Three Decades of Forest Carbon Dynamics Modeling Using CO2FIX: A Bibliometric Analysis

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Three Decades of Forest Carbon Dynamics Modeling Using CO2FIX: A Bibliometric Analysis

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Abstract Forest carbon modeling is essential in climate change mitigation activities. Projection of forest carbon for a certain period can be used to develop other actions to mitigate climate change, such as public policy, forest management scenarios, and other interventions to reduce greenhouse gas emissions. The CO2FIX model estimates carbon content through empirical growth data that is a user-friendly measurement for forest managers. This review article aims to describe the research trends in forest carbon dynamics modeling using CO2FIX. Our findings show that CO2FIX has been applied to a wide range of forest types in 27 countries. The most productive researchers have come from China, India, the Netherlands, and Spain. However, collaboration among researchers across countries has been limited. The number of articles related to CO2FIX indexed by the Scopus or the Web of Science (WoS) database has gradually increased since the first was published in 1995. Furthermore, the top five items used in the CO2FIX publications were carbon sequestration, CO2FIX, carbon, forestry, and forest management. In conclusion, CO2FIX is a user-friendly, forest carbon dynamics model that is used widely by researchers for various types of forests and results in a precise estimation. Furthermore, based on 63 articles indexed by the Scopus database and 50 articles indexed by WoS, collaboration among researchers should increase to solve more complex problems related to climate change mitigation in the forestry sector.

Keywords: climate change, forest types, research trends, carbon sequestration, VOSviewer

Introduction

Climate change mitigation through forest carbon accounting

Climate change mitigation is a global issue that receives serious attention from various parties, primarily actions to keep the earth's temperature rising less than 1.5°C by reducing greenhouse gas (GHG) emissions. The Intergovernmental Panel on Climate Change[1)] stated that GHG emissions have continued to grow, causing the earth's temperature to rise. In 2023, July was confirmed as the hottest month on record since 1940[2)]. Furthermore, Copernicus has reported that rising temperatures have caused wildfires in some European countries[3)].

The most prominent mitigation actions are using renewable energy to minimize GHG emissions, managing forests as potential resources to sequester carbon from the atmosphere, and storing above- and below-ground biomass. Mechanisms of forest and bioenergy strategies to reduce CO_2 emissions are storing carbon in the biosphere, storing carbon in wood products, using bioenergy to substitute fossil fuel, and utilizing wood products to substitute other products that require fossil fuel in their production[4)]. Furthermore, transitioning energy from fossil fuel to renewable energy to generate electricity for industrial purposes is vital to reducing CO_2 emissions[5)]. Some potential renewable energies that can replace fossil fuels in power plant generation and industries are solar cells[6)], wind[7)], geothermal[8,9)], and bioenergy[10–13)]. Biomass from microalgae[14,15)], agricultural products (coconut shell)[11)], sugarcane bagasse[16)], olive pomace[17)], oil palm trunk[10)], municipal and industrial waste[18)], and bioenergy plantations[12,13)] are potential sources of fuel for the transition to clean energy.

Globally, climate actions are focused on lowering carbon dioxide emissions and increasing carbon dioxide sinks[19)]. Forest loss due to natural and anthropogenic disturbances has contributed to 20% of greenhouse gas emissions worldwide[20)]. In contrast, sustainable forests have the potential to sequester and store carbon in above- and below-ground biomass. For instance, mangrove forests in the Indo-Pacific have the potential to store around 1,023 Mg C/ha of carbon[21)]. Furthermore, the estimation of carbon stock in tropical, temperate, and boreal forests is 447, 169, and 458 Mg C/ha [22)]. Hence, forests play a role in a carbon neutrality scheme that can absorb CO_2 from the atmosphere through photosynthesis and release the emission to the atmosphere through forest degradation[23].

Forest inventory plots, atmospheric inversions, satellite images, and modeling are methods for measuring forest carbon dynamics[24]. Time series data from the forest inventory plots database is vital to projecting forest carbon dynamics through empirical growth data. For example, the Korean government has projected 26 million tons of carbon sequestration in forestry in the Nationally Determined Contribution by 2030[25]. Some examples of sources of input data in forest modeling are national forest inventories (species, diameter, height, density), climate data (temperature, precipitation, evapotranspiration), and forest management systems[26].

Forest carbon modeling

Understanding forest carbon dynamics is essential to better understanding the distribution of carbon pools (trees, soil, and wood products). Tree species diversity, geography, and climate conditions pose challenges to forest carbon dynamics modeling[27]. Some software has been developed to simulate forest carbon dynamics. It estimates carbon stocks based on photosynthetic processes and empirical growth data[28,29]. Furthermore, terrestrial carbon cycle modeling can be classified based on biogeographic models (BIOME, MAPSS) and biogeochemical models (CENTRY, BIOME-BGC, and TEM)[30].

However, the review implementation of carbon dynamic modeling has not been widely carried out for almost three decades. There were two review articles on carbon budget modeling (CBM) in the Scopus database. Hall and Richardson[31] discuss the energy from forest project in Canada to better understand nutrient cycling, carbon dynamics, and production technologies for energy plantations. Moreover, Biggs and Craig[32] elaborate on carbon offset in afforestation projects in Canada. The Scopus database includes two review papers for the European Forest Information Scenario (EFISCEN) model. Lindner[33] elaborates on biomass projection from forest harvest residues, while Nabuurs[34] discusses EFISCEN for the carbon dynamics model from plot level to regional and country scales.

