Tracing the contribution of cattle farms to methane emissions through bibliometric analyses [1]

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Abstract

Methane contributes to global warming, and livestock is one of the sources of methane production. However, methane emission studies using bibliometric tools in livestock are lacking. Given the negative impact of climate change on the ecosystem and the rise in methane emissions, it is essential to conduct a bibliometrics study to provide an overview and research trends. We used the Bibliometrix package and VOSviewer to decipher bibliometric indices for methane emissions in cattle farms (MECF). Current dataset were collected from the Web of Science (Core Collection) database, and 8,998 publications were analyzed. The most co-occurring keywords scientists preferred were methane (1528), greenhouse gas (443), methane emissions (440), and cattle (369). Methane was the most frequently used keyword in the published scientific literature. Thematic evolution of research themes and trend results highlighted carbon dioxide, methane, dairy cattle, cattle, and risk factors during 1999-2017. Chinese Academy of Sciences ranked on top with 485 publications, followed by Agriculture & Agri-Food Canada, University of Colorado, National Oceanic and Atmospheric Administration, and Aarhus University. Chinese Academy of Sciences was also the most cited organization, followed by the University of Colorado, Agriculture & Agri-Food Canada, National Oceanic and Atmospheric Administration, and United States Geological Survey. Source analysis showed that the Science of the Total Environment was cited with the highest total link strength. “Science of the Total Environment” ranked first in source core 1 with 290 citation frequencies, followed by “Journal of Dairy Science” with 223 citation frequencies. Currently, no bibliometric study has been conducted on MECF, and to fill this knowledge gap, we carried out this study to highlight methane emissions in cattle farms, aiming at a climate change perspective. In

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this regard, we focused on the research productivity of countries authors, journals and institutions, co-occurrence of keywords, evolution of research trends, and collaborative networking. Based on relevance degree of centrality, methane emissions and greenhouse gases appeared as basic themes, cattle, and dairy cattle appeared as emerging/declining themes, whereas, methane, greenhouse gas and nitrous oxide appeared to fall amongst basic and motor themes. On the other hand, beef cattle, rumen and dairy cow seem to be between motor and niche themes, and risk factors lie in niche themes. The present bibliometric analysis provides research progress on methane emissions in cattle farms. Current findings may provide a framework for understanding research trends and themes in methane emissions in cattle farms (MECF) research.

Keywords: methane emission; cattle farms; climate change; greenhouse gases; networking; bibliometrics

1. Introduction

Increased anthropogenic activities and greenhouse gases have contributed to climate change in recent years. The rising rate of greenhouse gases threatens the ecosystems and risks ecosystem stability and sustainability. Among greenhouse gases, methane (CH_4) is essential, as it has a much greater global warming potential than carbon dioxide per molecule, and scientific data has revealed that methane emissions have increased by 70% (Black *et al.* 2021). Methane is an abundantly found greenhouse gas, and its emissions will increase by 30% according to future predictions (Reisinger *et al.* 2021). Fossil fuel production, agriculture, livestock, and aquatic systems are reservoirs for methane production (Crippa *et al.* 2021; Liu *et al*. 2021; Rosentreter *et al.* 2021; Baceninaite *et al.* 2022). Cattle production contributes 14.5% of global greenhouse gas (GHG) emissions, of which 40% is enteric methane from cattle (Tee *et al.* 2022).

Moreover, the high demand for agricultural and dairy products has increased the CH_4 emissions; dairy cattle also contribute to greenhouse gas emissions. Identifying spatial variations in CH4 emissions may help develop inventories to record emissions rates, which have implications for climate change policy (Gong and Shi 2021).

Reducing methane emissions is vital to curb climate change and the long-term sustainability of the dairy industry (Kamalanathan *et al*. 2023). Data shows that 80% of the methane source is livestock systems (Gerber *et al*. 2013). According to the United States Environmental Protection Agency (USEPA), global enteric CH4 emissions are predicted to increase by 23% from 2015 to 2050 (USEPA 2019; Tee *et al*. 2022).

Recent developments in software and computer programs have illuminated scientific fields, and presenting scientific data through graphs and summary statistics is relatively easy. Techno-scientific is the collection of computer packages, algorithms and scientific methods/techniques to answer questions related to various fields. Previous studies have coined and implemented terms to describe research trends, networks, and collaboration (Hood and Wilson 2001; Milojevic and Leydesdorff 2013). Bibliometrics and scientometrics tools offer methods to study different scientific topics. These methods can identify leading countries, institutions, prolific authors, keywords, and journals. Bibliometric tools have paved our understanding of research productivity, topics, research trends, collaboration networks, and upcoming frontiers (Aria and Cuccurullo 2017; Zaib *et al.* 2022; Bogdan *et al.* 2023). Previously, bibliometric studies were confined to a specific topic; nonetheless, bibliometric approaches are widely used in all fields (Guler *et al.* 2016; Aria *et al.* 2020; Zaib *et al*. 2023).

Given the current climate change scenario and the rise in methane emissions, it is necessary to study and highlight methane production in cattle farms. Assessing methane emissions through bibliometrics tools and methods provides an overview of methane emissions in cattle farms (MECF). And such a study is absent. Therefore, we carried out a bibliometrics study to highlight methane

emissions in livestock. We aimed to study methane emissions and highlight the contribution of methane to climate change by bibliometric tools. We focused on research productivity, co-occurrence, leading countries, institutions, prolific authors, keywords, collaborative networks, and prolific journals. The current study will help to identify methane emissions bibliometrically. The present study has implications to understand research trend and progress in cattle farms.

