A scientometric analysis of the critical role of composite materials in dealing with climate change (2004 – 2024)

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Abstract. Due to its detrimental effects on the environment and human life, climate change has drawn the attention of numerous researchers and academics from a wide range of fields. This systematic review tackles this significant subject. This study gathers and examines data from various research publications, polls, and reports to give a thorough picture of the current status of climate change. The assessment also seeks to highlight the critical role that composite materials play as a cutting-edge material utilized in many industries to address the climate catastrophe. The review specifically looks at the many types of composite materials, how they are made, and how they might be used in particular industries. The research also examines the efficacy of current advancements in composites and policy solutions used worldwide to fight global warming. The review attempts to give a comprehensive picture of composite materials that play a vital role in conservation by combining data from other studies, pointing out knowledge gaps, and recommending future research approaches. This thorough analysis is invaluable for environmental scientists, decision-makers, and other community members engaged in climate conservation.

1 Introduction

Human activities, including technological advancements, damage the planet through pollution and resource consumption. Climate change is a significant threat, with glaciers disappearing, desertification increasing, and water shortages in Africa. Climate change presents a collective challenge, requiring global efforts for mitigation and adaptation. The Copenhagen Summit highlighted global concerns about these issues. Climate change, air pollution, natural resource depletion, waste production, water pollution, and urban decay are global issues that require urgent action. To address these threats, the world must cut emissions by 50% below current levels by 2050 [1, 2]. Traditional solutions can contribute to the global

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climate problem, making developing more efficient, affordable, and environmentally sustainable systems critical.

Climate change is a global issue that requires balancing short-term costs and long-term benefits. Investing in clean technologies and abatement equipment is necessary for reducing greenhouse gas emissions [3]. However, the benefits are not limited to the lifetime of physical capital but also the lifetime of greenhouse gases. Therefore, climate change policies must balance these benefits with current costs. To effectively control climate change, strategies must include not only CO2 emissions but also other greenhouse gases. Comparing the impacts of each gas is challenging because of their different lifetimes and impacts. A cost-effective approach must consider each greenhouse gas's abatement methods and impacts. To plan for the future, the researchers must understand how climate impacts change as greenhouse gas concentrations increase. The probability that observed warming is due to natural causes is less than five percent. To express the risk of exceeding 2°C of global warming and CO2 concentrations [4], the researchers must consider the global average surface temperature increase of 0.74°C over the past century. CO2 concentrations have increased by 37% since the Industrial Revolution, while methane and nitrous oxide have also increased. New technologies, such as ocean power [5] and photovoltaics [6], are essential for the climate response. This technology can help mitigate climate change and enable societal adaptation, with early action and widespread deployment slowing its impacts.

Economic, social, and environmental reasons drive the development of new materials and unconventional technologies in engineering. The crisis of raw materials and energy sources and the increasing human aggression towards the environment have led to the evolution of technologies in engineering [7, 8]. Composite materials, which combine these qualities, represent the future of engineering. They allow the creation of materials with specific properties that meet technical parameters. Composite materials are increasingly replacing classical materials in various fields, including household goods, spacecraft, and nuclear power plants. Sustainability is a compelling argument in material selection, with fiber-reinforced polymer composites increasingly being adopted in the transportation, construction, and renewable energy markets. Composite structures offer a long service life, low maintenance requirements, and lower energy consumption. However, maximizing the sustainability benefits of composite components requires considering the entire life cycle. This study compiles and analyzes data from various academic articles, surveys, and reports to provide a comprehensive picture of the current state of climate change. By integrating information from other studies, highlighting knowledge gaps, and offering suggestions for future research directions, this study aims to provide a comprehensive picture of composite materials necessary for conservation in the face of climate change. This comprehensive bibliographic literature review analysis is invaluable for environmental scientists, policymakers, and other members of the public involved in climate conservation.

2 Methodology

To show the latest scientometric results, this study selects databases available on the internet and analyzes them qualitatively and quantitatively using bibliometric tools. The methodology used is to determine relevant documents using titles, abstracts, and keywords related to the focus of this study. The targeted publications are those related to the keywords "composite," "material," "climate," and "change," published from 2004 to 2024. The selection of unique criteria was added only for publications in English with a final publication status. In addition, the open access criterion was chosen because it indicates that the publication can be accessed for free and without restrictions by all researchers worldwide—the process of selecting papers with these provisions until the desired results are illustrated in Figure 1.

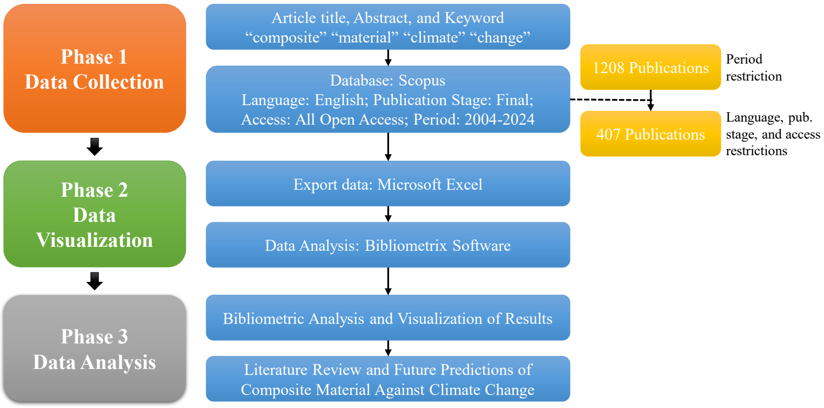

Fig. 1. The Methodology Flowchart.