To the authors' knowledge, the review articles on CO2FIX conducted in 2015 emphasized the comparison of four types of forest carbon dynamics software. This review article analyzes forest carbon dynamics modeling using empirical growth data, namely, CBM-CFS3, CO2FIX, CASMOFOR, and EFISCEN[28].

Furthermore, Kim et al.[28] observe that carbon dynamics modeling with empirical growth data (CBM-CFS3, CASMOFOR, EFISCEN, CO2FIX) has been widely used by researchers because growth data is more user-friendly to measure than the photosynthetic process. The CO2FIX model is good software for developing empirical models of forest carbon dynamics because of its precision and ease of use[27]. The use of CO2FIX in modeling forest carbon dynamics has been applied to various forest types in both tropical and temperate regions. CO2FIX has been extensively implemented to estimate carbon dynamics in forestry, agriculture, and agroforestry sectors[35]. It has some additional modules based on the cohort approach, which is appropriate for people interested in a wide range of carbon dynamics in small-scale forests[28]. Furthermore, this review aims to describe the research trends in CO2FIX software for modeling forest carbon dynamics in various types of forests.

Methods

Literature search

This study used 113 articles to analyze the research trends in implementing CO2FIX software to model forest carbon dynamics worldwide. Data was retrieved from the WoS and Scopus databases on August 9, 2023. For 15 years, from 2004 to 2018, researchers from around 140 countries and regions have contributed to publishing their articles in journals indexed in the WoS or Scopus database[36]. Although WoS and Scopus have been used widely in bibliometric analysis, they have different formats for providing the database and require specific techniques to merge their database into a single format[36–38]. Researchers who have merged Scopus and WoS databases in the bibliometric analysis did not mention specifically the method on how to merge these database[38]. Based on the author's experience, although the downloaded databases from Scopus and WoS are in CSV file (.csv), the format of database Scopus and WoS are different. Moreover, in the VOSviewer analysis, the database files of Scopus are RIS (.ris) or CSV (.csv), meanwhile the WoS database file is Plain text (.txt). Furthermore, Echchaoui[38] notes that, in some cases, scholars have analyzed the WoS and Scopus databases separately. Few researchers have integrated the WoS and Scopus databases into their bibliometric analysis because of the difficulty of merging them[37,38]. Because of the uniqueness of these databases, in this bibliometric analysis, we analyzed the WoS and Scopus databases separately.

We used the topic search "CO2FIX" and found the number of documents in the Scopus and WoS databases was 63 and 50, respectively. The query string in the Scopus database was TITLE-ABS-KEY(CO2FIX), and TS=(CO2FIX) was applied in the Web of Science (WoS) database. The full record was exported in different file formats for further analysis. The format of the retrieved database was a CSV file (.csv) for analyzing the description of reviewed articles (research growth, most influential articles, and distribution by countries). Moreover, RIS (.ris) from the Scopus database and Plain Text (.txt) from the WoS database were used to analyze the networks (country, author, and keywords co-occurrences) among the reviewed articles. We did not apply limitations for the type of document, publication period, language, type of accessibility, or source of articles.

Data analysis

Retrieved articles were analyzed descriptively to obtain information on the growth of publication over time, the most influential articles, and the distribution of research sites on forest carbon modeling using CO2FIX. Descriptive analysis can assist people who are interested in obtaining basic information about these topics[19]. Furthermore, Huang et al.[19] argue that bibliometric analysis is a prominent approach for depicting the trends of a specific topic from a large number of studies in a certain period.

In bibliometric analysis, different software can be used to analyze scientific parameters (authors, institutions, citations, and collaborations). These are Bibliometrix, VOSviewer, CiteSpace, Biblioshiny, SciMat, and Sci^{2}Tool[39]. Researchers have been using the VOSviewer software in bibliometric analysis because this software is user-friendly (does not need a programming language) and powerful in visualization co-citation, co-authorship, and collaboration links[39,40].

Furthermore, VOSviewer software was applied to analyze the network among authors, keywords, and countries. VOSviewer software has been used to visualize research trends, collaboration among authors and countries, and networks among keywords[41–43]. In the research on forestry and environmental sciences, bibliometric analysis has been applied by Soegoto et al.[44] to describe the management of bioenergy. Singh[45] links forest fire emissions to global climate change. Biancolillo et al.[46] discuss the forest bioeconomy, and Huang et al.[47] visualize the research trends on forest carbon sequestration.

Results and Discussion

General overview of CO2FIX research

According to the WoS and Scopus databases, 113 documents were published between 1995 and 2023 (August). The published documents in the Scopus and WoS databases are dominated by article papers (88.88%; 96%), articles written in English (92.06%, 98%), and articles published in journals (90.48%, 98%) (Table 1). Meanwhile, only one review paper was found in the Scopus database, which shows that review papers on implementing CO2FIX software in forest carbon dynamics modeling is still rare.

Table 1. Description of the reviewed articles on CO2FIX software

Description	Number of documents	
	Scopus (n = 63)	WoS **(n = 50)**
A. Type of document		
- Article	56	48
- Conference paper	5	1
- Book chapter	1	-
- Review	1	-
- News item	-	1
B. Language		
- English	58	49
- Spanish	3	1
- Chinese	2	-
- German	1	-
C. Source		
- Journal	57	49
- Conference Proceeding	5	1
- Book series	1	-

Masera et al.[48] has written the most influential article, which examined the structure of CO2FIX software version 2 and its application in five types of forests in tropical and temperate regions (Table 2). This finding is also strengthened by Fig. 3, which shows that the number of publications on CO2FIX increased gradually from 2004 to 2023, except in 2005 and 2020.

