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Review

Pathways to Carbon Neutrality: A Review of Strategies and Technologies Across Sectors

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Abstract: Climate change, driven by human-induced greenhouse gas emissions, poses a critical threat to the planet, prompting countries worldwide to pledge carbon neutrality by the mid-century. This literature review identifies and analyzes strategies and technologies for achieving carbon neutrality across various sectors and regions. The study aims to determine the research focus across sectors, highlighting the well-studied sectors while identifying critical gaps in other sectors, offering policymakers and researchers a clearer understanding of which sectors need more attention and investment to achieve carbon neutrality goals. Through employing a systematic literature review approach, PRISMA 2020, 113 articles published between 2019 and 2023 were analyzed using content and bibliometric analysis. The results of the content analysis show that the energy sector is the most extensively studied, with a focus on the integration of renewable energy sources, energy efficiency, and carbon capture technologies. Furthermore, results showed promising developments in energy-efficient electrification methods, and circular economy principles can be seen in the building, transportation, and industrial sectors. On the other hand, while having a large potential for sequestering carbon, the agriculture and forestry sectors are still understudied. As for the bibliometric analysis, this study reveals the complex interplay between technological innovation, sectoral strategies, and policy intervention in achieving carbon neutrality. It highlights the need for integrated, interdisciplinary approaches that consider interactions between technological, economic, social, and environmental factors. The analysis also emphasizes the importance of lifecycle assessment, economic complexity, and investments in shaping effective carbon neutrality strategies. As such, future research should address the identified gaps, particularly in agriculture and forestry, and develop more comprehensive models for the transition to carbon neutrality that incorporate both technological solutions and broader socio-economic considerations.

Keywords: carbon neutrality; strategies; technologies; sectors

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Citation: Al Khaffaf, I.; Tamimi, A.; Ahmed, V. Pathways to Carbon Neutrality: A Review of Strategies and Technologies Across Sectors. *Energies* **2024**, *17*, 6129. https://doi.org/10.3390/en17236129

Academic Editor: Francesco Nocera

Received: 2 November 2024
Revised: 27 November 2024
Accepted: 27 November 2024
Published: 5 December 2024

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1. Introduction

Climate change, which is mostly caused by human-generated greenhouse gas (GHG) emissions, presents a threat to the planet and its inhabitants [1]. The rise in greenhouse gasses like carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) in the atmosphere has resulted in global temperature and sea-level increases, and more frequent extreme weather events [2]. These effects have implications for ecosystems, biodiversity, human health, food security, and socioeconomic progress [3].

Scientific studies from the Intergovernmental Panel on Climate Change (IPCC) and other respected sources link actions, especially the use of fossil fuels, to the observed change in the Earth's climate system [1]. If global temperatures reach 2 °C above industrial levels, experts predict severe and irreversible harm to both natural environments and human societies due to climate change inaction [4]. According to the Centre for Research on the Epidemiology of Disasters (CRED), in 2018, the world encountered 315 instances of natural disasters, many of which are linked to climate change. There were $131.7 billion in

economic losses, and a total of 68.5 million people were impacted. The most vulnerable industries to climate change disasters are food, water, health, ecosystems, human habitats, and infrastructure [5].

Recognizing the pressing need to tackle climate change, the Paris Agreement, founded in 2015 as part of the United Nations Framework Convention on Climate Change (UNFCCC), aims to limit warming to below 2 °C compared to pre-industrial levels, with a preference for staying under 1.5 °C. To reach this goal, nations worldwide have committed to achieving carbon neutrality or net zero emissions by the mid-21st century [6].

Carbon neutrality, also called net zero emissions, signifies a state where an equal amount of carbon removal or offsetting measures balances human-induced (GHG) emissions, as demonstrated in Figure 1. This objective can be met by reducing emissions from different sectors and deploying negative emissions technologies (NETs) that actively extract GHGs from the air [7]. The impact of carbon neutrality and utilization on energy industries such as oil extraction is gradually deepening [8,9]. Attaining carbon neutrality poses a multifaceted challenge that demands transformative shifts across different sectors such as energy, transportation, industry, agriculture, forestry, and waste management. It entails transitioning towards different strategies, low-carbon technologies, sustainable practices, and systemic alterations in production and consumption behaviors [10].

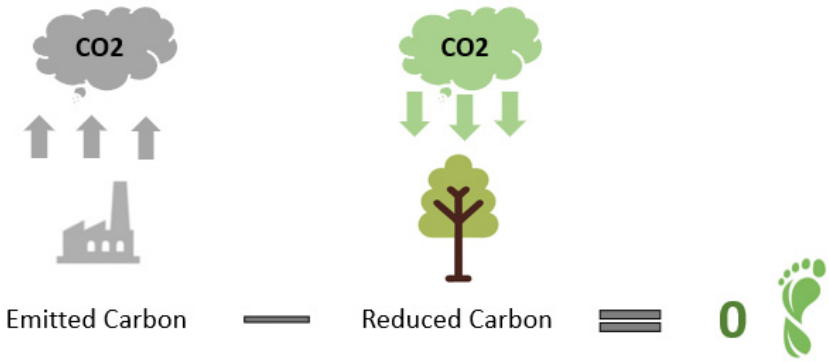

Figure 1. Carbon neutrality concept.

In the pursuit of carbon neutrality, strategies and technologies play distinct but interconnected roles. Strategies represent overarching, long-term approaches that guide policy and decision-making across multiple sectors [10]. These might include transitioning to renewable energy, improving energy efficiency, or enhancing natural carbon sinks [4]. Technologies, on the other hand, are the specific tools and applications that implement these strategies, such as solar panels, carbon capture technologies, or electric vehicles [11]. While strategies provide the broader framework and direction, often implemented through policies and regulations, technologies offer the practical means to achieve the goals set by these strategies [12]. Strategies tend to have a longer-term focus and involve multiple stakeholders, whereas technologies are often sector-specific and can evolve rapidly with innovation [13]. For instance, the strategy of transitioning to renewable energy might employ technologies like solar photovoltaic cells or wind turbines. Both elements are crucial in pathways to carbon neutrality: effective strategies guide the development and deployment of appropriate technologies, while advancements in technologies can enable more ambitious strategies [14].

Several pathways and strategies have been suggested to facilitate this transition, each presenting its strengths, limitations, and potential co-benefits or trade-offs. The transition to energy sources like solar, wind, and hydroelectric power is seen as crucial in reducing emissions on the supply side. Improving energy efficiency in buildings using energy-saving appliances and optimizing processes are also important steps to minimize energy use and emissions [15]. In transportation, switching to vehicles adopting biofuels and alternative fuels, promoting public transport, and walking/cycling are key strategies.

Urban planning and smart mobility solutions can further help by promoting compact and mixed-use development and encouraging modal shifts toward more sustainable modes of transportation [16].

Additional pathways that have been suggested include the adoption of circular economy principles and waste management practices to reduce emissions from resource extraction, manufacturing, and waste disposal [17]; the implementation of carbon pricing mechanisms and market-based instruments to drive investment in low-carbon technologies [18]; and sustainable agriculture and forestry practices, such as conservation agriculture, afforestation, and improved livestock management [19].

However, moving towards carbon neutrality faces many challenges and barriers. Technological barriers such as the nature of renewable energy sources, the necessity for advanced energy storage solutions, and the limited implementation of carbon capture and storage (CCS) technologies have been recognized as potential obstacles [20]. Economic challenges, such as the initial costs of transitioning to low-carbon technologies and infrastructure, existing subsidies for fossil fuels, and insufficient financing mechanisms can impede progress [21]. Additionally, political and regulatory barriers like policies, regulatory ambiguity, and a lack of long-term political commitment pose significant challenges. Social and behavioral obstacles such as the acceptance of new technologies, reluctance to change lifestyles, and increased awareness and education on climate change mitigation must also be addressed.

Comprehensive policy interventions and enabling conditions are required to overcome these challenges and facilitate the transition to carbon neutrality. These may include regulatory instruments, such as emissions standards and building codes; economic instruments, such as carbon pricing and incentives for low-carbon technologies; and information-based instruments, such as labeling and public awareness campaigns. Additionally, institutional and governance structures, stakeholder engagement, international cooperation, and knowledge-sharing are crucial enabling conditions.

This systematic literature review aims to synthesize the current knowledge on pathways towards achieving carbon neutrality across various sectors and regions. By critically analyzing the available literature, this review seeks to provide a comprehensive understanding of the strategies through content analysis, and technologies through biblometric analysis, to facilitate the transition to a carbon-neutral future, and identify the research gaps in achieving carbon neutrality. The specific research question addressed is as follows:

What are the key strategies and technologies proposed for reducing greenhouse gas emissions and achieving carbon neutrality in different sectors?

By addressing this research question, this systematic review contributes to the growing body of knowledge on climate change mitigation. This systematic review contributes to the existing literature by providing a comprehensive, cross-sectoral analysis of carbon neutrality strategies and technologies. Unlike previous reviews that focus on specific sectors or technologies, our study offers a holistic view of the current state of research across energy, buildings, transportation, industry, and agriculture. By synthesizing findings from diverse fields, we identify not only the most promising approaches but also critical research gaps. This comprehensive approach enables us to highlight interdependencies between sectors and strategies, providing valuable insights for policymakers and researchers working towards integrated carbon neutrality solutions.

To provide a clear structure for this systematic review, a conceptual framework that illustrates the key components of this research and their interrelationships is developed, as presented in Figure 2. This framework outlines the main sectors involved in carbon neutrality efforts, the overarching strategies and technologies, the policy and regulatory context, and our research methods.

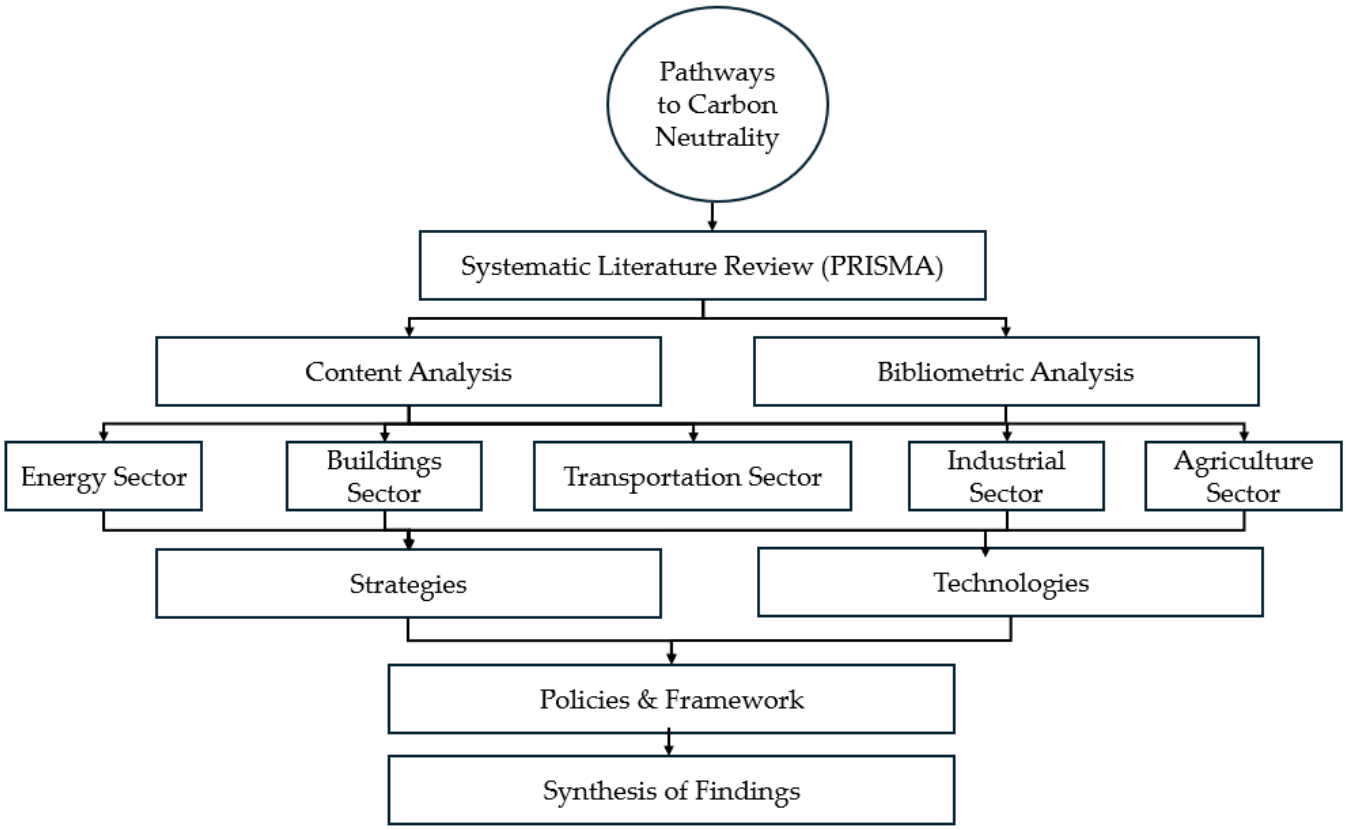

Figure 2. Conceptual framework for carbon neutrality strategies and technologies.

2. Materials and Methods

The methodology utilized in this study follows a systematic literature review to acquire and analyze literature concerning carbon neutrality. It encompasses four primary stages, outlined as follows:

a. Literature retrieval: This initial phase involves careful selection of the database and relevant search terms and phrases to identify relevant publications within the domain of interest. To address the research question and examine previous work in the field, studies were retrieved from the international digital library Scopus, utilizing a combination of keywords such as "Carbon Neutrality" AND "Strategies" AND "Technologies" AND "Sectors". A total of 186 documents were found. Figure 3 shows a significant growth in the field from 2013 to 2024, demonstrating a rise in the topic's interest among researchers. This activity signifies the increasing importance of carbon neutrality strategies across various sectors and the growing recognition of the need for comprehensive approaches to address climate change. In addition, analysis for the studied fields is presented in Data Analysis Section 3.3.2.

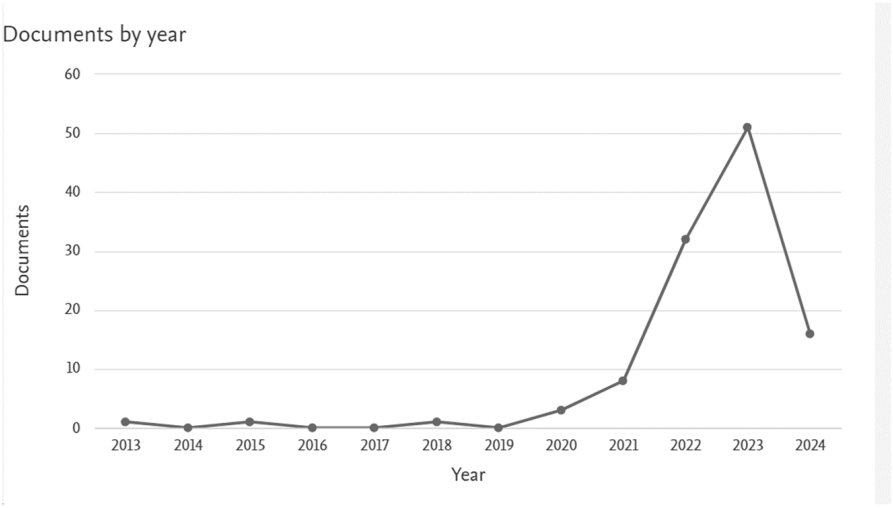

Figure 3. Number of publications by year (2013–2024), adopted from Scopus.

The Scopus database is utilized for literature retrieval due to its comprehensive coverage of the peer-reviewed literature across various disciplines relevant to carbon neutrality research. Scopus offers a broader coverage compared to other databases, particularly in applied sciences and engineering fields crucial to this topic [22]. It also provides robust tools for bibliometric analysis, which was essential for our study methodology. However, it is important to acknowledge Scopus's limitations. The database may underrepresent certain disciplines, especially in social sciences and humanities [23]. Additionally, Scopus's coverage of conference proceedings and books is less comprehensive than its journal coverage, which may affect the representation of the rapidly evolving fields often discussed in these formats [24]. Despite these limitations, Scopus's extensive coverage and analytical tools made it the most suitable choice for this systematic review, although future studies could benefit from incorporating multiple databases to address these limitations

b. Literature screening: The screening step was conducted through a systematic literature review using PRISMA 2020 (Preferred Reporting Items for Systematic Reviews and Meta-Analyses), a structured approach to ensure transparent reporting of the search, screening, eligibility, and inclusion process [25]. The resulting articles were screened by considering publications in relevant fields with a focus on studies related to carbon neutrality and climate change mitigation strategies written in the English language from the year 2019 to 2023. The systematic review ends at 2023 as it was conducted in 2024, ensuring that only complete annual datasets were included to maintain analytical rigor and avoid potential biases from partial-year data collection. This review includes varying forms of study to ensure comprehensive coverage. However, the dominance of research articles, being peer-reviewed and following strict methodological guidelines, provided the primary foundation for our analysis. Other document types, while valuable for context and supporting information, may offer different levels of detail and methodological approaches. More analysis on forms of study is discussed in Section 3.2.3. The systematic review methodology is presented in Figure 4.

