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Mapping Research Trends and Knowledge Structure on Carbon Footprint: A Bibliometric Review

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ABSTRACT

The growing urgency of climate change mitigation has positioned carbon footprint research as a critical foundation for understanding and reducing greenhouse gas emissions across sectors. This study aims to map research trends and the knowledge structure of carbon footprint studies through a comprehensive bibliometric review. Using bibliographic data retrieved from the Scopus database, this study analyzes the evolution, intellectual structure, and thematic focus of carbon footprint research employing VOSviewer for visualization and network analysis. Co-authorship, co-citation, and keyword co-occurrence analyses were conducted to identify influential contributors, dominant research clusters, and emerging themes. The findings reveal that carbon footprint research is strongly anchored in sustainability and life cycle assessment frameworks, with growing emphasis on energy efficiency, renewable energy, circular economy, and data-driven approaches such as machine learning. Overlay and density visualizations indicate a shift from emission measurement toward integrative, solution-oriented, and technology-enabled sustainability strategies. This study contributes to the literature by providing a structured and holistic overview of the field, offering insights that can guide future research agendas, policy development, and practical implementation of low-carbon initiatives.

Keywords: *Bibliometric analysis; Carbon footprint; Greenhouse; Life cycle assessment; Sustainability*

INTRODUCTION

The concept of carbon footprint has emerged as a central analytical lens in understanding the environmental consequences of human activities in the context of accelerating climate change. As global temperatures continue to rise and extreme climate events become more frequent, carbon footprint measurement has been widely adopted to quantify greenhouse gas (GHG) emissions associated with products, organizations, individuals, and nations [1]. This concept plays a crucial role in translating abstract climate targets into measurable indicators that can guide mitigation strategies across sectors such as energy, transportation, manufacturing, agriculture, and consumption systems [2]. Consequently, carbon footprint research has grown into a multidisciplinary field connecting environmental science, economics, engineering, policy studies, and sustainability management [3].

Over the past two decades, international climate agreements and policy frameworks (such as the Kyoto Protocol, Paris Agreement, and national net-zero commitments) have intensified academic and practical interest in carbon footprint assessment. Researchers have developed various methodological approaches, including life cycle assessment (LCA), input–output analysis, hybrid models, and consumption-based accounting, to estimate emissions more accurately and comprehensively [4]. These methodological advancements have not only improved measurement precision but also expanded the scope of carbon footprint studies from production-based perspectives to consumption- and trade-oriented analyses, highlighting the globalized nature of carbon responsibility.

In parallel, the concept of carbon footprint has increasingly been integrated into organizational strategy and corporate sustainability discourse. Firms are under growing pressure from regulators, investors, and consumers to disclose carbon-related information and demonstrate

emission reduction efforts. As a result, carbon footprint research has expanded into areas such as carbon accounting, environmental reporting, supply chain management, and environmental, social, and governance (ESG) performance [5], [6]. This shift reflects a broader transition from purely environmental measurement toward strategic and managerial applications of carbon footprint knowledge.

Furthermore, carbon footprint studies have become closely linked with behavioral and social dimensions of sustainability. Scholars have examined how consumer awareness, lifestyle choices, and cultural norms influence carbon-intensive behaviors, as well as how policy instruments such as carbon labeling, taxation, and nudging can drive low-carbon transitions [7]. This behavioral turn underscores the importance of integrating social science perspectives into carbon footprint research, enriching the field with insights from psychology, sociology, and behavioral economics. Given its rapid growth and increasing diversity, carbon footprint research now constitutes a complex and fragmented body of knowledge. Publications span multiple disciplines, employ heterogeneous methods, and address varied levels of analysis—from micro-level household behavior to macro-level national and global emissions. While this richness reflects the maturity of the field, it also creates challenges in identifying dominant research themes, intellectual foundations, influential contributors, and emerging research fronts. Understanding how the field has evolved and how knowledge is structured has therefore become essential for guiding future research and policy-oriented inquiry.