Table 2. The most influential articles on CO2FIX

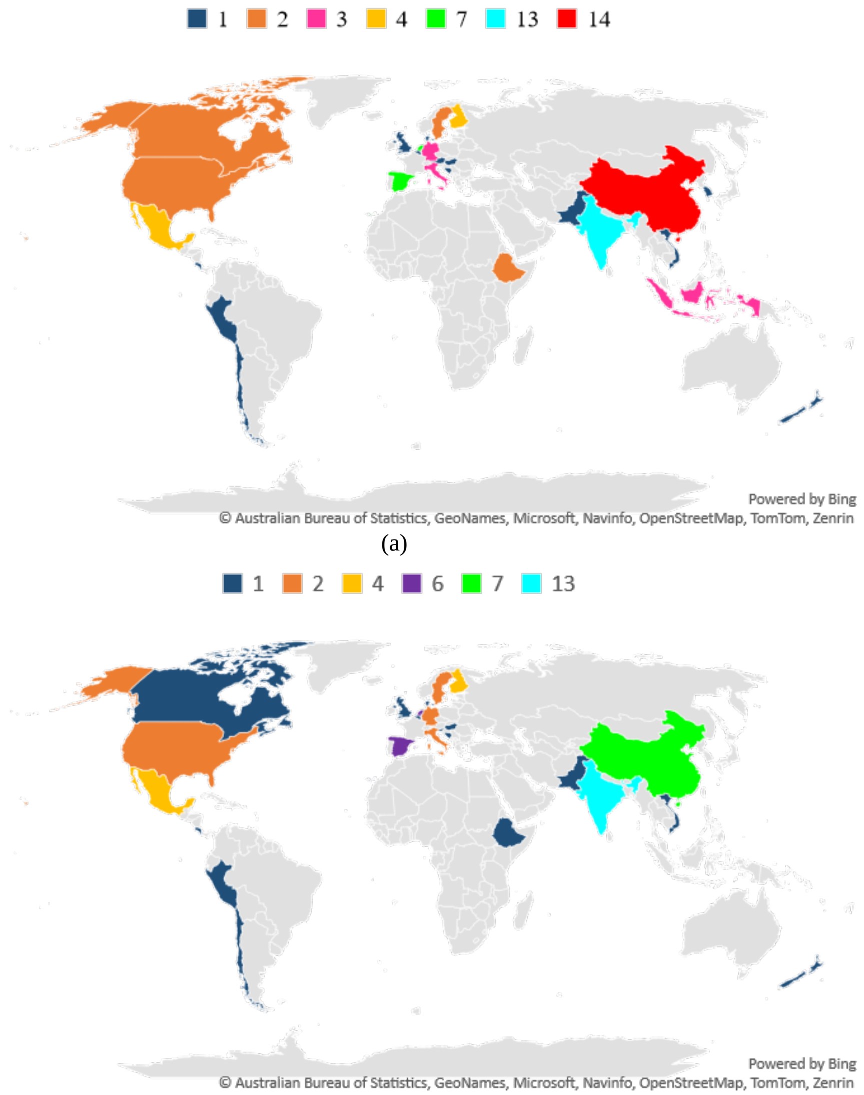
Title	Journal	Cited By	References
Scopus database			
Modeling Carbon Sequestration in Afforestation, Agroforestry and Forest Management Projects: The CO2FIX V.2 Approach	Ecological Modelling	238	48)
Managing Carbon Sinks by Changing Rotation Length in European Forests	Environmental Science and Policy	145	49)
Carbon Storage and Sequestration Potential of Selected Tree Species in India	Mitigation and Adaptation Strategies for Global Change	120	50)
Forest Management and Carbon Sequestration in Wood Products	European Journal of Forest Research	84	51)
Fossil Fuel Carbon Emissions from Silviculture: Impacts on Net Carbon Sequestration in Forests	Forest Ecology and Management	70	52)
Web of Science database			
Modeling Carbon Sequestration in Afforestation, Agroforestry and Forest Management Projects: The CO2FIX V.2 Approach	Ecological Modelling	225	48)

Managing Carbon Sinks by Changing Rotation Length in European Forests	Environmental Science and Policy	141	[49]
Carbon Storage and Sequestration Potential of Selected Tree Species in India	Mitigation and Adaptation Strategies for Global Change	103	[50]
Forest Management and Carbon Sequestration in Wood Products	European Journal of Forest Research	77	[51]
Fossil Fuel Carbon Emissions from Silviculture: Impacts on Net Carbon Sequestration in Forests	Forest Ecology and Management	63	[52]

Referring to Table 2, the order of articles that are highly cited in both the Scopus and WoS databases is the same. The difference between the two databases is the number of citations. The citation methods in some databases (Google Scholar, Scopus, and WoS) differ. Based on Martin et al.[53] the citation coverage of Google Scholar is the largest (93%–96%), followed by Scopus and WoS, 35%–77% and 27%–73%, respectively. The number of citations in the Scopus database is higher than in the WoS database because the coverage of the Scopus database is broader[54].