2. Material and Methods

2.1. Scientific Literature Search Strategy

We extracted data from the Web of Science, and the main focus was devoted to the core collection. Manuscripts and literature reviews published in SCI/SCIE journals were compiled for analysis. The time span was kept from January 1, 1999, to March 10, 2023. "Methane emission in cattle farms"OR"methane emissions"OR"cattle farms" was searched as the topic (sum of available published literature= 9,571). The dataset contained beef and dairy farms, with an emphasis on documenting methane emissions. The literature was refined by document type, and manuscripts other than original/research articles or review articles were excluded (available publications 9,342). Documents published in all languages were included (sum of accessible published literature = 8,998). Languages other than English were also included.

2.2. Data Collection

We also documented all necessary manuscript information and prepared files (plain text and tab-delimited files) according to software requirements.

2.3. Bibliometric Analysis

Bibliometrix is an R statistical package with rich statistical capabilities for analyzing and visualizing bibliographic data from various databases. It is written in R language and operates under the GNU operating system. R is distributed and archived by the CRAN network project (https://cran.r-project.org/) (Aria and Cuccurullo 2017). The network plot function plots a network created by biblioNetwork using R routines (Aria and Cuccurullo 2017) and VOSviewer software (Waltman *et al.* 2010; Waltman and van Eck 2012; Waltman and van Eck 2013). Co-occurrence, author-provided keywords and network analyses were performed in VOSviewer 1.6.16 (Kamada and Kawai 1989; van Eck and Waltman 2010; Waltman and van Eck 2012). Callons' centrality shows the association between nodes or networks and indicates the importance of nodes. In bibliometrics studies, measuring the research themes by Callon's centrality and Callon's density is common practice. Callon's centrality and density measure interaction and internal strength in research themes. Similarly, research trends, themes and topics are identified (Callon *et al*. 1991). We used the Kamada-Kawai layout (Kamada and Kawai 1989) in the co-occurrence network. This algorithm was developed to draw a graph and is a convenient method implemented in VOSviewer and Bibliometrix.

Clusters and density plots were drawn to display network visualization. Circle/node size exhibited the sum of author-provided keywords (co-occurrence)—the lines/edges between nodes displayed connectivity or link strength. Several colors in the networks indicate average publication years along with a timeline. Yellow color in density plot is a characteristic of most frequently occurring keyword (Zhang *et al.* 2019; Fan *et al.* 2022).

3. Results

3.1. Bibliometric research on methane emission in cattle farms

Nine thousand five hundred seventy-one (9,571) publications on Methane emission in cattle farms (MECF) were compiled. We focused our search on the core collection of the SCI/SCIE database. Among these, 229 publications with non-targeted manuscript types were excluded. In addition, 8,998 publications were finally qualified to meet the bibliometric analysis threshold after removing missing items and including languages other than English. 98% of the manuscripts were published in English, 0.27% in Spanish, and 0.51% in German, indicating English was the most preferred and defecto language in MECF. The data analysis revealed a sharp rise in the publication count after 2017 (Fig. 1A). In contrast, the average citation per year trend showed an irregular pattern of rise and decline trends over the years (Fig. 1B).

3.2. Author-provided keywords for frequency and co-occurrence analysis We followed and used the Kamada-Kawai layout for the co-occurrence network (Kamada and Kawai 1989) while performing the co-occurrence of author-provided keyword analysis. And selected threshold to the minimum number of occurrences of a particular keyword chosen 5 times. Among the 15,739 author-provided keywords, 11,33 initially met the designated threshold, and for the final threshold, 1,000 keywords with the most significant values of total link strength were selected. According to the analysis, the most co-occurring keywords scientists preferred were methane (1528), greenhouse gas (443), methane emissions (440), and cattle (369), which indicate the research priorities of the scientists/researchers across the globe. The density visualization (Fig. 2A) shows the co-occurrence frequency of author-provided keywords. This can be observed by the font and cluster density size. From 1999 to 2023, methane appeared the most frequently used keyword in the published scientific literature (Fig. 2B).

3.3. Thematic map and co-word factorial analysis

The thematic map analysis depicted the earlier research mainly focused on methane emissions and other greenhouse gas emissions. Still, gradually, the trend has been focusing on the contribution of dairy farms or cattle farms to methane emissions. Research on risk factors in a given domain appeared as a niche theme (Fig. 2C). Thematic evolution of research themes and trends during 1999-2017 was carbon dioxide, methane, dairy cattle, cattle, and risk factors. By 2018-2023, these topics focused on cattle, methane, climate change and prevalence (Fig. 2D). Multiple-

correspondence analysis (MCA) reduces data dimensions and displays graphs to reflect the affinity in data points. In bibliometric analysis, MCA identifies groups or clusters using conceptual structure algorithms (Aria and Cuccurullo 2017). Fig. 2E represents the MCA of the high-frequency author's keywords. Closely related author-provided keywords were connected and occupied central graph positions or single modules or clusters. Nevertheless, the author-provided keywords are more consistently spread and are considered less frequently conferred research topics or evolutions or changes to other themes.

