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GLOBAL RESEARCH TRENDS IN CARBON CAPTURE AND UTILIZATION TECHNOLOGIES FOR CEMENT PRODUCTION: A BIBLIOMETRIC ANALYSIS

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ABSTRACT

The cement industry is a significant contributor to global Carbon Dioxide (CO_2) emissions, necessitating the adoption of Carbon Capture and Utilization (CCU) technologies to mitigate environmental impacts. This study conducts a bibliometric analysis of CCU technologies for cement production, with a focus on research trends, influential publications, key authors, and emerging themes. Using Scopus as the data source and VOSviewer for network visualization, the study maps the intellectual structure of CCU research and examines global collaboration patterns. The study highlights the disparity in CCU research between developed and developing nations, emphasizing the need for more inclusive and regionally relevant studies. The findings provide insights for policymakers, industry professionals, and researchers to align the cement sector with global decarbonization trends. Recommendations are made for integrating CCU into the construction industry, considering economic, regulatory, and technological challenges.

Keywords: *Bibliometric Analysis; Carbon Capture and Utilization; Cement; VOSviewer.*

1. INTRODUCTION

Carbon Capture and Utilization (CCU) technologies have become increasingly important in addressing the environmental impact of the cement industry, which is a major contributor to global Carbon Dioxide (CO_2) emissions (Hanifa et al., 2022). Cement production is carbon-intensive due to processes such as calcination and high-temperature combustion (Agrawal et al., 2024). With urbanization driving demand for cement, the need for sustainable solutions has never been more critical (Huang et al., 2017). CCU offers a promising approach by converting CO_2 into useful products, such as concrete aggregates, fuels, and chemicals, thus contributing to the circular economy (Ghiat & Al-Ansari, 2021). This aligns with global efforts, such as the Paris Agreement, to mitigate

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climate change while fostering industrial sustainability (Aggarwal, 2024). However, the scalability, economic viability, and technical efficiency of CCU methods remain key areas of research (Hanson et al., 2024).

The global research landscape on CCU technologies in cement production has expanded significantly over the past two decades, with countries like China and the United States at the forefront of research and investment (Dziejarski et al., 2023). However, developing nations, including Sri Lanka, have been slower to adopt these technologies despite the importance of the cement industry to their infrastructure (Danieli et al., 2025). Sri Lanka's reliance on both imported and locally produced cement highlights the need for sustainable production techniques (Fernando et al., 2024). While global research is robust, Sri Lanka-specific studies on CCU remain limited, indicating a need for more localized investigations into the feasibility and applicability of these technologies in the country (Nasvi, 2021).

Therefore, this study aims to analyze global and regional research trends in CCU technologies for cement production by identifying key contributors, influential publications, major research institutions, and examining the evolution of research themes and keyword patterns within the field. By focusing on Sri Lanka, the study addresses the gap in region-specific knowledge and encourages international collaboration. This collaboration is essential for overcoming technical, financial, and regulatory barriers and promoting the sustainable transformation of Sri Lanka's cement sector. To achieve this aim, the following objectives are formulated.

- To analyse the global and regional research trends in CCU technologies for cement production.
- To identify key contributors, influential publications, and major research institutions in the field of CCU technologies.
- To examine the evolution of research themes and keyword trends in CCU for cement production.

2. LITERATURE REVIEW

Cement production is a vital industrial activity that plays a significant role in global carbon emissions, highlighting the need for a thorough understanding of its environmental impact and possible mitigation measures (Barbhuiya et al., 2024). The manufacturing process consists of multiple stages, including raw material extraction, calcination, and the final grinding of clinker with additives (Hanifa et al., 2022). A key source of emissions arises during calcination, where limestone (Calcium Carbonate) is subjected to high temperatures, resulting in the formation of lime (calcium oxide) and the release of CO_2 (Agrawal, 2024). On average, the production of one ton of cement clinker generates approximately 0.9 tons of CO_2, contributing to an estimated 5% to 8% of global anthropogenic CO_2 emissions (Barbhuiya et al., 2024). Additionally, the cement industry is highly energy-intensive, accounting for around 12% to 15% of total industrial energy consumption, further amplifying its carbon footprint (Barbhuiya et al., 2024).

