SYSTEMATIC REVIEW OF THE MANAGEMENT OF CO_2 CAPTURE AND STORAGE AS A CONTRIBUTION TO GREENHOUSE GAS REDUCTION

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ABSTRACT

Economic growth and the increase in population have caused greater generation and consumption of fossil energy, increasing CO_2 emissions into the atmosphere, directly impacting climate change and global warming. Carbon capture, utilisation, and sequestration (CCUS) are essential for reducing greenhouse gas (GHG) emissions and achieving carbon neutrality. This article aims to analyse the scientific production on CCUS in Scopus through the application of bibliometric techniques and a systematic review of the knowledge of the different techniques used, their distribution and trends. The methodological process consisted of three phases: (i) collection and processing of scientific information, (ii) bibliometric analysis using the Bibliometrix and VOSviewer software, and (iii) systematic review of the CCUS techniques used using the Preferred Reporting Items for Systematic method Reviews and Meta-Analyses (PRISMA). The results showed a growing trend of annual publications on CCUS in the last decade, highlighting improvements in the storage technique in geological formations and oil production processes. Similarly, methodological trends have been identified for industries that reduce GHG emissions. The results of this study represent a tool for researchers and decision-makers related to CCUS that allows them to know the areas investigated to date, including the different CCUS techniques and their respective benefits and limitations.

Keywords: carbon dioxide, carbon emissions, decarbonization, knowledge mapping, climate change.

1 INTRODUCTION

Economic growth and the increase in the global population at levels not expected in recent decades have created the need for energy generation so that human beings can pursue their activities [1]. According to the Intergovernmental Panel on Climate Change, anthropogenic activities have caused a greater amount of greenhouse gas (GHG) emissions during the last century, mainly due to the burning of fossil fuels, unsustainable energy and land use, and unsustainable consumption and production patterns [2].

GHGs cause the atmosphere to trap a greater amount of radiation than usual, causing the heat output to the atmosphere to be slower or preventing the heat output from completely out of the atmosphere and increasing the surface temperatures [3]. This has caused global warming of 1.1°C above pre-industrial levels, with CO_2 having the highest concentration of GHGs [4], generating extreme changes in the planet's climate and meteorology, compromising human and environment security [5].

CO_2 represents 65% of global emissions and is thus the most prevalent gas in the atmosphere [6]. The levels of CO_2 emissions have become important since the beginning of the industrial revolution owing to the dependence on fossil fuels for energy production [7]. Three major types of fossil fuels can generate CO_2 emissions: natural coal, oil, and natural gas [8]. In the hydrocarbon industry, oil is a fundamental source of energy generation for several industrial sectors. However, it is one of the activities with the greatest environmental

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impact [9], [10]. Thus, it is necessary to conduct a follow-up to determine the industrial sectors and the final users of fossil fuels to determine the production of GHG emissions [11] in terms of CO_2 emissions.

Carbon capture and storage (CCS) is the most appropriate technology for reducing emissions and stabilising atmospheric CO_2 concentrations [12]. CO_2 emissions are classified according to the state of storage; thus, black carbon is CO_2 that has not been sequestered or used and remains in the atmosphere for a long time, grey carbon, which is the CO_2 that is permanently fixed or sequestered in a geological body, and blue carbon, which is the CO_2 that can be converted into products for human use through biological, physical, and chemical processes [13].

One of the main disadvantages of the CCS technique from an economic perspective is the high investment capital required to perform this activity [14]. From a technical perspective, CO_2 leakage rates are still being determined; therefore, CCS is not a viable option in certain countries. For this reason, the carbon capture utilisation technique is being developed, converting CO_2 emissions into products with economic value and contributing to the mitigation of climate change [15]. Thus, the term carbon capture utilisation and storage (CCUS) has been developed, which is an ideal technique to reduce CO_2 emission levels without it being necessary to reduce energy generation due to the use of fossil fuels [16].