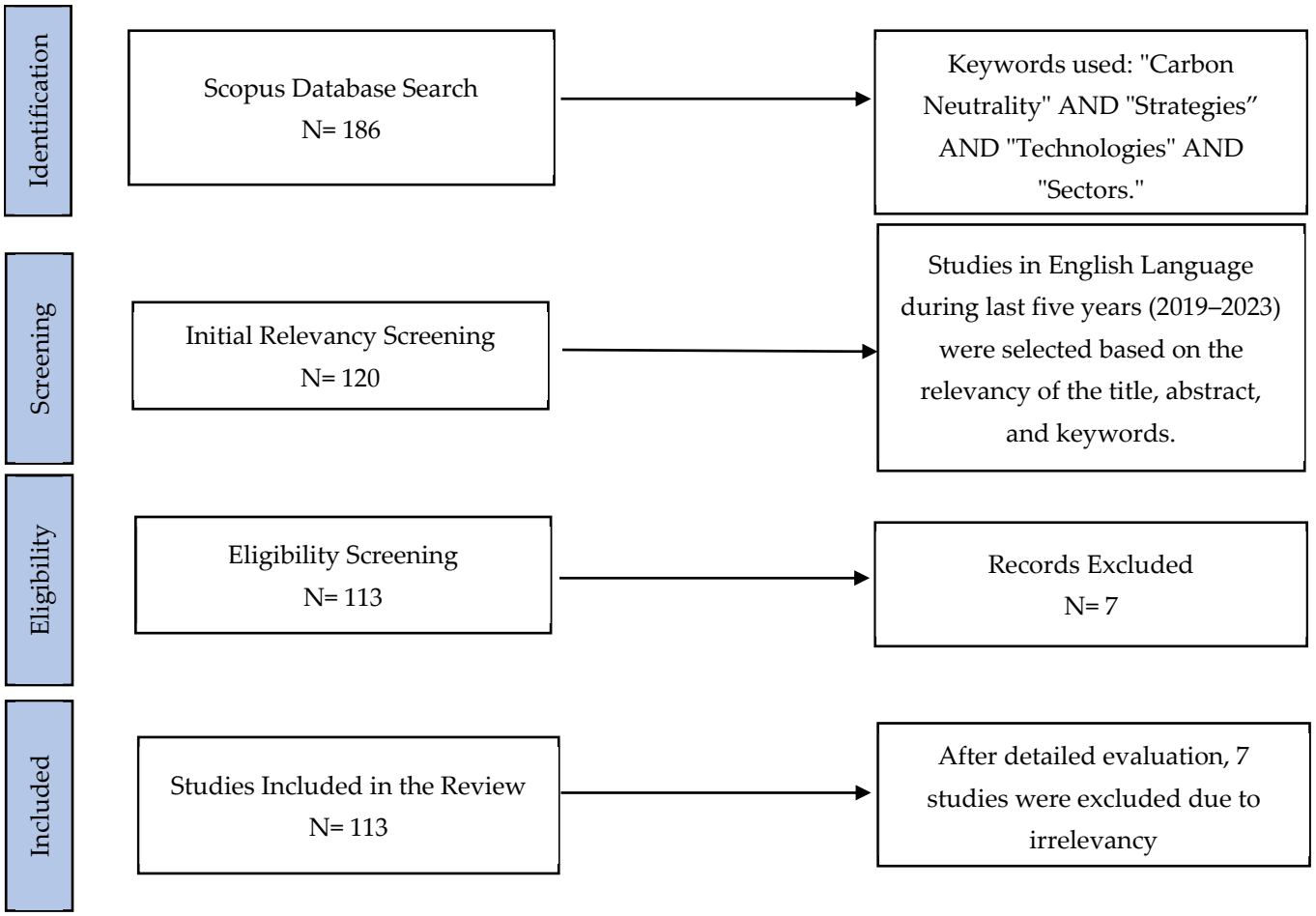

Figure 4. Systematic review methodology.

Initially, a total of 135 publications from 2019 to 2023 were retrieved using keywords such as "Carbon Neutrality" AND "Strategies" AND "Technologies" AND "Sectors" across titles, abstracts, and keyword fields in the Scopus database. After choosing publications in the English language, 120 publications remained. These publications were then thoroughly screened, with studies out of scope being further excluded, resulting in a final set of 113 papers for detailed analysis. The content of these 113 studies was extracted using the Excel format for data analysis and synthesis.

c. Content analysis: This step involves the meticulous analysis of gathered information, such as research publications, to reveal common themes and patterns. In this instance, content analysis focused on delineating the various pathways toward achieving carbon neutrality. Research papers were categorized and classified into different themes, these being sectors, and with the sub-themes being the technologies, facilitating a comprehensive understanding of strategies associated with carbon neutrality and enabling the extraction of meaningful insights.
d. Bibliometric analysis. This step involves conducting a bibliometric analysis through VOSviewer software 1.6.17.exe using the extracted file from the Scopus database, allowing for the visualization of co-occurrence networks based on keywords and co-authorship by country. This analysis provided insights into the main sectors, research focus, strategies and technologies, and policies in the field of carbon neutrality research. With bibliometrics, it is possible to identify developing research areas and leading countries. Such analysis facilitates researchers in understanding the progression of research topics and recognizing key figures in academia.

3. Analysis and Results

3.1. Content Analysis

This phase of the study examines the concept of carbon neutrality, offering insights categorized into primary themes along with their respective sub-themes. These overarching themes encompass various sectors such as energy, buildings, transportation, industrial, and agriculture. Specific sub-themes are the strategies that are implemented in each sector, offering a detailed analysis of particular aspects within the framework of each topic and providing a thorough grasp of the complexities involved in aiding effective carbon neutrality projects.

In the energy sector, which emerges as a critical focus area, the analysis reveals several key sub-themes. Renewable energies are highlighted as crucial, with studies emphasizing the need for the strategic deployment of solar, wind, and hydroelectric power. The potential of carbon capture and storage (CCS) technologies and broader electrification of energy systems is explored, revealing ongoing debates about their role in carbon neutrality strategies. Energy efficiency is underscored as important across various applications, from power generation to end-use consumption, with studies emphasizing the need for both technological advancements and policy interventions.

The buildings and infrastructure sector analysis examines strategies for reducing carbon emissions in the built environment. This includes a focus on energy-efficient building designs, materials, and technologies, as well as the integration of renewable energy systems into building designs. Various approaches to improve energy efficiency in both new constructions and existing buildings are covered. In the transportation sector, identified as a significant contributor to greenhouse gas emissions, key sub-themes include the electrification of transport, alternative fuels, and sustainable urban planning. Studies examine the potential of electric vehicles and supporting infrastructure, research sustainable biofuels and hydrogen as alternatives to fossil fuels, and analyze how urban design can contribute to reducing transport-related emissions.

The industrial sector presents unique challenges in achieving carbon neutrality. The analysis covers circular economy principles and carbon capture technology to reduce industrial emissions, as well as research on improving energy efficiency in industrial processes. Although less extensively covered in the literature, the agriculture sector analysis examines sustainable agricultural practices for reducing emissions from farming activities and research on the potential of agricultural lands to act as carbon sinks.

Finally, the analysis of policy and regulatory frameworks for carbon neutrality covers energy efficiency policies, carbon pricing mechanisms, and international cooperation. Studies on regulatory frameworks to promote energy efficiency, research on the effectiveness of various carbon pricing strategies, and the analysis of global efforts and agreements to combat climate change are included.

3.1.1. Carbon Neutrality and Energy Sector

In the analysis of study fields related to carbon neutrality in energy sector, a diverse range of strategies emerges, shedding light on the multifaceted nature of efforts to address carbon emissions and environmental sustainability.

a. Renewable Energies

The findings from the studies presented in Table 1 provide valuable insights into different aspects of decarbonization and carbon neutrality efforts in the energy sector by utilizing renewable energy.

Table 1. Sub-theme renewable energy.

Theme	Subtheme	Authors	Focus
Energy Sector	Renewable energy sources	Ahmed S.; Nguyen T., 2022 [26]	Evaluating carbon-neutral scenarios for Växjö's future energy system
		Jazinaninejad M. et al., 2022 [27]	Reviewing the literature on biomass supply chain management
		Hyun M. et al., 2023 [28]	Assessing the feasibility of decarbonization scenarios for Korea's power sector
		Hyvönen J. et al., 2023 [29]	Evaluating the feasibility of carbon neutrality in Finland
		Abbas S.M. et al., 2023 [30]	Reviewing ocean thermal energy conversion (OTEC) technology
		Buffi M. et al., 2022 [31]	Reviewing hydrogen production from biomass sources
		Yang Y. et al., 2022 [32]	Reviewing hydrogen applications and technologies for carbon neutrality
		Xia Q., 2023 [33]	Analyzing the impact of green technology and renewable energy standards on carbon emissions in China
		Plazas-Niño F.A. et al., 2023 [34]	Assessing decarbonization pathways in Colombia
		Arriet A. et al., 2022 [35]	Analyzing decarbonization pathways for Chile
		Zhong Z. et al., 2023 [36]	Reviewing power-to-hydrogen by electrolysis (PtHE) technology
		Pan X. et al., 2023 [37]	Analyzing power sector investments for carbon neutrality in China
		Fan Y. et al., 2022 [38]	Analyzing power system transitions in North China
		Che B. et al., 2023 [39]	Analyzing mineral requirements for China's energy transition
		Carnelli L. et al., 2021 [40]	Analyzing the integration of concentrating solar heat in oil and gas operations
		Constantino E.D.G. et al., 2021 [41]	Reviewing the potential of solar concentration systems in Angola
		Chen X. et al., 2021 [42]	Analyzing pathways for carbon-neutral electrical systems in China
		Podoba Z.S., 2021 [43]	Analyzing Japan's energy strategy and transition to green energy

An analysis of studies on renewable energy strategies reveals both consensus and divergence in approaches to achieving carbon neutrality. Refs. [31,36] both focus on hydrogen as a key component of future energy systems, but their approaches differ. Ref. [31] concludes that hydrogen from biomass can significantly contribute to renewable hydrogen supply, while ref. [36] emphasizes the importance of power-to-hydrogen by electrolysis (PtHE) technology. This contrast highlights the diversity of potential hydrogen sources in renewable energy strategies.

Refs. [37,38] both analyze energy transitions in China, but at different scales. Ref. [37]'s study on China's overall power sector concludes that 76–82% of future investments should be in wind and solar, while [38]'s focus on North China emphasizes the importance of inter-regional power transmission. These studies underscore the need for both national strategies and regional adaptations in renewable energy deployment.

Ref. [39] diverges from the predominant focus on energy production by examining the mineral requirements for China's energy transition. Their conclusion that some minerals will face supply risks highlights a critical aspect of renewable energy strategies often overlooked in other studies. Ref. [40] offers a unique perspective by examining the integration of concentrating solar heat in oil and gas operations. Their conclusion that this can significantly reduce CO_2 emissions in a traditionally high-emission sector presents a novel approach not addressed in other studies, emphasizing the potential for renewable technologies to transform even fossil fuel-based industries.

Refs. [42,43] both examine pathways to carbon neutrality in specific countries but reach different conclusions. Ref. [42] emphasizes the potential of the coordinated deployment of various technologies in China, including ultra-high-voltage transmissions and power-to-gas, in reducing carbon abatement costs from \$27/ton to \$−25/ton, potentially making carbon neutrality cost-competitive post-2050 when combined with carbon capture and sequestration technologies. Ref. [43] concludes that Japan's strategy focuses primarily on eliminating energy deficits before greening the sector. This contrast suggests that the optimal path to carbon neutrality may vary significantly based on a country's existing infrastructure and energy security concerns.

These comparative insights reveal that while there is consensus on the critical role of renewables in achieving carbon neutrality, researchers conclude that the most effective strategies are highly context-dependent, influenced by factors such as geographical scale, existing infrastructure, technological readiness, and even sector-specific opportunities. The studies also highlight the importance of considering often-overlooked aspects such as mineral supply chains and the potential for renewable technologies to transform traditional fossil fuel industries.

b. Carbon Capture technologies and Electrification

The findings from the studies presented in Table 2 provide valuable insights into different aspects of decarbonization and carbon neutrality efforts in the energy sector by utilizing carbon capture technologies. In addition, some studies integrate carbon capture technologies with renewable energies for better results.

Table 2. Sub-themes: carbon capture technologies and electrification.

Theme	Subtheme	Authors	Focus
Energy Sector	Carbon capture	Matamala Y. et al., 2023 [44]	Assessing the feasibility of sequestration reliance for climate targets
		Kato E.; Kurosawa A. 2021 [45]	Analyzing the role of NETs in Japan's energy transition
		Yang B. et al., 2021 [46]	Analyzing lifecycle costs of biomass co-firing power plants with CCS
	Electrification	Zhang H. et al. [47]	Analyzing the impact of load-side re-electrification on decarbonization
		Li X. et al. [48]	Analyzing the combined effects of electrification and digitalization on energy consumption

An analysis of studies on carbon capture reveals diverse conclusions about its role and potential in achieving carbon neutrality. Refs. [44,45] both examine the role of carbon sequestration technologies but reach different conclusions. Ref. [44] emphasizes the uncertainties and potential limitations of relying heavily on sequestration for climate targets, while ref. [45] highlights the crucial role of negative emission technologies (NETs) and carbon recycling in Japan's transition to net-zero CO_2 emissions. This contrast underscores the ongoing debate about the extent to which carbon capture should be relied upon in carbon neutrality strategies.

Refs. [46,47] offer different perspectives on the integration of carbon capture with existing energy systems. Ref. [46] focuses on the lifecycle cost assessment of biomass co-firing power plants with CO_2 capture and storage (CCS), concluding that multiple incentives are necessary for their economic viability. In contrast, ref. [47] examines the broader implications of load-side re-electrification, including its impact on decarbonization efforts. The research findings were illustrated by a case study of Northwestern China, which shows that an extensive load-side re-electrification can result in a maximum decrease in carbon dioxide emissions of up to 37.15% by 2060 without the need for carbon dioxide removal technology. These studies highlight the complex interplay between carbon capture technologies and wider energy system transformations.

Ref. [48] provides a unique perspective by analyzing the combined effects of electrification and digitalization on energy consumption. Their focus on the interplay between technological advancements and energy demand patterns offers insights into the systemic changes required for carbon neutrality, beyond just carbon capture technologies.

These comparative insights reveal that while researchers agree on the potential importance of carbon capture technologies in achieving carbon neutrality, there is significant divergence in conclusions about their optimal role, economic viability, and integration with other decarbonization strategies. The studies also highlight the need to consider carbon capture within the broader context of energy system transformations and technological advancements.

c. Energy Efficiency

The findings from the studies presented in Table 3 provide valuable insights into different aspects of decarbonization and carbon neutrality efforts in the energy sector by utilizing an energy efficiency approach.

Table 3. Sub-theme: energy efficiency.

Theme	Sub-Theme	Authors	Focus
Energy Sector	Energy Efficiency	Wen L.; Diao P., 2022 [49]	Simulating carbon emissions in China's electricity sector
		Zhang X. et al., 2023 [50]	Developing strategies for carbon emission reduction in power grid enterprises
		Yuan Y. et al., 2022 [51]	Optimizing electrodeionization systems for flexible load regulation
		Liu S. et al., 2022 [52]	Evaluating environmental impacts of various grid systems
		Pakere I. et al., 2023 [53]	Evaluating cost-effective pathways for reaching energy efficiency targets and carbon neutrality
		Licandeo F. et al., 2023 [54]	Analyzing impacts of emissions policies on water–energy–land nexus
		Lombardi F. et al., 2023 [55]	Analyzing computational strategies for energy infrastructure modeling
		Mehedi H. et al., 2023 [56]	Analyzing power generation expansion planning with carbon emission constraints
		Khanna N.Z. et al., 2023 [57]	Reviewing demand-side innovations for carbon neutrality
		Zhang T.-Y. et al., 2023 [58]	Analyzing blockchain-based smart contracts for carbon trading
		Misconel S. et al., 2022 [59]	Analyzing CO_2 abatement cost curves for decarbonization
		Ozawa A. et al., 2022 [60]	Analyzing pathways for carbon neutrality in Japan

Table 3. *Cont.*

Theme	Sub-Theme	Authors	Focus
Energy Sector	Energy Efficiency	Zhou Y. et al., 2023 [61]	Developing a cross-scale modeling approach for carbon neutrality pathways
		Aizhana et al., 2022 [62]	Analyzing marketing approaches for decarbonization in Kazakhstan's energy sector
		Maqableh A.; Saraireh M., 2023 [63]	Analyzing waste heat generation in integrated energy systems
		Phothisourinh N.; Singh J.G., 2022 [64]	Analyzing carbon neutral planning for Thailand's power sector
		Ku T.-Y. et al., 2022 [65]	Introducing energy maestro—transactive energy mechanism

Analyzing studies on energy efficiency reveals diverse conclusions about roles in achieving carbon neutrality. Refs. [49,50] both focus on China's electricity sector but reach different conclusions. Ref. [49] simulates carbon emissions under the dual-carbon target, emphasizing the importance of optimizing the energy structure, while ref. [50] proposes specific strategies for carbon emission reduction in power grid enterprises. This contrast highlights the multifaceted approach required in the electricity sector, from system-level changes to enterprise-specific strategies.

