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NAVIGATING SUSTAINABILITY: A BIBLIOMETRIC ANALYSIS OF CARBON MANAGEMENT ACCOUNTING

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ABSTRACT

In the era of increasing concerns over climate change and sustainable development, Carbon Management Accounting (CMA) research gains paramount attention. Previous studies focused on specific aspects of carbon accounting, leaving a gap in comprehensive exploration of CMA's holistic approach to sustainability challenges. This study aims to provide a comprehensive overview of the current state of CMA research and its implications for sustainability efforts. Bibliometric and network analyses, utilizing Harzing's Publish or Perish (PoP) and VOSviewer (VOS) software, 200 Scopus-indexed documents from 2013 to 2022 were examined. Performance analysis, citation analysis, journal analysis, and network analysis were employed to examine the field from research practice and system perspectives. From a practice-perspective, the analysis reveals CMA research as an "advancement," depicting progressive, impactful, and dynamism within the field. The system-perspective displays a “transformative” role characterized by prominence, synergy, and integration. Popular themes among researchers and countries include keywords like "carbon," "carbon accounting," "environmental policy," and "climate change." A significant gap between sustainability development and the carbon accounting model in CMA is identified, emphasizing the need for further integrated research. This study is pivotal for practitioners, policymakers, and researchers, aiding sustainability efforts and addressing global climate change.

Keywords: Carbon management accounting, bibliometric analysis, network analysis, carbon accounting model, sustainability development.

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1. INTRODUCTION

Sustainability is urgent for businesses and society, demanding immediate efforts to reduce carbon emissions and tackle climate change. Scholars have extensively focused various aspects of carbon emissions, including measurement, influencing factors, economic implications, and reduction strategies (Ma & Song, 2022). In recent years, carbon accounting research has become closely intertwined with environmental issues, garnering considerable attention from researchers aiming to achieve sustainable development goals (Kuriawan et al., 2022). Notably, Zheng et al. (2022), Kuriawan et al. (2022), and Rodrigues et al. (2021) conducted bibliometric analysis carbon accounting research in the social sciences. Zheng et al. (2022) explored the trends and features of carbon accounting research, focusing on the impact of international trade on responsibility allocation from a consumption perspective. Kuriawan et al. (2022) mapped carbon accounting research articles and projected a surge in future publications, with particular emphasis on 'emissions' and 'study' themes. Rodrigues et al. (2021) examined the evolution of information in social accounting, underscoring its relevance to sustainable development and its role in addressing challenges posed by climate change and carbon emissions. Collectively, these studies contribute to the comprehension of carbon accounting literature, its progression, and its implications for sustainability and addressing climate change concerns.

Although the aforementioned studies have provided valuable insights in specific areas, there is currently no comprehensive review that summarizes research trends and identifies emerging areas in CMA. Previous studies have taken a piecemeal approach, focusing on specific aspects of carbon accounting, leaving a gap in the holistic exploration of CMA from a sustainability perspective. This gap includes addressing challenges such as reducing greenhouse gas emissions, promoting sustainable resource management, assessing environmental impacts, integrating sustainability into financial decision-making, and supporting corporate sustainability reporting. Amid the increasing emphasis on sustainability, organizations are empowered to control greenhouse gas emissions through the adoption of carbon management practices, which serve as additional approaches (Suzuki et al., 2022). Various measures, including the deployment of carbon capture and storage technologies, offset procurement, and investments in renewable energy sources, have been implemented to pursue emission reduction (Warzywoda et al., 2022). CMA not only plays a crucial role in carbon emission mitigation but also enhances resource efficiency, stimulates innovation, and fosters sustainable development within organizations (Ong et al., 2021). Therefore, there is a need for a comprehensive review of CMA that encompasses various aspects and addresses the broader sustainability challenges. This review would enhance our understanding of the field, offer insights for future research and practice.

This study uniquely bridges a research gap and offers two significant contributions to the CMA literature. Firstly, it adopts a holistic perspective by integrating research practice and system perspectives, which effectively bridges the divide between sustainability development and carbon management models. Secondly, the study distinguishes itself by employing the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) methodology for a comprehensive analysis of selected publications, significantly enhancing the reliability and accuracy of the findings. Through these contributions, the study aims to provide a current map that visualizes and clusters a decade of Scopus datasets related to CMA research from 2013 to 2022, offering a valuable resource for researchers, practitioners, and policymakers to navigate and understand the