Implementation of CO2FIX

CO2FIX software has been applied worldwide to estimate forest carbon dynamics. There are 27 countries in the Scopus database and 25 in the WoS database (Fig.1). Indonesia and South Korea were not recorded in the WoS database as researchers from Indonesia and South Korea have published their works in journals that WoS does not index.



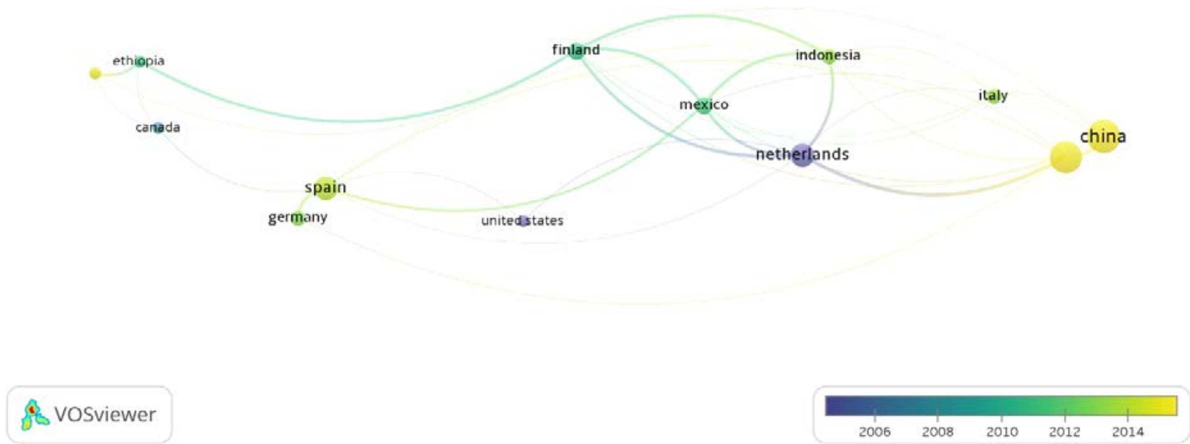
(b)

Fig. 1: Distribution of research on forest carbon dynamics using CO2FIX from a). Scopus, b). WoS database

According to Fig. 1, CO2FIX software has been applied in America, Africa, Asia, Australia and the Pacific, and Europe. However, in the Africa and the Australia and Pacific regions, the application of CO2FIX has been rare, only in Ethiopia and New Zealand. Furthermore, Asia, China, and India are the top countries that have used the CO2FIX model to estimate forest carbon dynamics.

The first version of CO2FIX was invented in the 1990s[55]. In the early 2000s, collaborative research developed the carbon dynamics model in afforestation, agroforestry, and forest management projects as the second and third versions[48,56]. In the visualization of co-occurrence analysis in VOSviewer, the Netherlands has been deemed the pioneer of CO2FIX modeling (the color represented before 2005). Furthermore, some researchers have been interested in applying this model and building a collaboration network. Researchers from China and India have dominated the collaboration, as seen in the big bullet size in the VOSviewer co-occurrence analysis (Fig. 2). In the research of carbon neutrality, the researchers from China were listed as the most productive, counting both single- and multiple-country publications[57].

The increase of research on carbon neutrality in China because of the policies of government of China to reduce CO_2 emissions and become carbon neutral in 2060[58]. The strategies to achieve carbon neutral in China can be achieved through carbon sink in the agricultural and forestry sectors, carbon capture and storage in industrial sectors, and energy transition in power plant generation[59]. Moreover, the government of China has encouraged the research institutions and universities to publish in internationally indexed journal and provide rewards for those who published[60].



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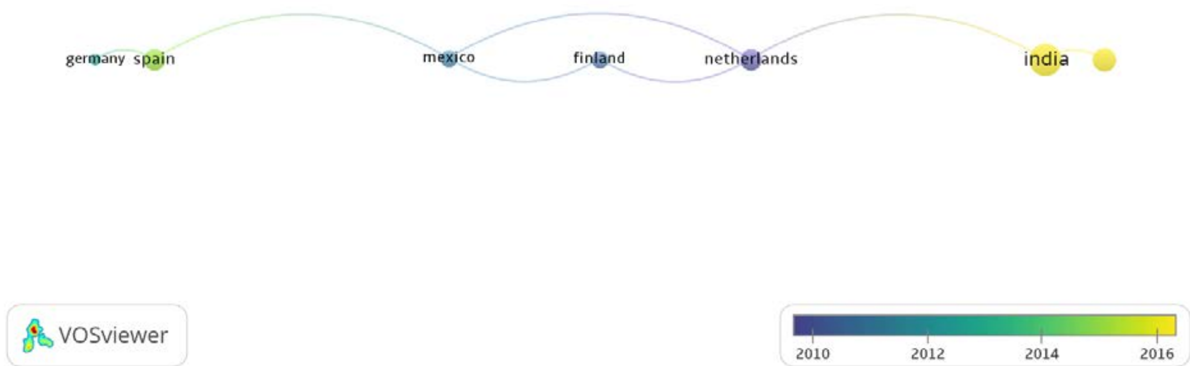


(b)

Fig. 2: Country collaboration based on a). Scopus, b). WoS databases

Referring to Fig. 2, collaboration among countries was still weak in both the Scopus and WoS databases. Our findings show that collaboration of more than two countries in the Scopus and WoS databases was 19% (12 articles) and 22% (11 articles), respectively. However, more than 90% of articles on forest carbon dynamics using CO2FIX have been written by more than a single author. These findings imply that the researcher had a network in their home country and researched specific sites in their home country.