Despite the substantial expansion of carbon footprint literature, there remains a lack of systematic, quantitative mapping of research trends and knowledge structures within this field. Existing review studies tend to focus on specific sectors, methods, or policy issues, often relying on narrative or systematic literature review approaches that may be limited in capturing large-scale intellectual patterns and network relationships among publications. Consequently, there is insufficient clarity regarding the evolution of core research themes, the interconnections between methodological approaches, the most influential authors and institutions, and the emerging topics shaping future carbon footprint research. This gap highlights the need for a comprehensive bibliometric analysis that can objectively visualize and analyze the intellectual landscape of carbon footprint studies. In response to this gap, the objective of this study is to map research trends and the knowledge structure of carbon footprint studies through a bibliometric review.

METHOD

This study employs a bibliometric analysis to systematically map research trends and the knowledge structure of carbon footprint studies. The data were retrieved from the Scopus database, selected for its comprehensive coverage of high-quality peer-reviewed journals across environmental science, sustainability, economics, and management disciplines. The search was conducted using relevant keywords related to carbon footprint in titles, abstracts, and author keywords, with the publication period covering all available years to capture the longitudinal development of the field. Only journal articles and review papers written in English were included to ensure academic rigor and consistency. The retrieved bibliographic data (including authors, titles, abstracts, keywords, citations, sources, and affiliations) were exported in compatible formats and analyzed using VOSviewer. VOSviewer was utilized to perform co-authorship, co-citation, bibliographic coupling, and keyword co-occurrence analyses, enabling visualization of collaboration patterns, intellectual foundations, and thematic clusters within carbon footprint research. Network maps were generated based on normalized citation and association strength measures to identify influential actors, core research themes, and emerging topics.