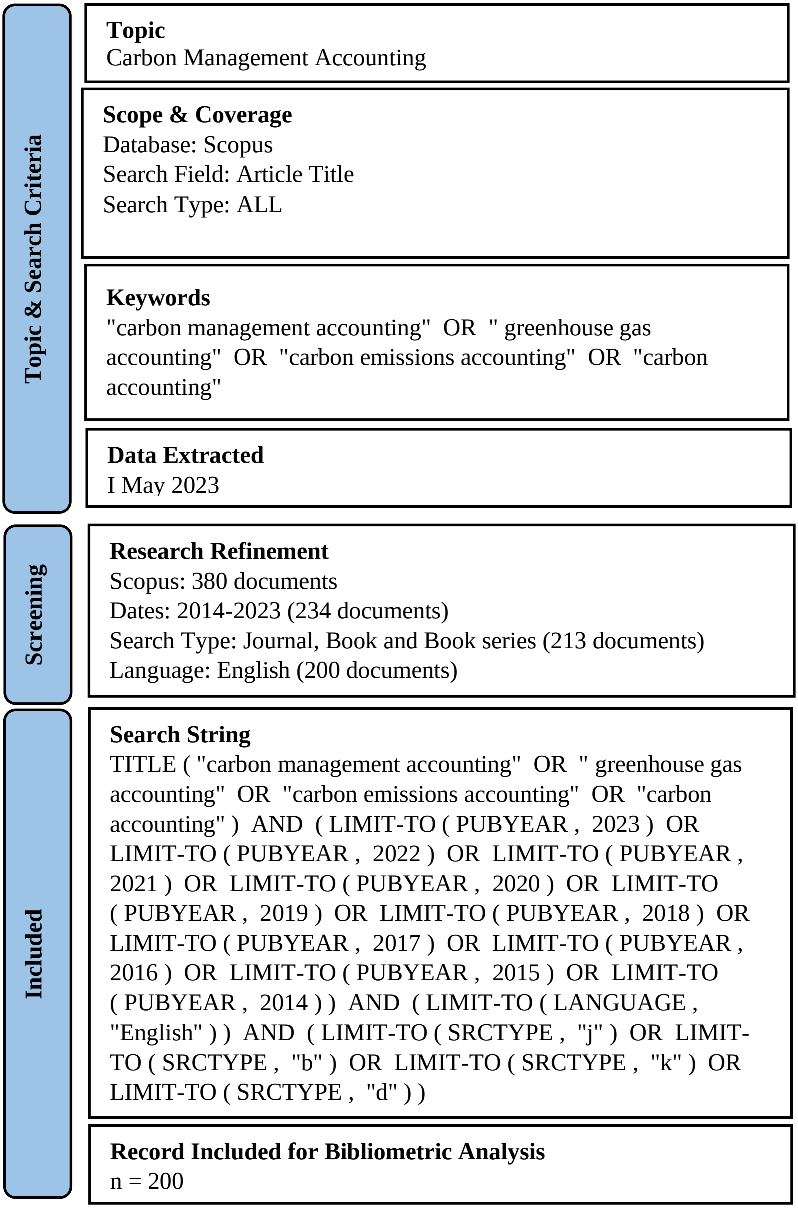
evolving landscape of carbon management in the context of sustainability. Thus, bibliometric and network analyses are needed for mapping and clustering the important information as an effective tool to conduct a quantitative analysis to gain a deeper understanding of the literature (Alsmadi & Alzoubi, 2022). The use of graphical representations in bibliometric analyses has grown in importance (Firmansyah & Rusydiana, 2021) due to their ability to present complex data patterns and relationships in a more accessible and intuitive manner. Building upon these contributions, the present study aims to address the following research questions:
RQ1: What is the impact of the growth rate on CMA research from a practice-perspective?
RQ2: What is the influence of citation counts on CMA research from a practice-perspective?
RQ3: What are the effects of journal visibility on CMA research from a practice-perspective?
RQ4: What is the role of network interconnection in influencing CMA research from a system-perspective?
RQ5: What are the future research directions in CMA research?

The remainder of this article is structured as follows. The next section introduces the methodology to address these research questions. Subsequently, a detailed presentation of the results and a discussion of the findings using various bibliometric tools will be provided. The article concludes with an examination of its limitations and offers future research directions in the field of CMA.

2. METHODOLOGY

This study employs bibliometric analysis, along with other valuable tools, to quantitatively assess past and present research activities in the field of CMA. The Scopus database (https://www.scopus.com) was chosen as the primary research platform due to its comprehensive coverage of academic publications and continuous expansion and updating, making it one of the largest searchable abstract and citation databases available (Rew, 2010; Wahid et al., 2020). The PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) methodology for data retrieval as shown in Figure 1. The process involves three stages: (1) The search criteria stage where relevant keywords are defined, resulting in 385 documents. (2) The screening stage sets a coverage period from 2013 to 2022, reducing the selection to 239 documents. (3) The filtration stage involves additional filtration based on publication stage, search type, and language, leading to 200 documents for bibliometric analysis. To conduct the bibliometric analysis, the filtered document data is exported and saved as an Excel file using Microsoft Excel (Office 365 A1 Plus). Additionally, the data is saved in RIS and CSV formats for further analysis. The RIS format is utilized for analysing academic citations, including citation metrics, number of papers, total citations, h-index, g-index, etc., using Harzing's Publish or Perish software (https://harzing.com/resources/publish-or-perish/os-x). The CSV files are used with the VOSviewer visualization software (https://www.vosviewer.com/download) which enables network analysis and data visualization mapping. VOSviewer is specifically chosen due to its capability to handle large bibliometric maps and provide easy-to-interpret visualizations, developed by Van Eck and Waltman (2009).

Figure 1: PRISMA flow chart of the search strategy



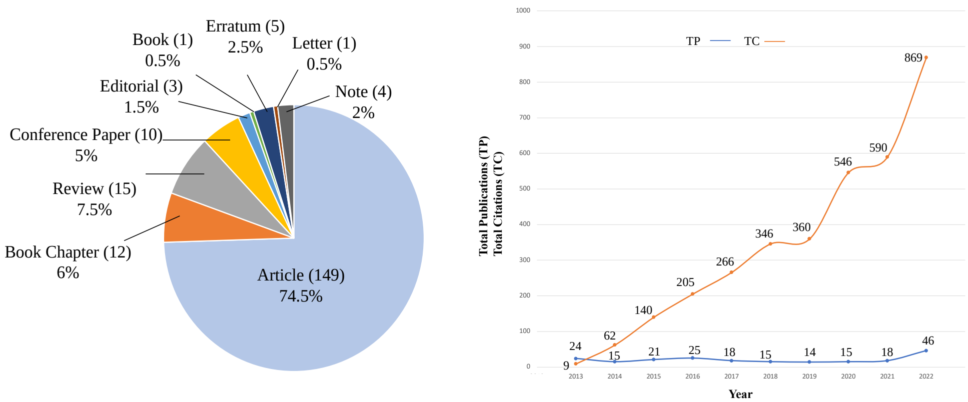
3. RESULTS

This bibliometric analysis study encompasses two perspectives: research-practice and system-perspectives. The research practice-perspective includes performance analysis, citation analysis, and journal analysis, while the system-perspective examines co-occurrence of keywords, and co-authorship patterns by authors and countries.

3.1. Performance analysis

Performance analysis in this study analyzes document source types and publication growth, to analyse on the research practice-perspective of CMA from 2013 to 2022. The document source types play a crucial role in understanding how CMA research is disseminated, encompassing categories such as research articles, conference papers, reviews, and other scholarly outputs. Figure 2(a) demonstrates that journal articles dominate as the primary medium for disseminating CMA research (74.50%), followed by book chapters (6.00%), reviews (7.50%), conference papers (5.00%), and others (4.50%) comprises editorials, books, errata, notes, letters, and retracted documents.