Research growth on CO2FIX

The total number of documents retrieved from the databases was 113: 63 articles from Scopus and 50 from WoS. Furthermore, we merged the database and found duplicated articles in Scopus and WoS with 47 documents. Duplicated articles mean that the journals were indexed in Scopus or WoS databases. Thus, the merged database contained 66 articles.

From 1995 to 2023 (August), the growth of articles fluctuated. Between 1995 and 2013, the trend increased gradually. However, the number of articles on forest carbon dynamics using CO2FIX for the last 10 years was unstable and peaked in 2015–2017 (Fig. 3)

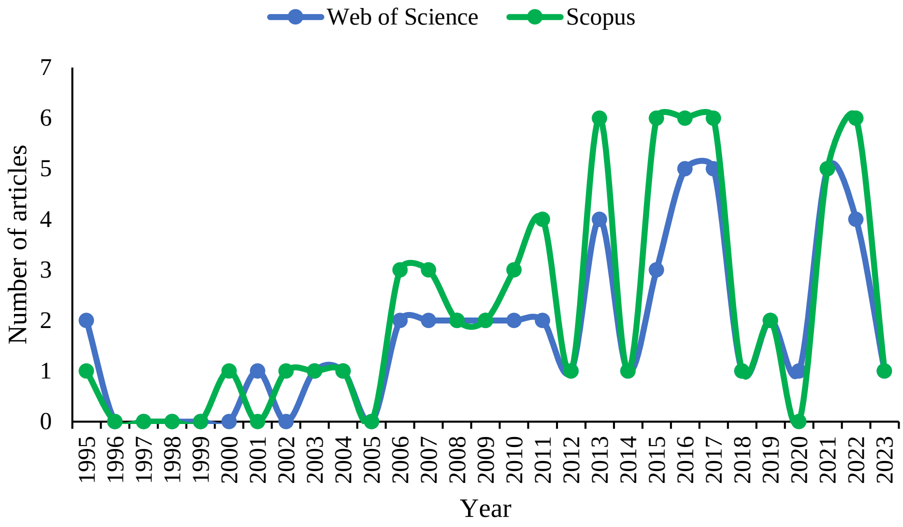


Fig. 3: Number of publications on CO2FIX

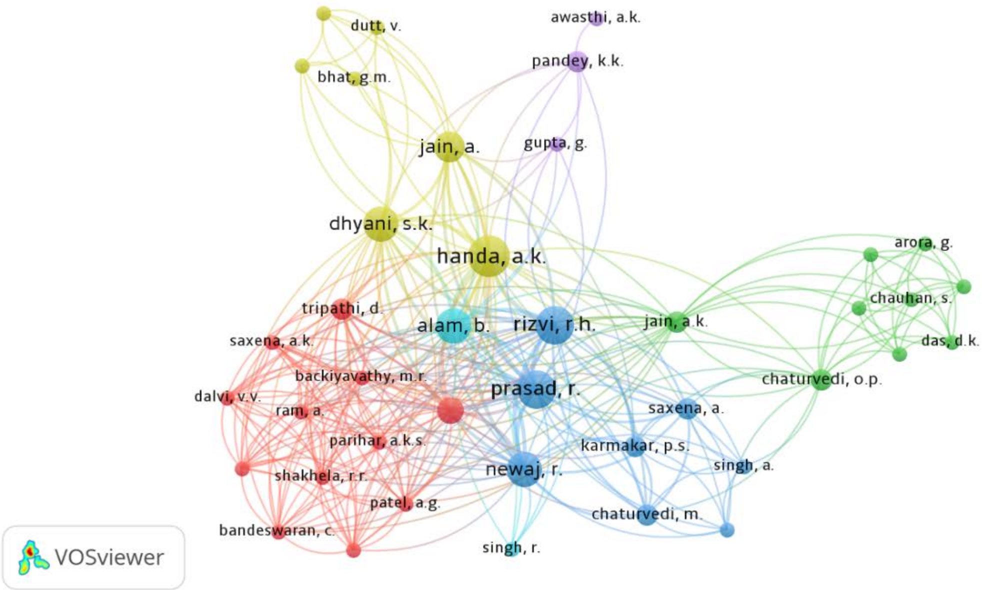
According to Fig. 3, the number of articles in the WoS database was generally lower than in the Scopus database. Although the WoS database is older than Scopus, the number of publications in Scopus has increased progressively compared to WoS.[36)] Originally, WoS was the most extensive database for bibliometric analysis, but since the launching of Scopus by Elsevier, it has emerged as a key competitor for doing bibliometrics analysis[38)].

From 1995 to August 2023, the average number of publications in the Scopus and WoS databases was 1.72 and 2.17 articles per year, respectively. In detail, we divided the analysis into 1995–2005, 2006–2015, and 2016–2023. In the first period, the total and average published documents in WoS and Scopus were five articles and 0.45 articles per year. The second (2006–2015) and third (2016–2023) showed a similar pattern. The highest was six documents and the lowest was one document, except in 2020, when there were zero documents related to CO2FIX in the WoS database. However, productivity in the second and third periods was higher than in the first, with an average of 3.1 and 3.6 articles per year, respectively. The research trend on future climate change scenarios through the Delphi-based scenarios process has shown a similar pattern in that fewer than 10 articles per year have been published[61)].