The environmental impact of cement production goes beyond CO_2 emissions, as the process also releases other carbon-containing greenhouse gases (CO, CH_4, HFC_s, PFC_s) and pollutants, negatively affecting air quality and contributing to climate change (Imboden et al., 2014). Lifecycle assessments of cement production indicate that a significant share of greenhouse gas emissions originates from the extraction and processing of raw materials, with research highlighting that raw material production is a major contributor (Dahanni et al., 2023). Additionally, the cement industry is frequently associated with biodiversity loss and habitat destruction due to quarrying activities (Imboden et al., 2014). Direct emissions from energy use and limestone calcination make up roughly 60% of total emissions, while indirect emissions from electricity and heat production account for another 40% to 50% (Sousa & Bogas, 2021).

2.1 CEMENT INDUSTRY IN SRI LANKA

In Sri Lanka, the cement industry is a key driver of infrastructure development, but it also faces significant challenges concerning environmental sustainability (Madhuwanthi & Somachandra, 2019). Sri Lanka has been making efforts to incorporate more sustainable approaches in cement manufacturing, such as utilizing alternative fuels and raw materials to lower carbon emissions (Usón et al., 2013). Studies suggest that the adoption of alternative fuels can substantially decrease emissions while also offering economic advantages (McLaughlin et al., 2023). Additionally, the feasibility of CCU technologies is being considered as a strategy to mitigate emissions from the cement industry (Monteiro & Roussanaly, 2022). As Sri Lanka's cement sector continues to expand, maintaining a balance between economic development and environmental stewardship is essential, ensuring that the industry supports national growth objectives while minimizing its environmental footprint (Ministry of Environment and Natural Resources, Sri Lanka, 2007).

At present, Sri Lanka has not yet implemented full-scale CCU facilities within its cement industry. However, several preliminary initiatives and feasibility studies have been undertaken to assess the country's readiness and potential for carbon capture deployment. The government, in collaboration with academic institutions and international environmental agencies, has started exploring CCU pathways more aligned with Sri Lanka's economic and technological landscape. Pilot projects focusing on low-cost carbon capture technologies such as chemical absorption using amine-based solvents, mineral carbonation using industrial by-products, and the integration of solid sorbents have been evaluated in academic and research contexts (Fernando et al., 2024).

2.2 OVERVIEW OF CO_2 CAPTURE TRANSPORT, STORAGE AND UTILIZATION

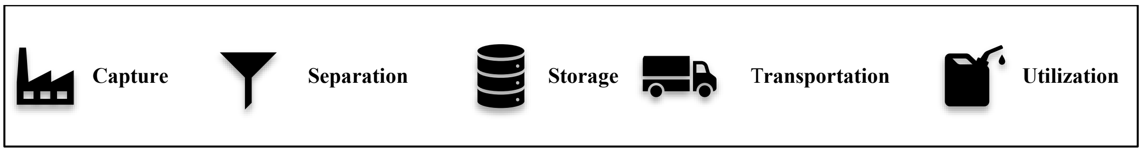

Figure 1: CCU process

Carbon emissions are a major contributor to climate change, primarily generated by industrial activities such as cement production, power generation, and steel manufacturing (Belaïd, 2022). CCU is a key strategy to mitigate these emissions by capturing CO_2 at the source, transporting it to appropriate locations, and either storing it safely or utilizing it for value-added applications (McLaughlin et al., 2023). Figure 1 illustrates the process of CCU technologies, providing a visual representation of how carbon dioxide is captured from industrial sources, transported, and either stored permanently or converted into useful products through various utilization pathways.