The literature review constitutes an essential role in academic research, which allows uniting existing knowledge and examining the state of the field being studied through specific frameworks, focusing on the research variables and understanding the evolution of the topic in time, synthesising primary currents, or even identifying new topics [17], [18]. Bibliometric analysis is a rigorous method for exploring and analysing large volumes of scientific information to systematically analyse and evaluate academic literature in a specific discipline through quantitative and statistical methods [19]. Currently, there are bibliometric studies related to CCUS [20], studies of global economic trends [21], and articles related to CO_2 neutrality [22].

It is important to reach a global understanding of research related to CCUS and the techniques applied to date. This study raises the following research questions: What research areas exist about CCUS? What are the CCUS techniques being applied globally? What is the contribution of CCUS techniques to mitigating climate change?

This study aims to integrate a quantitative and qualitative analysis through a bibliometric study and literature review of CCUS published in Scopus to identify current research areas, future trends, and knowledge of the main techniques applied at the global level.

2 MATERIALS AND METHODS

This study proposes a comprehensive methodological approach that combines the quantitative analysis of the scientific production of CCUS at a global level and a qualitative analysis of the methodologies used to define their contribution to the reduction of GHG and the mitigation of the effects of climate change. The process was developed through three work phases: (i) search strategies for obtaining and processing data published in Scopus, (ii) bibliometric analysis of scientific production, and (iii) systematic review using the Preferred Reporting Items method for Systematic Reviews and Meta-Analyses (PRISMA) [23], [24] (Fig. 1).

2.1 Stage I: Search strategies

The investigation begins with defining the search criteria based on four main terms: (i) carbon capture, utilisation, and sequestration; (ii) CO_2; (iii) GHSs; and (iv) oil industry. The selected

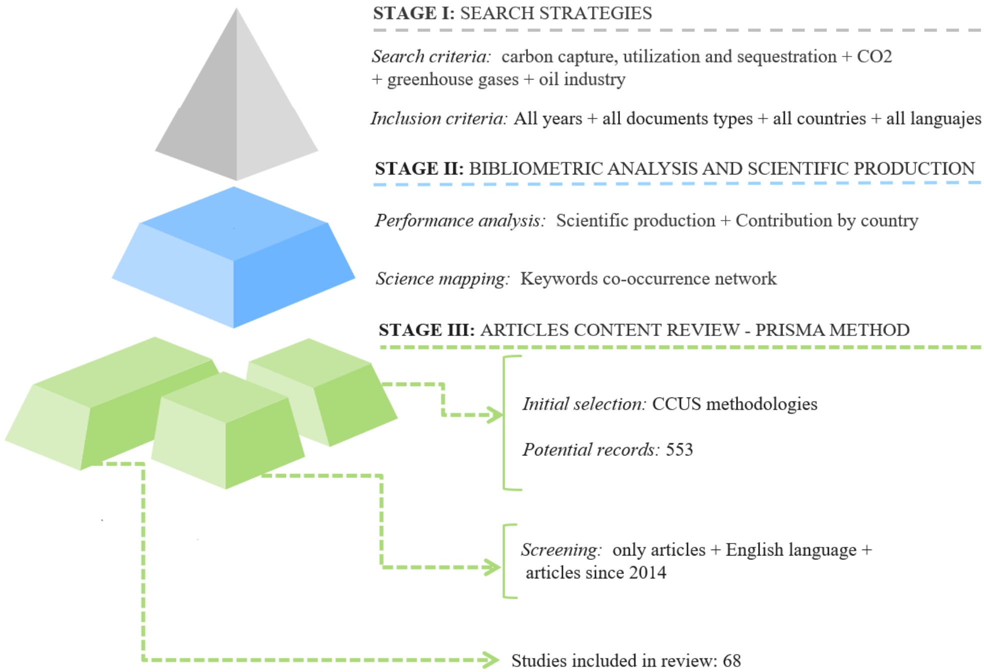

Figure 1: Methodological scheme of the study.