Refs. [51,52] offer contrasting insights on specific technologies. Ref. [51] focuses on optimizing electrodeionization systems for flexible load regulation. Results show that the optimized system can reduce power consumption and carbon footprint by up to 30.21% and 30.30%, respectively, suggesting a widely applicable strategy for design and operation optimization in renewable energy-dominated systems. Ref. [52] evaluates the environmental impacts of various grid systems in Guangdong using lifecycle assessment (LCA), including traditional, renewable energy, power storage, and microgrid systems. Results show that systematic grid improvements yield significant environmental benefits, with microgrid technology offering the highest carbon reduction potential of 23.8% compared to the baseline, while renewable energy integration reduces emissions by 7.9%. These studies underscore the range of technological solutions being explored to enhance energy efficiency and grid performance.

Refs. [53,54] both address broader policy implications but with different focuses: [53] evaluates cost-effective pathways for reaching energy efficiency targets and carbon neutrality, while ref. [54] analyzes the impacts of economy-wide emissions policies on water, energy, and land systems. This comparison highlights the need to consider both sector-specific strategies and cross-sectoral impacts in energy efficiency policies.

Refs. [55,56] examine computational approaches to energy system modeling, but with different emphases. Ref. [55] focuses on modeling trade-offs for energy infrastructure deployment, while ref. [56] analyzes power generation expansion planning with carbon emission constraints. These studies highlight the growing importance of sophisticated modeling techniques in planning energy-efficient and low-carbon systems.

Refs. [57,58] offer unique perspectives on innovative approaches. Ref. [57] explores demand-side technological and social innovations in carbon neutrality pathways, while ref. [58] analyze blockchain-based smart contracts for carbon trading in the electric power sector. These studies emphasize the potential of emerging technologies and social innovations in achieving energy efficiency goals.

Refs. [60,63] both develop modeling approaches for decarbonization pathways but at different scales. Ref. [60] analyzes Japan's pathways to carbon neutrality using an energy modeling methodology, while ref. [63] focuses on CO_2 abatement cost curves for sector-coupled energy systems. This contrast underscores the importance of considering both detailed economic factors and national-scale energy transitions.

These comparative insights reveal that while researchers agree on the critical role of energy efficiency and smart grid technologies in achieving carbon neutrality, their conclusions about the most effective strategies vary significantly. The studies highlight a range of approaches, from specific technological solutions to broader policy frameworks, and emphasize the need for integrated, multi-scale modeling approaches to navigate the complex landscape of energy system transformation.

3.1.2. Carbon Neutrality in the Building and Infrastructure Sector

This section explores a selection of research papers that highlight the critical requirement to address carbon emissions in the building and infrastructure sector and that showcase cutting-edge technical advancements and governmental interventions to hasten the transition to carbon neutrality. The documents are displayed in Table 4.

Table 4. Carbon neutrality in the building and infrastructure sector.

Theme	Sub-Theme	Authors	Focus
Building and Infrastructure sector	Green Buildings	Idrissi Kaitouni S. et al., 2023 [66]	Assessing energy performance of a NZEB in Morocco
	Renewable Energies	Rodgers M.D., 2021 [67]	Analyzing renewable energy investment strategies for higher education institutions
	Energy Efficiency	Cumo et al., 2022 [68]	Promoting a new production paradigm for building renovation
		Zhang C. et al., 2022 [69]	Analyzing spectral splitting PV/T systems for space heating
		Rivera-Marín A. et al., 2023 [70]	Estimating decarbonization potential at neighborhood level
		Xin L. et al., 2023 [71]	Predicting carbon emissions in megacity building sector
		Ma M. et al., 2022 [72]	Analyzing operational carbon emissions in commercial buildings
		Yang Q. et al., 2023 [73]	Analyzing impact of societal development indicators on building carbon emissions
		Xing Z. et al., 2023 [74]	Analyzing carbon emissions in Shanghai's construction sector
		Zhang Y. et al., 2022 [75]	Analyzing clean heating transitions in Northern China
		Zhang S. et al., 2022 [76]	Analyzing carbon abatement in commercial building operations

Analyzing studies on carbon neutrality in the building and infrastructure sector reveals diverse approaches and conclusions about effective strategies. Refs. [66,68] both focus on energy-efficient building designs but reach different conclusions. Ref. [66] assesses the energy performance of a net-zero energy building (NZEB) in Morocco, emphasizing the importance of empirical validation in semi-arid climatic contexts. Results show that the 47 m^2 Net Zero Energy Building, with earth-based materials and a 4 kW photovoltaic installation, achieves an annual self-sufficiency of 1.25, successfully offsetting its electrical needs and reaching zero-energy status. In contrast, ref. [68] proposes a new production paradigm for building renovation, focusing on digitalization, standardization, and performance optimization. This comparison highlights the debate between new construction and renovation strategies in achieving building energy efficiency.

Ref. [67] provides a unique perspective by focusing on renewable energy investments in higher education institutions, highlighting the potential for sector-specific strategies in achieving carbon neutrality. This approach contrasts with broader urban or national-scale studies, emphasizing the role of institutional leadership in driving building sector decarbonization.

Refs. [70,71] offer contrasting insights on urban-scale decarbonization. Ref. [70] estimates decarbonization potential at the neighborhood level in Valencia, Spain. Results show a decarbonization potential of 7488 tons of CO_2 (11% of overall emissions), with a cost of 200 €/t CO_2, highlighting the need for more aggressive measures to achieve complete decarbonization. Ref. [71] focuses on Beijing's building sector, predicting carbon emissions peaks and neutrality based on lifecycle CO_2 emissions. Results show a carbon peak can be achieved by 2025 through a 7% increase in renewable energy and retrofitting 60 million m^2 of buildings, while carbon neutrality requires a strategy integrating zero-carbon energy systems (reducing 58.6 Mt) and building measures (reducing 8.4–18.2 kg/m^2). This reveals the importance of long-term, city-wide planning. These differing approaches underscore the complexity of scaling building decarbonization strategies from individual structures to entire urban areas.

Refs. [72,73] examine carbon emissions in commercial buildings but draw different conclusions. Ref. [72] analyzes operational carbon transitions in megalopolises' commercial buildings, highlighting the importance of building-specific strategies. Ref. [73] investigates the influence of societal development indicators on building carbon emissions in China, concluding that broader socio-economic factors significantly impact building emissions. This contrast suggests the need to consider both building-specific technologies and wider societal trends in decarbonization efforts.

Refs. [75,76] both address sector-specific challenges but focus on different aspects. Ref. [75] analyzes clean heating transitions in Northern China, emphasizing the importance of regional climate considerations. The other study [76] examines historical carbon abatement in commercial building operations, comparing China and the US to highlight the impact of policy differences. These studies underscore the importance of considering both technological solutions and policy frameworks in building sector decarbonization.

These comparative insights reveal that while researchers agree on the critical role of the buildings and infrastructure sector in achieving carbon neutrality, their conclusions about the most effective strategies vary significantly. The studies highlight a range of approaches, from building-specific technologies to urban planning and policy interventions, and emphasize the need for context-specific solutions that consider climatic, socio-economic, and institutional factors.

3.1.3. Carbon Neutrality in the Transportation Sector

This section delves into a collection of research papers that emphasize the critical importance of addressing carbon emissions in the transportation sector and highlight innovative technological solutions and policy interventions to accelerate progress towards carbon neutrality. The papers are shown in Table 5.

Analyzing the studies on carbon neutrality in the transportation sector reveals diverse conclusions about the most effective pathways to reducing emissions. Refs. [77,78] both explore alternative fuel technologies but reach different conclusions. Ref. [77] focuses on hydrotreated vegetable oils (HVO) for sustainable transport, emphasizing their potential as a drop-in fuel for existing vehicles. Results show that HVO can significantly reduce emissions: it lowers CO_2, CO, THC, and PM emissions while maintaining a similar efficiency to diesel. HVO is highly compatible with existing engines and can reduce greenhouse gas emissions by up to 75% over its lifecycle. The research suggests HVO, combined with advanced technologies, could be an effective short-term solution for reducing both tailpipe and overall CO_2 emissions in road transport. In contrast, ref. [78] analyzes the potential of power-to-liquid (PTL) technology for achieving carbon neutrality in China's transportation sector, highlighting the importance of integrating renewable energy with fuel production.

Results show that PTL can reduce carbon emissions by up to 93% compared to oil-to-liquid. The most cost-effective deployment strategy increases total costs by 5–10%. PTL diffusion is significantly influenced by oil prices and technology learning. It can serve as a supplementary solution for net-zero emissions in transportation, alongside other low-emission technologies. This comparison underscores the ongoing debate between biofuel and synthetic fuel approaches in decarbonizing transportation.

Table 5. Carbon neutrality in the transportation sector.

Theme	Subtheme	Authors	Focus
Transportation Sector	Renewable energies	Pipicelli M. et al., 2023 [77]	Analyzing hydrotreated vegetable oil (HVO) for transportation
		Zhao J. et al., 2022 [78]	Analyzing potential of power-to-liquid (PTL) technology for carbon neutrality in transportation
	Carbon capture	Bello S. et al. [79]	Analyzing potential of BECCS for carbon-negative transport
	Energy efficiency	Cui P. et al., 2023 [80]	Analyzing integrated development of transportation and energy
		Li J. et al. [81]	Analyzing embodied energy use in China's transportation sector
	Sustainable urban planning	Zhu X. et al., 2023 [82]	Analyzing impact of green logistics and finance on transportation emissions
		Du J. et al., 2023 [83]	Analyzing impact of green logistics and financial innovation on carbon neutrality in BRICS-T countries
	Electrification	Tan K.M. et al., 2023 [84]	Analyzing competitiveness of EVs compared to ICE vehicles
		Akimoto K. et al., 2022 [85]	Analyzing options for achieving carbon neutrality in road transport
		Chen W. et al., 2022 [86]	Analyzing decarbonization strategies for China's passenger car sector
		Hossain M.S. et al., 2023 [87]	Analyzing decarbonization strategies for Indian road transport
		Park S. et al., 2023 [88]	Designing EV energy trading system for carbon-neutral society
		Saafi M.A. et al., 2023 [89]	Analyzing key parameters for new energy vehicles in China
		Khurshid A. et al., 2023 [90]	Analyzing impact of transport sector innovation on emissions and welfare
		Aryanpur V. et al., 2022 [91]	Analyzing decarbonization of passenger light-duty vehicles in Ireland
		Saafi M.A. et al. [92]	Analyzing potential of hydrogen vehicles in China's light-duty vehicle market

Refs. [79,80] offer contrasting insights on carbon capture and energy system integration in transportation. Ref. [79] examines the potential of bioenergy with carbon capture and storage (BECCS) for achieving carbon-negative transport, emphasizing the role of negative emissions technologies. Ref. [80], however, focuses on the integrated development of transportation and energy systems, highlighting the importance of a holistic approach to sector coupling. These differing perspectives highlight the complexity of aligning transportation decarbonization with broader energy system transitions.

Refs. [84,85] both analyze vehicle electrification but draw different conclusions. Ref. [84] compares electric and internal combustion engine vehicles globally, emphasizing the importance of considering regional variations in electricity grids and policy landscapes. Ref. [85] assesses comprehensive energy systems for achieving carbon neutrality in road transport, concluding that a mix of technologies, including hydrogen and biofuels, may be necessary alongside electrification. This contrast highlights the ongoing debate about the extent to which electrification alone can achieve transportation decarbonization.

Refs. [86,87] examine decarbonization strategies for specific countries but focus on different aspects. Ref. [86] analyzes China's passenger car sector, emphasizing the need for both short-term behavioral changes and long-term technological solutions. Ref. [87] investigates strategies for narrowing fossil fuel consumption in India's road transport sector, highlighting the importance of policy interventions and infrastructure development. These studies underscore the need for tailored approaches that consider each country's unique transportation landscape and development goals.

Ref. [88] offers a unique perspective by designing an electric vehicle (EV) energy trading system connected with buildings, photovoltaics, and energy storage systems for a carbon-neutral society. It presents a connection-based energy trading platform and a strategy to manage peak consumption. Simulations comparing the proposed system to existing buildings show potential electricity bill reductions of 38.3% (best case) to 78.5% (worst case), highlighting its effectiveness in managing building energy consumption and costs. This approach emphasizes the potential for integrating transportation with other sectors to achieve broader sustainability goals, a nuance not fully explored in studies focusing solely on vehicle technologies or fuel alternatives.

These comparative insights reveal that while researchers agree on the urgency of addressing emissions in the transportation sector, their conclusions about the most effective strategies vary significantly. The studies highlight a range of approaches, from alternative fuels and electrification to system integration and policy interventions, emphasizing the need for multi-faceted, context-specific strategies to achieve carbon neutrality in transportation. The diversity of conclusions underscores the complexity of decarbonizing the transportation sector and the importance of considering technological, infrastructural, and societal factors in developing effective solutions.

3.1.4. Carbon Neutrality in the Industrial Sector

a. Circular Economy and Carbon Capture in the Industrial Sector

This section examines several research studies that demonstrate the urgent need to address carbon emissions in the industrial sector, as well as innovative technological developments and governmental initiatives aimed at accelerating the shift to carbon neutrality. Table 6 presents the materials for viewing.

Table 6. Sub-themes: the circular economy and carbon capture in the industrial sector.

Theme	Sub-Theme	Authors	Focus
Industrial Sector	Circular Economy	Yousaf A.U. et al., 2023 [93]	Exploring energy conservation through green technology and circular economy in petroleum industry
	Carbon Capture Strategies	Guo X. et al., 2023 [94]	Reviewing photoenzymatic decarboxylation for sustainable aviation fuel production
		Thepsaskul W. et al., 2023 [95]	Analyzing business models for CCS in Thailand's oil refining industry
		Strunge T. et al., 2023 [96]	Analyzing CO_2 mineralisation in cement sector
		Yu X.; Tan C., 2022 [97]	Analyzing carbon neutrality pathways for China's iron and steel industry

Analyzing studies on the circular economy and carbon capture technologies in the industrial sector reveals diverse conclusions about their role in achieving carbon neutrality. Refs. [93,94] both focus on innovative approaches to industrial decarbonization but reach different conclusions. Ref. [93] explores energy conservation through green technology and circular economy principles in the petroleum industry, emphasizing the importance of smart supply chain management. In contrast, ref. [94] reviews photoenzymatic decarboxylation for sustainable aviation fuel production, highlighting the potential of biotechnology in creating low-carbon alternatives. This comparison underscores the range of approaches being explored, from systemic changes in supply chains to specific technological innovations.

Refs. [95,96] offer contrasting insights on carbon capture and utilization (CCU) technologies in different industrial contexts. Ref. [95] analyzes potential business models for carbon capture and storage (CCS) in Thailand's oil refining industry, emphasizing the importance of economic viability alongside environmental benefits. Ref. [96], focusing on the cement sector, uses multi-criteria decision analysis to prioritize CO_2 mineralization technologies, highlighting the need for sector-specific solutions. These studies underscore the complexity of implementing CCU technologies across diverse industrial sectors.

Ref. [97] provides a broader perspective by analyzing carbon neutrality pathways for China's iron and steel industry. Results show current technologies can reduce emissions by over 50%, but achieving neutrality requires innovative technologies. Combining conventional strategies with CCS and hydrogen metallurgy can achieve 80–90% emission reduction, aligning with 1.5 °C targets. Future reduction potential depends on power system decarbonization and innovative technology diffusion rates, emphasizing the need for rapid action. This highlights the importance of considering multiple factors in developing effective carbon neutrality strategies for energy-intensive industries.

These comparative insights reveal that while researchers agree on the potential of circular economy principles and carbon capture in contributing to industrial carbon neutrality, their conclusions about the most effective strategies vary significantly. The studies highlight a range of approaches, from specific technological solutions to broader systemic changes, emphasizing the need for sector-specific and context-dependent strategies. The diversity of conclusions underscores the complexity of decarbonizing the industrial sector and the importance of integrating technological innovations with supportive policy frameworks and business models.

b. Energy Efficiency in the Industrial sector

The findings from the studies presented in Table 7 provide valuable insights into different aspects of decarbonization and carbon neutrality efforts in the industrial sector by utilizing an energy efficiency approach and carbon capture technologies.

Analyzing studies on energy efficiency in the industrial sector reveals diverse conclusions about its role in achieving carbon neutrality. Refs. [98,99] both focus on China's iron and steel industry but reach different conclusions. Ref. [98] analyze pathways to zero CO_2 emissions, emphasizing the importance of technological innovation and policy support, while ref. [99] focuses on coordinating energy and material efficiency strategies, highlighting the potential of circular economy approaches. This contrast underscores the range of strategies being explored within a single industry.