Using co-authorship analysis with full fraction counting and a minimum number of one publication for each author, the results show that there were 197 authors in WoS and 221 in Scopus. Based on co-authorship analysis, the items in Scopus and WoS have been divided into four and five clusters, respectively (Fig. 4).

In the co-authorship visualization based on the Scopus database, Handa (7 documents, 90 citations), Prasad (6 documents, 90 citations), Rizvi (6 documents, 90 citations), Newaj (5 documents, 90 citations), and Alam (5 documents, 88 citations) were the authors who had the highest number of documents and citations. Meanwhile, in the WoS, the top five authors were Rizvi, R.H., Handa, A.K., Ajit, Prasad, R., and Newaj, R. The number of documents authored by Rizvi, Handa, Ajit, Prasad, and Newaj were 7 (76 citations), 7 (79 citations), 6 (65 citations), 6 (76 citations), and 6 (57 citations), respectively. The top five authors based on the VOSviewer analysis have high total link strength and are indicated with an extensive bullet in the co-authorship visual analysis.

According to Table 2, the most influential articles were written by Masera (225 citations), Kaipainen (141 citations), Kaul (103 citations), Proof (77 citations), and Markewits (63 citations). Although the number of their citations was high, the number of their documents and strength based on the VOSviewer analysis was low. Furthermore, their total link strength was also low. Based on the co-authorship analysis of the Scopus database, the total link strength of Masera, Kaipainen, Kaul, Proof, and Markewits was 11, 3, 2, 1, and 0, respectively. The total link strength for co-authorship analysis based on the WoS database also shows a similar result.



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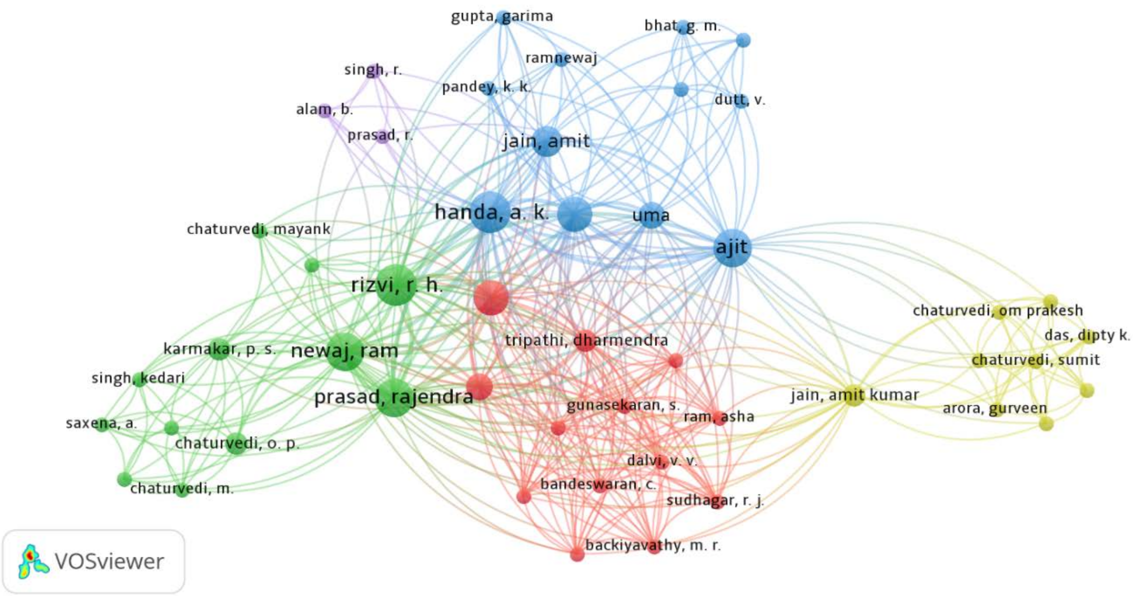
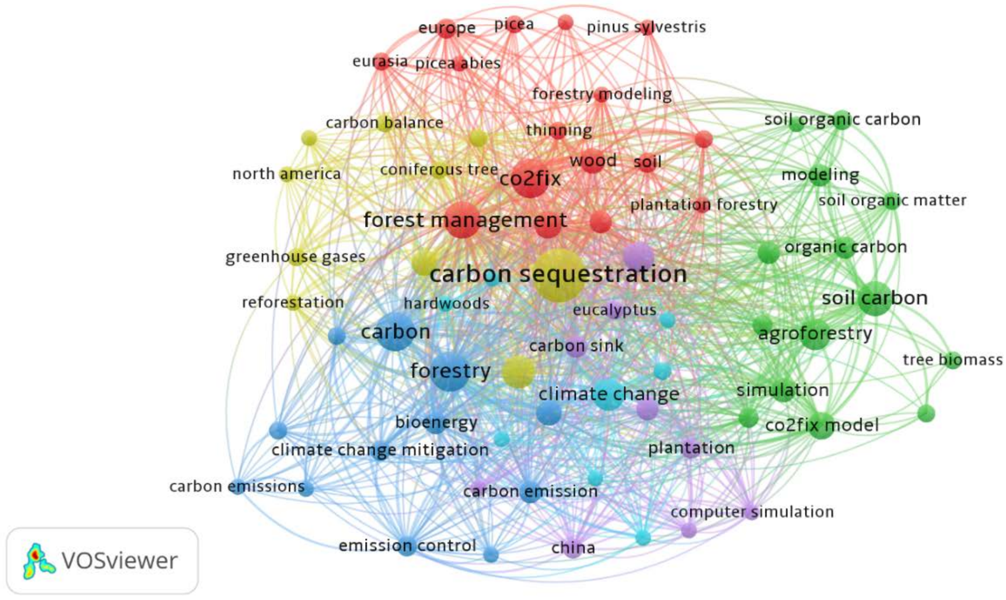