terms allowed defining the search equation in the Scopus database: (TITLE-ABS-KEY (“carbon capture, utilization and sequestration” OR “CCUS” OR “carbon capture utilization” OR “carbon sequestration” OR “carbon capture and storage” OR “CCU”) AND TITLE-ABS-KEY (“CO2” OR “carbon dioxide” OR “decarbonisation” OR “decarbonization” OR “carbon”) AND TITLE-ABS-KEY (“greenhouse gases” OR “greenhouse gas emission”) AND TITLE-ABS-KEY (“oil” OR “oil production” OR “oil industry” OR “oil extraction”)) from which 821 documents were obtained. The search considered all types of publications globally up to the present, limiting itself to English, considering that less than 5% of the results obtained were in other languages.

Once the search strategy has been defined, the data are extracted in comma-separated value (CSV) format for further processing, cleaning, and obtaining graphs of the investigated area’s production, evolution, and trends using Microsoft Excel software [25], [26]. The data cleaning process consisted of eliminating duplicate and incomplete data, resulting in 791 documents.

2.2 Stage II: Bibliometric analysis and scientific production

This phase contemplates defining the production, evolution, structure, and research trends related to CCUS through performance analysis and scientific mapping. The performance analysis allowed us to analyse the behaviour of CCUS research over time and the collaboration by country that exists to date. On the other hand, scientific mapping includes defining the main research areas within the CCUS field through an analysis of the co-occurrence of author words that allows the formation of relationships and building a domain structure according to the keywords of the different documents using VOSviewer software.

2.3 Stage III: Article content review – PRISMA method

Finally, in this phase, a systematic review using the PRISMA method of the methodologies applied for CCUS was carried out in two stages. The process included an 'initial selection' stage in which documents with investigations of CO_2 capture, storage, or use methodologies were selected, from which 553 records that met the criteria were obtained. The second stage, called 'screening', contemplated filtering processes of document type (considering only articles), language (English as a universal language), and articles from the last decade (since 2014), obtaining a database of 68 articles. Finally, the phase concludes with a full reading of articles to define the current methodologies developed within the field and their contribution to GHG reduction.

3 RESULTS

3.1 Evolution of the CCUS investigation

According to the scientific production on CCUS for years, it is possible to identify the beginning in Scopus in 1996 with the study by Riemer [27], in which the evaluation of technologies to reduce GHG emissions by the GHG R&D program of the International Energy Agency, contemplated an analysis of the cost and emissions associated with power generation, existing CO_2 capture methodologies, and their transportation and use. Scientific research has generally increased in the last 15 years, representing 91.5% of the total scientific production (Fig. 2). In this period (2009–2023), it is possible to show years like 2009, 2010, and 2013 with more than 1,800 citations (Fig. 2).

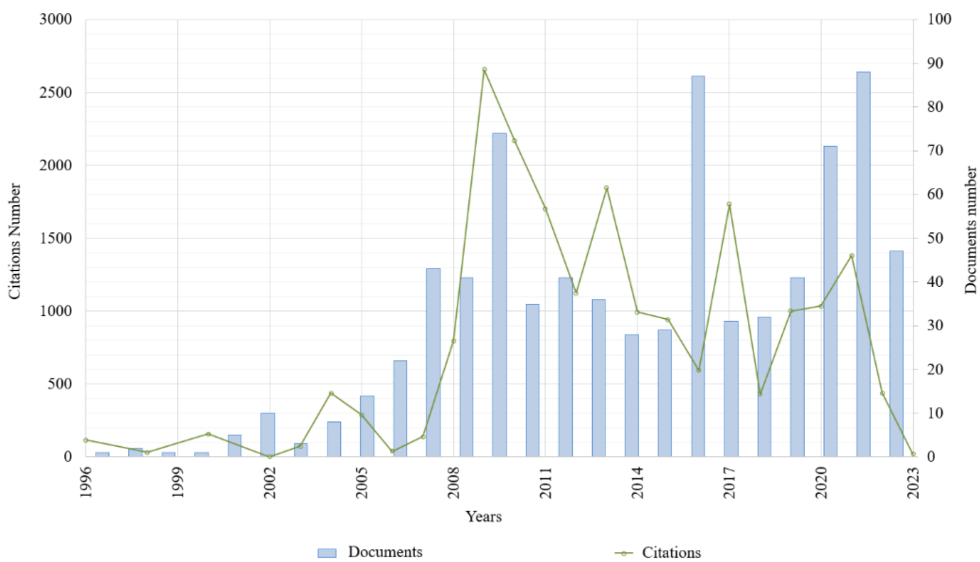

Figure 2: Scientific production of the CCUS in Scopus over time.