Refs. [100,101] offer contrasting insights on specific industrial contexts. Ref. [100] develops tools for monitoring GHG emissions in well operations, focusing on the oil and gas sector, while ref. [101] analyzes climate strategies of China's oil industry more broadly. The analysis of company reports reveals these firms have adopted national climate strategies, low-carbon energy systems, and emerging financial tools. Key drivers of their climate strategies include China's administrative system, international climate cooperation, energy mix transformation, and emerging market mechanisms, aligning with China's 2030 carbon peak and 2060 neutrality goals. These studies highlight the need for sector-specific approaches to energy efficiency and emission reduction.

Table 7. Sub-theme: energy efficiency in the industrial sector.

Theme	Subtheme	Authors	Focus
Industrial Sector	Energy Efficiency	Zhang S. et al., 2022 [98]	Analyzing pathways to zero CO_2 emissions in China's iron and steel industry
		Lin Y. et al., 2023 [99]	Analyzing decarbonization strategies for China's iron and steel sector
		Iorio V.S. et al., 2023 [100]	Developing tools for monitoring GHG emissions in well operations
		Wang S.; Altiparmak S.O., 2022 [101]	Analyzing climate strategies of China's oil industry
		Yi J. et al., 2023 [102]	Analyzing FDI impact on carbon emissions in China's manufacturing sector
		Xu X. et al., 2023 [103]	Analyzing green technology innovation in Chinese textile industry
		Rasheed R. et al., 2022 [104]	Analyzing carbon emissions in cement manufacturing
		Li Z.; Hanaoka T., 2022 [105]	Analyzing plant-level mitigation strategies for iron and steel sector
		Dong J. et al., 2023 [106]	Analyzing decarbonization pathways for China's energy-intensive sectors
		Zhang C. et al., 2023 [107]	Analyzing energy recovery in robotic excavators
		Dadi D. et al., 2023 [108]	Analyzing strategies for carbon neutrality in industrial companies

Refs. [102,103] examine the impact of external factors on industrial energy efficiency. Ref. [102] analyzes the impact of foreign direct investment on carbon emissions in China's manufacturing sector, while ref. [103] focuses on green technology innovation in the Chinese textile industry. Findings suggest enterprises should boost green innovation and balance economic and environmental benefits in R&D strategies. These studies underscore the importance of considering both economic and technological factors in industrial decarbonization strategies. In addition, refs. [104,105] both examine mitigation strategies but at different scales. Ref. [104] analyzes carbon emissions in cement manufacturing in a developing country context, while [105] focuses on plant-level mitigation strategies for China's iron and steel sector. This contrast highlights the need for both national and plant-level approaches to industrial decarbonization.

Ref. [106] provides a broader perspective by analyzing decarbonization pathways for China's energy-intensive sectors. Their comprehensive approach contrasts with the more sector-specific studies, emphasizing the need for integrated strategies across multiple industries. Ref. [107] offers a unique perspective by focusing on energy recovery in robotic excavators. Results suggest this innovation can significantly reduce energy consumption and carbon emissions in excavators.

These comparative insights reveal that while researchers agree on the importance of energy efficiency in industrial decarbonization, their conclusions about the most effective strategies vary significantly. The studies highlight a range of approaches, from sector-specific technological solutions to broader policy frameworks, and emphasize the need for considering both economic factors and technological innovations in developing effective industrial decarbonization strategies.

3.1.5. Carbon Neutrality in the Agriculture Sector

This section examines several research studies that demonstrate the urgent need to address carbon emissions in the agriculture sector, as well as innovative technological de-

velopments and governmental initiatives aimed at accelerating the shift to carbon neutrality. Table 8 presents the materials for viewing.

Table 8. Carbon neutrality in the agriculture sector.

Theme	Sub-Theme	Authors	Focus
Agriculture	Energy Efficiency	Zhu J. et al., 2023 [109]	Reviewing phase change energy storage technology in agricultural greenhouses
		Chen M. et al., 2022 [110]	Analyzing non-CO_2 GHG emissions from Chinese agriculture

Aanalyzing studies on carbon neutrality in the agriculture sector reveals diverse approaches to addressing emissions and enhancing sustainability. Refs. [109,110] both focus on technological solutions for the agricultural sector but reach different conclusions about priority areas.

Ref. [109] reviews phase change energy storage (PCEST) technology in agricultural greenhouses, emphasizing the potential for energy efficiency improvements in controlled environment agriculture. Their study highlights the role of innovative energy management systems in reducing the carbon footprint of intensive farming practices, particularly in regions with extreme climates or limited resources.

In contrast, ref. [110] analyzes the trajectory and technical mitigation potential of non-CO_2 greenhouse gas emissions from Chinese agriculture, highlighting the importance of addressing methane and nitrous oxide emissions alongside CO_2. Their research emphasizes the need for a comprehensive approach to agricultural emissions, recognizing that carbon dioxide is not the only significant greenhouse gas produced by farming activities.

This comparison underscores the range of approaches being explored in the agricultural sector, from energy management to direct emissions reduction. While ref. [109] focuses on improving the efficiency of agricultural infrastructure. PCEST can achieve solar energy "peak load shifting", reduce temperature fluctuations, prevent heat and frost damage, and lower building energy demand. Ref. [110] advocates for a broader strategy that targets multiple greenhouse gasses across various agricultural practices. Results show that implementing 17 identified technologies could reduce emissions 32–50% by 2060, with feed supplements, improved feed quality, slow-release fertilizers, and water management being the most effective.

These studies collectively suggest that achieving carbon neutrality in agriculture will require a multifaceted approach, combining improvements in energy efficiency with targeted efforts to reduce non-CO_2 emissions. The diversity of conclusions highlights the complexity of the agricultural sector's role in climate change mitigation and the need for context-specific strategies that consider both technological innovations and the unique characteristics of different agricultural systems.

It is worth noting that while the studies by [109,110] provide valuable insights into energy efficiency and non-CO_2 emissions in agriculture, they do not explore the critical aspect of carbon sequestration. This is a significant limitation, as carbon sequestration by plants through practices such as improved soil management, agroforestry, and reforestation plays a crucial role in agriculture's potential to contribute to carbon neutrality. The omission of carbon sequestration from these studies highlights a gap in the research, suggesting a need for more comprehensive analyses that integrate emission reduction, energy efficiency, and carbon sequestration potential in agricultural systems. Future research should aim to address this gap by examining how various agricultural practices can not only reduce emissions but also enhance the sector's capacity to act as a carbon sink.

3.1.6. Policy and Regulatory Framework for Carbon Neutrality

This section examines several studies that demonstrate the urgent need to address carbon emissions in the industrial sector, as well as innovative technological developments

and governmental initiatives aimed at accelerating the shift to carbon neutrality. Table 9 presents the materials for viewing.

Table 9. Policy and regulatory framework for carbon neutrality.

Theme	Sub-Theme	Authors	Focus
Policy and Regulatory Frameworks	Energy Efficiency	Kato S. et al., 2023 [111]	Analyzing economic impact of Japan's carbon neutrality goals
		Anderson B. et al., 2023 [112]	Evaluating policy packages for industrial decarbonization
		Du X., 2023 [113]	Discussing strategies for achieving carbon peaking and neutrality in China
		Guo N., 2023 [114]	Analyzing legal aspects of decarbonization in China
		Xiao L. et al., 2022 [115]	Analyzing CO_2 emissions and drivers in 2004 EU accession countries
		Bai S. et al., 2023 [116]	Analyzing relationship between low-carbon economic development, health, and GDP
		Chen L. et al., 2022 [117]	Reviewing strategies for achieving carbon neutrality
		Numan U. et al., 2023 [118]	Analyzing impact of economic complexity and energy sector on sustainability
		Hakovirta M. et al., 2023 [119]	Analyzing role of start-ups in corporate innovation for climate change mitigation
		Wang P.; Liang S., 2022 [120]	Analyzing impact of environmental regulations on energy efficiency
		Saqib N. et al., 2023 [121]	Analyzing factors affecting CO_2 emissions in G-10 countries
		Stepnov I.M. et al., 2023 [122]	Analyzing impact of green protectionism on technological inequality
		Popova I.; Kolmar O., 2023 [123]	Analyzing Russia's low-carbon development policy
		Yao L. et al., 2023 [124]	Reviewing carbon emission reduction strategies and policies
		Zhang Y., 2023 [125]	Analyzing AI-powered carbon neutrality strategies for sports event management
		Heggelund G.M., 2021 [126]	Analyzing China's climate and energy policy development
		Safonov G. et al., 2022 [127]	Analyzing global decarbonization perspectives
		Fu J. et al., 2021 [128]	Analyzing climate mitigation and adaptation efforts in China
		Wang C. et al., 2021 [129]	Analyzing technology lists for addressing climate change in China
		He J. et al., 2022 [130]	Analyzing China's long-term low-carbon transition pathways

Analyzing studies on policy and regulatory frameworks for carbon neutrality reveals diverse conclusions about effective governance approaches. Refs. [111,112] both examine policy impacts but reach different conclusions. Ref. [111] analyzes the economic impact of Japan's carbon neutrality goals using a macro-econometric model, emphasizing the need for sector-specific policies and highlighting potential economic trade-offs. In contrast, ref. [112] evaluates policy packages for industrial decarbonization in the Netherlands, concluding

that a comprehensive, multi-instrument approach is most effective. This comparison underscores the debate between targeted sectoral policies and integrated policy frameworks.

Refs. [113,114] offer contrasting insights on China's approach to carbon neutrality. Ref. [113] discusses strategies for achieving carbon peaking and neutrality in China, emphasizing the importance of technological innovation and market mechanisms. Ref. [114] however, analyzes legal pathways of decarbonization in China from an emissions trading perspective, highlighting the role of regulatory frameworks. These studies underscore the complexity of balancing economic development with environmental goals in rapidly growing economies.

Refs. [114,116] examine different aspects of carbon emissions drivers. Ref. [114] analyzes CO_2 emissions and drivers in 2004 EU accession countries, emphasizing the role of economic structures and energy efficiency. Ref. [116] investigates the relationship between low-carbon economic development, health, and GDP, highlighting the potential co-benefits of climate policies. This contrast suggests the need to consider both economic and social factors in policy design.

Refs. [117,118] both address broader strategic approaches but focus on different aspects. Ref. [117] reviews strategies to achieve a carbon-neutral society, emphasizing the need for systemic changes across sectors. They discuss decarbonization technologies, negative emissions technologies, carbon trading, and carbon tax. The proposed plan includes shifting to renewable energy, developing low-carbon technologies and agriculture, changing diets, utilizing agricultural waste, building resilient cities, implementing decentralized energy systems, and electrifying transportation. Ref. [118] analyzes the impact of economic complexity and the energy sector on sustainability in exporting economies, highlighting the role of economic structures in emission patterns. These studies underscore the importance of considering both sector-specific and economy-wide factors in policy development.

Ref. [119] provides a unique perspective by focusing on corporate net-zero strategies and the role of start-up-driven climate innovation. The analysis of start-up businesses in climate innovation from 2000 to 2022 shows that the total post-valuation of climate innovation start-ups reached EUR 27 billion. During this period, the share of these start-ups grew by 2000%, while financial investments or deals in this sector increased by 2811%. These results highlight start-ups' significant contribution to corporate innovation and sustainability strategies, particularly in helping companies achieve ambitious carbon zero targets. This approach emphasizes the potential for private sector leadership in driving carbon neutrality, a nuance not fully explored in studies focusing on government policies.

These comparative insights reveal that while researchers agree on the importance of policy and regulatory frameworks in achieving carbon neutrality, their conclusions about the most effective approaches vary significantly. The studies highlight a range of strategies, from sector-specific interventions to economy-wide transformations, and emphasize the need for context-specific policies that consider economic structures, technological capabilities, and social factors. The diversity of conclusions underscores the complexity of designing effective carbon neutrality policies and the importance of integrated approaches that balance economic, environmental, and social objectives.

By synthesizing findings from these diverse sectors, this content analysis offers valuable insights into the most promising pathways towards carbon neutrality, while also identifying critical research gaps and areas for future investigation. The analysis reveals the complex interplay between technological innovation, policy intervention, and sectoral strategies in achieving carbon neutrality, highlighting the need for integrated, interdisciplinary approaches that consider interactions between technological, economic, social, and environmental factors.

3.2. Bibliometric Analysis

In this section, a comprehensive systematic literature review is conducted with a focus on the broader topic of achieving carbon neutrality and its policy implementation. The objective is to summarize the latest significant findings and research in this crucial area

by analyzing a diverse range of academic papers and empirical studies obtained from the Scopus database. The goal is to highlight the primary themes and empirical evidence that contribute to understanding effective strategies for achieving carbon neutrality through meticulous screening and rigorous analysis. The investigation covers various topics, including carbon neutrality strategies, technologies, and policies, as well as assessments of carbon national contexts and the role of technology in achieving carbon neutrality. Examining the results and visual representations reveals the development paths of research, patterns of term co-occurrence, and prevalent technology applications, in the context of countries achieving carbon neutrality. This bibliometric analysis methodology follows established practices in the field of scientometrics [131]. A co-occurrence analysis of keywords and analysis of co-authorship by country were employed, techniques that have been proven effective in mapping scientific fields [132].

Utilizing VOSviewer, three distinct visualization maps are generated to provide a comprehensive overview of the current state of achieving carbon neutrality. These maps aim to offer a detailed examination of the topic. Each map represents various entities, including terms, researchers, and publications, through circles. The size of each circle and the text within it indicate the level of activity associated with that entity. Larger circles and larger font sizes represent higher activity, while smaller circles and smaller font sizes indicate lower activity. The distance between any two terms in the diagram reflects their degree of association with each other. A shorter distance signifies a stronger association [133].

3.2.1. Co-Occurrence Map Based on Text Data

Analyzing text data extracted from 113 selected publications, prominent terms frequently referenced in the field were identified. This process involved examining the titles and abstracts of these articles to highlight significant terms and establish connections between them based on their co-occurrence. Such an examination facilitates the identification of emerging trends and the recognition of influential terms within the realm of achieving carbon neutrality [134]. Using VOSviewer, a total of 3920 terms were identified, with 63 terms meeting the minimum threshold of appearing at least eight times. VOSviewer assigned a significance score to each term, selecting the top 60% of terms considered most relevant, resulting in 44 terms depicted in the network shown in Figure 5. Terms with higher significance scores indicate more specific topics represented in the text data, while terms with lower scores typically pertain to broader subjects [134].

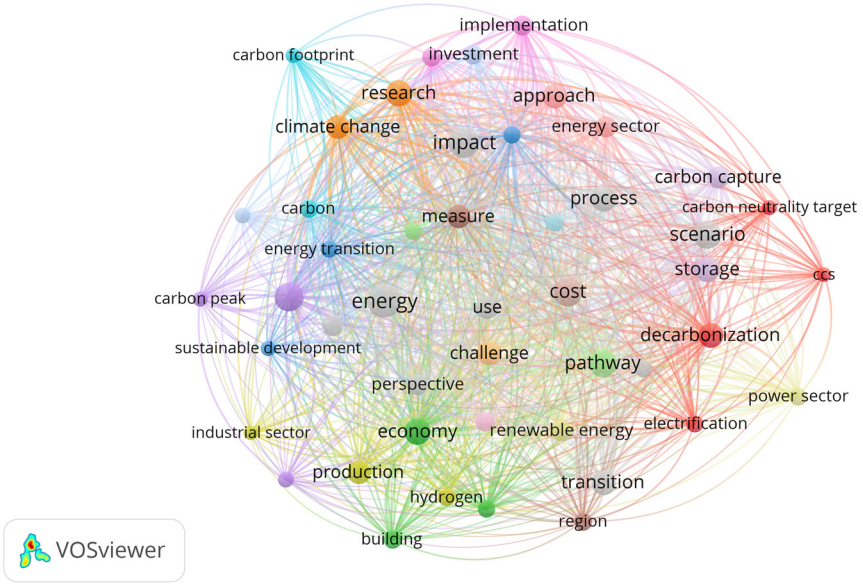

Figure 5. Co-occurrence map based on text data.

Figure 5 visualizes the relationships between key terms in the literature. Larger nodes indicate more frequently occurring terms, while lines between nodes represent co-occurrence in publications. The colors represent different thematic clusters where terms of the same color are more closely related in the literature. For example, the red color shows the connection between decarbonization and carbon neutrality targets with electrification and CCS. The green color shows the connection between building and hydrogen and its relation to a pathway for carbon neutrality. The lines between nodes indicate co-occurrence relationships, with line thickness representing the strength of connection between terms. The interconnected network of crucial concepts suggests that carbon neutrality target, decarbonization, climate change, and energy, all have been central topics in the literature on carbon neutrality and its implementation.

The overarching goal of carbon neutrality serves as the driving force behind a complex interplay of strategies, technologies, and sectors. This goal necessitates a comprehensive approach to decarbonization across multiple domains of human activity and industry. In this figure, key strategies and technology keywords are revealed such as "carbon capture", "electrification", "renewable energy", and "hydrogen", which play pivotal roles in enabling this transition. The figure also reveals keywords related to sectors the "power sector", "transportation sector", "industrial sector", "energy sector", and "buildings". The power sector is the subset of the energy sector. The sector-related keywords confirm the sectors that were identified in the content analysis.

Strategies for achieving carbon neutrality are multifaceted, often involving a mix of technological innovation, policy implementation, and behavioral changes.