RESULT AND DISCUSSION

Co-Authorship Analysis

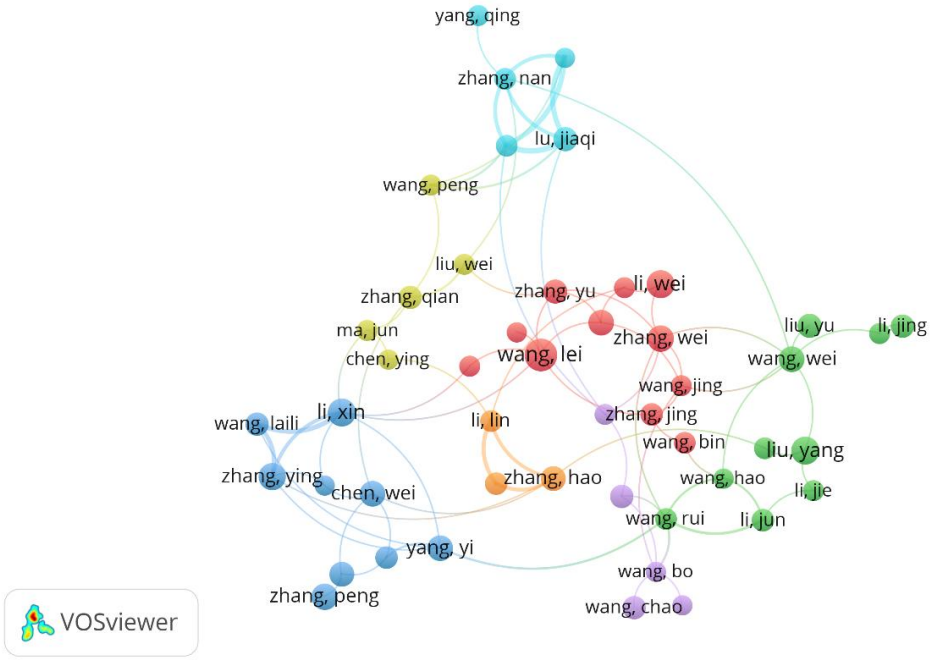

Figure 1. Author Visualization
Source: Data Analysis

Figure 1 illustrates the collaboration structure among influential authors in carbon footprint research, revealing several distinct yet interconnected research clusters. Prominent authors such as Zhang Wei, Wang Lei, Li Wei, and Zhang Jing occupy central positions, indicating their significant roles in knowledge production and collaboration across groups. The presence of multiple color-coded clusters suggests the existence of stable research teams or institutional networks, often characterized by frequent co-authorship within clusters and selective cross-cluster collaboration. Notably, bridging authors—such as Zhang Yu and Wang Jing—connect different clusters, facilitating knowledge diffusion and interdisciplinary integration within the field.

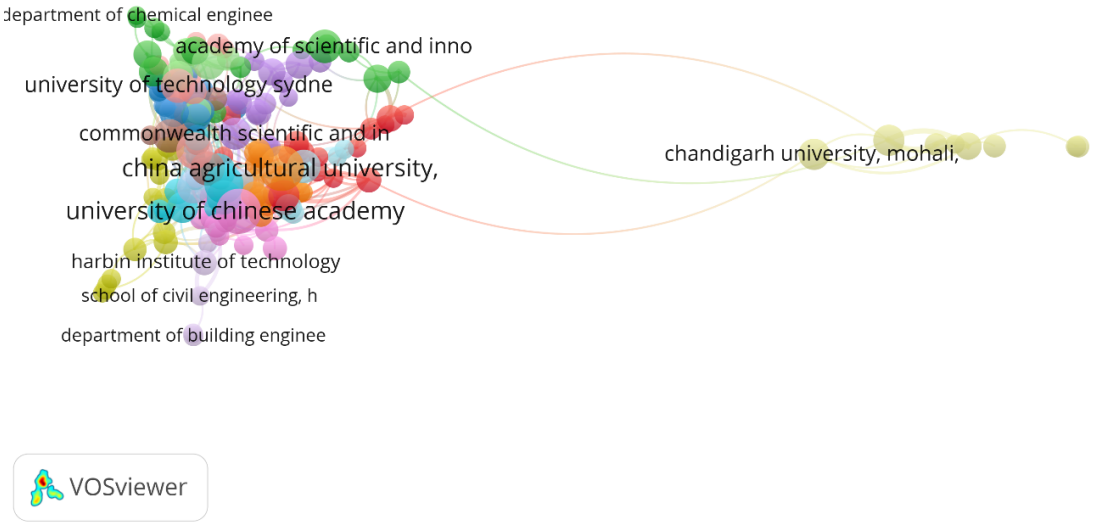

Figure 2. Affiliation Visualization
Source: Data Analysis

Figure 2 reveals the dominant role of major universities and research institutions in shaping carbon footprint research, with a dense core formed by organizations such as the Chinese Academy of Sciences, China Agricultural University, University of Chinese Academy of Sciences, and Harbin Institute of Technology. The strong interconnections among these institutions indicate intensive collaboration, particularly within engineering, environmental science, and agricultural research domains. International institutions, including the University of Technology Sydney and related research departments, are closely integrated into this core network, highlighting the global and interdisciplinary nature of carbon footprint studies. In contrast, Chandigarh University, Mohali appears more peripheral yet connected to the central cluster, suggesting emerging participation from institutions in developing regions.

