 2. The top fifteen keywords in agricultural carbon emission research

Keywords	Total link strength	Occurrences	Cluster number
China	225	150	1
Carbon Footprint	237	117	5
Carbon Emissions	84	82	1
Greenhouse Gas Emissions	146	72	2
Climate Change	118	68	1
Agricultural Carbon Emissions	64	66	1
Nitrous Oxide	160	65	6
Agriculture	94	57	1
Soil Organic Carbon	116	57	7
Greenhouse Gas	101	52	2
Life Cycle Assessment	89	51	5
Carbon Sequestration	94	57	10
Methane	122	45	4
Biochar	70	42	6
Global Warming Potential	86	39	2

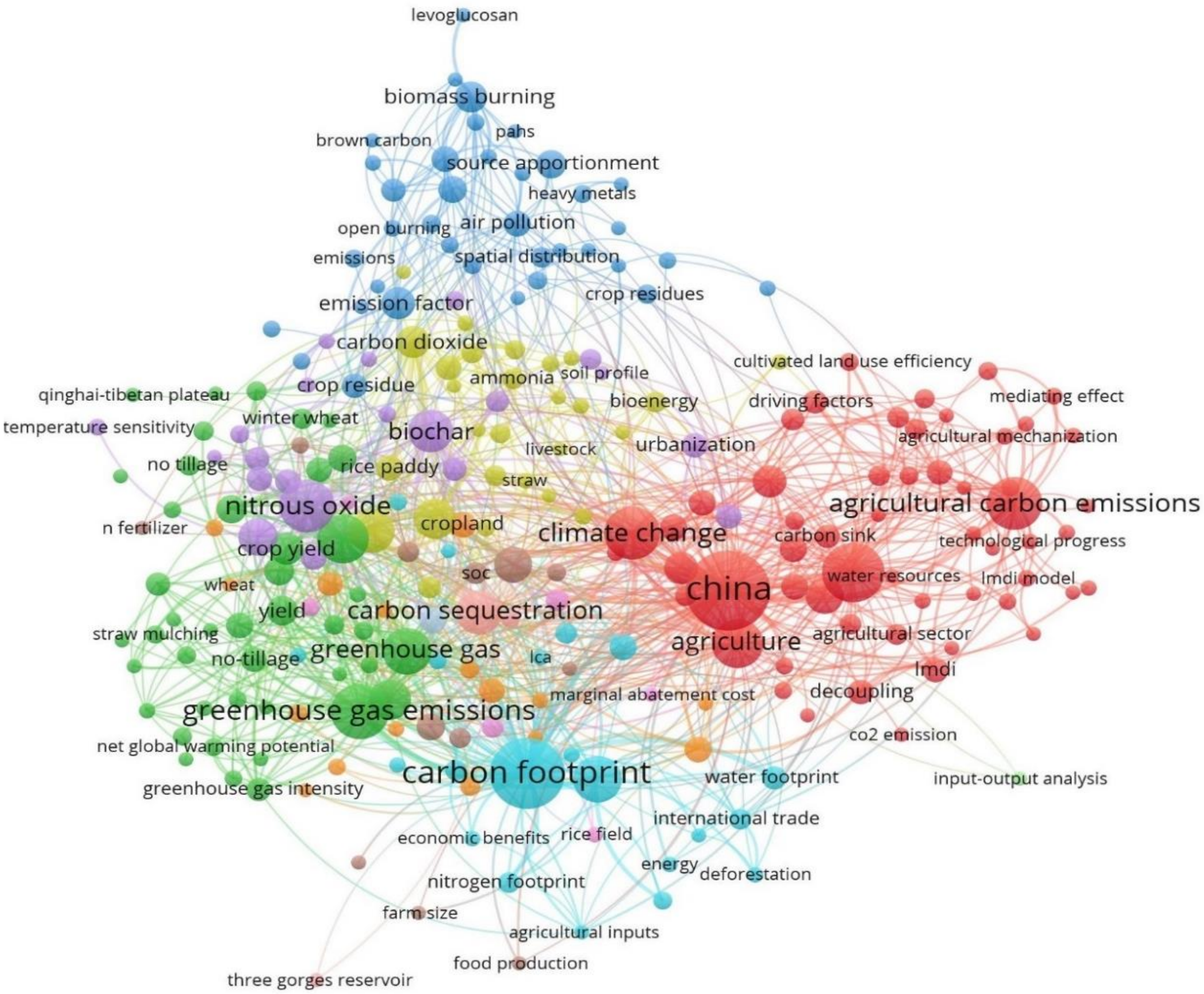

Figure 3. Co-occurrence of keywords with network visualization

4.2.2. Geographical spread of documents and citations

The following table presents a summary of the ranking of countries based on their research outputs concerning agricultural carbon emissions in rural China (Table 3). China demonstrates a substantial lead in this field, with a total of 67,419 citations from 1,806 documents, significantly surpassing all other countries (Figure 4). This considerable advantage establishes China as the primary contributor to research on its carbon footprint. The United States occupies the second position with 17,926 citations from 272 entries, indicating international interest and valuable contributions despite lower production. The United Kingdom emerges in third place with 7218 citations from 103 documents, demonstrating significant impact in this subject area. The Germany, ranked fourth, exhibits an atypical trend whereby 85 documents garnered 6084 citations, suggesting the presence of highly influential publications. Netherlands occupies the fifth position among all countries with 3800 citations from 36 published documents. Australia and France follow in sixth and seventh places, with comparable citation figures like 3601 citations from 79 documents and 2872 citations from 25 documents respectively. Canada follows with 2761 citations from 51 documents. The special administrative region of Hong Kong ranks ninth with 2646 citations derived from 34 documents, recognized for its distinct research output. Japan completes the top ten with 2486 citations from only 39 documents, demonstrating