3.4 Prolific countries and organizations contributing to MECF research

We analyzed front-runner countries and organizations in the interactive R package biblioshiny and obtained the results as a world map. Prolific countries' results revealed the top 3 leading countries (USA, China, UK) in MECF research (Fig. 3A). A total of 129 countries published articles on MECF. Most of the corresponding authors were from the USA (1,757 articles, Frequency 0.195), where out of 1,757 articles, 1,255 were single-country publications, and 502 were multiple-country publications, with MCP Ratio 0.286. The USA was followed by China (1,266 articles, Frequency 0.141, MCP Ratio 0.373), Canada (568 articles, 0.063, MCP Ratio 0.352), United Kingdom (538 articles, frequency, 0.06, MCP Ratio 0.45), and Germany (429 articles, Frequency 0.055, MCP Ratio 0.431) (Fig. 3B). The citation analysis provided insight into published articles. United States received the most citations (112312), followed by China (40153), Canada (40131), Germany (38752), and England (782) (Fig. 3C). USA had the largest sum of published literature and citations, contributing the most to MECF research. Regarding international collaborations, scholars from the USA and China collaborated the most. The countries are classified into six clusters based on the degree of betweenness and closeness. The first cluster has a red node color, dominates most of the research in MECF, and has a higher degree of betweenness and closeness. Subsequently, cluster 2, identified by its blue color, follows. Cluster 3 is the second smallest cluster and consists of three countries with green node colors. (Fig. 3D). Cluster 4 is purple and consists of South American countries. The majority of European countries and African countries were in cluster 5. Node 6 (brown-colored) is the smallest among all and includes Pakistan. The USA, China, Germany, and Canada dominated the global trend of international collaboration. These countries influenced the research trends of MECF. Various countries have distinct breeds of cattle on their dairy and beef farms, tailored to meet the nutritional requirements of their populations. Additionally, governments have implemented policies in dairy farms to reduce methane emissions. We provide an overview of methane emission characteristics of dairy and beef farms in prolific countries (Supplementary Table).

An aggregate of 7307 research organizations contributed and published scientific literature related to MECF from 1999 to 2023. Conferring to the co-authorship analysis of organizations, the minimum threshold was set to five manuscripts per organization, and 1006 met the analysis threshold. The research organizations were further shortlisted for the final analysis based on the

highest total link strength. The analysis revealed Chinese Academy of Sciences ranked on top with 485 documents, followed by Agriculture & Agri-Food Canada (218 documents), the University of Colorado (151), and National Oceanic and Atmospheric Administration (151 documents), and Aarhus University (150 documents) (Fig. 3E). Whereas, citation analysis showed Chinese Academy of Sciences ranked first as the published scientific literature was cited 18509 times (Fig. 3F), followed by the University of Colorado (10786 citations), Agriculture & Agri-Food Canada (10351 citations), National Oceanic and Atmospheric Administration (8935 citations) and United States Geological Survey (8155 citations). According to the most relevant affiliation analysis, the University of Colorado and Aarhus University contributed the largest numbers (194 and 174 articles), followed by University of California Davis (167 articles), University of Helsinki (164 articles), Harvard University (146 articles), and University of Edinburgh (143 articles) (Fig. 3G).

3.5. Authors, prolific document and source analysis

Fig. 4A displays the authors' analysis, where the prolific authors' production over time can be observed. The size of the node and the depth of the sphere's color relate with the annual count of article citations. It confirms that Christensen T.R. has been scientifically active for a longer time. This analysis also presents ample evidence that Beauchemin K.A. has published a greater number of research publications on MECF research and has garnered more attention in a shorter period of time. Lotka's law (Fig. 4B), also termed the "inverse square law of scientific production," was used to provide information on the author's distribution based on the sum of publications (Lotka 1926) and is considered one of the eminent laws in bibliometric studies (Andreo-Martinez *et al.* 2020). It generally describes the frequency of publications by authors in a given discipline. Most local cited authors analysis calculates local citations of the authors of a bibliographic collection, where local citations measure how many times an author included in the collection has been cited by research publications, which is also included in the dataset of a specific field of study. The most locally cited authors in MECF research were Dlugokencky E.J. (2088 times), Sweeney C. (1806 times), Bastviken D. (1734 times), Beauchemin K.A. (1638 times) and Bousquet P. (1576 times) as mentioned/shown in Fig. 4C. During the analysis, a sum of 34752 authors was included, but they were funneled based on the minimum number of documents of the author. We selected a minimum number of 5 documents; due to this threshold chosen; 1247 authors met the threshold criteria. As the analysis proceeded further, it was observed that the most extensive set of connected items (authors) was further reduced to 920 and revealed Beauchmin KA as the top-ranked author with 51 published documents/manuscripts, followed by Jacob DJ (43 documents), Chen H (40 documents), Sweeney C (36 documents) and Maasakkers JD with 35 manuscripts (Fig. 4D).

During the network analysis of the cited documents, a sum of 9,342 research publications met the criteria, and only 1000 were finalized for the final network analysis threshold (Fig. 5A). The leading publication of Saunois (2016) was top-ranked with 655 citations and 151 links, whereas another publication of the same author in 2020 ranked second with 625 citations and 140 links, followed by

Bousquet (2006; 651 citations and 103 links), Nisbet (2020; 89 citations and 96 links) and Bridgham (2013; 357 citations; 93 links). The most globally cited article was Chinese research, with 2256 total citations and 250.67 total citations per year, published in Environmental Science and Technology (2015) by Zhang QQ et al. (Table 1).