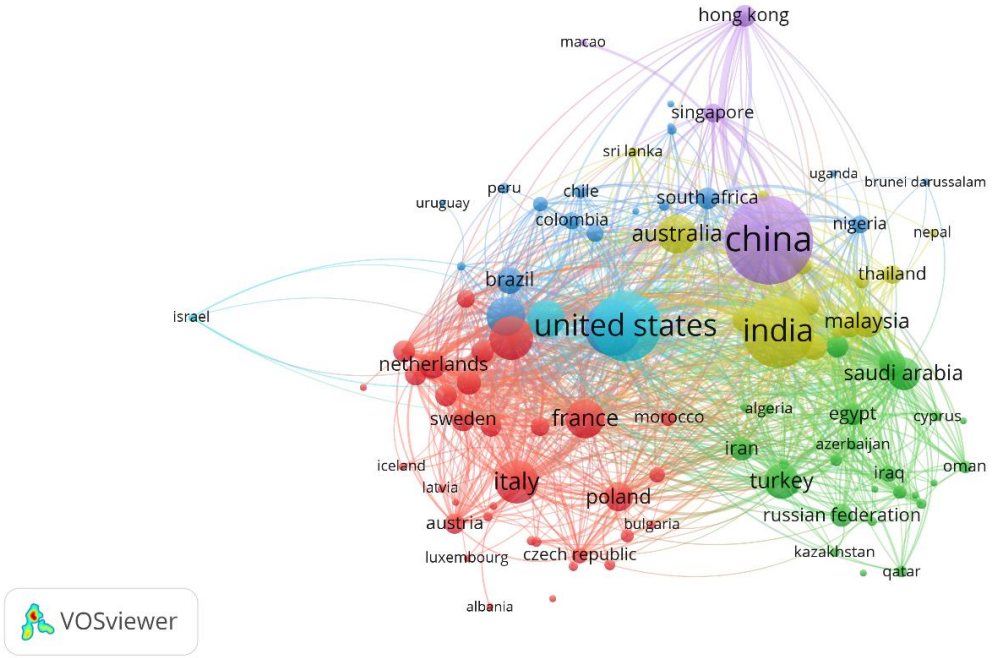

Figure 3. Country Visualization
Source: Data Analysis

Figure 3 illustrates the global distribution and international interconnectedness of carbon footprint research, with the United States, China, and India emerging as the most influential and highly connected contributors. These countries occupy central positions with extensive collaboration links, indicating their dominant roles in knowledge production and cross-national research partnerships. European countries such as Italy, France, the Netherlands, Sweden, and Poland form a dense collaborative cluster, reflecting strong regional cooperation within the European research ecosystem. Meanwhile, countries from Asia, the Middle East, and Africa (including Malaysia, Turkey, Saudi Arabia, Iran, South Africa, and Egypt, are increasingly integrated into the global network, suggesting the expanding geographical scope of carbon footprint research.

Citation Analysis

Table 1. Most Cited Article

Citations	Author and Year	Title
670	[8]	A comprehensive review of natural fibers and their composites: An eco-friendly alternative to conventional materials
391	[9]	Renewable energy integration with electric vehicle technology: A review of the existing smart charging approaches
311	[10]	Assessing the environmental impacts of renewable energy sources: A case study on air pollution and carbon emissions in China
292	[11]	Green and sustainable synthesis of nanomaterials: Recent advancements and limitations
278	[12]	Integrated global assessment of the natural forest carbon potential
260	[13]	Dynamic Reconstitution Between Copper Single Atoms and Clusters for Electrocatalytic Urea Synthesis
256	[14]	â€œColorsâ€ of hydrogen: Definitions and carbon intensity
255	[15]	Green hydrogen-based E-fuels (E-methane, E-methanol, E-ammonia) to support clean energy transition: A literature review
232	[16]	Chloride electrolyte enabled practical zinc metal battery with a near-unity Coulombic efficiency

Citations	Author and Year	Title
211	[17]	Contribution of plastic and microplastic to global climate change and their conjoining impacts on the environment - A review