3.2 Contribution by country

The results obtained from the bibliographic coupling of countries with at least one CCUS research article reflect the contribution of 69 countries globally, highlighting the participation of the United States, United Kingdom, and China as the top three in CCUS research with the highest number (Fig. 3), representing approximately 54% of the total production.

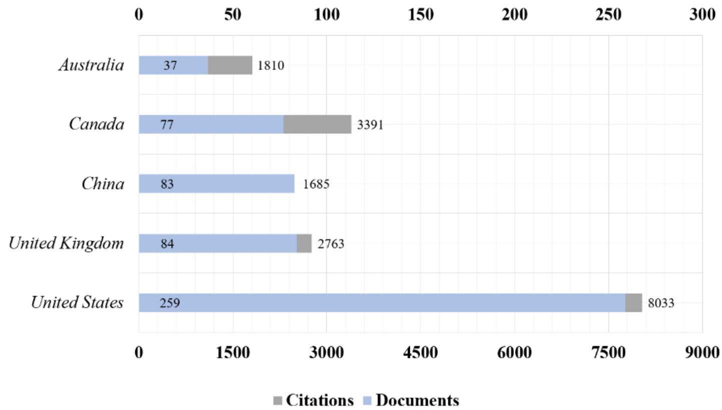

Figure 3: Top five CCUS scientific production by country.

Fig. 4 shows the linkage by country according to the affiliations of each author through nodes grouped into six clusters with links between countries that reflect the existing collaboration. The size of the nodes varied according to the number of documents. For example, countries like the United States, a leader in scientific production, collaborate with more than 90% of countries within the field, highlighting China, the United Kingdom, and Germany as the top three collaborators (Table 1).

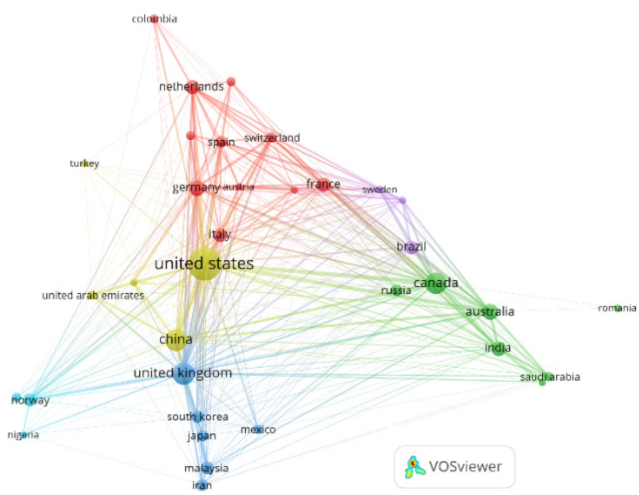

Figure 4: Country contribution bibliometric map.

Table 1: Collaboration level of the most productive country by cluster within the CCUS field.

Cluster	Country	Number of documents	Country with the most collaboration	Link strength
1	Germany	34	United States	491
2	Canada	77	United States	751
3	United Kingdom	84	United States	1025
4	United States	259	China	1292
5	Brazil	24	Canada	185
6	Norway	20	United States	250

3.3 Research areas in CCUS

The analysis of the co-occurrence of keywords in CCUS research reflects the grouping of 59 keywords (with at least five occurrences) in six clusters of different colours represented by nodes connected through links to identify the relationship between the different themes (Fig. 5). The keywords carbon capture and storage, carbon capture, GHG emissions, carbon storage, and carbon dioxide represent the top five of the author's words with the highest number of occurrences that match the terms associated with the search equation.