3 Literature review

3.1 Composite material classification

A composite material combines two or more chemically distinct substances with an interface, where each component retains its identity but together forms a material with unique properties. It consists of a continuous matrix phase and a discontinuous reinforcement phase that enhances its characteristics. Fibers primarily resist tension, while the matrix has more excellent elongation and tensile strength, effectively distributing stress. Essentially, composites possess qualities that individual materials alone may not have. Fiber-reinforced composites fall into four main categories [9]:

a. Polymer Matrix Composites (PMCs) – These consist of thermosetting resins (such as epoxy, polyimide, or polyester) or thermoplastics reinforced with fibers like glass, carbon, boron, or aramid (Kevlar). They are typically used in applications with relatively low working temperatures, sometimes as low as 400°C in injection-molded thermoplastics.
b. Metal Matrix Composites (MMCs)—Made with metal matrices like aluminum, magnesium, titanium, or copper alloys, these composites incorporate reinforcements such as boron, graphite, or ceramic fibers (alumina or silicon carbide). Due to the matrix's softening or melting, their working temperatures are usually limited to 800°C. Nickel-based superalloys can be used for higher temperatures but come with the drawback of high density, increasing the structure's weight.
c. Ceramic Matrix Composites (CMCs) – Designed for high-temperature applications above 1000°C, these composites are based on materials like silicon carbide (SiC), alumina (Al_2O_3), and glass. Their reinforcement typically consists of ceramic fibers, often in short-staple form.
d. Reinforced Carbon-Carbon (RCC) – These composites feature a carbon or graphite matrix reinforced with graphite fibers or fabric. While expensive, they offer unmatched properties such as low density, minimal thermal expansion, and the ability to withstand extreme temperatures up to 3000°C.

Carbon fiber, fiberglass, and Kevlar are among the most widely used fiber-reinforced composites, each valued for its strength and lightweight properties.

3.2 Utilization of composite materials

Composite fiber materials exhibit exceptional versatility and have become integral to various high-performance sectors, including aerospace, automotive manufacturing, consumer electronics, and sustainable energy systems [10]. In the automotive industry, the demand for materials that reduce overall vehicle mass has intensified due to the push for improved fuel economy. As a result, carbon fiber-reinforced polymers (CFRPs) are increasingly replacing traditional metal components [11]. Leading automakers, such as Tesla and BMW, have incorporated CFRPs into electric vehicle designs to extend operational range and align with environmental objectives [12]. In civil engineering applications, these fiber composites outperform standard construction materials in terms of resilience, erosion resistance, and architectural adaptability. They are now a common feature in the development of infrastructure—bridges, structural frameworks, and fluid transport systems—where they contribute to improved durability and reduced structural degradation over time [13]. The lightweight profile of these materials not only streamlines the construction process but also ensures high resistance to corrosion and seismic impacts. Environmentally, composite fibers aid in conserving raw materials, minimizing energy demand, and curbing emissions of greenhouse gases [14]. Their integration in transportation sectors—especially in vehicles and aircraft—yields marked improvements in energy efficiency and reduced environmental burdens. Additionally, their mechanical robustness reduces maintenance frequency, thereby delivering both economic and ecological benefits [15].

4 Bibliometric results

The bibliometric results are displayed in Table 1. These results present the most discoveries of this bibliometric considering the role of composite materials in fighting climate change, covering the period from 2004 to 2024. It uncovers those 221 sources that were counselled, counting journals and books, coming about in 407 documents. The yearly development rate of the distribution was 25.02%, with a normal archive age of 4.17 a long time and a normal of 19.61 citations per document. Regarding substance, 3631 extra keywords and 1462 author keywords were recognized. The think about included 1870 authors, 10 of whom composed solo archives. Creator collaboration appears that 10 documents resulted from individual work, with a normal of 4.88 co-authors per document, and 34.15% of work included universal co-authors. Concerning archive sorts, 267 are articles, 71 are reviews, 62 are conference papers, 2 are short surveys, 2 are book chapters and editorials, and 1 document was retracted.

Table 1. Main Information.