Source: Scopus, 2025

Keyword Co-Occurrence Network Analysis

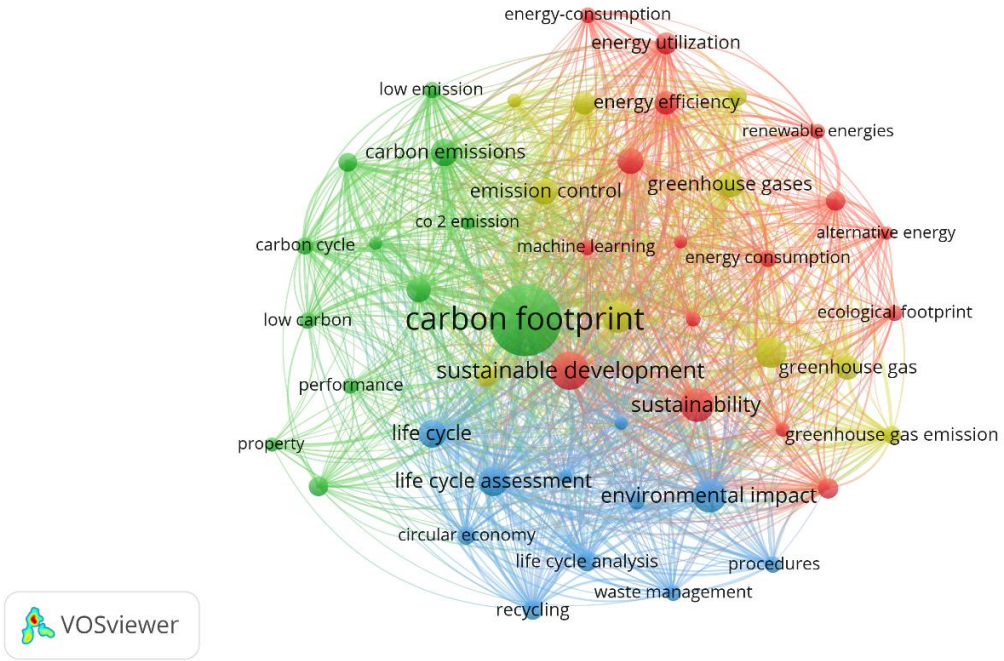

Figure 4. Network Visualization
Source: Data Analysis

Figure 4 illustrates that "carbon footprint" occupies a highly central position, confirming its role as the core conceptual anchor of the research field. Its strong connectivity with terms such as sustainable development, carbon emissions, life cycle assessment, and greenhouse gases indicates that carbon footprint research is inherently interdisciplinary and policy-relevant. The dense interlinkages surrounding the central node suggest that the concept is not treated in isolation, but rather as an integrative metric connecting environmental impact assessment, sustainability transitions, and emission mitigation strategies across sectors. The green cluster, which prominently includes keywords such as carbon emissions, CO_2 emission, carbon cycle, low carbon, and low emission, reflects a dominant stream of research focusing on emission measurement and reduction pathways. This cluster emphasizes macro- and meso-level analyses, including national emissions, sectoral performance, and decarbonization strategies. The presence of terms like performance and carbon cycle suggests that this stream not only quantifies emissions but also evaluates the effectiveness of mitigation efforts and their alignment with broader climate system dynamics.

The blue cluster centers on life cycle assessment, life cycle analysis, environmental impact, waste management, recycling, and circular economy. This cluster highlights the methodological backbone of carbon footprint research, where LCA-based approaches dominate the assessment of environmental impacts across product, process, and system boundaries. The strong association between carbon footprint and life cycle–related terms indicates that the field heavily relies on cradle-to-grave or cradle-to-cradle perspectives, reinforcing the importance of systems thinking and resource efficiency in sustainability research. In contrast, the red and yellow clusters emphasize energy-related and technological dimensions, including energy consumption, energy efficiency, renewable energies, alternative energy, greenhouse gas emission, and emission control. These clusters reflect applied and solution-oriented research streams that link carbon footprint outcomes

to energy systems transformation. The proximity of machine learning within this area suggests the emergence of data-driven and computational approaches for emission prediction, optimization, and decision support, signaling a shift toward more advanced analytical techniques in recent studies.

