

EXPLORING THE EVOLUTION OF CARBON OFFSET RESEARCH: A BIBLIOMETRIC PERSPECTIVE ON SUSTAINABLE PRACTICES

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ABSTRACT

Amidst the growing concerns of global climate change, sectors worldwide face increased pressure to adopt sustainable practices and enhance carbon management strategies. Carbon offsetting, wherein organizations counterbalance their greenhouse gas emissions by investing in projects that reduce or eliminate emissions elsewhere, has emerged as a pivotal strategy, especially within the building industry due to its substantial carbon footprint reduction potential. This paper delves into the current state and emerging trends in carbon offsetting within the building sector through a bibliometric analysis of literature from the Web of Science Core Collection. Using VOS viewer, the analysis maps bibliographic data from 87 relevant articles, identifying four thematic clusters from 611 keywords with a minimum co-occurrence threshold of two. The findings reveal key thematic areas, including renewable energy integration, urban planning, and challenges in methodological frameworks, providing actionable insights for policy development and industry practices. The study emphasizes the critical need for robust methodologies in carbon offset projects to ensure genuine environmental benefits, addressing challenges like baseline manipulation. Finally, the research identifies opportunities for future exploration in socio-economic impacts and advanced modeling tools for carbon management in the built environment.

KEYWORDS

carbon offsetting, building industry, bibliometric analysis, sustainability, rooftop photovoltaics, urban planning

1. INTRODUCTION

With the aggravation of global climatic change, many sectors have been under new stress on sustainable practices and carbon management. Among the most profound strategies that have been enlisted to help counteract adverse effects of climatic change is carbon offsetting. This is where an organization compensates for its emission of greenhouse gases by investing in a project

that will either reduce or eliminate emissions somewhere else. This method has gained significant impetus in the building industry, considering the huge potential that exists for carbon footprint reductions.

In this background, voluntary carbon offset schemes have emerged as a significant building block. Liu and Cui, in their 2017 article, bring to the forefront the challenges and opportunities of such schemes while laying great emphasis on baseline manipulation-phenomena that greatly influence carbon offsetting projects' credibility and actual outcomes. The article stresses the urgency of sound methodologies for the purpose of guaranteeing real environmental value addition through carbon offset projects.

Similarly, rooftop photovoltaic systems have been identified as one of the ways of maximizing carbon offset potential in urban cities. Chen, Yang, and Lai (2024) assess the impact of rooftop PV systems in China. These authors demonstrate that rooftop PVs will make significant contributions to the production of energy, which translates into a reduction of carbon emissions. This supports the policy of implementing renewable sources of energy within the urban planning and building design to give carbon neutrality.

However, carbon-neutrality on the urban built environment goes beyond solutions that lie within the realm of energy to urban dynamics and scenario making analysis. Huang and collaborators (2022) made an expansive analysis of the urban built environment, highlighting how it is time the world struggled to think again about urban planning and development. There is a demonstration of interwoven factors affecting carbon-neutrality and, therefore, suggests an approach that will incorporate economic, environmental, and social dimensions in arriving at holistic strategies.

Building on these insights, this research employs a bibliometric approach to investigate the current state of knowledge and emerging trends in the field of carbon offsetting within the building sector. Using data from the Web of Science Core Collection, an all-fields search was conducted with the keywords "carbon offset" AND "building," yielding 87 relevant results. These results were downloaded in plain text format and imported into VOS viewer for analysis.

The methodological framework involved creating a map based on bibliographic data, with a minimum co-occurrence threshold of two. Of 611 keywords, 119 met this threshold. To enhance the relevance of the analysis, terms deemed unimportant, such as geographical locations and specific terminologies not central to the research focus, were excluded. This process resulted in four distinct clusters, each representing a different thematic area within the broader context of carbon offsetting and sustainability in building practices.

This study aims to provide a comprehensive qualitative analysis of these clusters, shedding light on the key themes and trends that define the current landscape of research in this domain. By examining the interrelationships among keywords and their respective clusters, the research seeks to identify critical areas for future investigation and contribute to the ongoing discourse on sustainable building practices and carbon management.

2. LITERATURE REVIEW

The literature on carbon offset programs and strategies presents a multifaceted landscape, ranging from baseline manipulation to the design of carbon-neutral buildings and the potential of rooftop photovoltaic systems. Baseline manipulation, as discussed by Liu and Cui (2017), underscores the importance of accurately determining the reference emissions level against which carbon offset credits are measured. This manipulation can significantly impact the effectiveness and integrity of voluntary carbon offset programs. Chen, Yang, and Lai (2024) further contribute to

this discourse by examining the carbon offset potential of rooftop photovoltaic systems, particularly in the context of China. Their study highlights the role of renewable energy technologies in mitigating carbon emissions.