In addition, Figure 5 shows the interconnectedness of strategies and technologies, which underscores the need for an integrated approach to the energy transition. Success in one sector can catalyze progress in others, just as challenges in one area can create obstacles elsewhere. For instance, advancements in renewable energy technology in the power sector directly impact the feasibility of electrification in transportation and buildings. Ultimately, the relationship between the main goal, technologies, strategies, and sectors in the context of carbon neutrality is one of mutual dependence and reinforcement. Progress towards carbon neutrality requires coordinated efforts across all these dimensions, with each element contributing to and being influenced by the others in the pursuit of sustainable development and effective climate change mitigation.

3.2.2. Co-Occurrence Map Based on All Keywords

By examining the bibliometric details from a set of 113 chosen publications, a comprehensive range of 1254 keywords emerged. From this collection, a subset of 60 keywords was extracted, each appearing at least ten times, as described in Figure 6. Employing VOSviewer, these keywords underwent normalization, leading to the refinement of the list by eliminating redundant entries. This figure shows the relationships between keywords across the analyzed publications. The size of each node corresponds to the frequency of the keyword, while the lines represent co-occurrence. The colors indicate different thematic clusters. Colors in the visualization differentiate between different research themes or clusters. Each color represents a distinct research focus area within carbon neutrality studies. The thickness and color of connecting lines indicate the strength and frequency of keyword co-occurrence in the literature. This figure reveals keywords related to strategies.

The analysis of keywords in Figure 6 highlights significant themes in discussions surrounding carbon neutrality, with "climate change", "carbon emissions", and "carbon neutrality" emerging as central focal points. These terms underscore the critical challenges and imperatives in achieving carbon neutrality goals, emphasizing the urgency of reducing carbon emissions and transitioning to sustainable energy sources and practices.

Furthermore, the analysis of keywords in Figure 6 shows key strategies for achieving carbon neutrality. The analysis reveals five primary clusters of terms closely associated with carbon neutrality efforts. The "Renewable Energy" cluster emphasizes the critical role of transitioning to clean energy sources such as solar, wind, and hydroelectric power

in reducing greenhouse gas emissions as it is linked to keywords such as "wind Power", "alternative energy", and "optimization". Energy efficiency highlights the importance of optimizing energy use across various sectors, including terms related to "energy consumption" and "energy utilization" measures. The "Carbon Capture" cluster reflects the growing interest in strategies designed to capture, store, or utilize carbon emissions. Additionally, the "Energy Policy" cluster emerged, highlighting the crucial role of governmental and institutional frameworks in guiding and accelerating the transition to carbon neutrality through regulations, incentives, and strategic planning. These clusters align closely with our research question, providing insight into the key strategies and technologies proposed for reducing greenhouse gas emissions across different sectors.

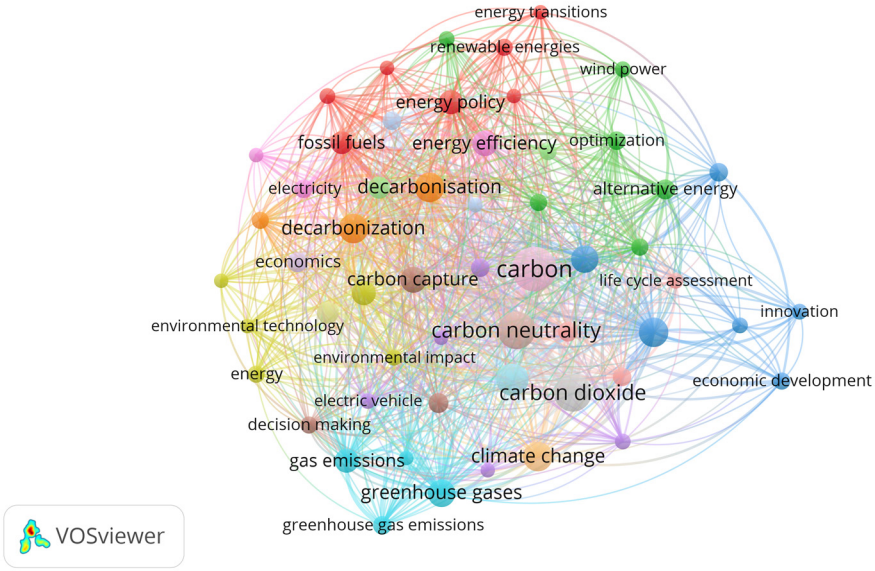

Figure 6. Co-occurrence map of all keywords.

The analysis also reveals that while renewable energy and energy efficiency are well-represented in the literature, there appears to be less focus on some potentially important strategies. For instance, terms related to nature-based solutions or sustainable agriculture are less prominent despite their potential for both emissions' reduction and carbon sequestration, suggesting these areas may be underrepresented in current carbon neutrality research, indicating potential areas for future research focus.

Continuing the exploration, another supplementary keyword diagram was developed. This diagram visualizes the most frequently used author-specified keywords. These were refined to those appearing at least three times, yielding a network of 18 distinct author keywords, as illustrated in Figure 7. This visualization represents the most common author-defined keywords. The color clusters represent groups of frequently co-occurring author-specified keywords. Each color indicates a distinct research focus area: blue for carbon neutrality approaches, red for technology, and green for climate change mitigation. The size of nodes represents keyword frequency, while line connections show co-occurrence strength.

In addition, Figure 8 shows the relationships between index keywords. The size of each node corresponds to the frequency of the keyword in the index, while the connections represent co-occurrence. Colors distinguish between different thematic areas in the indexed keywords. Green clusters represent technological solutions, green shows economic aspect, blue indicates sectoral approaches, and yellow highlights social aspects. Line thickness represents the strength of relationships between keywords. The co-occurrence map of index keywords, enriched with additional terms from author keywords, reveals even more information about strategies and technologies for achieving carbon neutrality. Like other figures, in Figure 8, the central node "carbon neutrality" is closely linked to

"decarbonization" and "climate change", emphasizing the urgency and scope of the challenge. "Alternative energy", including "solar energy" and "wind power", emerges as a crucial strategy, highlighting the importance of renewable sources in transitioning away from carbon-intensive energy production. "Carbon capture" and "carbon sequestration" represent key technologies for mitigating emissions, especially in hard-to-abate sectors, while "energy efficiency" appears as a cross-cutting strategy linked to both environmental and socio-economic aspects.

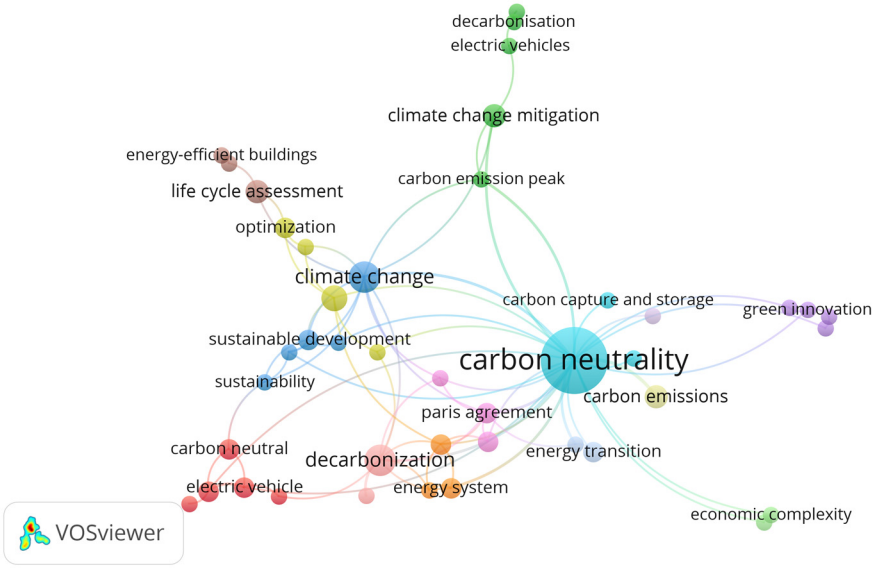

Figure 7. Co-occurrence map of author keywords.

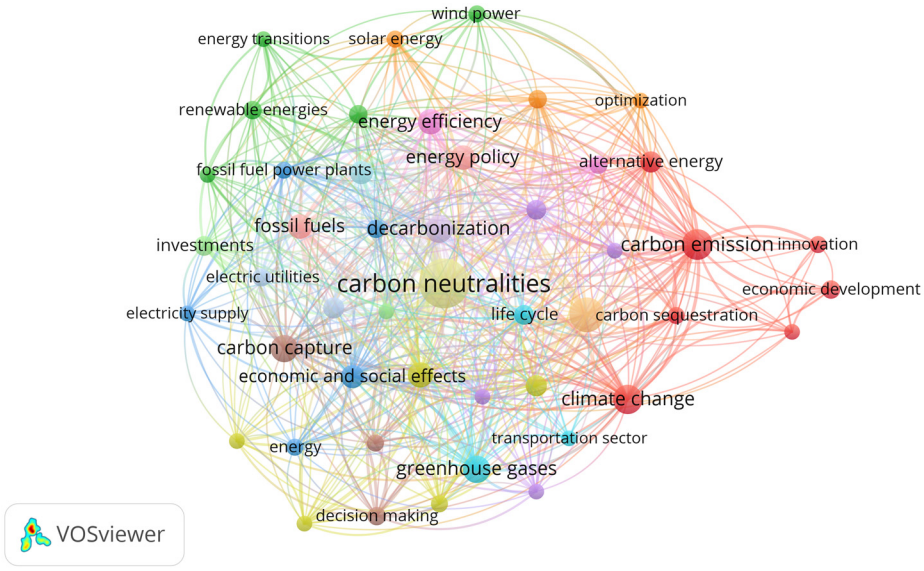

Figure 8. Co-occurrence map of index keywords.

This figure reveals more information: the inclusion of the "energy efficient buildings" keyword underscores the significance of the built environment in carbon neutrality efforts, while "electric vehicles" and "transportation sector" highlight the critical role of mobility in emission reduction strategies. "Energy transitions" encapsulates the broader process of systemic change required across all sectors. "Lifecycle assessment" emerges as a vital methodological approach for evaluating the true environmental impact of various technologies and strategies, ensuring a holistic view of emission reduction efforts.

In addition, economic considerations are prominently represented through keywords such as "economic complexity", "investments", and "economic and social effects". These terms emphasize the need to consider broader implications of carbon neutrality strategies, including financial requirements, economic structures, and societal impacts. "Electricity supply" underscores the critical role of the power sector in achieving carbon neutrality, linking to strategies like renewable energy integration and grid modernization.

This rich analysis of keywords illustrates that achieving carbon neutrality requires a multifaceted approach combining technological innovations, efficiency improvements, sector-specific strategies, and the consideration of broader socio-economic impacts. It highlights the need for significant investments, systemic changes, and holistic evaluation methods. The map effectively demonstrates that strategies and technologies for carbon neutrality span multiple sectors, require economic and social consideration, and must be assessed comprehensively to ensure their effectiveness in reducing overall emissions. This expanded perspective provides an interconnected view of the pathways towards a carbon-neutral future, addressing our research question by showcasing the diverse and interrelated strategies and technologies necessary for this global transition.

3.2.3. Co-Occurrence Map Based on Country of Co-Authorship

Moreover, the examination of the data exposed the geographical distribution of the discussed articles. The map depicting the countries engaged in co-authorship exclusively featured those with a minimum of five documents attributed to each country. Out of the 44 countries assessed, only 7 surpassed this criterion. Different colors indicate distinct collaboration clusters between countries, with countries of the same color showing stronger research collaboration patterns. The connecting lines between nodes represent co-authorship relationships, with line thickness indicating collaboration frequency. The results are depicted in Figure 9.

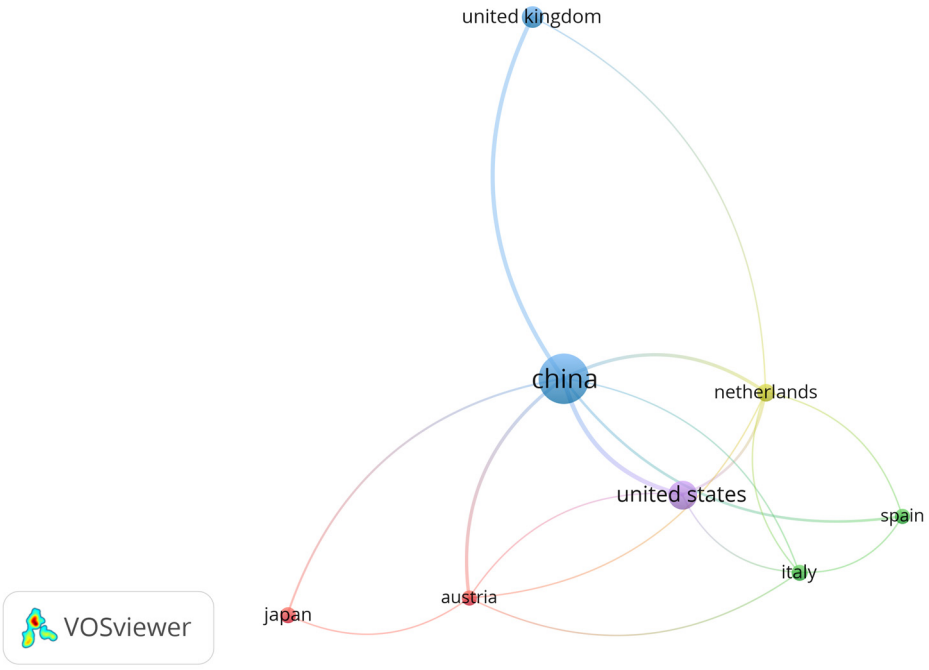

Figure 9. Country of co-authorship.

China emerges as the clear leader in carbon neutrality research, with the highest number of publications and citations. This is followed by significant contributions from the United States and the United Kingdom. The dominance of Chinese research in this field likely reflects the country's ambitious carbon neutrality goals and substantial investments in clean energy technologies. Other countries, including the Netherlands, Italy, Spain,

and Japan, are also prominently featured, indicating their growing influence in carbon neutrality research within the framework of environmental studies.

The distribution of research publications across these countries suggests a broad, global interest in exploring carbon neutrality strategies and solutions. Moreover, the dominance of English-speaking countries such as the United States, the United Kingdom, and Australia at the top of the list underscores their leadership in environmental research and innovation. However, the increasing contributions from nations like China, the Netherlands, Italy, Spain, and Japan signify a widening global engagement with carbon neutrality themes.

Enhanced collaboration and the exchange of insights across different countries and cultures are crucial for fostering a diverse, cross-cultural understanding of carbon neutrality. This collaborative approach can facilitate the development of effective strategies and policies to address climate change challenges on a global scale.

To sum up, this bibliometric analysis not only identifies key strategies and technologies for achieving carbon neutrality—such as renewable energy, energy efficiency, and carbon capture—but also reveals potential areas for future research and development. By highlighting both the well-represented and underexplored strategies, this analysis provides a comprehensive answer to our research question, offering insights into the current state of carbon neutrality proposals and pointing towards areas where further investigation could yield valuable contributions to achieving carbon neutrality across different sectors.

3.3. Data Analysis

3.3.1. Data Analysis on Article Sources

To investigate the origins of the 113 publications, a compilation of all distinct sources were generated and organized in descending order based on the frequency of articles. The *Journal of Cleaner Production* emerged as the top-ranked source, with fifteen publications, followed by the *Energies* journal with six publications. Figure 10 presents a bar graph depicting the top 10 sources ranked by publication count.

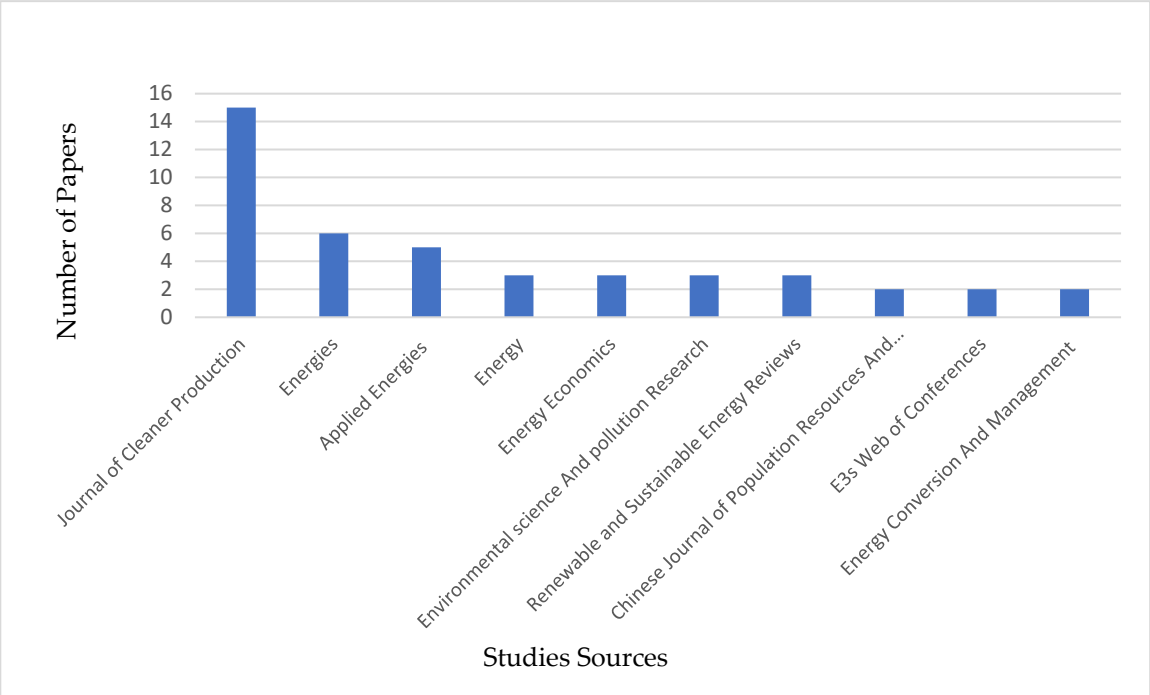

Figure 10. Top 10 sources by number of publications.