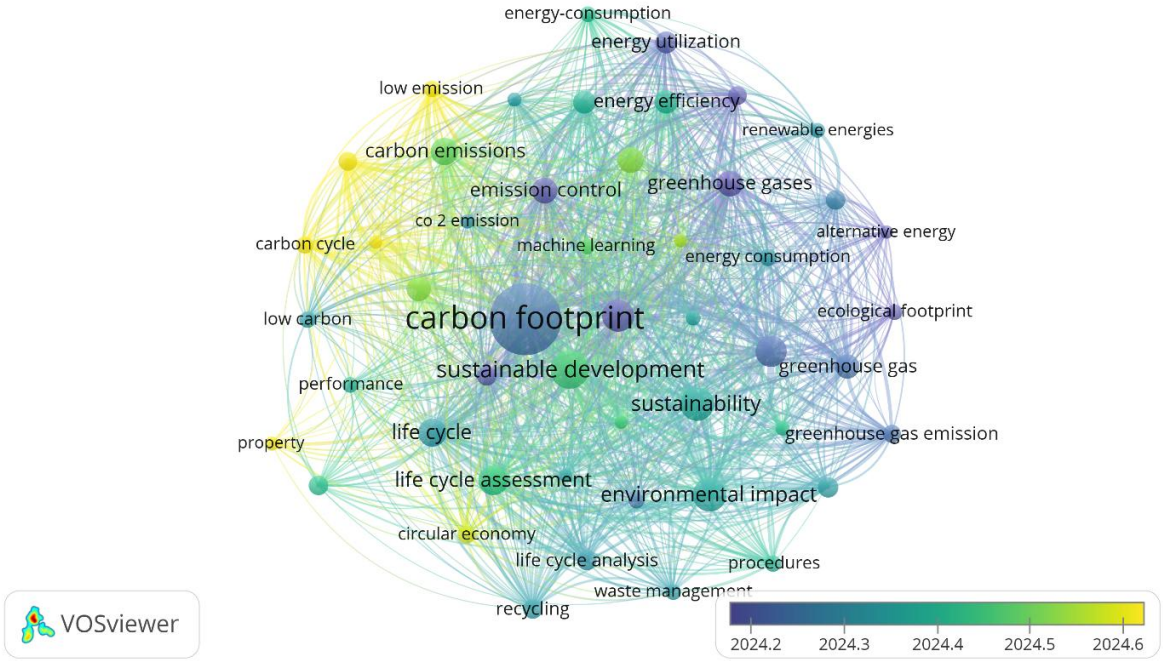

Figure 5. Overlay Visualization
Source: Data Analysis

Figure 5 illustrates the temporal evolution of carbon footprint research, with node colors indicating the average publication year of keywords. The central position of carbon footprint (colored in a green–cyan tone) suggests that it remains a consistently relevant concept that bridges both earlier and more recent studies. Its close association with sustainable development and sustainability indicates that carbon footprint research has increasingly been framed within broader sustainability and development discourses rather than treated solely as a technical emission metric. Keywords shown in cooler blue tones, such as greenhouse gas, greenhouse gas emission, ecological footprint, and alternative energy, reflect relatively earlier thematic emphases. These topics are closely related to foundational discussions on climate change, emission accounting, and environmental impact assessment. Their prominence indicates that early carbon footprint studies were largely concerned with identifying emission sources, quantifying greenhouse gases, and linking carbon footprint to broader ecological impact indicators, particularly within energy and environmental policy contexts. In contrast, warmer green-to-yellow nodes, including energy efficiency, energy utilization, low emission, carbon emissions, machine learning, life cycle assessment, and circular economy, represent more recent research directions. This shift highlights a growing focus on solution-oriented, efficiency-driven, and technology-enabled approaches to carbon footprint reduction. The emergence of machine learning alongside life cycle–based terms signals an ongoing methodological transition toward data-driven modeling and advanced analytics.