Figure 2: Document source type and publication growth



(a) Document Source Types

(b) Total Publications and Total Citations

The tracking of publication growth indicates quantitative snapshot of the trends in CMA-related publications and citations. Figure 2(b) displays the temporal pattern of CMA-related total publications (TP) and total citations (TC). The blue line graph shows TP's gradual increase from 24 in 2013 to a peak of 46 in 2022, while the orange line graph depicts TC's rise from 9 in 2013 to a significant peak of 590 in 2022, indicating substantial citation activity. Based on the provided information, the annual growth of TP and TC related to CMA for the past 10 years were calculated as follows:

TP Annual Growth Rate = ((Ending Value / Starting Value)^(1/Number of Years)) – 1
= ((46 / 24)^(1/10)) – 1
= (1.9167)^(1/10) – 1 ≈ 0.0672
TC Annual Growth Rate = ((869 / 9)^(1/10)) – 1
= (96.5556)^(1/10) – 1 ≈ 0.5793

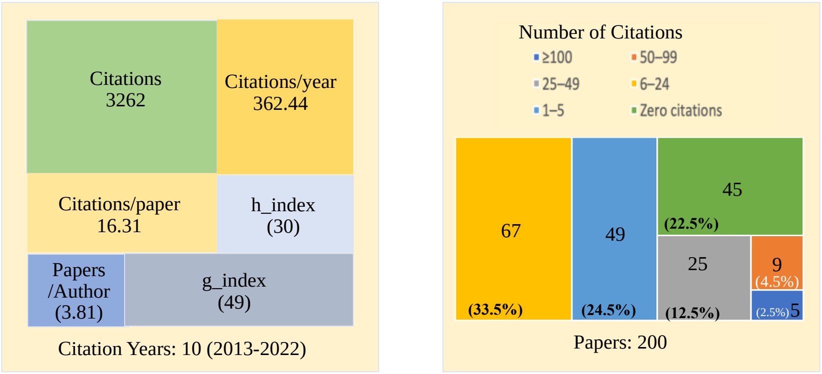
where,"10" as the exponent is because the growth rate is calculated over a span of 10 years (from 2013 to 2022). The trend analysis indicates an annual growth rate of approximately 6.72% for publications and 57.93% for citations over the same period. The positive growth rate for both publications and citations indicate demonstrates a growing interest and research activity in the field of CMA during the study period (Ahmi & Mohammad, 2019).

To answer RQ1, the impact of the growth rate on CMA research from a practice-perspective can be described as progressive. High-caliber articles contribute to enhancing the quality and quantity of relevant research (Su & Chang, 2022). The growing interest in CMA research signifies its growing relevance and impact, which benefits practitioners and strengthens the CMA community. Fostering a broader professional CMA community can enhance collective efforts in strengthening and enhancing the robustness of CMA practices (Kazemian et al., 2022). The rising number of publications and citations also suggests a growing body of evidence and insights for practitioners to adopt effective carbon management strategies and practices. Therefore, there are opportunities for future research and practical advancements in specific decision scenarios.

3.2. Citation Analysis

The citation analysis in this study analyzes the citation metrics, citation structures, highly cited articles, and most active source type, to analyse on the research practice-perspective of CMA from 2013 to 2022. Citation metrics demonstrate the impact and visibility of scholarly articles by analysing the frequency of their citation in other research publications. In Figure 3(a), this study comprises 200 papers published over 10 years with 3262 citations. The average citations per year are 362.44, indicating ongoing relevance and impact. Each paper has an average of 16.31 citations, indicating substantial individual impact. On average number, each author has contributed to 3.81 papers. The h-index of 30 suggests at least 30 highly impactful papers, while the g-index of 49 at least 49 papers with significant citations. Citation structures involve the distribution of the number of articles and their corresponding number of citations in the field (Zupic & Cˇater, 2015; Jiménez-García et al., 2020). In Figure 3(b), 2.50% (5 articles) have received 100 or more citations, indicating high influence; 4.50% (9 articles) received between 50 and 99 citations, showing moderate impact; 12.50% (25 articles) received between 25 and 49 citations, suggesting relatively high impact; 33.50% (67 articles) received between 6 and 24 citations, indicating a moderate level of impact; 24.50% (49 articles) received 1 to 5 citations, signifying low impact but valuable contributions; and 22.50% (45 articles) have not received any citations yet, possibly due to their recent publication. Hence, the citation structures demonstrate most articles have received 24 or fewer citations, while fewer have received 50 or more citations.

Figure 3: Publication Years: 2013–2022 (a) Citations metrics (b) Citations structures



(a) Citation Metrics (b) Citation Structures

Table 1 presents the findings a list of top 10 highly cited articles. While Kander et al. (2015) and Rossel et al. (2014) have similar total citations (176), Kander et al. have a higher citations-per-year average (20) compared to Rossel et al. (18). However, Butman et al. and Wei et al. (2020) ranked third and ninth but have similar citations-per-year as Kander et al. and Rossel et al. This indicates that an article's influence is not solely determined by the total number of citations but also by the rate of citation accumulation over time. The list includes several articles that focus on specific aspects of carbon accounting, such as the burning of forest bioenergy (Ter-Mikaelian et al., 2015; Miner et al., 2014), calcium carbonate cycling (Macreadie et al., 2017), and biofuels-induced land use change (Plevin et al., 2015). This suggests the complexity of the CMA field, requiring specialized knowledge and ongoing research. The most recent article in the list, entitled "Multi-scope electricity-related carbon emissions accounting: A case study of Shanghai" by Wei et al. (2020), demonstrates that carbon accounting and management remains an active area of research.