that even with fewer publications, they produce research with global impact. These countries thus demonstrate that research regarding agricultural carbon emissions in rural China is a significant endeavor with global implications. The ratio of citations to documents across different countries indicates variations in research approaches and recognition of works, with some countries producing fewer but higher-impact documents while others have a higher number of publications.

Table 3. Top ten countries with number of publications and citations

Rank	Country	Total Citations	Total Documents
1	China	67419	1806
2	USA	17926	272
3	United Kingdom	7218	103
4	Germany	6084	85
5	Netherlands	3800	36
6	Australia	3601	79
7	France	2872	25
8	Canada	2761	51
9	Hong Kong	2646	34
10	Japan	2486	39

Figure 4. Geographical spread of citations in the world

4.2.3. Country of the corresponding authors

China exhibits the highest number of corresponding authors (1808), significantly surpassing all other countries (Figure 5). This predominance is anticipated given the research objective of quantifying carbon emissions in rural China's agricultural sector, a matter of national importance. The United States follows with 274 authors, indicating substantial international collaboration. Other notable contributors include the United Kingdom (105), Germany (86), Australia (81), and Canada (53), reflecting their extensive environmental research and frequent climate change collaborations with Chinese scholars. Additional countries, including Japan (40), Netherlands (38), Pakistan (38), Hong Kong (34), India (31), and France (27), demonstrate varying degrees of involvement, presenting a more nuanced spectrum of cross-border participation. This distribution underscores China's leadership in the field and highlights the global significance of agricultural carbon emissions, evidenced by the participation of both Western and developing nations. The figure suggests robust international collaboration centered on the global challenge of reducing the carbon footprint in agriculture, with China emerging as one of the leading global research priority areas.