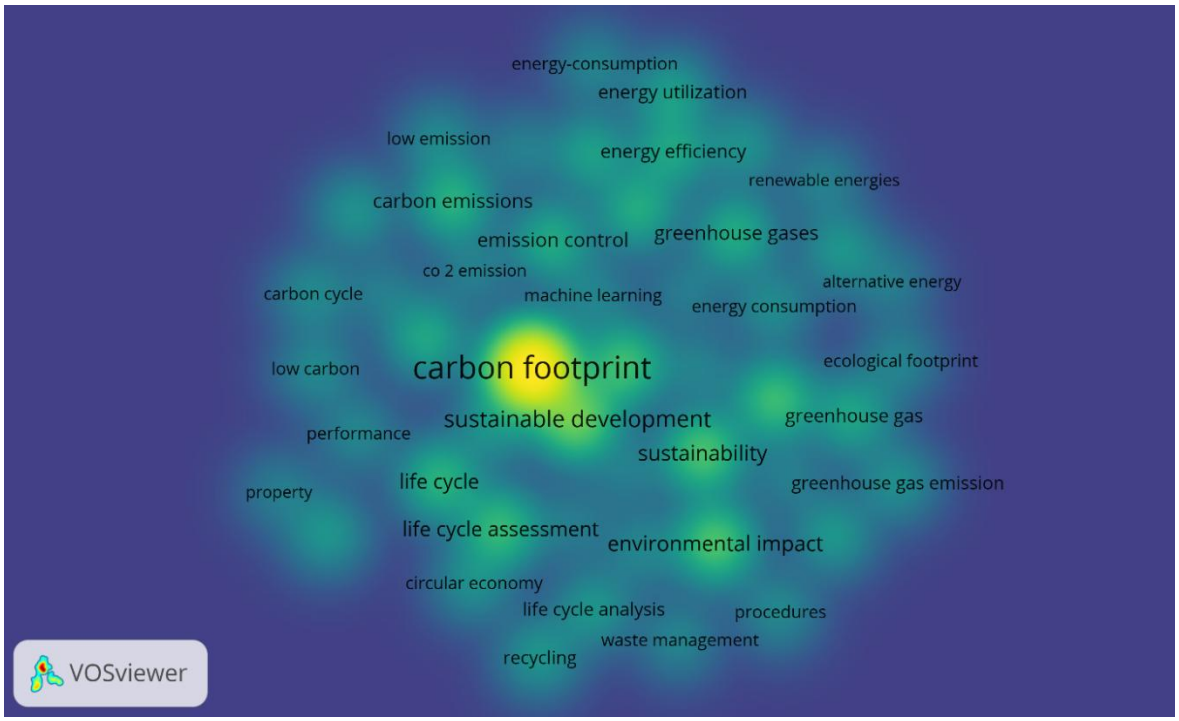

Figure 6. Density Visualization
Source: Data Analysis

Figure 6 highlights "carbon footprint" as the most dominant and intensively studied concept in the literature, as indicated by the bright yellow concentration at the center of the map. This high-density area reflects the centrality of carbon footprint as a unifying concept that connects multiple research themes, including sustainable development, sustainability, life cycle assessment, and environmental impact. The strong density around these keywords suggests that a substantial portion of carbon footprint research focuses on integrating emission measurement with sustainability assessment frameworks and life cycle–based approaches, reinforcing the role of carbon footprint as a core indicator in environmental and sustainability studies. Surrounding the central hotspot, moderately dense areas (green to light blue) correspond to thematic clusters related to greenhouse gases, carbon emissions, energy efficiency, renewable energies, energy consumption, circular economy, and waste management. These areas indicate well-established but slightly less concentrated research streams that support and extend the core concept of carbon footprint. The relatively lower density at the periphery suggests emerging or more specialized topics, such as machine learning and alternative energy, which are gaining attention but have not yet reached the same level of maturity as foundational themes.