(b)

Fig. 4: Co-authorship visualization based on a). Scopus, b). WoS database

The other finding in the CO2FIX research network analysis was the co-occurrence analysis based on keywords. All keywords in WoS were 311, while in the Scopus database, they were 642. In the co-occurrence analysis, we limited at least three similar keywords among the reviewed articles and found 41 keywords in the WoS and 69 in the Scopus databases (Fig. 5).

The keywords co-occurrence analysis in VOSviewer resulted in six clusters with 69 items for Scopus and five with 41 items for the WoS database (Table 3). Items are objects of interest in the co-occurrence analysis[62]. Furthermore, Van Eck and Waltman[62] explain that the items are grouped into clusters, and in the visualization of the map, items with a high weight are represented by bigger bullets than the lower-weight items. Our findings show that the five most prominent items are carbon sequestration, CO2FIX, carbon, forestry, and forest management.



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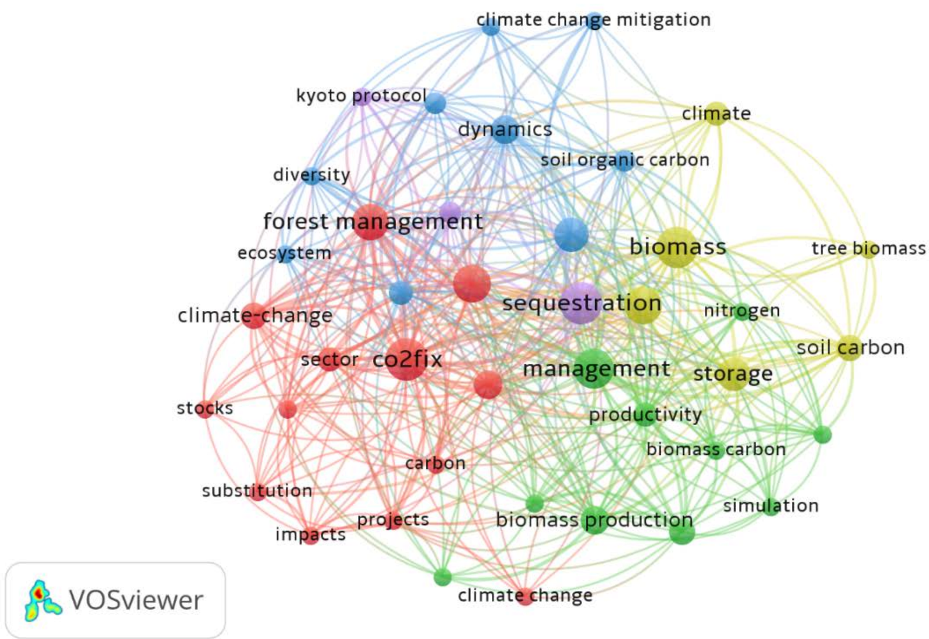

(b)

Fig. 5: Keywords co-occurrence visualization based on a). Scopus, b). WoS database

Table 3. Cluster of items based on keywords

Database	Cluster					
	I	II	III	IV	V	VI
Scopus	**16 items** CO2FIX, Eurasia, Europe, Forest, Forest Management, Forestry modeling, Greenhouse gas, Kyoto Protocol, Picea, Picea abies, Pinus sylvestris, Plantation forestry, Rotation length, Soil, Thinning, Wood	**14 items** Above-ground biomass, Agroforestry, Carbon sequestration, CO2FIX model, India, Modeling, Numerical model, Organic carbon, Simulation, Soil carbon, Soil organic carbon, Soil organic matter, Tree, Tree biomass	**12 items** Bioenergy, Carbon, Carbon emission, Carbon emissions, Chelation, Climate change mitigation, Emission, Emission control, Forest carbon sinks, Forest ecosystem, Forestry, Harvesting	**10 items** Afforestation, Biomass, Carbon balance, Carbon sequestration, Coniferous tree, Ecosystem modeling, Estimation method, Greenhouse gases, North America, Reforestation	**9 items** Article, Carbon dioxide, Carbon sink, China, Computer simulation, Ecology, Eucalyptus, Plantation, Trees	**8 items** Carbon footprint, Carbon storage, Climate change, Environmental economic hardwoods, Rotation, Sustainable development, Wood products
WoS	**13 items** Carbon, Carbon sequestration, Climate change, Climate-change, CO2FIX, Forest management, Growth, Impacts, Projects, Sector, Stocks, Substitution, Wood products	**10 items** Biomass carbon, Biomass production, FO2FIX model, Management, Nitrogen, Plantations, Poplar, Productivity, Simulation, System	**9 items** Agroforestry, Climate change mitigation, Diversity, Dynamics, Ecosystem, Mitigation, Rotation length, Sinks, Soil organic carbon	**6 items** Afforestation, Biomass, Climate, Soil carbon, Storage, Tree biomass	**3 items** Kyoto Protocol, Model, Sequestration	-