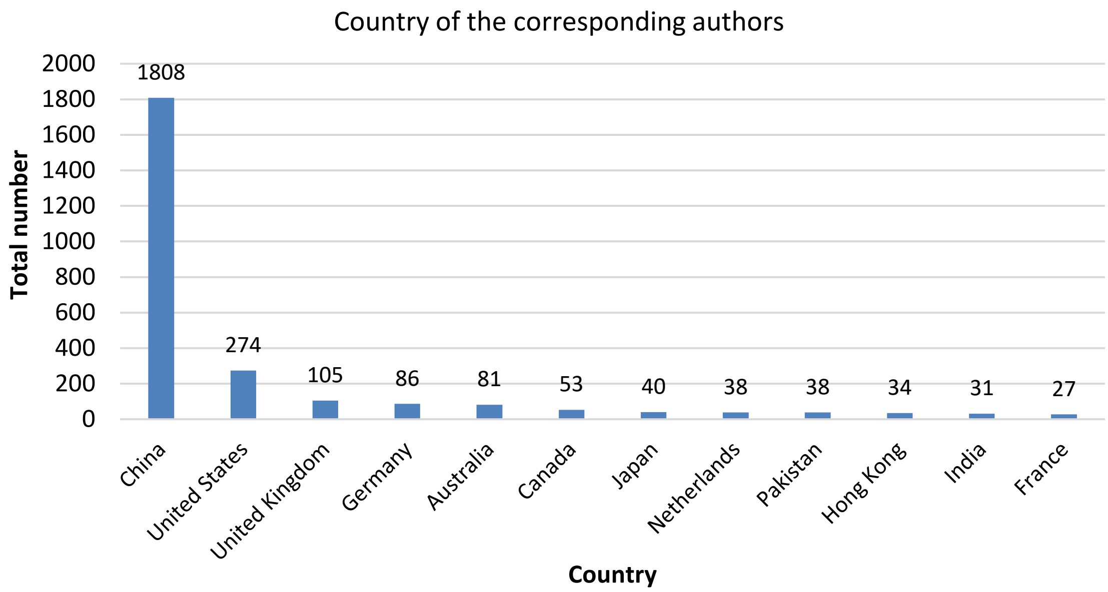

Figure 5. Geographical spread of corresponding authors

4.2.4. Discipline-wise publications

This research also described how scholars belonging to the different disciplines have published on carbon emissions in agriculture linking the papers to their respective departments of affiliation of the different disciplines (Table 4). At 40.73% of all documents (1433), environmental science is undoubtedly the most prevalent in publications, indicating that it is the main field studying carbon emissions from agriculture. After that Agricultural and Biological Sciences cover considerable representation with 13.62% of publications (479) dealing with energy consumption in agriculture. The data is closely followed by Energy and Earth and Planetary Sciences, responsible for 347 documents (9.86%) and 289 documents (8.21%) respectively. Engineering clearly focuses on the ways to reduce emissions, yielding 6.68% (235 documents) publication (Figure 6). There are 184 documents placed in the category of Social Sciences (5.23%), where agricultural emissions could be relevant for example regarding policy and societal aspects. Business, Management, and Accounting (3.89%, 137 documents) could investigate the economic consequences of Biochemistry, Genetics, and Molecular Biology (2.05%, 72 documents), which could be researching biological processes for the use of carbon cycles in agriculture.

Table 4. Discipline-wise publications

Subject Area	Total documents	Percentage
Environmental Science	1433	40.73
Agricultural and Biological Sciences	479	13.62
Energy	347	9.86
Earth and Planetary Sciences	289	8.21
Engineering	235	6.68
Social Sciences	184	5.23
Business, Management, and Accounting	137	3.89
Medicine	105	2.98
Computer Science	89	2.53
Economics, Econometrics and Finance	89	2.53
Biochemistry, Genetics and Molecular Biology	72	2.05
Multidisciplinary	59	1.68