Description	Results
Main Information about Data	
Timespan	2004:2024
Sources	221
Documents	407
Annual Growth Rate (%)	25.02
Document Average Age	4.17
Average Citation per Doc	19.61
Document Contents	
Keyword Plus (ID)	3631
Author's Keywords (DE)	1462
Authors	
Authors	1870
Authors of Single-Authored Docs	10

Description	Results
Authors Collaboration	
Single-Authored Docs	10
Co-Authored per Docs	4.88
International Co-Authorships (%)	34.15
Document Types	
Article	267
Book Chapter	2
Conference Paper	62
Editorial	1
Erratum	1
Retracted	1
Review	71
Short Survey	2

4.1 Overview

In the first decade, annual scientific production totaled 20 papers. Then, in the following decade, it increased significantly (Figure 4). This shows that this topic has a strong indication of quite a lot of interest and is one of the rising topics. Meanwhile, the annual citation report (Figure 5) data shows that the number of citations varies. 2016 was the peak year, with an average of 8.5 citations annually.

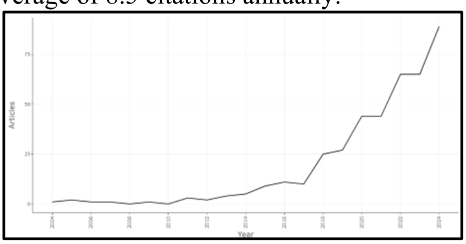

Fig. 4. Annual Scientific Production.

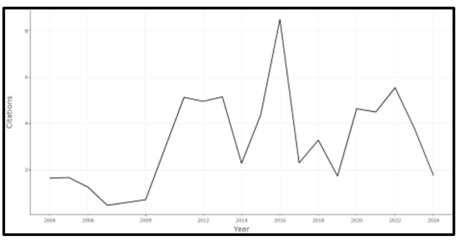

Fig. 5. Annual Citation per Year.

4.2 Conceptual & intellectual structure

The conceptual structure map highlights key research themes in climate change studies, with "climate change" as the central topic connecting various subfields. The analysis reveals two major clusters: one focused on energy efficiency and sustainable building materials, including thermal insulation, heat storage, and phase change materials, and another emphasizing material science and industrial applications, such as composite materials, polymers, and reinforced composites. The strong connections between these areas indicate an interdisciplinary approach, integrating environmental impact assessment, innovative materials, and energy-efficient solutions to support sustainability efforts.
Therefore, the intellectual structure analysis in Bibliometrix reveals the foundational and evolving research landscape through co-citation networks and thematic clustering. The co-citation network highlights key influential works, such as "cabeza l. 2007" and "evola g. 2013", which serve as central references in the field. Thematic clustering further shows how research has developed over time, with newer influential studies like "pisicopo g. 2020" and "roy r. 2023" contributing to expanding knowledge. These visualizations illustrate the interconnected nature of research themes and the progression of scholarly contributions.

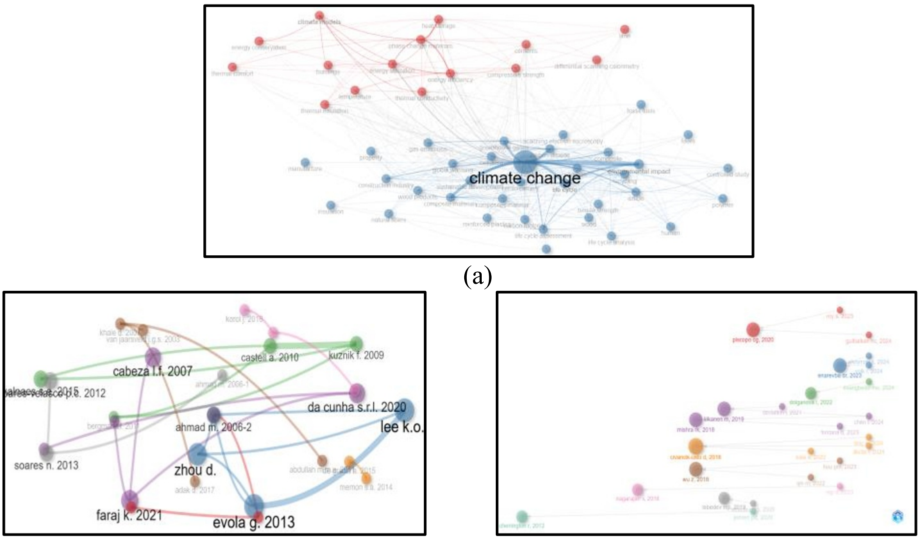

Fig. 5. Conceptual and Intellectual Structure: (a) Co-occurrence Network, (b) Co-citation Network, and (c) Historiograph.

5 Conclusions

This study highlights the vital role of composite materials in addressing climate change challenges by offering innovative solutions to improve energy efficiency, reduce carbon emissions, and extend the life and reliability of structures across industries. The increasing research trend in the last two decades shows the global interest in sustainable technologies, especially in transportation, construction, and renewable energy applications. Composite materials based on polymers, metals, ceramics, and carbon have improved fuel efficiency in the automotive and aviation sectors while strengthening infrastructure against corrosion and natural disasters. However, a holistic approach is needed throughout the material life cycle to maximize sustainability benefits, including more environmentally friendly production and recycling strategies. Therefore, collaboration between academia, industry, and policymakers is key to developing more sustainable composite materials while opening up opportunities for further research on biodegradable materials and more efficient recycling technologies.

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