Table 1: Top 10 Most Cited Articles

Authors (Year)	Title	Citations	Citations /Year	Authors (Year)
Kander et al. (2015)	National greenhouse-gas accounting for effective climate policy on international trade	176	20	Kander et al. (2015)
Rossel et al. (2014)	Baseline map of organic carbon in Australian soil to support national carbon accounting and monitoring under climate change	176	18	Rossel et al. (2014)
Butman et al. (2016)	Aquatic carbon cycling in the conterminous United States and implications for terrestrial carbon accounting	163	20	Butman et al. (2016)
Afionis et al. (2017)	Consumption-based carbon accounting: does it have a future?	132	19	Afionis et al. (2017)
Steininger et al. (2016)	Multiple carbon accounting to support just and effective climate policies	123	15	Steininger et al. (2016)
Ter-Mikaelian et al. (2015)	The burning question: Does Forest bioenergy reduce carbon emissions? A review of common misconceptions about forest carbon accounting	90	10	Ter-Mikaelian et al. (2015)
Macreadie et al. (2017)	Addressing calcium carbonate cycling in blue carbon accounting	81	12	Macreadie et al. (2017)
Plevin et al. (2015)	Carbon accounting and economic model uncertainty of emissions from biofuels-induced land use change	78	9	Plevin et al. (2015)
Wei et al. (2020)	Multi-scope electricity-related carbon emissions accounting: A case study of Shanghai	72	18	Wei et al. (2020)

Accordingly, Table 2 presents the findings a list of the top 10 most active source. Based on the information, the Journal of Cleaner Production published by Elsevier has the highest number of TP (12) and the highest percentage of TP (6.0%). It also boasts the highest CiteScore of 15.8, signifying frequent citations of its articles in another research. Additionally, Science of the Total Environment, also published by Elsevier, holds the highest SJR 2021 score of 14.1 and the highest SNIP 2021 score of 2.175, indicating its articles' high influence and significant impact in the field. Notably, the Journal of Industrial Ecology published by Wiley has a high CiteScore of 12, and the Journal of Environmental Management published by Elsevier has a high SJR 2021 score of 11.4. These scores suggest that the journals on this list are well-regarded and influential in the field of environmental science, particularly in areas related to sustainability, accounting, and policy.

Table 2: Top 10 Most Active Source

Source Title	Publisher	TP	%	Cite Score	SJR 2021	SNIP 2021
Journal of Cleaner Production	Elsevier	12	6.0 %	15.8	1.921	2.444
Journal of Forestry	Society of American Foresters	5	2.5%	3.7	0.663	1.033
Sustainability Accounting Management and Policy Journal	Emerald	5	2.5%	4.8	0.748	1.063
Environmental Science and Policy	Elsevier	4	2%	10	1.683	1.916
Journal of Industrial Ecology	Wiley	4	2%	12	1.733	1.803
Science of the Total Environment	Elsevier	4	2%	14.1	1.806	2.175
Agriculture Ecosystems and Environment	Elsevier	3	1.5%	10.3	1.664	2.013
Journal of Environmental Management	Elsevier	3	1.5%	11.4	1.481	1.907
Environmental Science and Pollution Research	Springer	3	1.5%	6.6	0.831	1.154
Carbon Management	Taylor & Francis	2	1.0%	4.8	0.575	0.886

To answer RQ2, the influence of citation counts on CMA research from a practice- perspective can be described as impactful. The citation metrics demonstrate continuous recognition, high average citations per paper, and the existence of highly cited papers, indicating substantial contributions of CMA research to the field of science (Uysal et al., 2021). The impactful citation analysis emphasises a highly influential article in CMA might propose a new method for assessing and reporting carbon emissions across the supply chain, leading to improved environmental performance and cost savings for companies (Fok & Morgan, 2022). The citation structures show a range of impact on CMA practice, from highly influential to relatively low impact articles. Highly influential and moderately impactful articles serve as a basis for advancing CMA theory and practice, while also promoting visibility and collaboration among researchers. It becomes a reference point for other researchers, practitioners, and organizations to evaluate and monitor environmental performance enables comparison among similar companies, promoting competition and continual improvement in a positive direction aligned with sustainable development policies (Chalak et al., 2020). Companies that adopt the strategies outlined in the article may experience improved environmental performance, cost savings through energy efficiency measures, enhanced stakeholder engagement, and reputation benefits (Farza et al., 2021; Sijing, 2022). The highly cited articles provide insights into the timeliness and ongoing relevance of CMA research, while the most active source analysis showcases reputable journals that significantly contribute to CMA research, shaping its direction and quality. However, limitations on data reliability may affect the effectiveness of analytical methods in assessing corporate carbon management (Tóth & Suta, 2021). Therefore, policymakers should recognize the significance of CMA and consider establishing guidelines or standards to enhance its practice (Kazemian et al., 2022; Rasheed et al., 2022). By establishing clear frameworks, policymakers can promote consistency, comparability, and effectiveness in CMA, ultimately driving improved environmental performance and sustainability outcomes.

3.3. Journal Analysis

The journal analysis in this study analyzes geographical and funding agency distribution pattern, to analyse on the research practice-perspective of CMA from 2013 to 2022. Geographical distribution analysis identifies strengths and collaboration opportunities in research, while funding agency distribution analysis reveals available financial support for CMA research.

Table 3: Top 10 Country Productivity

Country	Total Publication	%	Continent
China	42	21.00%	Asia
United States	37	18.50%	North America
Australia	33	16.50%	Oceania
United Kingdom	22	11.00%	Europe
Germany	15	7.50%	Europe
Canada	13	6.50%	North America
France	11	5.50%	Europe
Italy	9	4.50%	Europe
Spain	9	4.50%	Europe
Malaysia	8	4.00%	Asia

Table 3 presents the top 10 countries with the highest contributions to CMA publications. Europe has the highest country productivity among the mentioned continents, followed by Asia and North America, while Oceania has the lowest productivity. The higher number of publications from Europe suggests a higher emphasis on research and development in that region. Similarly, the relatively lower number of publications from Oceania suggests a lower emphasis on research in that region. This information also indicates the areas of strength or focus for each continent. For example, Asia's higher number of publications aligns with its strong technology and engineering industries, while North America's publication numbers reflect its emphasis on scientific research and development.

Table 4: Funding Agency Distribution of Publications.

Funding Agencies	Number of Articles	%
National Natural Science Foundation of China	16	8.00%
Australian Research Council	9	4.50%
Economic and Social Research Council	6	3.00%
Natural Sciences and Engineering Research Council of Canada	6	3.00%
Engineering and Physical Sciences Research Council	4	2.00%
European Commission	4	2.00%
National Science Foundation	4	2.00%
China Postdoctoral Science Foundation	3	1.50%
Research Councils UK	3	1.50%
U.S. Department of Agriculture	3	1.50%
Others	142	71.00%
Total Articles	200	100%

Table 4 presents the distribution pattern of funding agencies for 200 articles. The results reveal a wide variety of funding sources, with no agency heavily funding most articles. The National

Natural Science Foundation of China sponsored the most articles (16 or 8%), followed by the Australian Research Council (9 or 4.5%), the Economic and Social Research Council, and the Natural Sciences and Engineering Research Council of Canada (6 each or 3%). Several other agencies funded 2% or 1.5% of the articles. Overall, the analysis highlights a diverse funding landscape without one agency dominating the funding allocation.