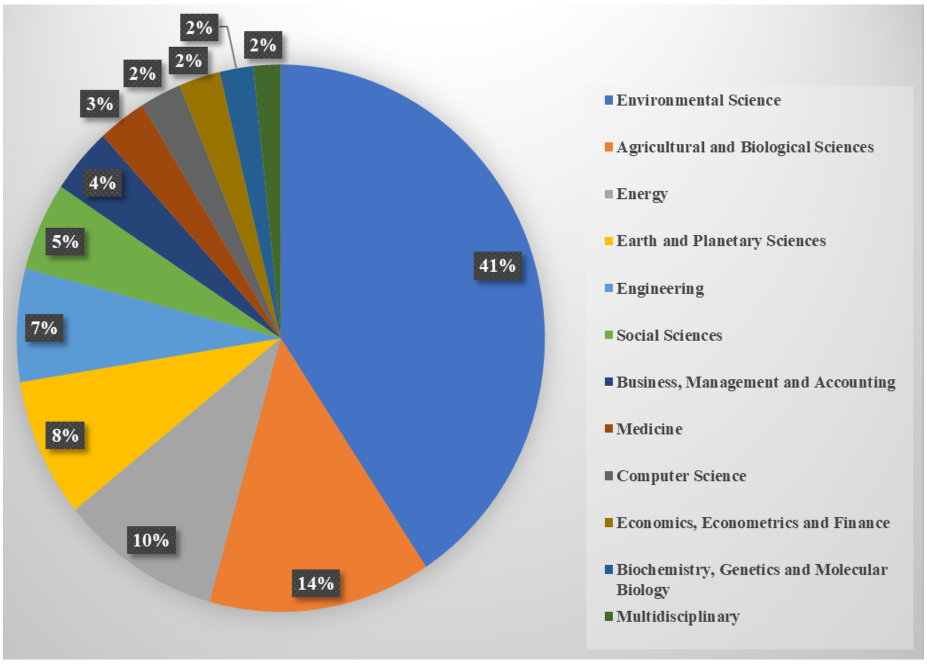

Figure 6. Number of publications produced according to the subject area

4.2.5. Journal publications

The following figure illustrates the distribution of articles pertaining to China's agricultural carbon emissions across various academic journals (Figure 7). Science of the Total Environment published the highest number of publications (181), indicating its prominent role in disseminating research findings in this field. The Journal of Cleaner Production ranks second with 126 publications, highlighting the importance of sustainable agricultural practices. Environmental Science and Pollution Research (ESPR) follows with 113 articles, emphasizing the environmental impact aspect of agricultural emissions. Sustainability, published by MDPI, encompasses related but more general concepts of sustainability, with approximately 93 articles. Atmospheric Environment and the International Journal of Environmental Research and Public Health each published 61 articles, addressing air quality and health implications of the issue. Environmental Pollution and Agriculture Ecosystems and Environment published 44 and 43 articles, respectively, focusing on specific environmental or ecosystem consequences. Plos One, a multidisciplinary journal, contributed 32 articles, indicating a degree of interdisciplinarity in this field of study. These journals represent the diverse nature of agricultural carbon emissions research in China, spanning environmental, sustainability, atmospheric, and health science disciplines.

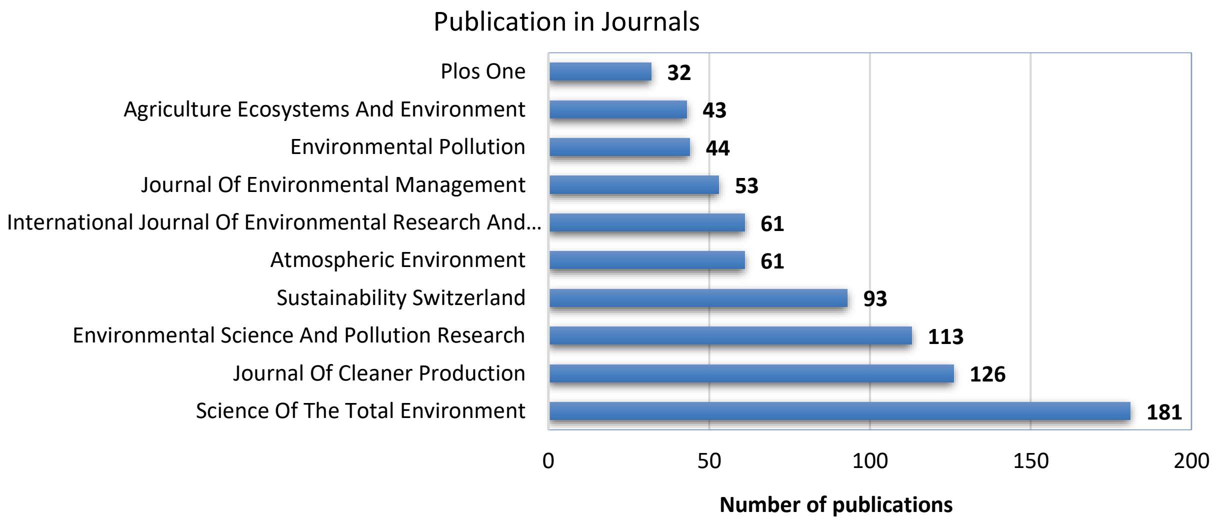

Figure 7. Number of productions in different journals

4.3. Key drivers of carbon emission in China

Different drivers have impact on agricultural carbon emissions in rural China. Major drivers are agricultural intensification, land use change, digital economy, industrial agglomeration and technological innovation. These drivers are collaborated with agricultural carbon emissions in rural China with different publications. This research will demonstrate the individual driver relation with ACM.