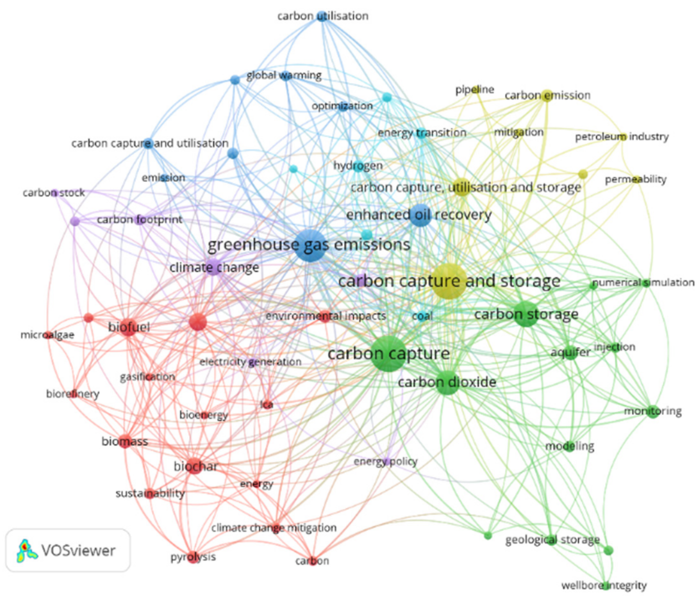

Figure 5: Author keyword co-occurrence bibliometric map of the CCUS.

Cluster one (red colour) groups research related to the production of biofuels to promote sustainable energy sources through the concept of biorefinery to mitigate GHG emissions [28], [29], and life cycle assessment for the methodologies used [30]. Cluster two (green colour) represents an area with scientific contributions on the potential for the capture and underground storage of CO_2 in aquifers and the dependence of this alternative against geological knowledge for which several studies of numerical simulations are developed [31], [32]. Cluster three (blue colour) group studies focused on the design of CO_2 capture, transport, and storage systems [33], [34], as well as the analysis of the use of CO_2, mainly in the production of fuels, chemical products, raw materials for plastics, and urea production, including food and beverage processing [35], [36].

On the other hand, cluster four (yellow colour) represents an area of CCUS with a clear research objective related to the operation and problems associated with wells in the CCS process, including temperature analysis, carbon degradation, well casing, geopolymer permeability, as well as advances in technical, economic, and legal solutions that guarantee the integrity of oil wells [37], [38]. Cluster five (purple) includes studies of different CCUS techniques and their contribution to mitigating the effects of climate change, contributing to the decarbonisation of the planet [39], [40]. Finally, cluster six (light blue) represents one of the smallest areas within the field with technical and economic evaluation studies of hydrogen production from biomass or underground coal gasification [41], [42], as well as the importance of promoting green energy production and the main technical, economic, and political challenges presented by CCS [43], [44].

3.4 Current methodologies for CCUS

The systematic literature review process included 68 articles, in which the most current methodologies/technologies for capturing, storing, and using CO_2 at a global level were presented, highlighting their contribution to reducing GHG emissions and mitigating climate change (Table 2).

4 DISCUSSION

The present investigation combines qualitative and quantitative analyses of the scientific production of CCUS for the definition of research areas of the field and methodologies/technologies used in the last decade. In general, the field of the CCUS in Scopus contemplates a high and current production at a global level, registering the year 2022 with the highest scientific production (88 documents) and the year 2009 with the highest number of citations (2,658 citations), reporting the United States, United Kingdom, and China as the top three countries with the highest production that coincides with developed countries, with higher GHG emissions and a higher level of awareness towards mitigating the effects of climate change.