Examining the sources of articles offers valuable insights into the interdisciplinary nature of research on carbon neutrality, showcasing its relevance across various fields such as energy, environmental science, and policy. This interdisciplinary approach emphasizes

the importance of addressing carbon neutrality from diverse perspectives and disciplines, reflecting the multifaceted challenges and opportunities associated with achieving carbon neutrality goals.

3.3.2. Data Analysis on Document Fields, Types, and Form of Study

In the analysis of study fields related to carbon neutrality, a diverse range of sectors emerges, shedding light on the multifaceted nature of efforts to address carbon emissions and environmental sustainability, as presented in Figure 11. The prominence of energy and environmental science, with 70 and 66 papers, respectively, underscores the central role of these disciplines in understanding and mitigating carbon footprints across various industries. Engineering, with 50 papers, indicates a strong focus on developing innovative solutions for carbon capture, renewable energy, and sustainable infrastructure.

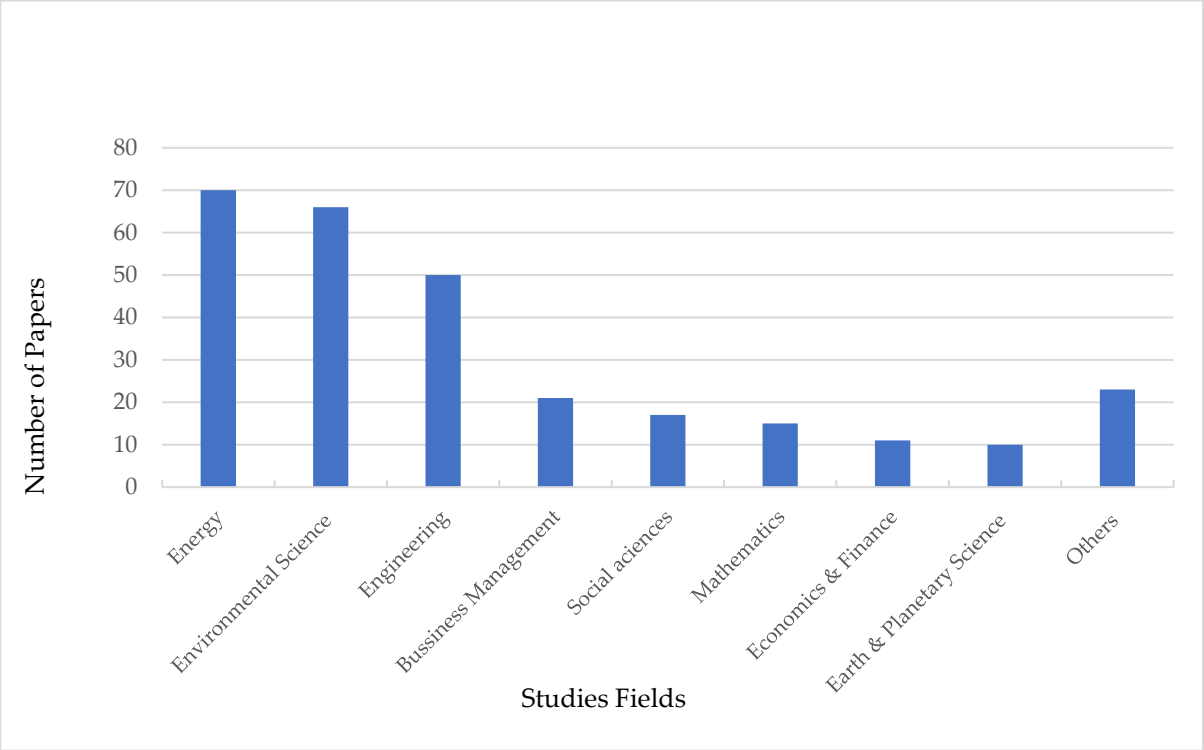

Figure 11. Study field occurrence.

Furthermore, business management and accounting, economics and finance, and social sciences, with 21, 17, and 15 papers, respectively, highlight the intersection between carbon neutrality and economic systems, organizational strategies, and societal dynamics. Mathematics, with 11 papers, likely contributes to modeling and analyzing carbon emissions and mitigation strategies.

In contrast, sectors like agriculture, medicine, and physics, though less represented with one paper each, underscore the expanding scope of carbon neutrality research into diverse domains beyond traditional environmental and energy studies.

This comprehensive overview of study fields provides valuable insights into the breadth and depth of research on carbon neutrality, emphasizing the collaborative and interdisciplinary efforts needed to address the complex challenges of climate change and environmental sustainability.

Following that, an exploration into the diverse research methodologies utilized within the realm of achieving carbon neutrality was undertaken, with the objective of illuminating the core focus and intensity of academic pursuits in this sphere. This analysis offered insights into the scholarly endeavors within the field, as depicted in Figure 12. Upon

scrutinizing 113 papers, each manuscript was meticulously categorized into one of the six distinct research types: empirical, analytical, case study, review/descriptive, conceptual, and developmental, in alignment with their respective research objectives. The analysis reveals that empirical research, those studies with data collection and analysis, statistical modeling, and scenario analyses based on real-world data, emerges as the dominant category, constituting 48 papers. Following this are analytical studies, focusing on mathematical modeling, optimization, and theoretical analyses, constituting 29 papers. Case studies that examine specific countries, regions, or organizations in detail, constituted 18 papers. Descriptive research, centered on detailed portrayal or narration, is represented by 12 papers, while conceptual and developmental research, though acknowledged, are comparatively less prevalent. This meticulous classification offers a panoramic view of the research landscape of articles, exemplifying the dominance of analytical methodologies, followed by conceptual approaches.

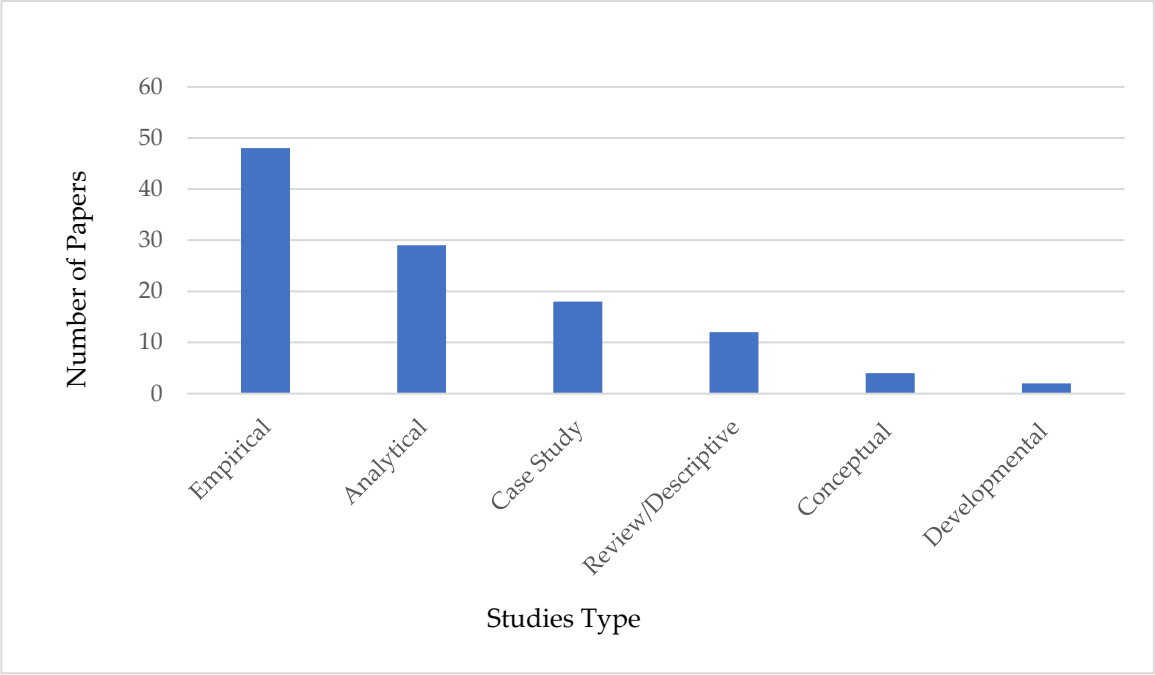

Figure 12. Occurrence of research type.

3.3.3. Data Analysis on Form of Study

Furthermore, the analysis of the form of study presented in Figure 13 reveals that from the total 113 publications, the majority were research articles (94), representing 83.2% of the total documents. Conference papers constituted the second largest category, with 13 publications (11.5%), followed by book chapters (3, 2.7%). The remaining document types each contributed one publication: book (0.9%), editorial (0.9%), and short survey (0.9%). This distribution emphasizes the strong presence of peer-reviewed research articles in carbon neutrality strategies and technologies, suggesting a mature research area with substantial scholarly investigation. The dominance of peer-reviewed research ensures high-quality, scientifically validated findings. Articles represent original research, undergo rigorous peer review, and provide detailed methodologies and conclusions that can be critically evaluated. This reveals the quality of evidence that focuses on the most current, peer-validated research in the rapidly evolving field of carbon neutrality.

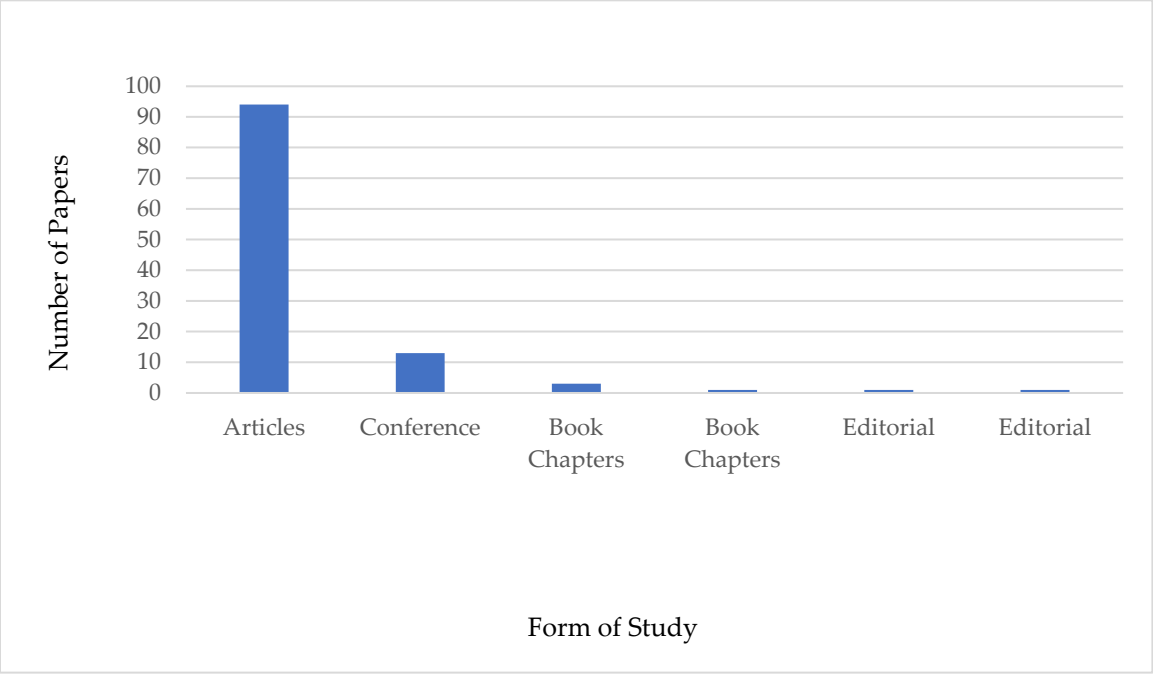

Figure 13. Occurrence of form of Study.

4. Synthesis of Content and Bibliometric Analysis

The analysis revealed a comprehensive landscape of strategies and technologies for achieving carbon neutrality across various sectors, and is summarized in Figure 14. The diagram employs a two-tiered structure to clearly showcase the data, with the primary level focusing on the main themes identified across numerous publications. The varying sizes of circles in this layer illustrate the frequency of these themes, based on the number of scholarly articles in each thematic area. Moreover, each sub-theme is further divided into more specific points, represented by smaller secondary circles highlighting significant terms. The dimensions of these sub-circles indicate the importance of the terms, reflected in their frequency and the number of related academic works. This comprehensive spider chart succinctly captures the breadth and impact of carbon neutrality, offering a concise view of the field's ongoing research and practical applications. It highlights the interconnected nature of carbon neutrality strategies across different sectors, while also allowing for easy identification of sector-specific approaches.

In summary, research intensity across sectors showed distinct patterns. The top-ranked and the most extensively studied area is the energy sector, with analysis centered on three key sub-themes: renewable energies, carbon capture technology and electrification, and energy efficiency. The literature emphasized the critical role of transitioning to renewable energy sources, while also exploring the potential and challenges of carbon capture and storage (CCS) technologies. Energy efficiency emerged as a cross-cutting theme, applicable from power generation to end-use consumption.

The transportation sector ranked second in research focus, with studies examining renewable energy, energy efficiency, carbon capture, and electrification as key strategies. The industrial sector followed as the third most researched area, with studies exploring circular economy principles, waste management, and energy efficiency in industrial processes.

The buildings and infrastructure sector ranked fourth, with analysis covering green building designs, renewable energy integration, and energy efficiency measures. Finally, the agriculture sector received the least attention, showing very limited studies despite its significant potential for carbon sequestration and emissions reduction. This research gap was particularly evident in the scarce literature on sustainable agricultural practices and the potential of agricultural lands to act as carbon sinks.

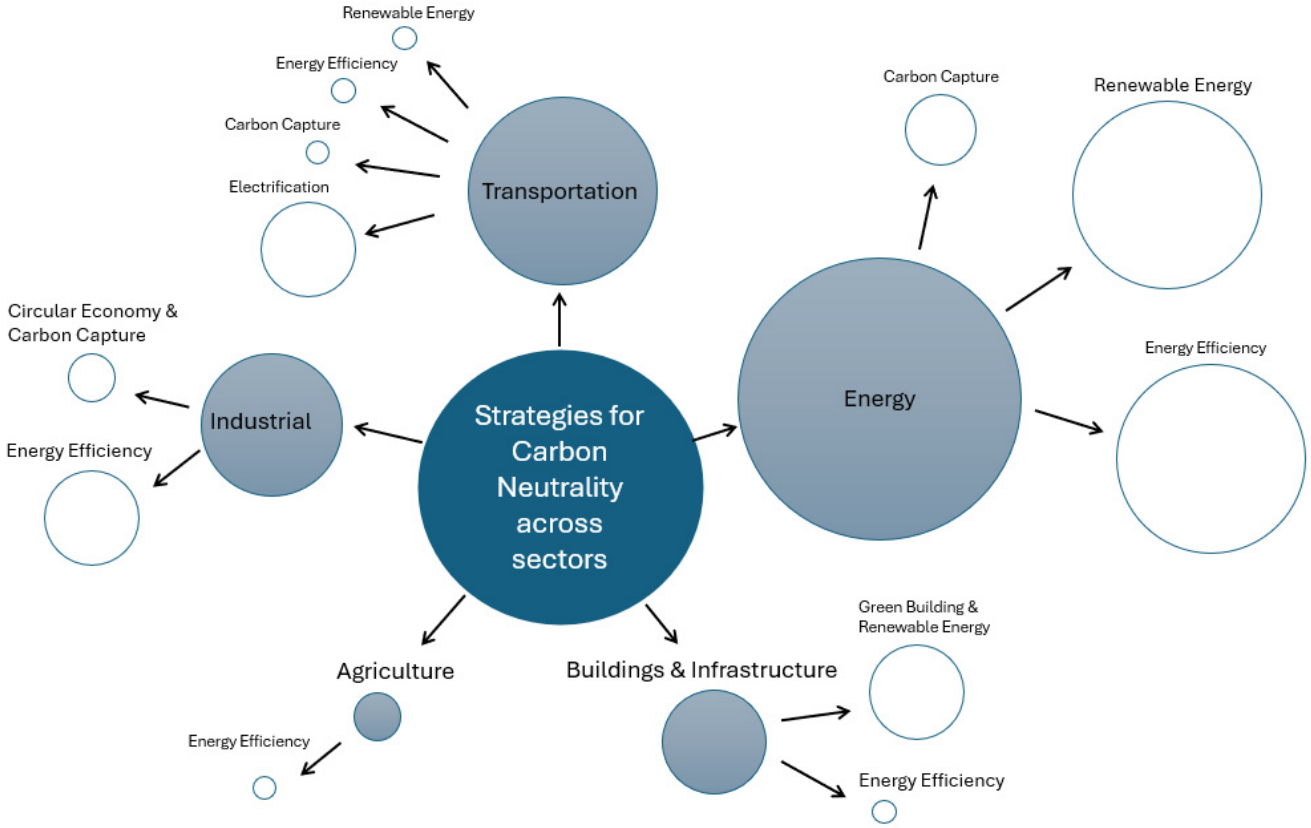

Figure 14. Summary of main strategies and technologies across sectors for achieving carbon neutrality.