4.3.1. Agricultural intensification

China is experiencing rapid increase of carbon emissions due to agricultural intensification. A total of 35 publications are found between 2000 to 2023 for this driving force. China has a great deal of potential to restore damaged and desertified ecosystems and intensify agriculture in order to absorb soil carbon [59]. Though soil organic carbon in northern China has grown due to agricultural intensification, rising N2O emissions have negative climatic implications that must be addressed [60]. A good number publications thoroughly examine the benefits and difficulties that China's intensifying agriculture presents [61][62][63][64][65].

4.3.2. Land use change

Land use change is one of the important driver for intense agricultural carbon emission in China. Numerous researchers have employed different methods to find relation between land use and carbon emission in agricultural China. It is found that about 113 manuscripts published between 2000 to 2023. The table illustrates the geographical location of authors who contributed to the publications on land use change and agricultural carbon emission (Table 5). Each country likely has signed up contributions to research the linkages between use of land alterations including deforestation, land degradation or land expansion for agriculture and carbon emissions from the agricultural sector.

China is expected to have the largest number of publications (101) since the country has a vast rural populace, massive agriculture activity, and is working on reducing carbon emissions as part of climate change initiatives. This country also has highest number of citations (2786) due to large number of publications. Other developed countries with authors such as the United States (19), Hong Kong (5) and United Kingdom (4) can follow the same notion due to having developed agricultural research departments, strong orientation to climate change issues, and international partnerships. They play a role in offering opinions and solutions on sustainable agriculture and land use to minimise carbon output.

Table 5. Publications of authors in land use change with ACM in different countries

Country	Documents	Citations
China	101	2786
United States	19	274
Hong Kong	5	353
United Kingdom	4	87
Japan	3	137
Canada	3	148
Australia	2	55

4.3.3. Digital economy

Digital economy as a driving factor has close relationship with agricultural carbon emissions. It is found that 18 manuscripts published from 2000 to 2023 in different reputed journals. Most of the articles published in 2022 and 2023. Current emergent papers have focused on the consequences of the digital economy on agricultural carbon emissions within the China region. In light of this, the present study examines this issue utilizing data from China's provincial panel [66]. Multiple analyses indicate that the digital economy significantly reduces agricultural carbon intensity and, consequently, emissions. This is attributed to its stimulation of agricultural technology development and green innovation. The effects are also demonstrated to vary by region, with stronger impacts observed in western and north-eastern China [67][68][69]. Spillover effects is also apparent, demonstrating that establishing a digital economy in one area decreases agricultural carbon emissions in nearby provinces [70]. Based on these findings, it may be preliminarily concluded that promoting the digital economy can contribute to the reduction of agricultural carbon emissions in China as a whole.

4.3.4. Industrial agglomeration

Industrial agglomeration is also an important driving force for carbon emission in China. This research found about 10 research outputs that is corelated with industrial agglomeration and agricultural carbon emissions. Most of the industrial areas in China rely on coal other non-renewable sources of energy, a factor that greatly contributes to the carbon footprints [71][20]. Concentration of industries tends to bring about increased pressure on agricultural activities since the industrial sectors that support food processing and production tend to locate themselves in particular areas [72]. This is because agglomeration raises the level of transport operations, which result in emissions in the transport of goods and raw materials in clusters [73]. These findings highlight the challenges of balancing economic growth and sustainable agriculture practices in China's low-carbon transition.

4.3.5. Technological innovation

Technology is considered as most prominent driver for agricultural carbon emission in China. This research found that about 153 publications published between 2000 to 2023. Precision farming technologies, including water management methods like smart drip irrigation systems, mechanization like drones, and automated farm machines have helped farmers conserve resources such as water, fertilizers and pesticides, which are significant sources of emissions. This table presents comparisons of published metrics on technology innovation and agricultural carbon emissions in China and other countries (Table 6). China emerges as the most productive nation in this field of study, contributing 134 documents with a notably high citation count of 4883. This indicates that China is not only the leading producer of research in this area but also demonstrates the highest impact in terms of cited work. The United States follows in second position, albeit with a significant gap, producing 19 documents and garnering 1493 citations. Japan, the United Kingdom, and the Netherlands complete the top five, each with single-digit document counts but varying degrees of citation impact. Notably, the Netherlands exhibits a substantial citation count per document (311) despite having only five published documents. According to our findings, information technology promotes sustainability and efficiency in Chinese agriculture [74]. Developments in digital technology and the internet encourage China's agriculture to grow sustainably and environmentally [75]. In order to fully realize the promise of digital technology in agriculture, authorities have to prioritize market regulation, farmer training, and government-led initiatives [76][77].