To answer RQ3, the impact of journal visibility on CMA research is dynamic from a research practice perspective. Europe's higher number of publications and diverse funding sources indicate a productive and impactful research environment, emphasizing the importance of international collaboration and financial support for advancing CMA research. For example, the European Commission's funding enables in-depth studies on carbon management practices, leading to effective strategies. International collaboration fosters a comprehensive understanding of the field (Kim et al., 2021; Bashir et al., 2021). A China-Australia research collaboration develops innovative carbon accounting methodologies for multinational corporations, enhancing the practical relevance of CMA research by addressing real-world complexities.

Overall, from a practice-perspective, the findings of performance, citation, and journal analyses reveal the current state of CMA research as an "advancement". This word encapsulates the notions of progressive (RQ1), impactful (RQ2), and dynamism (RQ3) observed in the field. In the sustainability context, it reflects the continuous evolution and positive trajectory of CMA research towards achieving more sustainable goals and addressing environmental, social, and economic challenges.

3.4. Network Analysis

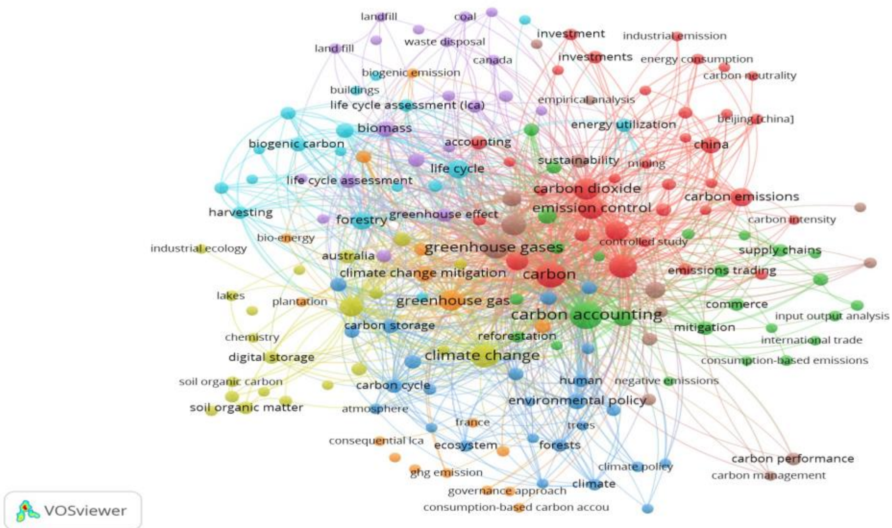
The network analysis in this study focuses on co-occurrence keywords and co-authorship by authors and countries, to analyse on the research system-perspective of CMA from 2013 to 2022.

3.4.1. Co-occurrence **network** *of keywords*

The co-occurrence keyword network map highlights the frequent associations and relationships between specific topics or concepts in scholarly research within the field of CMA. By using VoSviewer, a visualization map was generated, depicting the relationships between 1,639 keywords from publications spanning the years 2013 to 2022. Out of these keywords, 175 met the threshold requirement of at least three occurrences.

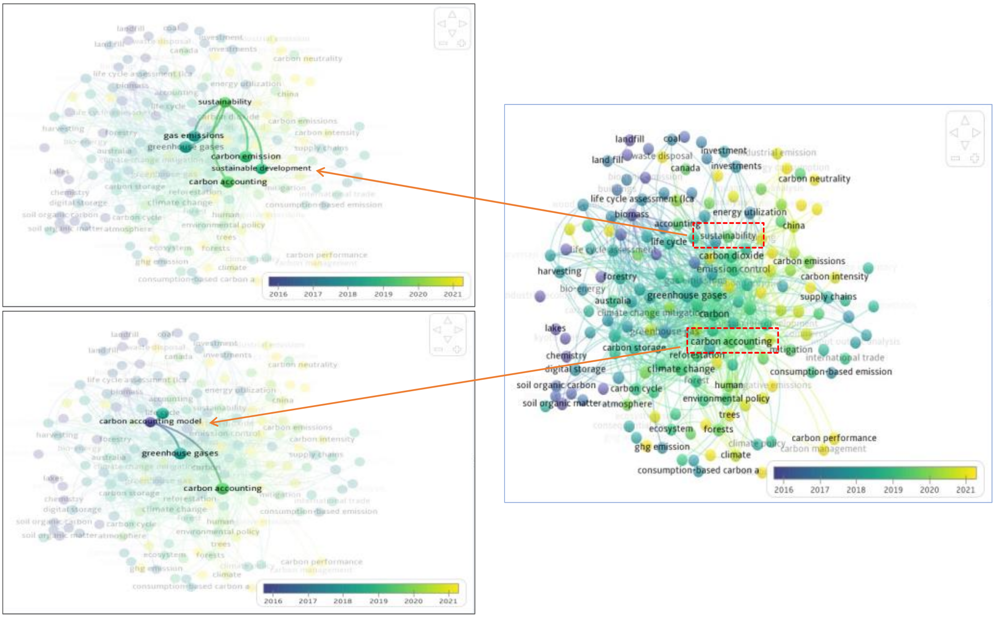
Figure 4 displays a co-occurrence network map with eight distinct clusters, each represented by a unique color, representing subfields within CMA. Keywords are represented by circles, sized based on their publication frequency, and their proximity indicates frequent associations in the research literature. The identified clusters and their corresponding colours include: Cluster 1 (red) focuses on "carbon" related topics such as carbon emissions, control, footprint, electricity, and china. Cluster 2 (green) centers around "carbon accounting" with environmental economics and life cycle analysis subfields. Cluster 3 (blue) pertains to "environmental policy", focus on forests, humans, carbon storage, and ecosystems. Cluster 4 (yellow) is centered on "climate change", with carbon sequestration subfield. Cluster 5 (purple) revolves around "biomass", including greenhouse effect and land use subfields. Cluster 6 (turquoise) highlights the "life cycle" perspective, specifically in forestry and wood. Cluster 7 (orange) focuses on "greenhouse gases" and their association with climate change mitigation. Cluster 8 (brown) centers around greenhouse gases, with subfields on gas emissions and sustainable development. Thus, the analysis identifies four prominent keywords (carbon, carbon accounting, environmental policy, and climate change) that indicate "prominence" areas of focus within CMA research.