According to bibliometric analysis, six main areas (clusters) were identified within the field. The first cluster includes investigations of the importance and use of captured CO_2, such as the production of biofuels, while cluster two considers underground CO_2 capture technologies and their technical, environmental, and economic feasibility. On the other hand, clusters three and five are strongly related to research on CCUS methodologies at the global level, with an analysis of their contribution to mitigating GHG emissions. Area four includes the analysis of the main technical and economic limitations of implementing CCUS techniques. Finally, cluster six includes research on the optimisation of CCUS systems considering the importance of clean energy production within the political framework of each country.

The literature review of the most current CCUS techniques reflects three main CO_2 capture methodologies: pre-combustion, oxy-combustion, and post-combustion with storage, mainly in geological formations, oil fields, aquifers, and vegetation [45]. It is important to highlight that there are approaches to oceanic storage as an alternative to CO_2 storage;

Table 2: CCUS techniques in the last decade.

Technique	Contribution	References (DOI)
CO_2 capture		
Pre-combustion	The technology captures CO_2 by converting fuel into a mixture of carbon monoxide and hydrogen. The CO_2 obtained is stored for later use, and the hydrogen is used to produce energy.	10.1016/j.apenergy.2016.09.103 10.1016/j.envres.2021.112219
Oxy-combustion	Carbon-based fuel-burning processes with highly pure oxygen and recycled flue gas for CO_2 capture and storage.	
Post-combustion	Expensive technology involves separating CO_2 from combustion gases through absorption, adsorption, membranes, microalgae, and cryogenic processes.	
CO_2 storage		
Underground storage	These techniques are considered anthropic, in which CO_2 is stored in geological formations, aquifers, or injected into oil fields, and is mainly characterised by a high storage capacity, porosity, and confinement that prevent future leaks.	10.1016/j.gr.2023.07.003 10.1016/j.ijggc.2015.11.032 10.1016/j.ijggc.2016.07.026
Ocean storage	This research technique involves injecting CO_2 into the sea at depths greater than six kilometres to allow storage and prevent water contamination by acidification.	10.1007/s12182-019-0340-8 10.1016/j.egypro.2017.03.1686
Land storage	These techniques are characteristic of CO_2 storage in soils and vegetation to reduce GHG emissions.	10.1007/s11356-017-9742-6
CO_2 utilisation		
CO_2 storage has a variety of uses, including biofuel production, energy production, construction, chemical production, urea production, thermochemical processes, seawater desalination, food processing, and polymer development.		10.1016/j.cej.2020.128138 10.1073/pnas.1821029116 10.1016/j.jcou.2021.101580

however, there are still debates about its effectiveness and the level of water contamination [46]. From the viewpoint of CO_2 utilisation, several studies have analysed the success of CO_2 in energy production an
d food processing, including construction processes [47], [48]. The findings of this study agree with the existing literature review investigations [36], [49], suggesting a main research gap in the political-economic analysis that would represent the implementation of CCUS techniques in different developing countries.

CCUS is a constantly growing area of research that offers an alternative to combat the effects of exploiting fossil fuels that compromise human and environmental wellbeing. The proposed methodological approach represents a tool for future work of CCUS that allows researchers to identify the main areas that have been investigated to date with the most current technologies applied globally. The study's main limitation is the use of a database (Scopus); future literature reviews in the field could include the combination of two or more databases to guarantee a comprehensive analysis of the different research published globally.

5 CONCLUSIONS

The dependence on fossil fuels to meet the global energy demand is one of the main sources of atmospheric pollution. Investigating the capture, storage, and use of carbon (CCUS) is a tool that combines the effects produced by the emission of GHGs that contribute to global warming. This document reviews bibliometric techniques and literature on the research areas within the CCUS and exposes the main techniques used in the last decade.

In general, the research published in Scopus reflects six main areas of research that include the design and evaluation of CCUS techniques and the analysis of its functionality and technical, economic, and environmental aspects of its implementation. The literature review reports that pre-combustion, oxy-combustion, and post-combustion are the three main carbon capture techniques associated with underground, oceanic, and vegetable storage for later use in the energy, chemical, construction, and food industries.

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