A total of 1323 journals preferred to publish all 8,998 articles related to MECF research. Five minimum numbers of sources were kept as threshold requirements, resulting in 335 sources fulfilling these analysis requirements and unveiled the Science of the Total Environment was cited with the highest total link strength (260680 total link strength), followed by Biogeosciences (234868 total link strength), Global change biology (216736 total link strength), Journal of Geophysical Research (215505 total link strength), Journal of Dairy Science (197398 total link strength), and Atmospheric Chemistry and Physics (195645 total link strength) (Fig. 5B), (Table 2). Other popular bibliometric indicators are h-index, g-index, and m-index. The 'Hirsch index' or h-index is known as a leading source/author-level research metric, and its value symbolizes the 'h', the number of papers having at least an 'h', the number of citations (Hirsch 2005); it's a popular mainstream indicator, which tends to be influenced by the career length of a researcher or lifespan of citedness (Fraumann and Mutz 2021). In the data analysis for sources, we found Global Change Biology leads to h-index =60 for 11319 total citations of 133 published manuscripts (Table 2). The g-index measures a better set of global citation performance of articles/sources. The g index is an essential indicator in bibliometrics and measures the performance of published articles (Egghe 2006). Scientists use the m-index to describe journals or researchers' productivity and timespan of the research activity (Bornmann *et al*. 2008). We mentioned h, g, and m indexes in Table 2. According to Bradford's Law of Scattering, there are a few very productive periodicals in a specific research domain, a large sum of more moderate and many constantly diminishing productive, which fall in respective zones or cores based on their citations (Brookes 1969). According to Bradford's model, "Science of the Total Environment" ranked first in source core 1 with 290 citation frequencies, followed by "Journal of Dairy Science" with 223 citation frequencies (Fig. 5C).

3.6 Three- factor analysis of major aspects of the data

Prolific countries, keywords, and sources/journals in Fig. 6 represent the three- factor analysis of the relationship among countries (left), keywords (middle), and sources/journals (right). It shows that seven prolific countries (USA, China, United Kingdom, Canada, Australia, France, and Germany) published MECF scientific literature primarily using four main keywords (methane, greenhouse gas, methane emission, and climate change). These countries and keywords strongly relate to five scientific journals/sources (Science of the Total Environment, Journal of Geophysical Research-Biogeosciences, Journal of Cleaner Production, Atmospheric Environment, and Global Change Biology).

4. Discussion

Worldwide, methane emission is a major climate change issue, and cattle farming is one of the key anthropogenic sources of greenhouse gas emissions in the environment (Johnson and Johnson 1995; Liu *et al.* 2021; Baceninaite *et al.* 2022). Previous studies have highlighted the potential of methane for global warming and argued that agriculture and livestock farming contribute to methane emissions (Le Mer and Roger 2001; Liu *et al.* 2021; Smith *et al.* 2021; Coderoni *et al*. 2024). Research on methane emissions from cattle farms is currently a hotspot in environmental sciences research, where the total sum of publications is 8,998 in the years 1999-2023. Cattle farming research on greenhouse gas emissions, mainly focusing on methane emissions, has been one of the prime topics among scientists in the last decades. Annual publications have raised (65-1041) from 1999 to 2022. This continuously increasing sum of published research manuscripts directly represents a growth of research trends, indicating that more scientists have taken a keen interest in this research arena. A total of 129 countries have contributed with their published manuscripts in the MECF research field. The USA, China, and the UK emerged as the leading countries.

On the other hand, these findings contradict other studies where China and India appeared as leading countries due to the maximum number of published manuscripts on climate change and paddy research (Ali *et al*. 2022). It is important to note that the USA, China, and the UK contribute significantly to studying climate change using bibliometrics approaches (Aleixandre-Tudo *et al.* 2021; Hou and Wang 2021). In China, livestock is the second largest source attributed to methane emissions (Peng *et al.* 2016); the most plausible explanation for a spike in methane emissions is to meet the challenges of fulfilling the nationwide consumption requirements of meat and milk (Yang 2013). Several factors contribute to increased methane emissions in livestock, such as population, livestock productivity improvement, and international trade increase/raise methane emissions (Zhang *et al.* 2022). Research on methane emissions requires interdisciplinary and multidisciplinary approaches to study methane fluxes. Nascent development in scientific tools has paved the way to fathom methane emissions at a local scale (Shaw *et al.* 2021). Research fields/domains, including environmental sciences, agriculture, dairy science, animal science, metrology, atmospheric sciences, geosciences, environmental engineering, ecology, microbiology, ecosystems, bioresource technology, and biochemistry, complement each other to provide a broad understanding of methane emissions at a regional and global scale. The evolution of the keywords over the study period revealed that MECF research contributes to agricultural methane, methane emissions, greenhouse gas, cattle, and climate change. These findings showed a slight difference between the findings of Wang et al. (2013) on anaerobic digestion of methane, where anaerobic digestion, biogas and methane appeared with significant margins from 1994-2011 (Wang *et al.* 2013). Our thematic analysis also validates the conclusions of Wang et al. (2013). Some environmental, agricultural, and livestock research hotspots related to the MECF are considered imperative for structuring this field, such as carbon dioxide, methane, dairy cattle, cattle, and risk factors, and almost in the past decade, these hotspots focused on cattle, methane, climate change

and prevalence. These hotspots (emerging, persistent, and diminishing) are closely centered around MECF research perspectives.