Figure 4. Co-occurrence network visualization map (Keywords)



This study expands on the findings from Figure 4 by presenting an overlay visualization in Figure 5, illustrating the evolution of CMA research over time. The analysis reveals that prior to 2017, research focused on foundational topics such as biomass, greenhouse gas accounting, and soil organic matter, indicating an emphasis on establishing the groundwork and understanding the climate change effects related to CMA. During this period, the application of CMA may have been limited to these specific areas. However, from 2018 onwards, there has been a noticeable shift in the research landscape of CMA. The foundational research has expanded to include keywords such as carbon accounting, carbon emission, environmental management, and sustainable development. This broader range of keywords suggests a more comprehensive approach to CMA, incorporating not only accounting aspects but also considering environmental and sustainability dimensions. Furthermore, recent studies have extended the research scope to include keywords related to carbon performance, ecosystems, waste management, economic development, and emissions trading. This expansion indicates a growing recognition of the interconnectedness between carbon management, environmental factors, economic considerations, and policy frameworks. It reflects a more holistic approach to CMA, incorporating diverse aspects of carbon performance, ecosystem preservation, waste reduction, and economic implications.

Figure 5. Evolution of CMA based on the author keywords (Overlay Visualisation)

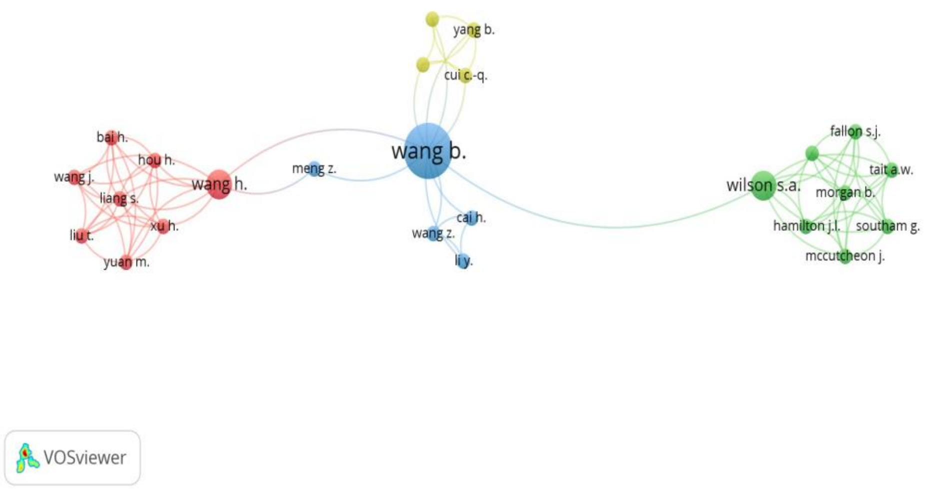


The findings of this study highlight a notable disparity between the research endeavours concerning "sustainable development" within the sustainability cluster in recent years and the "carbon accounting model" within the carbon accounting cluster in previous years. The distinction is clear: sustainability development in the CMA domain prioritizes environmentally responsible and economically viable approaches, while the primary focus of the carbon accounting model lies in the development of accurate methodologies for measuring and managing carbon emissions. The emphasis on the carbon accounting model in the early years aligns with the foundational stage of CMA research, where establishing accurate accounting models was crucial for understanding and managing carbon-related issues. The shift towards sustainability recognizes that carbon management involves more than just measurement and reporting, encompassing broader implications on environmental, social, and economic dimensions. Acknowledging this disparity, the study highlights the need for further research and exploration to bridge the gap and effectively integrate “sustainability development” with the “carbon accounting model” within the context of CMA. By doing so, researchers and practitioners can develop holistic approaches that align environmental responsibility with accurate measurement and accounting methodologies, resulting in more comprehensive sustainability frameworks. This integration can inform the development of informed policies and practices that promote both environmental and economic sustainability within CMA.

3.4.2. Co-authorship network (Authors)

The co-authorship authors’ network highlights the interdisciplinary nature of CMA research and the existence of distinct thematic clusters where authors with similar research interests collaborate and contribute to a broader understanding of environmental issues. Out of the 694 authors included in the network, 573 met the thresholds for inclusion based on the number of published articles and citations. However, the network visualization map in Figure 6 illustrates only 25 items formed 4 interconnected clusters from the largest set.

Figure 6. Co-authorship network visualization map (Authors)



These 25 authors suggest that they represent the most prominent and influential collaborations within the field of CMA. Additionally, the 4 clusters likely reflect the major research themes or areas of specialization and the strong interconnections among authors working on related topics within CMA. The lines connecting the authors represent their cooperation links, while the different colours indicate the collaboration clusters among them. These interconnected items revolve around specific themes, as illustrated in Figure 4's keywords network visualization map based on the keywords. The identified clusters and their corresponding colours include: Cluster 1 (red) focuses on "carbon" related research, studying various aspects like carbon emissions, control, footprint, and their association with factors like electricity. Cluster 2 (green) centers around "carbon accounting", measuring and analyzing carbon-related data, assessing its economic and environmental implications, and developing accounting frameworks and methodologies. Cluster 3 (blue) explores "environmental policy", examining policy frameworks, interventions, and regulatory measures related to carbon management and its environmental impact. Cluster 4 (yellow) emphasizes "climate change", investigating various aspects like causes, impacts, mitigation, and adaptation.

The visualization map reveals that authors in Cluster 1 (red) on carbon research, including Wang H., Xu Hu., Yuan M., Liu T., Liang S., Wang J., Hou H., and Bai H., likely collaborate with authors in Cluster 3 (blue) on environmental policy, such as Wang B., Wang Z., Cai H., and Li Y. Similarly, authors in Cluster 2 (green) on carbon accounting, including Wilson S.A., Hamilton J.L., McCutcheon J., Southam G., Morgan B., Tait A.W., and Fallon S.J., primarily collaborate with authors in Cluster 3 (blue) on environmental policy. Authors in Cluster 3 (blue) with a focus on environmental policy collaborate with authors in Cluster 1 (red) on carbon research and Cluster 2 (green) on carbon accounting. Authors in Cluster 4 (yellow) on climate change, specifically Cui C.Q. and Yang B., do not collaborate with any other clusters, suggesting potential opportunities for future collaboration. This is evident by the total link strength as shown in Table 6.