Table 1 presents a comprehensive categorization of the key technological domains associated with CCU systems. It outlines the primary categories that must be considered in the implementation of CCU frameworks, highlighting the multiple options available for each stage of the process.

Table 1: CCU process different options
Source: (Hanson et al., 2024)

Category	Options
CO_2 Capture	Industrial Separation, Post-combustion capture, Oxy-fuel combustion capture, Pre-combustion capture
Separation	Solvents (Absorption), Membranes, Solid sorbents, Cryogenic
CO_2 Storage (Sequestration)	Deep Saline Aquifers, Depleted Oil & Gas Reservoirs, Basalt & Mineralization Storage, Ocean Storage (Under Research)
CO_2 Transport	Pipeline Transport, Ship Transport, Truck and Rail Transport
CO_2 Utilization	Products Providing Permanent Storage, Products Potentially Providing Long-Term Storage
	Intermediates for Products, Products Providing Short-Term Storage and Utilizing CO_2 in the Conventional Production Process, Products Providing Short-Term Storage and Utilizing CO_2 in Nonconventional Processes, Utilization of CO_2 for Renewable Fuel Production

3. RESEARCH METHODOLOGY

This section explains how the literature was extracted and the types of analysis used to scrutinize it.

3.1 MATERIAL EXTRACTION

In this study, Scopus was selected as the primary data source for bibliometric analysis due to its comprehensive coverage of peer-reviewed literature. Scopus provides advanced search functionalities that allow for precise filtering based on keywords, publication years, document types, and citation metrics (Powell & Peterson, 2017). By using Scopus, this study ensures the inclusion of authoritative and up-to-date research on carbon capture and utilization technologies in cement production, supporting a robust bibliometric analysis (Elsevier, 2024). The query below was developed to extract the material related to this study from Scopus.

Table 2- Literature extraction

Criteria	Description
Sources website	Scopus
Years	2015 January to 2025 February
Searching terms	"Carbon Dioxide", "Carbon Capture", "Cements", "Carbon Capture and Utilization", "Carbon", "Carbon Capture and Storage", "Adsorption", "Cement Industry", "Cement", "Carbon Storage", "Construction Industry", "Carbon Utilization", "CCS", "CCUS", "Cement Production"
Inclusions Criteria	All Open Access Final Articles

Criteria	Description
Exclusion Criteria	Other languages Articles, Books, Proceeding Papers, Review Articles, Book Chapters, Letters, Editorial materials, Early Accesses
Sample size	5984

In the search query, a focused selection of academic articles published between 2015 and 2025 was utilized to explore the latest developments in carbon capture and utilization technologies within the context of cement production. 17 specific keywords (Carbon Dioxide, Carbon Capture, Cements, Carbon Capture And Utilization, Carbon, Carbon Capture And Storage, Adsorption, Cement Industry, Cement, Carbon Storage, Concrete, Concretes, Construction Industry, Carbon Utilization, CCS, CCUS, Cement Production) were strategically chosen to capture a broad yet relevant range of literature, ensuring comprehensive coverage of the subject area. The application of these keywords resulted in the retrieval of 5,984 articles, which formed the dataset for the bibliometric analysis. To maintain the quality and relevance of the analysis, only English-language articles categorized as final stage publications were included, ensuring the study focused on peer-reviewed, finalized research that reflects the most recent high-quality academic work in the field. All materials were downloaded on March 12, 2025, thereby ensuring the timeliness and consistency of the dataset. This stringent selection process resulted in a robust and up-to-date sample that supports the comprehensive bibliometric analysis of carbon capture technologies in cement production.

To analyse and visualize the structure and evolution of research related to CCU technologies in cement production, this study adopted a bibliometric analysis approach, which offers a systematic and quantitative means of evaluating scholarly literature (Donthu et al., 2021). Bibliometric analysis was selected for its ability to reveal trends, intellectual structures, and collaboration dynamics within a specific research domain (Aria & Cuccurullo, 2017). It provides critical insights into the development of the field, key contributors, and influential research clusters, thereby establishing a foundation for deeper content analysis and decision-making in subsequent stages of the research (Zupic & Čater, 2015).