The research manuscripts related to the MECF research arena are published mainly in professional scientific journals, such as “Science of the Total Environment,” “Biogeosciences,” “Global Change Biology,” and “Journal of Geophysical Research”; the current findings do not coincide with the previous results of Aleixandre-Tudo *et al*. (2021), where they found “Journal of Cleaner Production” as a leading journal, followed by “Energy Policy, Agriculture Ecosystems & Environment,” and “Environmental Science Technology” respectively (Aleixandre-Tudo *et al.* 2021). According to another study, “Waste Management” emerged as the leading source, followed by “Journal of Cleaner Production” and “Waste Management Research” (Zhang *et al.* 2019). Conversely, “Agriculture, Ecosystems, and Environment Nutrient Cycling in Agroecosystems” and “Science of the Total Environment” were the leading sources for publishing scientific research manuscripts (Sossa *et al.* 2022). These findings illustrate that the scientific research of MECF appears to be an interdisciplinary research field. Our study unveiled that the Chinese Academy of Sciences (CAS) ranked on top as the most productive research institution/organization for MECF research, followed by Agriculture & Agri-Food Canada and the University of Colorado. These findings were similar to previous research in which the Chinese Academy of Sciences (CAS) led the specific research domain (Zhang *et al.* 2021; Xu and Xiao 2022).

The present study assessed research productivity in the field of MECF at the global level. However, there are some limitations in the current research. We focused on the core collection and did not consider other databases. Incorporating databases such as Scopus and Google Scholar could render a broader picture of research progress in any field (Haunschild et al., 2016; Zaib et al., 2022). In addition to this, articles and reviews were included in our work. A newly emerging trend, i.e., the contribution of gender (gender analysis) to scientific work, was not considered. Gender analysis was not conducted to study females’ global contribution to the MECF research. Future work in these domains may provide a thorough, comparative, and cumulative aspect of the MECF literature available on these databases. Nonetheless, we deciphered methane emissions in livestock through bibliometric tools to provide an overview of the contribution of methane to climate change.

5. Conclusion and implications

This study provides a detailed systematic bibliometric overview of methane emission in cattle farms, with an overview by quantifying and thorough insights into previous, current, and forthcoming research trends in the given field, and helps researchers to comprehend and trace out current research progress on MECF and aid in understanding research interest among scientists and policymakers globally. The keyword analysis of the related published manuscripts illustrates the importance of the topic and the latest emerging discussions. In the past decades, the continuous

rise in the sum of publications has been proliferating in the field of MECF, verifying that this research arena has attracted the attention and curiosity of researchers worldwide. Most of these studies were devoted to environmental sciences, agriculture, dairy science, and animal science, and journals such as Science of the Total Environment, Biogeosciences, Global Change Biology, and Journal of Geophysical Research were the substantive sources/journals. The United States and the Chinese Academy of Sciences (CAS) contributed the maximum number of articles. The US substantially impacts as a leading country, whereas China maintains the closest ties with countries worldwide.

In the current work, emphasis was paid to deciphering methane emissions through bibliometrics; our findings may pave a basis for understanding research trends and themes in methane emissions in cattle farms. Scientific literature suggests technological methods coupled with farmers' education level, behavior and social factors (socio-spectrum) play a central role in climate change and policy related to methane emissions (Wang *et al*. 2023; Coderoni *et al*., 2024).

Future research should concentrate more on the innovation of diverse MECF research to cope with methane emissions, explore agronomically and dairy, minimize methane emissions or recycling mechanisms of dairy and cattle by-products, and contribute more to the environmental and economic benefits. We suggest reducing methane emissions in cattle farms by changing feed quantity, quality, and gut microflora alterations. Our findings have implications for highlighting methane emissions in cattle farms via a bibliometric method. Researchers may conduct studies on beef or dairy farms to point out the contribution of methane emissions of a specific type of farm. Prospective investigations may include methane emissions characteristics of breed types. The application of scientific discoveries and technological advances can effectively mitigate global carbon/methane emissions. Using data analysis, machine learning, drones, satellites, etc., we can effectively monitor and understand carbon and methane emissions. Renewable energy and carbon/methane emissions reduction technologies are essential to ensure a sustainable future. Public-private cooperation and support policies are needed to achieve the adoption of low-carbon technology and innovation. Academics, industry, and governments must cooperate to combat climate change by sharing technologies and data.

Declaration of competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

Ming Xu was supported by the Special Fund for Science and Technology Innovation Strategy of Guangdong Province, China under Grant No. 2022660500250009604.