Discussion

Practical Implications

The findings of this bibliometric review offer several important practical implications for policymakers, industry practitioners, and sustainability professionals. The dominance of themes related to carbon footprint, sustainable development, life cycle assessment, and energy efficiency indicates that carbon footprint metrics have become a widely accepted tool for evaluating environmental performance and guiding emission reduction strategies. Policymakers can use these insights to design more evidence-based climate policies that integrate life cycle–based carbon accounting into national emission inventories, energy planning, and sustainability reporting frameworks. In addition, the strong linkage between carbon footprint research and energy-related themes highlights the importance of promoting renewable energy adoption, energy efficiency improvements, and low-carbon technologies as key levers for achieving climate targets.

For businesses and organizations, the results underscore the strategic value of carbon footprint assessment in corporate sustainability management and ESG reporting. The growing emphasis on life cycle analysis, circular economy, and waste management suggests that firms should adopt holistic approaches that consider emissions across the entire value chain rather than focusing solely on direct operational emissions. Furthermore, the emergence of machine learning and data-driven approaches indicates new opportunities for organizations to leverage advanced analytics for emission monitoring, scenario modeling, and optimization of resource use. These practical insights can support more effective decision-making and accelerate the transition toward low-carbon and sustainable production and consumption systems.

Theoretical Contributions

From a theoretical perspective, this study contributes to the carbon footprint literature by providing a comprehensive mapping of its intellectual structure and thematic evolution. By integrating co-occurrence, overlay, and density analyses, the study reveals how carbon footprint research has evolved from a primarily measurement-oriented domain toward a more integrative field that combines environmental accounting, sustainability theory, and technological innovation. The central role of life cycle assessment confirms its position as a foundational theoretical and methodological framework underpinning carbon footprint studies, while the strong association with sustainable development and sustainability highlights the normative and policy-oriented dimensions of the field. Moreover, the identification of emerging themes such as machine learning, circular economy, and energy optimization extends existing theoretical perspectives by illustrating how carbon footprint research increasingly intersects with digital transformation and systems-based sustainability paradigms. This study also advances bibliometric scholarship by demonstrating how knowledge structure analysis can uncover hidden relationships between research streams and reveal shifts in theoretical emphasis over time. As such, the findings provide a structured foundation for future theory-building efforts that seek to integrate carbon footprint assessment with broader frameworks such as sustainability transitions, dynamic capabilities, and data-driven environmental governance.

Limitation and Future Direction

Despite its contributions, this study has several limitations that should be acknowledged. First, the analysis relies exclusively on the Scopus database, which, although comprehensive, may not capture all relevant publications, particularly those indexed in other databases or published in non-English languages. This may result in the underrepresentation of region-specific or policy-oriented studies. Second, bibliometric analysis focuses on quantitative patterns of publication and citation, which limits its ability to capture the nuanced content, contextual interpretations, and methodological depth of individual studies. Future research could address these limitations by integrating multiple databases, such as Web of Science or regional indexing platforms, and combining bibliometric techniques with qualitative systematic literature reviews. Additionally, longitudinal content analysis could provide deeper insights into how conceptual definitions, methodological choices, and policy implications of carbon footprint research have evolved over time. Expanding the scope to include sector-specific or regional analyses may also help uncover context-dependent dynamics and support more targeted low-carbon strategies.

CONCLUSION

This bibliometric review provides a comprehensive overview of the research trends and knowledge structure in carbon footprint studies, revealing the central role of carbon footprint as an integrative concept connecting sustainability, life cycle assessment, and emission reduction strategies. The findings demonstrate that the field has evolved from a primary focus on greenhouse gas measurement toward more holistic and solution-oriented approaches that incorporate energy efficiency, circular economy principles, and emerging data-driven methods such as machine learning. By mapping influential themes, methodological foundations, and emerging research

directions, this study offers valuable insights for researchers, policymakers, and practitioners seeking to advance low-carbon transitions. Overall, the results highlight the growing maturity and interdisciplinary nature of carbon footprint research while underscoring the need for continued integration of innovative methodologies and policy-relevant perspectives to address complex global climate challenges.

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