Application of CO2FIX in a wide range of forest ecosystems

According to Table 1 in the previous subsection, the review paper on CO2FIX was the only study for almost three decades. It was conducted by Kim et al.[28] to analyze the strengths and weaknesses of four forest carbon dynamics models (CBM-CFS3, CO2FIX, CASMOFOR, and EFISCEN) using empirical growth data. In this review paper, we describe the implementation of CO2FIX in a wide range of forest ecosystems. CO2FIX has been applied in a wide range of land uses, such as tropical forests (natural and plantation), subtropical forests (natural and plantation), temperate forests (natural and plantation), shifting fallows, and agricultural land[63].

Furthermore, the CO2FIX in forest carbon dynamics is also applied in forest types based on topography, geography, and climate variations. Topographically, the application of CO2FIX on a projection of forest carbon dynamics has been applied in lowlands[27,64], sub-mountain[65], and mountainous areas[66–68]. Geographically and climatically, estimation of forest carbon dynamics using CO2FIX has been conducted in tropical lowland forests[55], tropical dryland forests [69], tropical humid forests[66], tropical savannas[70], temperate semi-arid forests[65,71,72], temperate semi-humid forests[65,71,72], temperate humid forests[73], and boreal forests[74]. Thus, CO2FIX is applied in many types of forests, from lowland to mountainous areas within tropical to temperate regions.

For almost three decades, the implementation of CO2FIX dominated the forest plantation and agroforestry systems. Only a little research was conducted in natural, conservation, and community forests. Referring to Nabuurs and Schelhaas[75], in the early stages of the development of CO2FIX, this software was tested in 16 types of forests across Europe. Nowadays, based on forest management purposes, CO2FIX is applicable in natural forests[55,66], forest plantations[55,65,73], conservation forests[76], community forests[67], afforestation and reforestation projects[55,77,78], and agroforestry systems[71,72].

According to the dominant tree species, our findings showed that the perennial woody species as the object of the CO2FIX model varied among the research sites (Table 4). The purposes of CO2FIX modeling for forest management were a source of wood supply for fuel wood and wood products (sawn, pulp and paper, veneer, and furniture). Moreover, based on the time span of simulation, there were less than 25 years[35,49,79], 25–50 years[71,72,80], 50–100 years[52,74], and more than 100 years[65,69,73,81].

Table 4. Wide range of applications of CO2FIX

No	Tree species	Forest types	Products	Countries	References
1	*Larix gmelinii*	Plantation	Wood products	China	65)
2	*Picea mariana*	Afforestation	Wood products	Canada	74)
3	*Populus alba*	Floodplain forest	Fuel for energy	Hungary	81)
4	*Salix alba*	Floodplain forest	Fuel for energy	Hungary	81)
5	*Populus deltoids*	Agroforestry	Fuel for energy	India	71,72)
6	*Eucalyptus tereticornis*	Agroforestry	Wood products	India	71,72)
7	*Madhuca latifolia*	Agroforestry	Wood products	India	35,71,72)
8	*Melia azedarach*	Agroforestry	Wood products	India	71,72)
9	*Azadirachta indica*	Agroforestry	Wood products	India	71,72)
10	*Albizia procera*	Agroforestry	Wood products	India	35,71,72)
11	*Terminalia arjuna*	Agroforestry	Wood products	India	35,71,72)
12	*Mangifera indica*	Agroforestry	Wood products	India	71,80,82,83)
13	*Ziziphus mauritiana*	Agroforestry, dry forest	Wood products	India, Indonesia	69,80,82,83)
14	*Tectona grandis*	Agroforestry, dry forest	Wood products	Indonesia	35,69,82,83)
15	*Diospyros celebica*	Dry forest	Wood products	Indonesia	69)
16	*Eucalyptus urophylla*	Dry forest	Wood products	Indonesia	69)
17	*Pinus patula*	Mountainous forest	Wood products	Mexico	66)
18	*Quercus* sp.	Mountainous forest	Wood products	Mexico, Spain	66,73)
19	*Pinus radiata*	Forest plantation	Wood products	Spain	73)
20	*Eucalyptus globulus*	Forest plantation	Wood products	Spain	73)
21	*Pinus taeda*	Forest plantation	Fuel for energy	United States	52)
22	*Pseudotsuga menziesii*	Forest plantation	Fuel for energy	United States	52)

Conclusions and Recommendations

In conclusion, the CO2FIX model is software for estimating forest carbon dynamics in short-, medium-, and long-time simulations. This model has been implemented in various types of forests on the basis of the variation of geography, climate, topography, forest management scenarios, and dominant tree species. However, the research growth of the CO2FIX model was less than 10 articles per year from 1995 to 2023 (August). Researchers from China and India published around 30% of the total publications during this period.

Based on our findings from 113 reviewed documents, the research of CO2FIX has been dominated by forest plantation. Furthermore, we recommend implementing CO2FIX in various types of natural and community forests to obtain better information about forest carbon dynamics that will support actions to mitigate climate change.

Acknowledgments

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Nomenclature

CBM	Carbon Budget Modeling
EFISCEN	European Forest Information Scenario
GHG	Greenhouse gasses
WoS	Web of Science

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