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Figure Legends

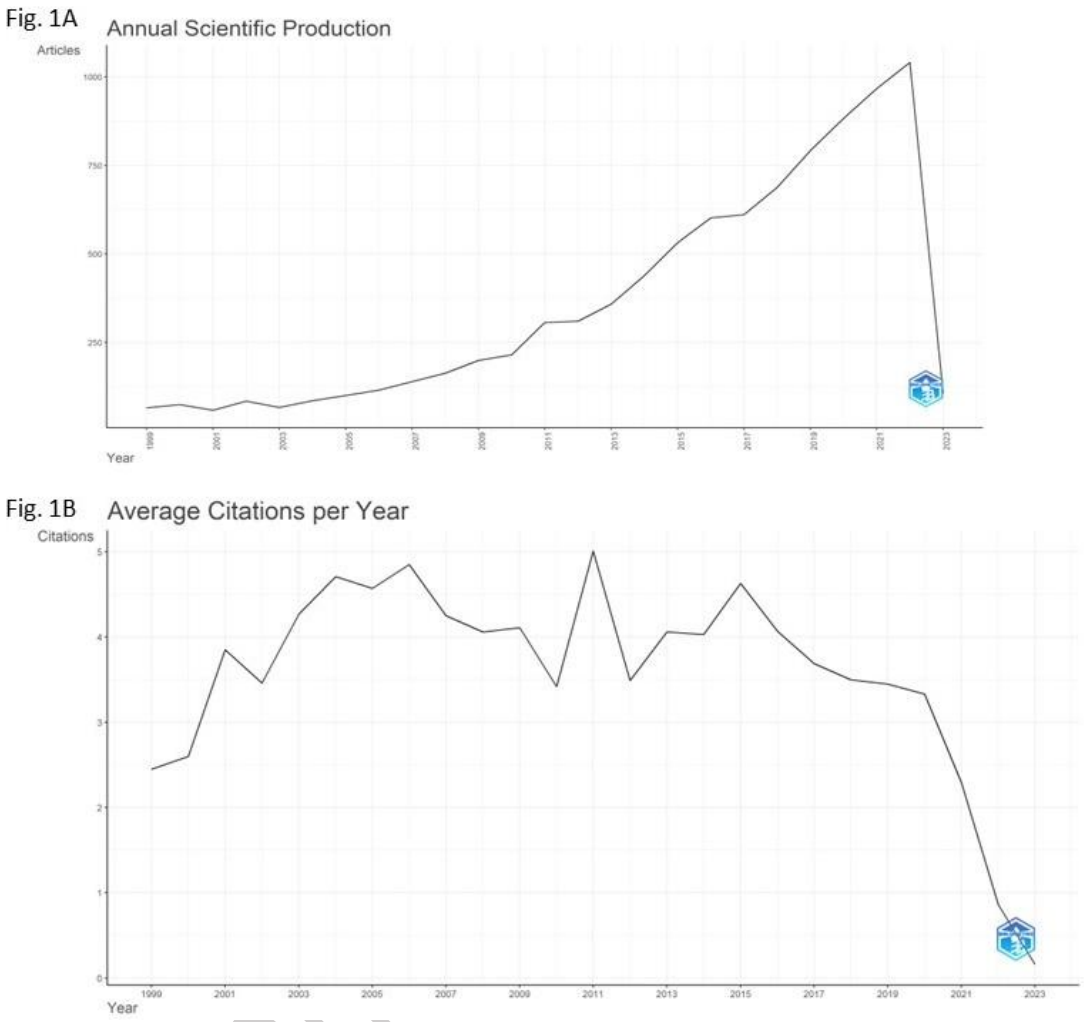

Fig. 1 Overall MECF research. A, The trend of annual scientific production in Methane emission in cattle farms from 1999-2023. B, Average per year manuscript citation in Methane emission in cattle farms from 1999-2023.