Ventilation strategies also emerge as a significant consideration in carbon offset initiatives. McArthur (2020) conducts a benefit-cost analysis of increased outdoor air provision as a carbon-offset measure. This underscores the need for innovative approaches to building design and operation to reduce carbon footprints while maintaining indoor air quality standards. Similarly, Hossaini, Hewage, and Sadiq (2018) advocate for a path toward net-zero buildings, emphasizing the integration of natural capital assessment frameworks to guide sustainable building practices.

The literature also addresses challenges and approaches in forest carbon offset projects. Pan et al. (2022) identify key challenges and strategies for addressing barriers in forest carbon offset projects, shedding light on the complexities involved in implementing such initiatives. Shinbrot et al. (2022) present a case study spanning over 14 years in an indigenous community in Panama, examining both the natural and financial impacts of payments for forest carbon offsets. This study underscores the importance of understanding the socio-economic dynamics and environmental implications of carbon offset initiatives in diverse contexts.

Furthermore, research on carbon-neutral building design and carbon offset service guidelines contributes to the discourse on sustainable urban development. Jo, Park, and Kim (2019) propose guidelines for tree planting in multifamily residential sites in Korea to enhance carbon offset services. Wang et al. (2023) present a case study on the design of carbon-neutral buildings in rural China, emphasizing the importance of integrating sustainable practices into architectural design.

In the agricultural sector, strategies for effective carbon offset design are explored. Boatey, Goddard, and Mohapatra (2019) discuss environmentally friendly breeding practices and spatial heterogeneity as means to enhance carbon offset effectiveness in beef cattle farming. This highlights the importance of incorporating sustainable practices across various sectors to achieve carbon neutrality goals. Similarly, Morand and Thomassin (2005) simulate shifts in Quebec's cropping practices driven by carbon offset markets. Their research demonstrates how market incentives can drive changes towards more sustainable agricultural practices, aligning economic incentives with environmental goals.

The literature also touches upon pricing mechanisms in carbon offset markets. Fulton and Vercaemmen (2009) analyze optimal two-part pricing strategies in carbon offset markets, comparing different organizational types. Their findings contribute to the understanding of pricing mechanisms and market dynamics in carbon offset trading.

In recent literature, the discourse on carbon offset strategies and sustainable built environments has evolved significantly, encompassing a diverse array of approaches and findings. Studies such as Huang et al. (2020) and Liang et al. (2021) highlight the pivotal role of renewable energy integration and life cycle assessments in promoting sustainable practices within the built environment. Huang et al. (2020) emphasize the ecological-economic benefits of renewable energy deployment, underscoring its potential to mitigate carbon emissions and foster sustainable development. Liang et al. (2021), through their environmental LCA of high-rise mass timber buildings, demonstrate the environmental advantages and cost-effectiveness of integrating sustainable materials in construction. Moreover, research by Dyussembekova et al. (2022) on energy efficiency measures in educational buildings and Meng et al. (2023) on innovative carbon reduction strategies in building design further contribute to understanding effective pathways toward achieving carbon neutrality. These studies collectively emphasize the interdisciplinary

nature of sustainable building practices, integrating technological innovation, environmental assessment, and policy frameworks to address global climate challenges.

Recent literature reflects a diverse array of strategies and challenges in advancing carbon neutrality and sustainability within the built environment. Studies by Akbarnataj, Saffaripour, and Houshfar (2024) on novel CCHP system designs highlight technological innovations aimed at achieving nearly zero-carbon building standards. These advancements underscore the critical role of integrated energy systems in reducing carbon footprints and enhancing building efficiency.

Furthermore, Gembali, Kumar, and Sarma (2024) analyze socio-technical challenges in decarbonizing the construction industry, emphasizing the need to integrate socio-economic factors with technical solutions. Their study maps out influential barriers and opportunities for adopting decarbonization and circular economy practices, illustrating the complexity of transitioning towards sustainable building practices.

Anderson, Long, and Luckert's (2015) financial analysis of poplar plantations for carbon offsets in Alberta and British Columbia provides insights into the economic viability of afforestation as a carbon sequestration strategy. This study underscores the dual benefits of forestry-based offset projects, balancing economic returns with environmental benefits.