Table 6: Top 10 authors publishing on CMA (rank based on total link strength).

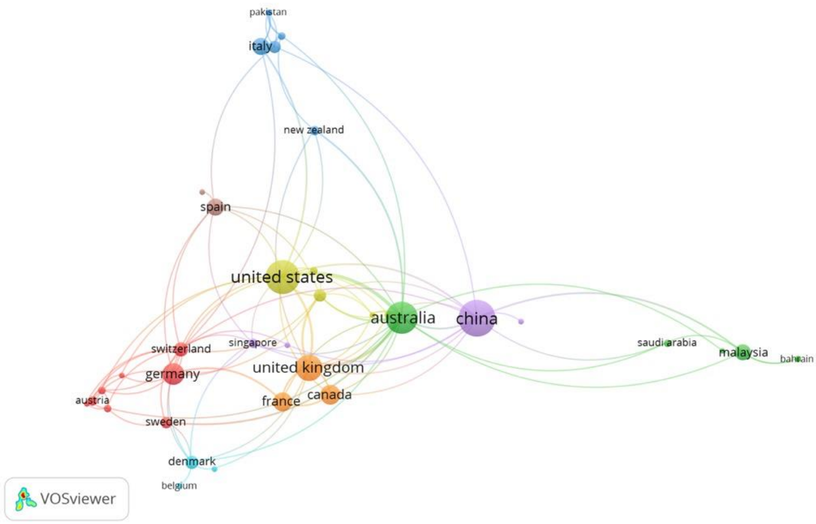
Author	Documents	Citations	Total link strength	Link	Cluster	Theme
Wang H.	2	59	9	9	1	carbon
Wilson S.A.	2	3	8	8	2	carbon accounting
Liang S.	1	33	7	7	3	environmental policy
Southam G.	1	3	7	7	2	carbon accounting
Hamilton J.L.	1	3	7	7	2	carbon accounting
Bai H.	1	33	7	7	3	environmental policy
Liu T.	1	33	7	7	3	environmental policy
Wang B.	4	75	4	10	3	environmental policy
Yang B.	1	17	4	4	4	climate change
Cui C. Q.	1	17	4	4	4	climate change

Based on the network map in Figure 6 and the information in Table 6, the following observations can be made into the author's network collaboration on CMA: (1) Wang H. stands out as the top author based on total link strength but the overall link strength is relatively low. This suggests that their collaborations may be limited in terms of the depth and impact of their research connections. (2) Wilson S.A., Southam G., and Hamilton J.L. have low citation counts compared to their document count and total link strength. This raises questions about the quality and impact of their published work. It is important to consider the relevance and significance of the citations received by these authors. (3) Despite their relatively low document and citation counts, Liang S., Bai H., and Liu T. have notable link strengths. This indicates that they may have strong collaborations within their respective research areas of "carbon accounting" and "environmental policy." However, further investigation is needed to assess the quality and impact of their collaborative work. (4) QWang B., Yang B., and Cui C. Q. have lower link strengths and relatively fewer documents and citations. This suggests that their contributions to CMA research may be limited or less recognized within the research community. Overall, authors in the "carbon" and "carbon accounting" topics demonstrate strong interconnectedness and knowledge-sharing, evident from their connections with other clusters. The findings reveal collaboration patterns between clusters, suggesting potential areas of synergy and opportunities for further collaboration.

3.4.3. Co-authorship network (Countries)

The co-authorship countries' network analysis provides insights into active engagement, cooperation, and knowledge exchange in CMA research between countries, highlighting key players and research distribution. The analysis involved 52 countries, out of which 37 countries met the threshold of at least 1 published document with a minimum of 1 citation. These countries were grouped into 8 distinct clusters, as depicted in Figure 7.

Figure 7: Co-authorship network visualization map (Countries)



The identified clusters and their corresponding colours include: Cluster 1 (Red): Germany, Switzerland, Sweden, Austria strong emphasis on “carbon” related research and understanding within CMA. Cluster 2 (Green): Australia, Saudi Arabia, Malaysia, Bahrain focus on accurate measurement and accounting of “carbon accounting” data, highlighting the importance of transparent reporting within CMA. Cluster 3 (Blue): Pakistan, Italy, New Zealand emphasis on “environmental policy” and the development of interventions and regulatory measures related to carbon management within CMA. Cluster 4 (Yellow): United States highlights on “climate change” and the role of carbon sequestration in mitigating its impacts within CMA. Cluster 5 (Purple): China and Singapore explore the potential of “biomass” as a renewable energy source and its environmental implications within CMA. Cluster 6 (Turquoise): Denmark, focuses on “life cycle” analysis, particularly in relation to forestry and wood-based industries, within CMA. Cluster 7 (Orange): United Kingdom, France, Canada focus on “greenhouse gas” emissions, mitigation strategies, and climate change-related research within CMA. Cluster 8 (Brown): Spain highlights research on greenhouse gases and sustainable development, emphasizing the integration of environmental considerations into carbon management practices within CMA. These clusters offer insights into the specific research directions and areas of expertise within different regions, contributing to a more comprehensive understanding of CMA on a global scale. This is evident by the total link strength as shown in Table 7.