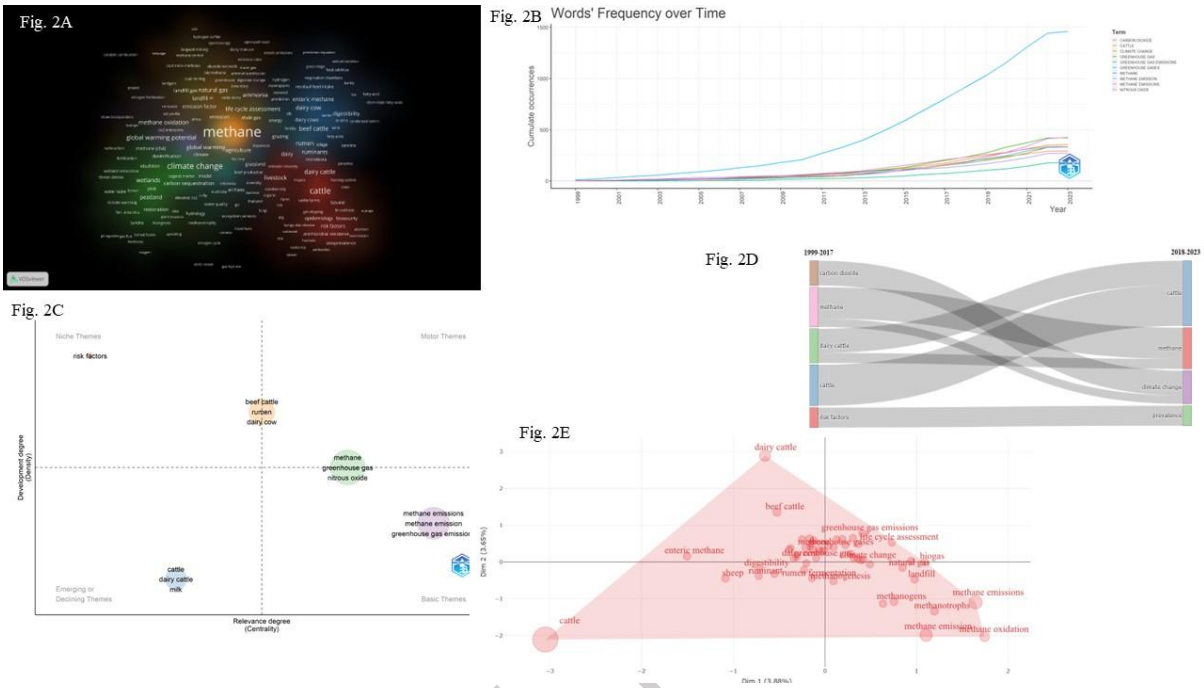

Fig. 2 Research themes and trend evaluation based on author-provided keyword analysis. A, Cluster density visualization of Co-occurrence of author-provided keywords analysis. B, Author-provided keywords frequency over time. C, Thematic mapping of various themes in MECF. D, Thematic evolution of research themes. E, Co-word factorial analysis in MECF

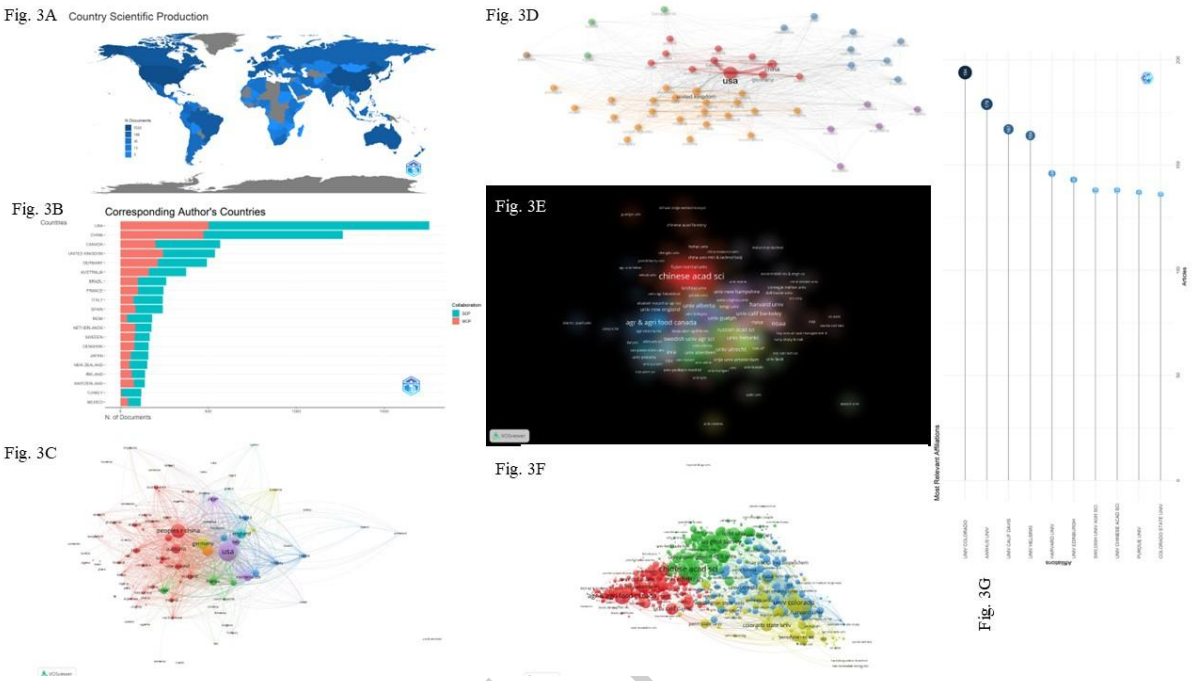

Fig. 3 Prolific countries and international research organizations were contributing to MECF research. A, World map indicating prolific countries contributing to MECF research. B, corresponding author's country analysis. C, Network mapping of citation analysis of countries. D, Collaboration network analysis of countries. E, Cluster density plot of co-authorship analysis of research organizations. F, Network mapping of citation analysis of international research organizations. G, The most relevant research organizations published scientific literature in MECF.