In addition, the analysis of policy and regulatory frameworks highlighted the importance of energy efficiency policies, carbon pricing mechanisms, and international cooperation in achieving carbon neutrality goals. Therefore, there is a need for integrated approaches that consider both technological advancements and supportive policy environments.

Further analysis is conducted to reveal the interconnectedness and interdependencies in strategies between the top three ranked sectors. Figure 15 illustrates the distribution of carbon neutrality strategies across three major sectors: the energy, transportation, and industrial sectors. It highlights how strategies like carbon capture and energy efficiency are universally applied across all three sectors, underscoring their fundamental importance in achieving emission reduction goals. The shared implementation of renewable energy strategies between the energy and transportation sectors reflects the growing interdependence of these fields, particularly in the context of the electrification of transport systems. Sector-specific strategies such as electrification in transportation and circular economy principles in the industrial sector demonstrate the tailored approaches required to address unique challenges within each domain. The exclusive focus on electrification in the transportation sector emphasizes the critical role of electric vehicles and associated infrastructure in decarbonizing mobility. Similarly, the industrial sector's singular emphasis on circular economy strategies highlights the importance of sustainable resource management and waste reduction in manufacturing processes. This distribution of strategies across sectors illustrates both the common ground and the specialized approaches necessary for a comprehensive carbon neutrality framework, by illustrating how various strategies and technologies contribute to the overall goal of carbon neutrality.

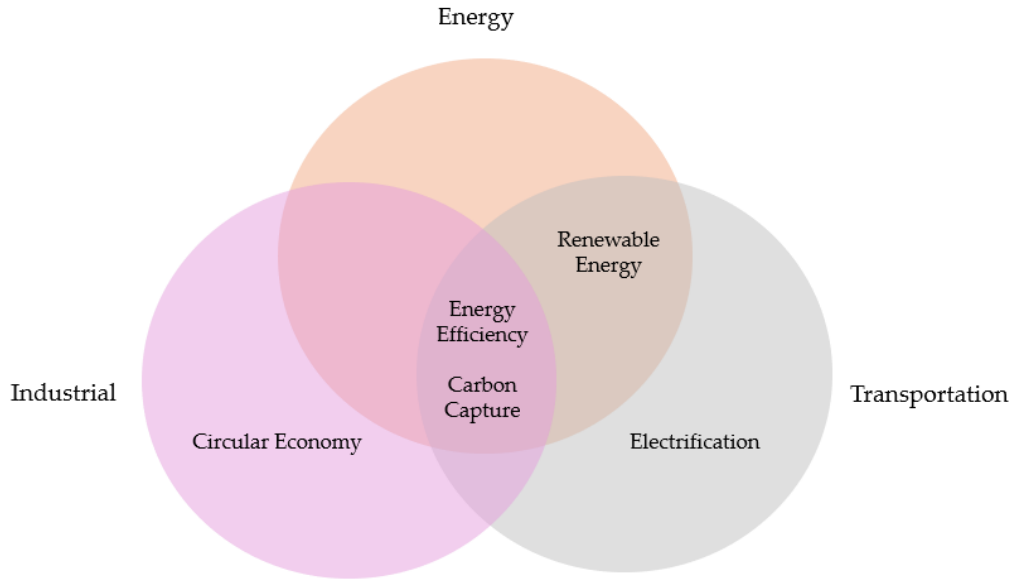

Figure 15. Venn diagram of three main sectors and common strategies and technologies in achieving carbon neutrality.

The bibliometric analysis, conducted after the content analysis, largely corroborated these findings, while providing additional insights into research trends and focus areas. It highlighted four key clusters of strategies and technologies: renewable energy, energy efficiency, carbon capture, and carbon sequestration. This alignment with the content analysis findings reinforces the importance of these areas in carbon neutrality research.

However, the bibliometric analysis also revealed some discrepancies. While it confirmed the dominance of energy and industrial sector research, it highlighted the underrepresentation of agriculture and forestry in the literature. This aligns with the content analysis finding limited research in these sectors, despite their potential significance in achieving carbon neutrality.

The bibliometric analysis also provided insights into research collaboration patterns, revealing that countries like China, the United States, and the United Kingdom are leading in carbon neutrality research. This geographical distribution of research efforts suggests potential areas for increased international collaboration and knowledge sharing.

The expanded keyword analysis further enriched our understanding of the strategies and technologies for carbon neutrality. It highlighted the multifaceted nature of the challenge, encompassing technological solutions (like energy-efficient buildings and electric vehicles), methodological approaches (lifecycle assessment), broader systemic changes (energy transitions), economic considerations (economic complexity and investments), and the need to account for wider societal impacts.

This comprehensive view underscores the need for a balanced research agenda that addresses all aspects of carbon neutrality, from technological advancements to policy frameworks, and across all relevant sectors. The synthesis illustrates that achieving carbon neutrality requires a combination of technological innovations, efficiency improvements, and sector-specific strategies (such as in energy and transportation).

Future research should aim to fill the identified gaps, particularly in underrepresented sectors like agriculture and forestry, and foster more integrated, cross-sectoral approaches to achieving carbon neutrality. The synthesis also highlights the importance of considering economic structures, investment patterns, and social implications alongside technological solutions.

In conclusion, this synthesis of content and bibliometric analyses provides a nuanced and interconnected view of the pathways towards a carbon-neutral future. It addresses our research question by showcasing the diverse and interrelated strategies and technologies

necessary for this global transition, while also highlighting the need for a more balanced and comprehensive approach to carbon neutrality research across all sectors.

5. Conclusions

This systematic review highlights both promising approaches and important gaps in the literature, while offering a thorough overview of recent research on carbon neutrality strategies across sectors. The analysis reveals that reaching carbon neutrality requires a multifaceted strategy that takes into account efficiency improvements, and sector-specific strategies, in addition to technology advancements and wider socioeconomic effects.

This systematic review has successfully met its primary objective of analyzing carbon neutrality pathways across sectors, though with varying degrees of completeness. The analysis revealed that the energy sector emerges as the most thoroughly researched, with the identification of carbon capture technologies, energy efficiency enhancements, and the integration of renewable energy as critical tactics. The building and transportation industries have demonstrated encouraging advancements in energy-efficient techniques and electrification, whilst the industrial sector has placed a strong emphasis on the circular economy concept and energy efficiency. Significant research gaps are also found in the evaluation, notably in the fields of forestry and agriculture. These industries are understudied, despite their potential to reduce emissions and sequester carbon, notably a critical area for research.

The bibliometric analysis reveals the interconnected nature of carbon neutrality research, emphasizing the need for interdisciplinary approaches. It also highlights the importance of considering economic factors, as evidenced by the prominence of keywords such as "economic complexity" and "investments" in the literature. Furthermore, the analysis emphasizes the need for policy frameworks that support technological advancements and facilitate systemic changes. The role of international cooperation and knowledge sharing is highlighted, particularly given the varying research output and focus across different countries. By identifying underexplored areas such as agriculture and forestry, and emphasizing the need for integrated, cross-sectoral approaches, this study can guide future research efforts. It underscores the importance of considering technological, policy and socio-economic factors in developing effective carbon neutrality strategies.

Researchers can use these insights to focus on understudied areas, develop more holistic models, and explore synergies between different sectors and strategies. Policymakers can benefit from the comprehensive view provided, helping them to develop more effective, integrated policies for achieving carbon neutrality goals. Ultimately, this research contributes to advancing the field by promoting a more systemic, interdisciplinary approach to carbon neutrality studies. It highlights the need for a balanced research agenda that addresses all aspects of carbon neutrality, from technological advancements to policy frameworks, and across all relevant sectors. Future research should aim to fill the identified gaps, particularly in underrepresented sectors, foster more integrated cross-sectoral approaches, and further explore the economic and social dimensions of the transition to a carbon-neutral society.

Author Contributions: Conceptualization, I.A.K., A.T. and V.A.; methodology, I.A.K. and V.A.; validation, I.A.K. and A.T.; formal analysis, I.A.K.; investigation, I.A.K.; resources, I.A.K.; data curation, I.A.K.; writing—original draft preparation, I.A.K.; writing—review and editing, I.A.K., A.T. and V.A.; supervision, A.T. and V.A.; project administration, I.A.K. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: The original contributions presented in this study are included in the article. Further inquiries can be directed to the corresponding author.

Acknowledgments: This paper represents the opinion of the authors and does not mean to represent the opinions of the American University of Sharjah. The views and conclusions expressed or implied are those of the authors and should not be interpreted as those of the donor or the institution.

Conflicts of Interest: The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

1. Masson-Delmotte, V.; Zhai, P.; Pirani, A.; Connors, S.L.; Péan, C.; Berger, S.; Caud, N.; Chen, Y.; Goldfarb, L.; Gomis, M.I. *Climate Change 2021: The Physical Science Basis*; Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change; Cambridge University Press: Cambridge, UK, 2021; Volume 2, p. 2391.
2. Pörtner, H.O.; Roberts, D.C.; Adams, H.; Adler, C.; Aldunce, P.; Ali, E.; Begum, R.A.; Betts, R.; Kerr, R.B.; Biesbroek, R. *Climate Change 2022: Impacts, Adaptation and Vulnerability*; Cambridge University Press: Cambridge, UK, 2022.
3. Stern, N.H. *The Economics of Climate Change: The Stern Review*; Cambridge University Press: Cambridge, UK, 2007.
4. Allen, M.; Dube, O.P.; Solecki, W.; Aragón-Durand, F.; Cramer, W.; Humphreys, S.; Kainuma, M.; Kala, J.; Mahowald, N.; Mulugetta, Y. *Global Warming of 1.5 C*; An IPCC Special Report on the Impacts of Global Warming of 1.5 C Above Pre-Industrial Levels and Related Global Greenhouse Gas Emission Pathways, in the Context of Strengthening the Global Response to the Threat of Climate Change, Sustainable Development, and Efforts to Eradicate Poverty; Sustainable Development, and Efforts to Eradicate Poverty; Cambridge University Press: Cambridge, UK, 2018.
5. Fawzy, S.; Osman, A.I.; Doran, J.; Rooney, D.W. Strategies for mitigation of climate change: A review. *Environ. Chem. Lett.* **2020**, *18*, 2069–2094. [CrossRef]
6. Black, R.; Cullen, K.; Fay, B.; Hale, T.; Lang, J.; Mahmood, S.; Smith, S. *Taking Stock: A Global Assessment of Net Zero Targets*; Energy & Climate Intelligence Unit and Oxford Net Zero; Energy & Climate: London, UK, 2021; Volume 23.
7. Fuss, S.; Lamb, W.F.; Callaghan, M.W.; Hilaire, J.; Creutzig, F.; Amann, T.; Beringer, T.; de Oliveira Garcia, W.; Hartmann, J.; Khanna, T. Negative emissions—Part 2: Costs, potentials and side effects. *Environ. Res. Lett.* **2018**, *13*, 063002. [CrossRef]
8. Li, Q.; Wang, Y.; Wang, F.; Ning, X.; Chuanbao, Z.; Zhang, J.; Zhang, C. Factor analysis and mechanism disclosure of supercritical CO 2 filtration behavior in tight shale reservoirs. *Environ. Sci. Pollut. Res.* **2021**, *29*, 17682–17694. [CrossRef] [PubMed]
9. Li, Q.; Wang, Y.; Wang, Y.; San, J.; Li, Q.; Foster, G. Synthetic process on hydroxyl-containing polydimethylsiloxane as a thickener in CO_2 fracturing and thickening performance test. *Energy Sources Part A Recovery Util. Environ. Eff.* **2018**, *40*, 1137–1143. [CrossRef]
10. Geels, F.W.; Sovacool, B.K.; Schwanen, T.; Sorrell, S. The socio-technical dynamics of low-carbon transitions. *Joule* **2017**, *1*, 463–479. [CrossRef]
11. Anadon, L.D.; Chan, G.; Harley, A.G.; Matus, K.; Moon, S.; Murthy, S.L.; Clark, W.C. Making technological innovation work for sustainable development. *Proc. Natl. Acad. Sci. USA* **2016**, *113*, 9682–9690. [CrossRef]
12. Rogelj, J.; Popp, A.; Calvin, K.V.; Luderer, G.; Emmerling, J.; Gernaat, D.; Fujimori, S.; Strefler, J.; Hasegawa, T.; Marangoni, G. Scenarios towards limiting global mean temperature increase below 1.5 C. *Nat. Clim. Chang.* **2018**, *8*, 325–332. [CrossRef]
13. Bataille, C.; Waisman, H.; Colombier, M.; Segafredo, L.; Williams, J.; Jotzo, F. The need for national deep decarbonization pathways for effective climate policy. *Clim. Policy* **2016**, *16*, S7–S26. [CrossRef]
14. Davis, S.J.; Lewis, N.S.; Shaner, M.; Aggarwal, S.; Arent, D.; Azevedo, I.L.; Benson, S.M.; Bradley, T.; Brouwer, J.; Chiang, Y. Net-zero emissions energy systems. *Science* **2018**, *360*, eaas9793. [CrossRef]
15. Lucon, O.; Ürge-Vorsatz, D.; Ahmed, A.Z.; Akbari, H.; Bertoldi, P.; Cabeza, L.F.; Eyre, N.; Gadgil, A.; Harvey, L.D.; Jiang, Y. Buildings. In *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*; Cambridge University Press: Cambridge, UK, 2014.
16. Lah, O. Decarbonizing the transportation sector: Policy options, synergies, and institutions to deliver on a low-carbon stabilization pathway. *Wiley Interdiscip. Rev. Energy Environ.* **2017**, *6*, e257. [CrossRef]
17. Ghisellini, P.; Cialani, C.; Ulgiati, S. A review on circular economy: The expected transition to a balanced interplay of environmental and economic systems. *J. Clean. Prod.* **2016**, *114*, 11–32. [CrossRef]
18. Schmalensee, R.; Stavins, R.N. Policy evolution under the clean air act. *J. Econ. Perspect.* **2019**, *33*, 27–50. [CrossRef]
19. Roe, S.; Streck, C.; Obersteiner, M.; Frank, S.; Griscom, B.; Drouet, L.; Fricko, O.; Gusti, M.; Harris, N.; Hasegawa, T. Contribution of the land sector to a 1.5 C world. *Nat. Clim. Chang.* **2019**, *9*, 817–828. [CrossRef]
20. Diewvilai, R.; Audomvongseree, K. Possible Pathways toward Carbon Neutrality in Thailand's Electricity Sector by 2050 through the Introduction of H_2 Blending in Natural Gas and Solar PV with BESS. *Energies* **2022**, *15*, 3979. [CrossRef]
21. Knobloch, F.; Hanssen, S.V.; Lam, A.; Pollitt, H.; Salas, P.; Chewpreecha, U.; Huijbregts, M.A.; Mercure, J. Net emission reductions from electric cars and heat pumps in 59 world regions over time. *Nat. Sustain.* **2020**, *3*, 437–447. [CrossRef]
22. Martín-Martín, A.; Orduna-Malea, E.; Thelwall, M.; López-Cózar, E.D. Google Scholar, Web of Science, and Scopus: A systematic comparison of citations in 252 subject categories. *J. Informetr.* **2018**, *12*, 1160–1177. [CrossRef]
23. Mongeon, P.; Paul-Hus, A. The journal coverage of Web of Science and Scopus: A comparative analysis. *Scientometrics* **2016**, *106*, 213–228. [CrossRef]
24. Leydesdorff, L.; de Moya-Anegón, F.; Guerrero-Bote, V.P. Journal maps on the basis of Scopus data: A comparison with the Journal Citation Reports of the ISI. *J. Am. Soc. Inf. Sci. Technol.* **2010**, *61*, 352–369. [CrossRef]
25. Page, M.J.; Mckenzie, J.E.; Bossuyt, P.M.; Boutron, I.; Hoffmann, T.C.; Mulrow, C.D.; Shamseer, L.; Tetzlaff, J.M.; Akl, E.A.; Brennan, S.E.; et al. The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *BMJ* **2021**, *372*, n71. [CrossRef]