Table 7: Top 20 countries based on total link strength

Country	Documents	Citations	Total link strength	Link	Cluster	Theme
Australia	33	852	33	18	2	carbon accounting
United States	37	752	27	16	4	climate change
United Kingdom	22	770	22	11	7	greenhouse gas
China	42	464	16	13	5	biomass
Netherlands	5	123	14	10	4	climate change
Switzerland	7	88	14	14	1	carbon
Germany	15	335	11	10	1	carbon
Denmark	6	187	8	8	6	life cycle
Singapore	3	42	8	8	5	biomass
Spain	9	90	8	8	8	greenhouse gases
Canada	13	206	7	5	7	greenhouse gas
France	11	117	7	4	7	greenhouse gas
Italy	9	95	7	6	3	environmental policy
Malaysia	8	14	7	6	2	carbon accounting
Portugal	2	37	7	7	1	carbon
Brazil	5	58	6	6	3	environmental policy
Japan	2	6	6	6	4	climate change
Norway	2	207	6	6	1	carbon
United Arab Emirates	2	4	6	6	3	environmental policy
Austria	3	169	6	5	1	carbon
New Zealand	3	45	5	4	3	environmental policy
Qatar	1	2	5	5	4	climate change

Based on the network map in Figure 7 and the information provided in Table 7, the co-authorship network of countries in CMA research highlights the presence of distinct thematic clusters and active alliances among countries. For example, Australia leads the network with strong collaborations within its cluster (Saudi Arabia, Malaysia, Bahrain) in carbon accounting, and connections to other clusters such as carbon (Germany, Switzerland, Sweden, Austria), environmental policy (Pakistan, Italy, New Zealand), climate change (United States), greenhouse gas (United Kingdom, France, Canada), biomass (China), and life cycle (Denmark, Belgium). The United States ranks second, showcasing active collaborations in environmental management. It has strong connections to other clusters related to carbon (Germany, Switzerland, Sweden, Austria), greenhouse gas (United Kingdom, France, Canada), and biomass (China). The United Kingdom holds the third position, focusing on greenhouse gas, exhibits collaborations within its cluster (France, Canada) and connections to carbon-related research (Germany, Switzerland, Sweden, Austria), environmental policy (Pakistan, Italy, New Zealand), climate change (United States), and life cycle (Denmark, Belgium). In summary, the collaboration among authors on CMA research signifies “synergy”, while the collaboration among countries indicates “alliances". In sustainability, synergy means integrating efforts, expertise, and resources in CMA research to achieve shared goals. Alliances promote cooperation and knowledge exchange for sustainable development.

To address RQ4, the collective impact of prominent keywords, author synergy, and country alliances signifies a transformative role in the CMA field. This transformation indicates a shift towards a more holistic, collaborative, and integrated approach to tackle sustainability challenges. It can lead to innovative solutions, policy advancements, and a deeper understanding of human-environment interactions, contributing to sustainable development goals. "Sustainable development" encapsulates the notions of "advancement" from a practice-perspective and "transformation" from a system-perspective in CMA research, promoting responsible practices for a sustainable and resilient future.

Finally, to answer RQ5, the identification of a notable gap between "sustainability development" topics and the "carbon accounting model" within the network highlights an important area for further research and calls for a more integrated and holistic approach to carbon management practices. The distant positioning of these two areas suggests a significant divide that needs to be addressed to effectively align sustainability goals with carbon management strategies. To address the observed disparity, future research should focus on promoting a more integrated framework, such as Carbon Management Systems (CMS), which can effectively combine sustainability development objectives with carbon reduction strategies. Various accounting concepts and strategies, including reporting protocols, performance assessment, risk analysis, and goal setting, are integrated into CMS, enabling businesses to effectively address the challenges of climate change (Tang & Luo, 2014). CMS provides a structured approach for organizations and governments to measure, track, and manage their carbon emissions while considering the broader environmental, social, and economic impacts. However, fostering sustainable development, which has been defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987) (p. 41) and contributing to sustainable development goals (UNESCO, 2017) requires collaboration across sector boundaries (Waddock, 1988). For example, this approach is suitable for the construction of the initial carbon management system in areas dominated by electricity consumption, taking into account the two dimensions of economy and environment, and can be applied to various decision-making scenarios, which is beneficial for local governments to quickly start the carbon management system (Zhu et al., 2022). This could involve assessing and addressing the social consequences and benefits of carbon reduction initiatives such as equity, social justice, health and well-being, employment opportunities, community engagement, and the overall social impact on local residents and stakeholders. This holistic approach helps create a more comprehensive and inclusive CMS for mitigating climate change and achieving sustainable development goals.

4. CONCLUSIONS

This bibliometric analysis provides valuable insights into the field of CMA and its implications for sustainability efforts. The study rigorously followed the systematic approach outlined in the PRISMA guidelines for data retrieval. Data analysis and visualization mapping were conducted utilizing Harzing's Publish or Perish software and VOSviewer visualization software. From a practice-perspective, the results show that CMA research is experiencing "advancement," characterized by progressive performance, impactful citations, and dynamic journals. From a system-perspective, the results collectively showcase a "transformative" role for CMA research, marked by prominent keywords, author synergy, and countries' alliances. These perspectives together signify that CMA research is evolving, making significant contributions, and driving positive change in the field. Ultimately, the advancement and transformative potential of CMA research provide a foundation to bridge a research gap in carbon accounting model and sustainability development within the realm of CMA. This highlights the need for further research and emphasizes the importance of adopting a more integrated and holistic approach such as, CMS.

Accordingly, the findings from the bibliometric analysis align with existing literature on CMA research, emphasizing the urgency of addressing carbon emissions and the evolving nature of CMA (Ma & Song, 2022; Kuriawan et al., 2022). Scholars have advocated for an integrated approach, CMS to drive positive change (Rodrigues et al., 2021). The analysis confirms these perspectives, revealing the dynamic evolution of CMA research and its transformative role in sustainability efforts. The study underscores the need for further research while enriching the understanding of CMA's implications for sustainability. Despite its contributions, this study has limitations. The analysis solely relied on the Scopus database, and other sources might provide additional publications relevant to CMA research. Furthermore, the study focused on bibliometric analysis and did not delve into the qualitative aspects of the included publications. Future research can address these limitations and explore specific areas, such as the integration of carbon management models with sustainability development principles. Investigating the effectiveness of different carbon management strategies, exploring the role of technology in CMA, and examining the socio-economic implications of carbon accounting are potential avenues for further investigation.

In conclusion, this bibliometric analysis provides a compelling snapshot of the current state of CMA research and paves the way for future advancements in the field. The revealed trends, identified gaps, and collaborative networks serve as a roadmap for driving progress in CMA, enabling informed decision-making, and fostering the development of sustainable business strategies that tackle carbon management challenges head-on. Armed with this knowledge, the insights gleaned from this study shed light on the pivotal role accounting can play in CMA, propelling the collective efforts towards the paramount objective of attaining carbon neutrality by 2050.

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