In forestry and land-use contexts, Fisher et al. (2018) explore justice considerations in carbon offset forestry projects in Uganda, highlighting the importance of equitable distribution of benefits and participatory approaches in project outcomes. Their findings emphasize the need for socially inclusive strategies to ensure sustainable and acceptable outcomes in carbon offset initiatives.

Looking at innovative marine-based solutions, Collins et al. (2022) evaluate the economic and environmental sustainability of seaweed farming for carbon offsets in Ireland. Their analysis underscores the potential of oceanic resources in contributing to global carbon mitigation efforts, offering scalable solutions for sustainable agriculture and carbon sequestration.

Moreover, Bosehans, Bolderdijk, and Wan (2020) examine the behavioral impacts of integrated carbon offsets on air travel decisions, revealing insights into consumer psychology and the effectiveness of guilt-reducing strategies in promoting sustainable travel behaviors.

Sadat et al. (2024) emphasize the alignment of net-zero energy, carbon neutrality, and regenerative concepts in sustainable architectural practices. Their exemplary study underscores the integration of innovative design principles to achieve holistic environmental benefits, illustrating practical pathways towards sustainable building standards.

In the tourism sector, Zeppel and Beaumont (2013) assess motivations for carbon offsetting among environmentally certified enterprises, revealing varying drivers and barriers that influence participation in voluntary carbon markets. This study contributes insights into the complexities of aligning environmental stewardship with business operations in the tourism industry.

Goodfield, Anda, and Ho (2011) discuss the development of a carbon-neutral mine site accommodation village model, highlighting practical challenges and solutions in implementing sustainable practices within industrial contexts. Their model serves as a benchmark for integrating carbon neutrality strategies into resource-intensive sectors.

In the realm of user interface design for carbon markets, Guzij et al. (2022) explore the design of trustworthy interfaces to enhance user engagement and transparency in voluntary carbon offset

platforms. Their findings underscore the importance of user-centered design principles in promoting trust and efficacy in carbon offset transactions.

Robinson et al. (2014) provide a snapshot of Australia's indigenous carbon economy, highlighting indigenous communities' participation in carbon offset projects and the socio-economic impacts of such initiatives. This study contributes to understanding the intersection of environmental policy, indigenous rights, and economic development in carbon markets.

Wu and Biljecki (2021) introduce Roofpedia, an automated mapping tool for green and solar roofs, facilitating the evaluation and integration of sustainable urban features. Their research supports urban planning efforts aimed at enhancing sustainability through rooftop infrastructure.

Examining consumer behavior in aviation, Cordes, Baumeister, and Käyrä (2024) review factors influencing the willingness to pay for voluntary carbon offsets in air travel, shedding light on consumer preferences and market dynamics in carbon offsetting within the aviation industry.

Table 1 presents a comparative analysis of current and proposed research

Table 1: Comparative Table for Related Work

Study	Methodology	Findings	Gap Addressed by This Research
Liu & Cui (2017)	Baseline manipulation analysis	Challenges in voluntary offset program integrity	Context-specific application in the building industry
Chen, Yang, & Lai (2024)	Carbon offset potential of rooftop PV	PV systems' role in urban emission reduction	Broader bibliometric insights into trends
Shinbrot et al. (2022)	Case study of forest offset projects	Socio-economic impacts in indigenous settings	Thematic clustering across multiple sectors
Current Study	Bibliometric analysis using VOSviewer	Identifies key thematic clusters	Synthesizes trends and actionable insights

These studies collectively highlight the multifaceted nature of carbon offset strategies, spanning technological innovations, socio-economic considerations, consumer behaviors, and regulatory frameworks. Integrating these diverse insights is crucial for developing comprehensive and effective approaches to achieve carbon neutrality and sustainability goals in the built environment and beyond.

3. METHODOLOGY

In this bibliometric analysis, we utilized the VOSviewer software to map and analyze the research landscape related to the keywords "carbon offset" and "building." The methodology employed in this study is outlined in the following subsections.

3.1. Data Collection

An all-fields search was performed within the Web of Science (WoS) Core Collection database. The search used the keywords "carbon offset" AND "building" without applying any additional constraints. This search strategy yielded a total of 87 relevant publications. The results were then downloaded in plain text format, suitable for bibliometric analysis.

ensuring the efficacy of carbon offset projects. The inclusion of "buildings," "bioenergy," "biomass," "environmental services," "footprint," "life cycle assessment," and "sustainability" indicates an emphasis on integrating sustainable practices within the built environment.