Table 6. Publications of source country for technology with carbon emissions

Country	Documents	Citations
China	134	4883
USA	19	1493
Japan	9	518
United Kingdom	6	167
Netherlands	5	311
Australia	3	188
Italy	3	137
Canada	3	84

5. Discussion

The systematic review and meta-analysis of agricultural carbon emissions in rural China demonstrate that the subject is diverse and continuously expanding. The number of publications on this topic has increased significantly, as has the citation rate per year since 2010, correlating with growing concern for climate change and carbon reduction policies in agriculture. The research primarily falls within the fields of environmental and agricultural science, with China being the leading country in terms of publications and citations. However, collaborative work is conducted globally. It can be seen from the keyword co-occurrence analysis that the most commonly occurring phrases are "China," "greenhouse gas emissions," "carbon footprint," "carbon emissions," and "climate change." The following scatterplot diagram seems to indicate a pattern of the occurrence of the keywords on both the x and y axes, which may show the connectivity of those specific keywords (Figure 8). The dispersed plotted dots show no obvious linear link; instead, they form a slightly compact cluster around the center, suggesting that there is a significant directional relationship but not a strong co-occurring pattern between the terms. It appears that the values on the x- and y-axes range from about -1.5 to 1.5. These points are located on the two quadrants with positive and negative values along the X and Y axes equally distributed around the central point of (0,0). This points to fairly balanced distribution of co-occurrences as the highlight of this discourse has it. The axes prove useful in mapping the interconnection of keywords and the strength of the connection between the pair of keywords. They probably normalize scores obtained from a higher text or data analysis, and let the visualization of relations of the particular subjects or keywords within a higher textual or data set. These metrics may be as straightforward as the number of studies under consideration or they may be more closely related to the type of approach used in the underlying study for instance frequency, strength, or relevance.