The analysis was conducted using VOSviewer, a specialized software tool designed for constructing and visualizing bibliometric networks. Its advanced capabilities in handling large datasets and generating interpretable graphical maps made it particularly suitable for this study (van Eck & Waltman, 2014). The techniques selected for this study are closely aligned with its core objectives, ensuring a comprehensive and systematic understanding of the research landscape surrounding CCU technologies in cement production.

To achieve objectives, 'Collaboration Network Analysis' through bibliometric coupling of countries and regions is employed. This method reveals the geographical distribution of research efforts, highlighting which nations or regions are actively contributing to CCU research in the cement sector. Additionally, co-authorship analysis among authors uncovers patterns of academic collaboration, providing insights into how research networks are formed and how knowledge is shared across institutions and borders. In addressing the objective of identifying key contributors, influential publications, and major institutions, Density Visualization based on citation intensity plays a crucial role. This technique emphasizes highly cited works and prolific authors or institutions, allowing the study to pinpoint where and by whom impactful research is being produced.

Citation density also serves as a proxy for academic influence and recognition within the field.

To examine the evolution of research themes and emerging research areas, 'Overlay Visualization' is applied to the bibliometric coupling of sources. This enables a temporal view of how research interests and focal points have shifted over time, identifying transitions in dominant themes and the emergence of novel areas of inquiry. Furthermore, 'Word Cloud Analysis' of author keywords visually distils the most frequently used terms, highlighting prevalent topics and signalling upcoming research directions based on recent keyword trends.

4. RESULTS AND DISCUSSION

This section presents the findings derived from the literature and discusses the analytical techniques employed to interpret and evaluate the data.

4.1 CHRONOLOGICAL DISTRIBUTION OF SCIENTIFIC LITERATURE

Figure 2 presents the number of academic publications related to CCU technologies in cement production from 2015 to 2025. The main purpose of this graph is to show how research interest in this specific field has changed over time. The graph shows the annual number of publications, which helps to understand the level of academic attention given to CCU technologies in the cement industry. From the results, it is clear that the number of publications has been increasing steadily over the years. In 2015, there were 106 publications, and this number gradually grew each year, reaching 994 publications in 2023. This steady rise shows that research interest in this area has been growing consistently.

A significant increase is observed in 2024, with 1,635 publications, the highest number during the entire period. This suggests that CCU technologies in cement production have become a major topic of interest recently, possibly due to global climate concerns and advancements in carbon capture methods. However, in 2025, the number of publications drops to 510. It is important to note that this figure reflects data only up to February 2025. If the current publication rate continues consistently throughout the year, the extrapolated total for 2025 would be approximately 3,060 publications, almost double the number recorded in 2024. Therefore, the lower figure observed at this stage should not be interpreted as a decline in research interest but rather as a reflection of the early point in the publication calendar.