Moreover, this cluster includes "health," "land expectation value," "management," "markets," "policies," "products," and "profitability," which points to a multidisciplinary approach that considers economic, policy, and health implications of sustainable building practices. The term "soil organic matter" and "plantations" hint at the inclusion of land use and forestry practices in the broader context of sustainability. Overall, this cluster reflects the comprehensive effort to address climate change through sustainable building practices, carbon accounting, and market-based solutions.

Cluster 2: Carbon Markets and Offset Strategies

Cluster 2 highlights the operational and economic aspects of carbon offsetting, particularly within urban and forestry contexts. Keywords like "carbon credits," "carbon emission," "carbon market," "carbon neutral," "carbon neutrality," and "carbon offset" indicate a strong focus on market mechanisms for carbon trading and offsetting. The inclusion of "City," "co-benefits," "forests," "natural climate solutions," "network," and "offset schemes" suggests that urban environments and natural ecosystems are significant areas of interest.

This cluster also reflects on the impact and implementation of these schemes through terms like "generation," "impact," "impacts," "life cycle," "projects," "prospects," "sequestration," "small-scale farmers," "storage," and "sustainable development." These keywords indicate a detailed examination of how carbon offset projects are developed, their potential benefits, and their contributions to sustainability goals. The presence of "evolution" and "market" underscores the dynamic nature of carbon markets and the continuous development of new strategies and methodologies.

Cluster 3: Energy Efficiency and Carbon Management in the Built Environment

Cluster 3 focuses on the intersection of energy efficiency, carbon management, and the built environment. Keywords such as "built environment," "carbon footprint," "co2 emissions," "construction," "concrete," "design," "electricity-generation," "embodied carbon," "energy," "energy efficiency," and "energy performance" suggest a comprehensive examination of how buildings contribute to carbon emissions and what strategies can be employed to mitigate these emissions.

The cluster also includes "life cycle," "life cycle assessment (LCA)," "model," "multiobjective optimization," "renewable energy," "residential buildings," "sector," "sustainability assessment," "uncertainty," and "urban," highlighting a methodological and analytical approach to understanding and improving the carbon footprint of buildings. The emphasis on "uncertainty" and "multiobjective optimization" points to the use of advanced modeling and optimization techniques to enhance the sustainability of the built environment. This cluster underscores the importance of integrating energy efficiency and carbon management into the design, construction, and operation of buildings.

Cluster 4: Forestry, Agriculture, and Ecosystem Services

Cluster 4 centers on the role of forestry, agriculture, and ecosystem services in carbon sequestration and sustainability. Keywords such as "afforestation," "agriculture," "agroforestry," "carbon emissions," "carbon markets," "carbon sequestration," "carbon stocks," "conservation,"

"ecosystem services," "forest," and "forest carbon" indicate a strong focus on land-based carbon management strategies.

The cluster also includes terms like "incentives," "information," "institutions," "mitigation," "perceptions," "reforestation," "soil," "systems," and "trees," suggesting an interdisciplinary approach that encompasses economic, social, and institutional aspects of carbon sequestration. This cluster reflects the importance of integrating land use practices with broader environmental and sustainability goals, highlighting the potential of forests and agricultural systems to contribute to carbon sequestration and climate change mitigation.

Overall, these clusters collectively provide a comprehensive view of the diverse approaches and thematic areas in the study of carbon offsetting and sustainability in building practices. They underscore the importance of integrating economic, environmental, and social dimensions to address the multifaceted challenges of climate change.

4. DISCUSSION

The findings from this study underscore the multifaceted approaches and challenges in integrating carbon offset strategies within sustainably built environments. The methodology employed facilitated a comprehensive analysis of current literature, providing insights into technological advancements, socio-economic considerations, and regulatory frameworks crucial for achieving carbon neutrality.

The literature review highlighted significant advancements in technological innovations, such as novel Combined Cooling, Heating, and Power (CCHP) systems (Akbarataj et al., 2024) and automated mapping tools for green and solar roofs (Wu & Biljecki, 2021). These innovations play a pivotal role in enhancing building efficiency and reducing carbon footprints, aligning with global sustainability goals. Discussing these technologies in light of your results reinforces their potential impact on future building design and urban planning.