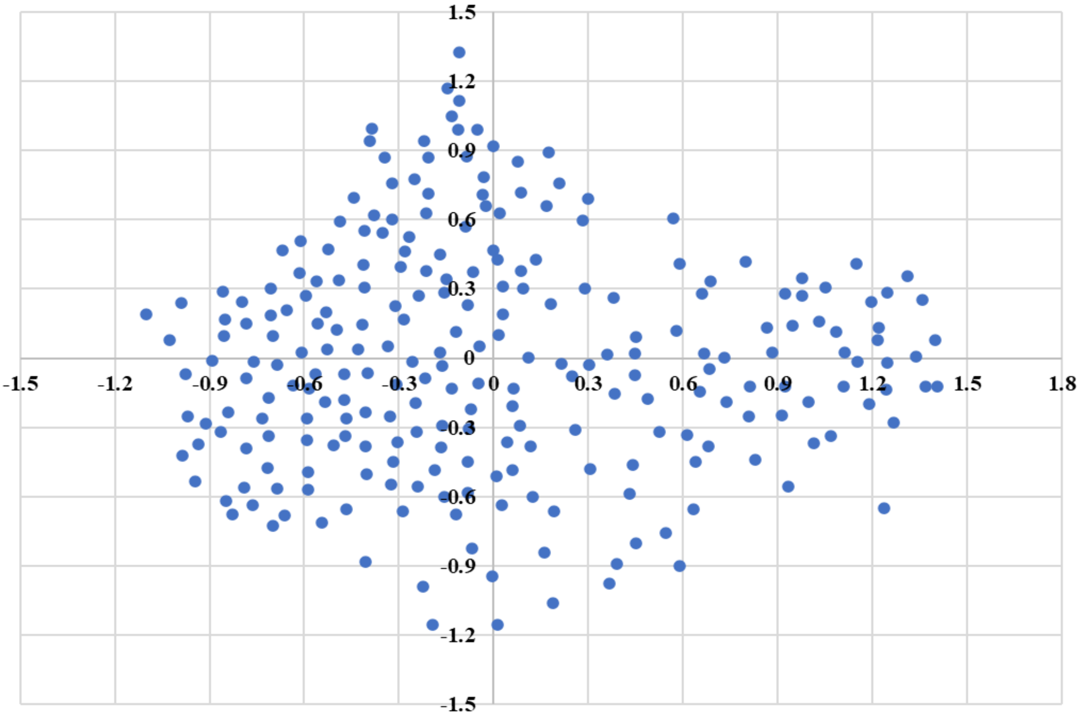

Figure 8. Scatterplot of co-occurrence of keywords

Several factors contribute to agricultural carbon emissions, including agricultural changes, land use alterations, digital economy, industrial agglomeration, and technological advancement. While concerns have been raised regarding agricultural intensification and land use changes as factors that may expose forests to conversion for other purposes, recent studies indicate that the digital economy holds the potential to reduce carbon intensity through innovation facilitated by the new economy. Innovations, particularly precision farming, are perceived to mitigate emissions and promote sustainable farming methods. However, these drivers affect the development of green supply chain management differently across Chinese regions, justifying a regional approach.

The results imply that further development of the digital economy and technology could support reducing the carbon footprint in agriculture. Nevertheless, this approach still faces the dilemma of balancing economic progress and development of economies of scale with environmentally friendly agricultural practices. The fragmented nature of the research indicates a need to address the subject through multiple methodologies and perspectives. Potential areas for further research could focus on exploring the effects of the digital economy in greater depth and synthesizing various drivers to provide a systematic approach for sustainable agriculture in China. The participation of researchers from other countries demonstrates global concern regarding carbon emissions in Chinese agriculture and the potential for sharing best practices. In conclusion, the research emphasizes the implementation of moderated strategies, specifically technological updates and sustainable use of production, to control carbon emissions without compromising future food production in rural China.

6. Limitations

The current research has certain limitations. There may be some bias in the conclusions drawn from this assessment because it only took into account English-language research on agricultural carbon emissions. We restricted our search terms to avoid including studies that would not have been included using CNKI and Scopus, two search engines. Furthermore, in synthesizing the body of knowledge, our wide search query could have oversimplified the results and missed particular traits and differences in China's agricultural carbon emissions.

7. Conclusion

This study aims to enhance our understanding of agricultural carbon emissions in China and provide insights for future research, policies and actions needed to reduce the carbon footprints. By conducting a comprehensive systematic literature review of over 1971 publications from 2000 to 2023, it significantly contributes to the existing body of knowledge, highlighting trends, thematic areas of agrarian carbon emission research across countries, authors and journals. This research has evolved into a multidisciplinary field, encompassing diverse themes such as environment, geography, soil science, climate change, renewable energy and ecology. China, the United States and the United Kingdom have been identified as the most productive countries in the area of ACM research and collaboration. Some drivers like intensification and land-use changes present a challenge in terms of emissions, and other drivers including the digital economy and technological development are likely to lower carbon intensity from innovation and improvements in efficiency. The research agenda for the future should focus on the following areas. To begin with, there is a serious lack of knowledge in terms of potential future trends in digital technologies and innovations affecting the carbon emissions in agriculture. This includes case studies on how precision farming, artificial intelligence, and high-level monitoring systems can assist the agriculture industry in achieving a more sustainable source of production. Second, research should progress to explain the strategies contextualized geographically and by economic zone within the China region, given the inability of a standardized strategy solution to fit the spectrum of Chinese geographical and economic space.

The policy recommendations should underscore the strategy of ‘Growth and Sustainability’ in the economy. This entails developing policies that will prompt farmers to embrace technology and practices that reduce emission of greenhouse gases with no negative impact to their ability to feed the nation. International cooperation will be important in this regard, as capacity building, technical knowledge sharing, technology diffusion and partnerships in research that can come up with sustainable models for tackling emission by agriculture will be critical.

However, any further research should attempt to analyze the role of carbon emissions in agriculture at the intersection with other pertinent issues such as rural development, technology, and climate change. The research should seek to produce holistic models for assessing carbon emissions and also for offering stimulus to policy makers in agriculture, agriculturists, and technologists in the field of agriculture. Further research on the topics identified in this study will help the researchers to enhance information flows and initialized a more environmentally friendly communication approach to agricultural development.

Declaration of competing interest

The authors declare that they have no known financial or non-financial competing interests in any material discussed in this paper.

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