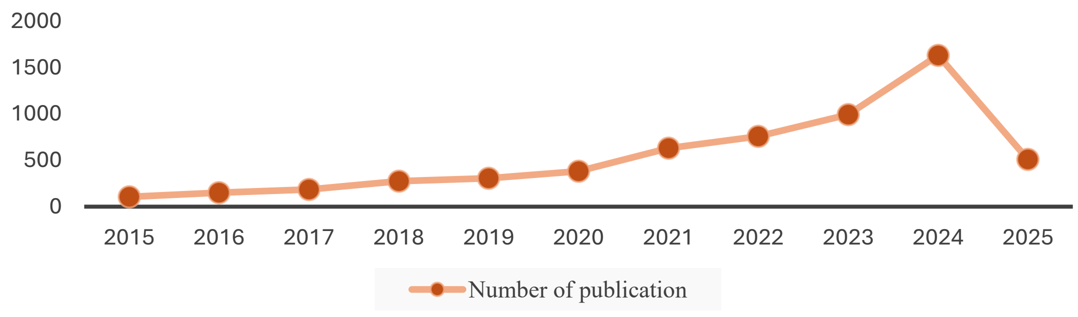

Figure 2: Number of publications in years

Overall, the data indicates a growing academic interest in CCU technologies in the cement industry between 2015 and 2024. This trend reflects the increasing importance of developing low-carbon solutions for one of the world's most emissions-intensive industries and directly supports the first objective of this study. Further analysis of the content of these publications can help identify the main focus areas, emerging themes, and gaps in the existing research.

4.2 INTERNATIONAL RESEARCH COLLABORATION- A BIBLIOMETRIC COUPLING ANALYSIS OF COUNTRIES AND REGIONS

Bibliometric coupling is a method used in bibliometric analysis to identify relationships between countries, authors, or institutions based on shared references in their publications. As per Figure 3, bibliometric coupling by country was used to understand how different nations are contributing to the research on CCU Technologies for cement Production. The purpose of this analysis is to identify leading countries in the field, understand patterns of international research efforts, and highlight global collaboration trends.

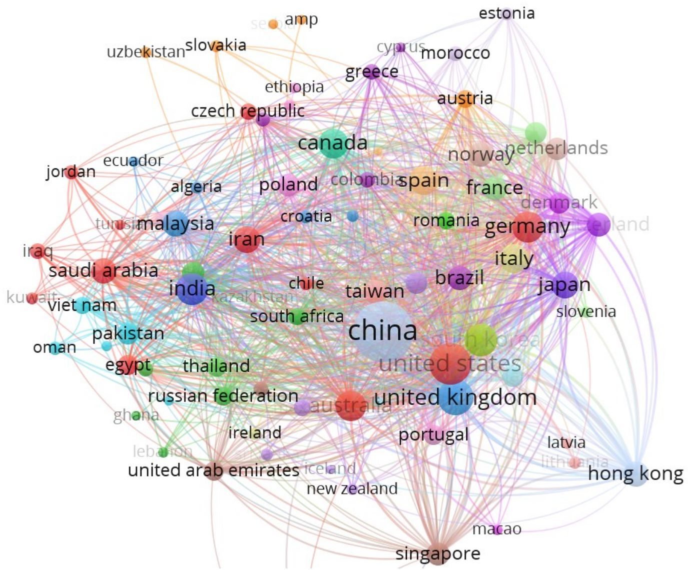

Figure 3: Countries/regions collaboration network (minimum 20 documents)

Table 2: Top 5 countries based on the number of publications

Rank	Country	Documents	Citation
1	China	2269	50845
2	United State	564	18893
3	United Kingdom	305	15994
4	South Korea	271	6348
5	India	236	5040

According to the results presented in Table 02, a total of 146 countries have published at least one article on this topic. This demonstrates a broad global interest in CCU technologies and a shared recognition of the need to address carbon emissions in cement production. Among all countries, China is the leading contributor, with 2,269 publications. It also has the highest citation count of 50,845, which reflects both the volume and influence of its research. The United States ranks second, with 564 publications and 18,893 citations, showing its strong presence in this area. The United Kingdom comes third, contributing 305 publications and receiving 15,994 citations.