Zeppel and Beaumont (2013) provided insights into the motivations of environmentally certified tourism enterprises for engaging in carbon offsetting, highlighting the influence of market incentives and regulatory frameworks. This discussion emphasizes the need for robust policies and incentives to foster broader participation in carbon markets across various sectors.

The study by Goodfield et al. (2011) on carbon-neutral mine site accommodations illustrated practical challenges and solutions in implementing sustainability practices within resource-intensive industries. This serves as a valuable case study for understanding the complexities involved in achieving carbon neutrality in industrial settings. Discussing these challenges alongside potential strategies enhances the applicability of your findings to diverse built environment contexts.

Fisher et al. (2018) explored justice considerations in carbon offset forestry projects, highlighting the importance of equitable distribution of benefits and community engagement. This discussion underscores the ethical dimensions of carbon offset initiatives and suggests pathways for fostering inclusive and sustainable outcomes in environmental projects.

While significant progress has been made in understanding and implementing carbon offset strategies, several research gaps and future directions emerge from the literature review. Areas needing further exploration include enhancing the transparency and trustworthiness of carbon offset platforms (Guzij et al., 2022), optimizing financial incentives for sustainable building

practices (Anderson et al., 2015), and integrating indigenous perspectives into carbon market frameworks (Robinson et al., 2014).

The review highlighted significant technological advancements, such as novel Combined Cooling, Heating, and Power (CCHP) systems and automated mapping tools for green roofs, which demonstrate promising avenues for enhancing building efficiency and reducing carbon footprints (Akbarataj et al., 2024; Wu & Biljecki, 2021; Popa et al., 2022; Opher et al., 2021). These innovations underscore the potential for technology to play a pivotal role in achieving carbon neutrality goals across urban and industrial contexts.

Insights from environmentally certified tourism enterprises and industrial facilities revealed diverse motivations and barriers, highlighting the critical role of socio-economic factors and regulatory frameworks in shaping carbon market dynamics (Zeppel & Beaumont, 2013; Goodfield et al., 2011). Policymakers are encouraged to develop clear and supportive regulations that balance environmental objectives with economic incentives to accelerate the adoption of sustainable building practices (Robinson et al., 2014; Becken & Mackey, 2017).

Studies examining justice considerations in forestry projects and consumer behaviors in aviation emphasized the need for equitable distribution of benefits and inclusive decision-making processes (Fisher et al., 2018; Cordes et al., 2024).

5. CONCLUSION

In conclusion, this discussion synthesizes key findings from the literature review, highlighting the integration of technological advancements, socio-economic considerations, and policy implications in advancing carbon neutrality in the built environment. The insights gathered contribute to a deeper understanding of the challenges and opportunities in implementing effective carbon offset strategies, paving the way for future research and practical applications aimed at achieving sustainable development goals.

This study has synthesized a wide array of literature and empirical findings to provide comprehensive insights into the integration of carbon offset strategies within sustainable built environments.

Moreover, the study examined socio-economic considerations that influence participation in carbon offset markets. Effective policy frameworks emerged as a crucial determinant in incentivizing sustainable practices and fostering broader engagement in carbon offset initiatives. Furthermore, discussions on environmental and social justice underscored the importance of equity and community engagement in carbon offset projects. Integrating these principles into carbon market frameworks can enhance project legitimacy and promote sustainable outcomes that benefit local communities.

Moving forward, the study identifies several implications and recommendations for advancing carbon neutrality in the built environment. Policymakers should prioritize the development of supportive policies that provide clarity and incentives for sustainable building practices. Technological integration should continue to be a focal point, with investments directed towards scalable solutions that improve building efficiency and facilitate renewable energy adoption. Additionally, fostering partnerships with local communities and indigenous stakeholders is essential to ensure that carbon offset projects align with broader environmental and social goals.

In conclusion, this study contributes valuable insights into the complexities and opportunities surrounding carbon offset strategies in sustainable built environments. By addressing

technological, socio-economic, and policy dimensions, stakeholders can collectively work towards achieving carbon neutrality targets while fostering resilient and equitable communities. Future research should continue to explore emerging trends and innovations to refine strategies for sustainable development in the face of global climate challenges.

The findings of this study address the thematic clusters within carbon offsetting research and provide actionable insights for policy development, urban planning, and renewable energy adoption. Future research should explore expanding bibliometric methodologies to other industries, such as agriculture and transportation. Additionally, assessing the socio-economic impacts of carbon offset programs and integrating advanced modeling tools for carbon management will further contribute to achieving sustainability goals.

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