Fig. 4A

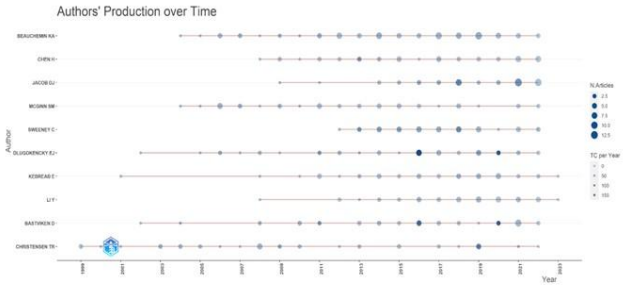

Fig. 4B

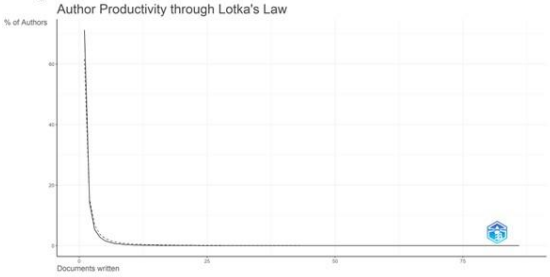

Fig. 4C

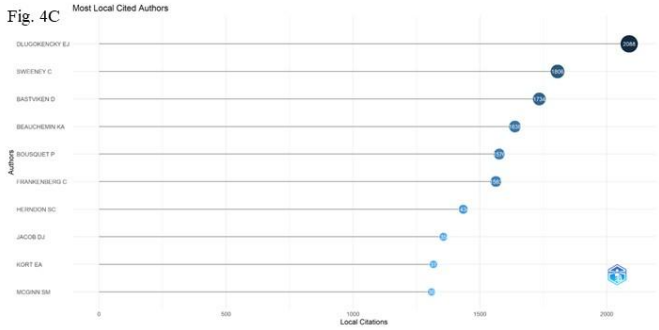

Fig. 4D

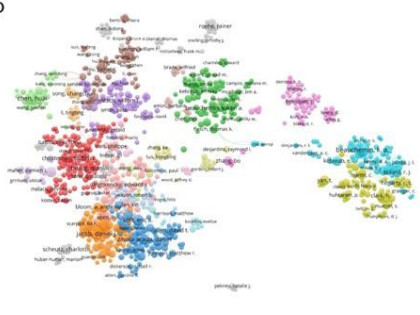

Fig. 4 Author analysis in the field of methane emission in cattle farms. A, Author's production over time. B, Lotka's law. C, Most locally cited authors. D, Network visualization mapping of co-authorship analysis of authors

Fig. 5A

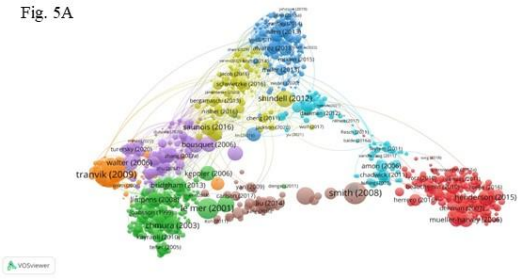

Fig. 5B

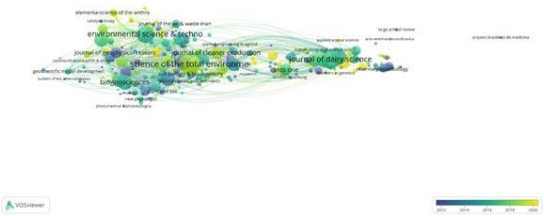

Fig. 5C

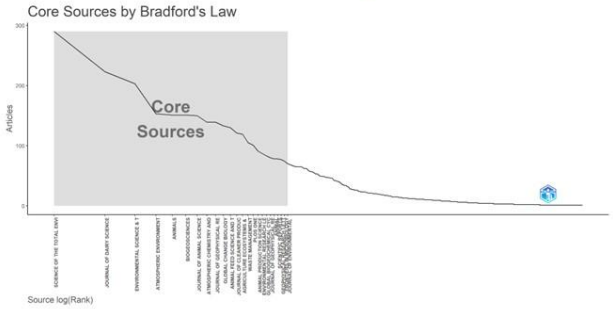

Fig. 5 Prolific publications and source analysis in the field of methane emission in cattle farms. A, Network visualization of citation analysis of prolific publications. B, Network mapping of overlay visualization of leading journals/sources. C, Mapping of leading sources according to Bradford's Law

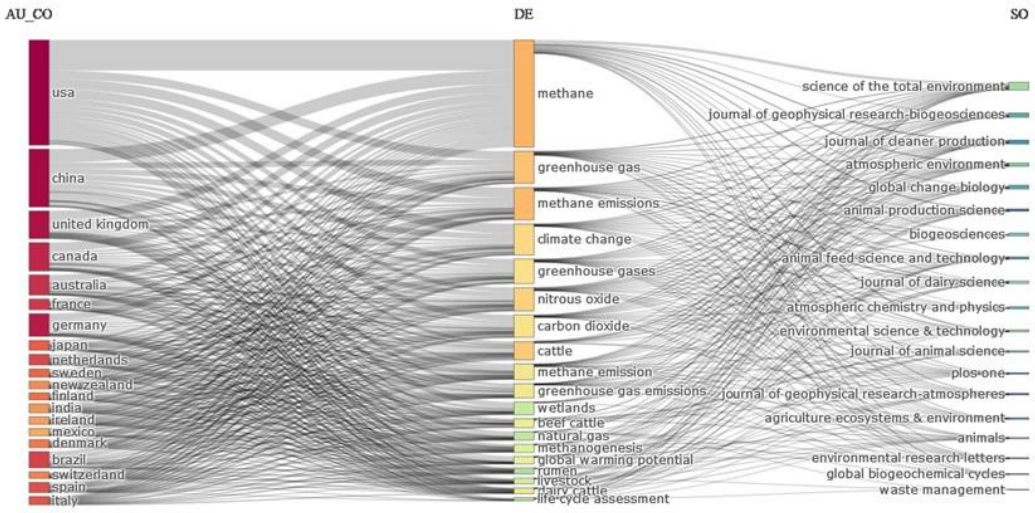

Fig. 6 Three-factor analysis visualization of MECF research