4.3 ANALYSING CITATION INTENSITY THROUGH BIBLIOMETRIC DENSITY MAPPING

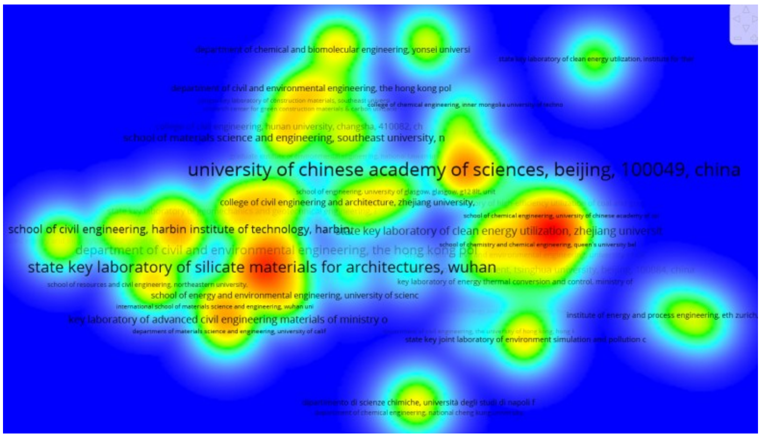

Figure 4: Citation intensity of density visualization clusters in institutional cooperation (minimum 5 documents)

Figure 4 presents a density visualization of citation intensity among research organizations engaged in carbon capture and utilization (CCU) technologies for cement production. This visualization highlights not merely the presence of collaboration but the academic impact of institutions, based on how frequently their work is cited. Warmer colours (red) indicate high citation concentrations, signifying institutions whose publications are widely referenced, whereas cooler regions (green and yellow) denote comparatively lower citation intensity.

From the analysis, several institutions emerge as key contributors. Notably, the University of Chinese Academy of Sciences appears in one of the densest red zones, suggesting its central role in high-impact CCU research. Similarly, Tsinghua University's School of Environment and School of Energy and Power Engineering demonstrate strong citation intensity, underscoring their reputation in environmental and industrial carbon studies. Other influential institutions include the State Key Laboratory of Clean Energy Utilization**, the** Department of Civil and Environmental Engineering and the School of Materials Science and Engineering, which collectively form visible clusters of academic recognition. These findings reflect a concentration of impactful CCU research in East Asia, particularly China, consistent with broader publication trends in the field.

4.4 RANKING OF RESEARCH INSTITUTIONS BY PUBLICATION OUTPUT

According to Table 3, Chinese organizations emerge as pioneers in this field, reflecting their strong commitment to reducing carbon emissions from the cement sector—one of the country's most emission-intensive industries. Leading the list is the Chinese Academy of Sciences, which has contributed 53 publications and received 1,125 citations, indicating both high output and significant academic impact. The Wuhan University of Technology (Silicate Material for Architecture) follows with 41 documents and 1,274 citations, demonstrating a strong specialization in materials research relevant to CCU technologies. Another prominent contributor is the Hong Kong Polytechnic University, with 30 publications and a higher citation count of 1,606, indicating substantial influence in the academic community.

Table 3: Top 5 institutions based on the number of publications

Rank	Organization	Documents	Citations	Country
1	Chinese Academy of Science	53	1125	China
2	Wuhan University of Technology (silicate material for architecture)	41	1274	China
3	Hong Kong Polytechnic University	30	1606	China
4	Harbin Institute of Technology	26	1009	China
5	Zhejiang University	24	476	China

In total, 12,994 organizations worldwide have contributed to research in this domain, highlighting the global scale of institutional involvement and collaboration. Table 4 provides a summary of the top 5 institutions based on the number of publications, offering insight into the key research leaders in the development of carbon capture and utilization technologies for cement production. These findings suggest that China's research institutions play a leading role in shaping the scientific advancements in CCU technologies. Their prominent presence in both publication volume and citation impact illustrates their strategic focus on sustainable technologies and positions them as global leaders in this critical area of environmental innovation.

4.5 BIBLIOMETRIC COUPLING OF SOURCES- A TEMPORAL OVERLAY PERSPECTIVE

Figure 5 and Table 4 present the results of a Bibliometric coupling of source analysis, which was conducted to identify the most influential academic journals contributing to the field of CCU Technologies for Cement Production. This type of analysis is important because it helps determine where research is being published, which journals serve as key platforms, and how scholarly communication is structured within the field. Understanding the distribution of publications across journals is valuable for recognizing reputable sources, tracking the dissemination of knowledge, and guiding researchers toward impactful publication venues. The analysis reveals that research in this area is highly interdisciplinary, with publications appearing in a total of 864 different journals. This wide distribution reflects the diverse nature of CCU research, which spans environmental science, materials engineering, construction, and energy systems.

Among the sources, the Journal of Cleaner Production stands out as the leading journal, having published 378 documents related to CCU in cement production. This journal focuses on sustainability, cleaner production, and environmental management, making it a suitable outlet for research in low-carbon cement technologies. The second most prominent journal is Construction and Building Materials, which has published 359 articles. This indicates a strong connection between CCU technologies and advancements in construction materials, especially in efforts to reduce the carbon footprint of traditional cement and concrete. The Journal of Carbon Dioxide Utilization also plays a significant role, contributing 196 publications specifically focused on innovative methods for capturing and converting CO_2 into useful products. This aligns directly with the core objective of the research domain.

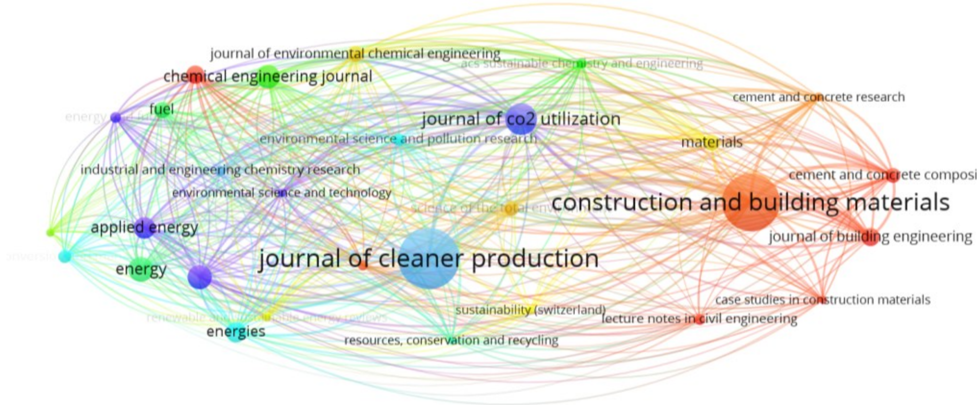

Figure 5: Overlay visualization of source journals(minimum 15 documents)

Overall, the source analysis highlights the interdisciplinary and evolving nature of CCU research within the cement industry. The concentration of publications in a few key journals suggests the presence of specialized platforms that are shaping the academic conversation and influencing research directions in sustainable cement production.

Table 4: Top 5 most cited journals with Cite score and impact factor

Rank	Source	Documents	Citation	Cite Score	Impact factor
1	Journal of Cleaner Production	378	13723	20.4	9.8
2	Construction and building materials	359	5945	13.8	7.4
3	Journal of carbon dioxide utilization	196	6272	13.9	7.2
4	Energy	155	3371	15.3	9.0
5	International Journal of Greenhouse Gas Control	133	1433	10.0	6.7

4.6 AUTHOR COLLABORATION NETWORKS- A CO-AUTHORSHIP ANALYSIS

Figure 6 presents the results of a co-authorship author network analysis, which was conducted to identify the most influential researchers and collaborative relationships in the field of CCU Technologies for Cement Production. This type of analysis focuses specifically on co-authorship patterns, revealing how researchers are connected through joint publications.

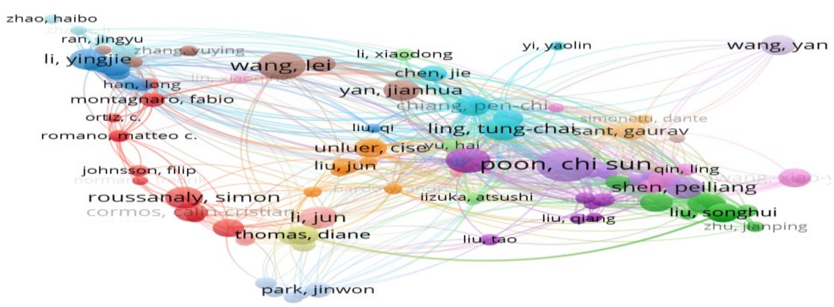

Figure 6: Network visualization map of authors (minimum 10 document)

The visualization map in Figure 6 illustrates the collaborative networks among authors by mapping out the relationships formed through co-authored research articles. Authors who frequently collaborate are grouped into clusters, and the strength of their connections is represented by the proximity and thickness of the linking lines.

Table 5: Top 5 authors based on number of publications

Rank	Author	Documents	Citation	Country
1	Poon, Chi Sun	35	1209	China
2	Wan, Lei	29	708	China
3	Wang, Tao	27	999	China
4	Ling, Tung-Chai	24	1142	China
5	Shen, Peiliang	23	216	China

According to Table 5, 21,416 authors have contributed to research in this field, highlighting the extensive global collaboration in advancing CCU technologies for cement production. Among the top contributors, Poon Chi Sun stands out with 35 publications and 1,209 citations, emphasizing advancements in sustainable construction materials.

4.7 KEYWORD ANALYSIS THROUGH WORD CLOUD VISUALIZATION

Figure 7 presents a word cloud view of author keywords from publications in the field of CCU Technologies for cement production. The word cloud technique is used to visually represent the frequency of terms or keywords in the literature, with the size of each word reflecting its importance or frequency. This technique is particularly useful for identifying prominent research topics, trends, and areas of focus within a large body of literature. It allows for an intuitive, quick understanding of what has been central to the research discussions and helps highlight emerging concepts or themes. In this study, the word cloud organizes the author keywords by their first appearance in the literature, showcasing the development of research topics since 2015 and directly supports the third objective of this study.

Figure 7: Word cloud of author keyword

The integrated bibliometric techniques employed in this study have collectively offered a comprehensive understanding of the global research landscape on CCU technologies in cement production. Collaboration network analysis has effectively identified the geographical distribution of research and the extent of academic partnerships across countries and institutions, reflecting the collaborative nature of advancements in this domain. Citation-based density visualization has highlighted the most influential authors, institutions, and publications, thereby uncovering the intellectual pillars shaping the field. The overlay visualization of bibliometric coupling among sources has provided a temporal perspective, tracing the evolution of scholarly focus and the emergence of novel research directions over time. Additionally, word cloud analysis of author keywords has illuminated dominant research themes and recurring concepts, offering a snapshot of both current priorities and potential future trends.

5. CONCLUSIONS

This study conducted a comprehensive bibliometric analysis to examine global and regional research trends in technologies within the cement industry, an essential sector in reducing industrial CO_2 emissions. The results mainly show global patterns, with most high-impact research coming from developed regions such as Europe, North America, and East Asia. In comparison, research from developing countries is limited, indicating a gap and pointing to the opportunity for these countries to increase their involvement in CCU development.

Although this study used only the Scopus database and English-language articles, which means that some local or non-indexed studies may not have been captured, it still provides useful knowledge that can help other countries develop their own CCU research and policies. These global findings can guide governments, researchers, and industries in making informed decisions, investing in cleaner technologies, and planning for low-carbon construction. To advance in this area, countries will need to strengthen local expertise, increase public awareness, and build partnerships with international research organizations. Future research should consider using additional databases and combining different methods to gather broader and more locally relevant information. This approach can better support climate action and help achieve long-term sustainability goals.

As CCU technologies are primarily adopted in developed countries, these findings underscore the potential for developing countries like Sri Lanka to leverage such technologies in the cement sector. A national plan should be established with clear policy direction, financial incentives, and collaboration among government agencies, the private sector, and academic institutions.

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