26. Ahmed, S.; Nguyen, T. Analysis of future carbon-neutral energy system—The case of Växjö Municipality, Sweden. *Smart Energy* **2022**, *7*, 100082. [CrossRef]
27. Jazinaninejad, M.; Nematollahi, M.; Shamsi Zamenjani, A.; Tajbakhsh, A. Sustainable operations, managerial decisions, and quantitative analytics of biomass supply chains: A systematic literature review. *J. Clean. Prod.* **2022**, *374*, 133889. [CrossRef]
28. Hyun, M.; Cherp, A.; Jewell, J.; Kim, Y.J.; Eom, J. Feasibility trade-offs in decarbonising the power sector with high coal dependence: The case of Korea. *Renew. Sustain. Energy Transit.* **2023**, *3*, 100050. [CrossRef]
29. Hyvönen, J.; Koivunen, T.; Syri, S. Possible bottlenecks in clean energy transitions: Overview and modelled effects—Case Finland. *J. Clean. Prod.* **2023**, *410*, 137317. [CrossRef]
30. Abbas, S.M.; Alhassany, H.D.S.; Vera, D.; Jurado, F. Review of enhancement for ocean thermal energy conversion system. *J. Ocean Eng. Sci.* **2023**, *8*, 533–545. [CrossRef]
31. Buffi, M.; Prussi, M.; Scarlat, N. Energy and environmental assessment of hydrogen from biomass sources: Challenges and perspectives. *Biomass Bioenergy* **2022**, *165*, 106556. [CrossRef]
32. Yang, Y.; Tong, L.; Yin, S.; Liu, Y.; Wang, L.; Qiu, Y.; Ding, Y. Status and challenges of applications and industry chain technologies of hydrogen in the context of carbon neutrality. *J. Clean. Prod.* **2022**, *376*, 134347. [CrossRef]
33. Xia, Q. Does green technology advancement and renewable electricity standard impact on carbon emissions in China: Role of green finance. *Environ. Sci. Pollut. Res.* **2023**, *30*, 6492–6505. [CrossRef]
34. Plazas-Niño, F.A.; Yeganyan, R.; Cannone, C.; Howells, M.; Quirós-Tortós, J. Informing sustainable energy policy in developing countries: An assessment of decarbonization pathways in Colombia using open energy system optimization modelling. *Energy Strategy Rev.* **2023**, *50*, 101226. [CrossRef]
35. Arriet, A.; Flores, F.; Matamala, Y.; Feijoo, F. Chilean pathways for mid-century carbon neutrality under high renewable potential. *J. Clean. Prod.* **2022**, *379*, 134483. [CrossRef]
36. Zhong, Z.; Fang, J.; Hu, K.; Huang, D.; Ai, X.; Yang, X.; Wen, J.; Pan, Y.; Cheng, S. Power-to-Hydrogen by Electrolysis in Carbon Neutrality: Technology Overview and Future Development. *CSEE J. Power Energy Syst.* **2023**, *9*, 1266–1283. [CrossRef]
37. Pan, X.; Ma, X.; Zhang, Y.; Shao, T.; Peng, T.; Li, X.; Wang, L.; Chen, W. Implications of carbon neutrality for power sector investments and stranded coal assets in China. *Energy Econ.* **2023**, *121*, 106682. [CrossRef]
38. Fan, Y.; Liang, Z.; Yao, X. Regional power system transitions towards carbon neutrality: The case of North China. *Econ. Political Stud.* **2022**, *10*, 416–441. [CrossRef]
39. Che, B.; Shao, C.; Lu, Z.; Qian, B.; Chen, S. Mineral Requirements for China's Energy Transition to 2060—Focus on Electricity and Transportation. *Sustainability* **2023**, *15*, 585. [CrossRef]
40. Carnelli, L.; Lazzari, C.; Passera, T.; Sartori, C.; Mengou, J.E. Integration of Concentrating Solar Heat into Oil and Gas Operations for Increased Sustainability. In Proceedings of the Abu Dhabi International Petroleum Exhibition & Conference, Abu Dhabi, UAE, 15–18 November 2021.
41. Constantino, E.D.G.; Teixeira, S.F.C.F.; Teixeira, J.C.F.; Barbosa, F.V. Innovative Solar Concentration Systems and Its Potential Application in Angola. *Energies* **2022**, *15*, 7124. [CrossRef]
42. Chen, X.; Liu, Y.; Wang, Q.; Lv, J.; Wen, J.; Chen, X.; Kang, C.; Cheng, S.; McElroy, M.B. Pathway toward carbon-neutral electrical systems in China by mid-century with negative CO_2 abatement costs informed by high-resolution modeling. *Joule* **2021**, *5*, 2715–2741. [CrossRef]
43. Podoba, Z.S. Energy Strategy and Transition to Green Energy in Japan. *Russ. Jpn. Rev.* **2021**, *4*, 29–53. [CrossRef]
44. Matamala, Y.; Flores, F.; Arriet, A.; Khan, Z.; Feijoo, F. Probabilistic feasibility assessment of sequestration reliance for climate targets. *Energy* **2023**, *272*, 127160. [CrossRef]
45. Kato, E.; Kurosawa, A. Role of NETs and carbon recycling technologies in the transitions of Japan's energy systems toward net-zero CO_2 emissions goal. In Proceedings of the 15th Greenhouse Gas Control Technologies Conference, Abu Dhabi, UAE, 15–18 March 2021.
46. Yang, B.; Wei, Y.M.; Liu, L.C.; Hou, Y.B.; Zhang, K.; Yang, L.; Feng, Y. Life cycle cost assessment of biomass co-firing power plants with CO_2 capture and storage considering multiple incentives. *Energy Econ.* **2021**, *96*, 105173. [CrossRef]
47. Zhang, H.; Ding, T.; Sun, Y.; Huang, Y.; He, Y.; Huang, C.; Li, F.; Xue, C.; Sun, X. How does load-side re-electrification help carbon neutrality in energy systems: Cost competitiveness analysis and life-cycle deduction. *Renew. Sustain. Energy Rev.* **2023**, *187*, 113745. [CrossRef]
48. Li, X.; Lepour, D.; Heymann, F.; Maréchal, F. Electrification and digitalization effects on sectoral energy demand and consumption: A prospective study towards 2050. *Energy* **2023**, *279*, 127992. [CrossRef]
49. Wen, L.; Diao, P. Simulation study on carbon emission of China's electricity supply and demand under the dual-carbon target. *J. Clean. Prod.* **2022**, *379*, 134654. [CrossRef]
50. Zhang, X.; Qu, Z.; Zhang, Y.; Cai, X.; Han, X.; Chai, Y. *Research on Carbon Emission Reduction and Carbon Peaking Strategies for Power Grid Enterprises*; Institute of Electrical and Electronics Engineers Inc.: Piscataway Township, NJ, USA, 2023; pp. 944–949.
51. Yuan, Y.; Qian, F.; Lu, J.; Gu, D.; Lou, Y.; Xue, N.; Li, G.; Liao, W.; Zhang, N. Design Optimization and Carbon Footprint Analysis of an Electrodeionization System with Flexible Load Regulation. *Sustainability* **2022**, *14*, 15957. [CrossRef]
52. Liu, S.; Dong, L.; Han, L.; Huan, J.; Qiao, B. Efficiency versus System Synergism: An Advanced Life Cycle Assessment for a Novel Decarbonized Grid System Innovation. *Energies* **2022**, *15*, 4214. [CrossRef]

53. Pakere, I.; Freimanis, R.; Alena-Ozolina, S.; Asaris, P.; Demurtas, A.; Gorner, M.; Yearwood, J. Cost-Optimal Policy Strategies for Reaching Energy Efficiency Targets and Carbon Neutrality. *Environ. Clim. Technol.* **2023**, *27*, 999–1014. [CrossRef]
54. Licandeo, F.; Flores, F.; Feijoo, F. Assessing the impacts of economy-wide emissions policies in the water, energy, and land systems considering water scarcity scenarios. *Appl. Energy* **2023**, *342*, 121115. [CrossRef]
55. Lombardi, F.; Pickering, B.; Pfenninger, S. What is redundant and what is not? Computational trade-offs in modelling to generate alternatives for energy infrastructure deployment. *Appl. Energy* **2023**, *339*, 121002. [CrossRef]
56. Mehedi, H.; Wang, X.; Ye, S.; Xue, G.; Md Shariful, I.; Shi, F. Power generation expansion planning approach considering carbon emission constraints. *Glob. Energy Interconnect.* **2023**, *6*, 127–140. [CrossRef]
57. Khanna, N.Z.; Zhang, J.; Lu, H.; Feng, W.; Johnson-Wang, M.; Zhou, N. Conceptualizing demand-side technological and social innovations in modeling pathways to carbon neutrality. *Energy Res. Soc. Sci.* **2023**, *100*, 103115. [CrossRef]
58. Zhang, T.; Feng, T.; Cui, M. Smart contract design and process optimization of carbon trading based on blockchain: The case of China's electric power sector. *J. Clean. Prod.* **2023**, *397*, 136509. [CrossRef]
59. Misconel, S.; Prina, M.G.; Hobbie, H.; Möst, D.; Sparber, W. Model-based step-wise marginal CO_2 abatement cost curves to determine least-cost decarbonization pathways for sector-coupled energy systems. *J. Clean. Prod.* **2022**, *368*, 133173. [CrossRef]
60. Ozawa, A.; Tsani, T.; Kudoh, Y. Japan's pathways to achieve carbon neutrality by 2050—Scenario analysis using an energy modeling methodology. *Renew. Sustain. Energy Rev.* **2022**, *169*, 112943. [CrossRef]
61. Zhou, Y.; Zheng, S.; Lei, J.; Zi, Y. A cross-scale modelling and decarbonisation quantification approach for navigating Carbon Neutrality Pathways in China. *Energy Convers. Manag.* **2023**, *297*, 117733. [CrossRef]
62. Aizhana, M.; Maira, D.; Assel, I.; Erkebulan, B. Improving Marketing Approaches to the Energy Sector of Kazakhstan for Decarbonization. *Int. J. Energy Econ. Policy* **2022**, *12*, 410–417. [CrossRef]
63. Maqableh, A.; Saraireh, M. A Novel Approach for Waste Heat Generation in Combined Heat and Power Generation in Integrated Energy System. *Int. J. Eng. Appl.* **2023**, *11*, 402–417. [CrossRef]
64. Phothisourinh, N.; Singh, J.G. *Reviewing and Comparing International Best Practices in Carbon Neutral Planning for Thailand Power Sector*; Institute of Electrical and Electronics Engineers Inc.: Piscataway Township, NJ, USA, 2022.
65. Ku, T.-Y.; Park, W.-K.; Choi, H. *Energy Maestro-Transactive Energy Mechanism*; Tsumoto, S., Ohsawa, Y., Chen, L., Van den Poel, D., Hu, X., Motomura, Y., Takagi, T., Wu, L., Xie, Y., Abe, A., et al., Eds.; Institute of Electrical and Electronics Engineers Inc.: Piscataway Township, NJ, USA, 2022; pp. 6727–6729.
66. Idrissi Kaitouni, S.; Mghazli, M.O.; Nait-Taour, A.; Es-Sakali, N.; El Mankibi, M.; Ahachad, M.; Brigui, J. *Empirical Validation and Analysis of the Energy Performance of an Ecological Net Zero Energy Building (NZEB) in Benguerir-Morocco*; Ooka, R., Ed.; EDP Sciences: Les Ulis, France, 2023.
67. Rodgers, M.D. Pathways to eliminate carbon emissions via renewable energy investments at higher education institutions. *Electr. J.* **2021**, *34*, 106952. [CrossRef]
68. Cumo, F.; Giustini, F.; Pennacchia, E.; Romeo, C. The "D2P" Approach: Digitalisation, Production and Performance in the Standardised Sustainable Deep Renovation of Buildings. *Energies* **2022**, *15*, 6689. [CrossRef]
69. Zhang, C.; Shen, C.; Zhang, Y.; Pu, J. Feasibility investigation of spectral splitting photovoltaic/thermal systems for domestic space heating. *Renew. Energy* **2022**, *192*, 231–242. [CrossRef]
70. Rivera-Marín, A.; Alfonso-Solar, D.; Vargas-Salgado, C.; Català-Mortes, S. Methodology for estimating the decarbonization potential at the neighborhood level in an urban area: Application to La Carrasca in Valencia city—Spain. *J. Clean. Prod.* **2023**, *417*, 138087. [CrossRef]
71. Xin, L.; Li, S.; Rene, E.R.; Lun, X.; Zhang, P.; Ma, W. Prediction of carbon emissions peak and carbon neutrality based on life cycle CO_2 emissions in megacity building sector: Dynamic scenario simulations of Beijing. *Environ. Res.* **2023**, *238*, 117160. [CrossRef]
72. Ma, M.; Feng, W.; Huo, J.; Xiang, X. Operational carbon transition in the megalopolises' commercial buildings. *Build. Environ.* **2022**, *226*, 109705. [CrossRef]
73. Yang, Q.; Wang, J.; Liu, X.; Liu, Y. Complexity influence of societal development comprehensive indicators on building carbon emission: Empirical evidence from China. *Environ. Sci. Pollut. Res. Int.* **2023**, *30*, 117179–117200. [CrossRef] [PubMed]
74. Xing, Z.; Pan, Y.; Liang, Y.; Wang, J. *Analysis of Carbon Emission Influencing Factors and Evaluation of Carbon Reduction Strategies in Shanghai's Construction Sector Based on LMDI-SA*; International Building Performance Simulation Association: Rapid City, SD, USA, 2023; pp. 3893–3901.
75. Zhang, Y.; Zheng, W.; Fang, H.; Xia, J. Clean heating in Northern China: Regional investigations and roadmap studies for urban area towards 2050. *J. Clean. Prod.* **2022**, *334*, 130233. [CrossRef]
76. Zhang, S.; Ma, M.; Li, K.; Ma, Z.; Feng, W.; Cai, W. Historical carbon abatement in the commercial building operation: China versus the US. *Energy Econ.* **2022**, *105*, 105712. [CrossRef]
77. Pipicelli, M.; Luca, G.D.; Ianniello, R. Hydrotreated Vegetable Oils for Compression Ignition Engines—The Way Toward a Sustainable Transport. *Energy Environ. Sustain.* **2023**, *2023*, 11–34. [CrossRef]
78. Zhao, J.; Yu, Y.; Ren, H.; Makowski, M.; Granat, J.; Nahorski, Z.; Ma, T. How the power-to-liquid technology can contribute to reaching carbon neutrality of the China's transportation sector? *Energy* **2022**, *261*, 125058. [CrossRef]
79. Bello, S.; Galán-Martín, Á.; Feijoo, G.; Moreira, M.T.; Guillén-Gosálbez, G. BECCS based on bioethanol from wood residues: Potential towards a carbon-negative transport and side-effects. *Appl. Energy* **2020**, *279*, 115884. [CrossRef]

80. Cui, P.; Gong, W.; Yu, Q.; Mao, N.; Liu, J.; Xu, D. *Situation, Challenges and Suggestions for the Integrated Development of Transportation and Energy*; Liu, B., Bashir, M.J.K., Nizami, A., Wan Ishak, W.M.F.B., Eds.; EDP Sciences: Les Ulis, France, 2023.
81. Li, J.; Fang, H.; Fang, S.; Zhang, Z.; Zhang, P. Embodied energy use in china's transportation sector: A multi-regional input–output analysis. *Int. J. Environ. Res. Public Health* **2021**, *18*, 7873. [CrossRef]
82. Zhu, X.; Jianguo, D.; Ali, K.; Kirikkaleli, D. Do green logistics and green finance matter for achieving the carbon neutrality goal? *Environ. Sci. Pollut. Res. Int.* **2023**, *30*, 115571–115584. [CrossRef]
83. Du, J.; Cheng, J.; Ali, K. Modelling the green logistics and financial innovation on carbon neutrality goal, a fresh insight for BRICS-T. *Geol. J.* **2023**, *58*, 2742–2756. [CrossRef]
84. Tan, K.M.; Yong, J.Y.; Ramachandaramurthy, V.K.; Mansor, M.; Teh, J.; Guerrero, J.M. Factors influencing global transportation electrification: Comparative analysis of electric and internal combustion engine vehicles. *Renew. Sustain. Energy Rev.* **2023**, *184*, 113582. [CrossRef]
85. Akimoto, K.; Sano, F.; Nakano, Y. Assessment of comprehensive energy systems for achieving carbon neutrality in road transport. *Transp. Res. Part D Transp. Environ.* **2022**, *112*, 103487. [CrossRef]
86. Chen, W.; Sun, X.; Liu, L.; Liu, X.; Zhang, R.; Zhang, S.; Xue, J.; Sun, Q.; Wang, M.; Li, X.; et al. Carbon neutrality of China's passenger car sector requires coordinated short-term behavioral changes and long-term technological solutions. *One Earth* **2022**, *5*, 875–891. [CrossRef]
87. Hossain, M.S.; Fang, Y.R.; Ma, T.; Huang, C.; Peng, W.; Urpelainen, J.; Hebbale, C.; Dai, H. Narrowing fossil fuel consumption in the Indian road transport sector towards reaching carbon neutrality. *Energy Policy* **2023**, *172*, 113330. [CrossRef]
88. Park, S.; Park, S.; Yun, S.; Lee, K.; Kang, B.; Choi, M.; Jang, H.; Park, S. Design and Implementation of a Futuristic EV Energy Trading System (FEETS) Connected with Buildings, PV, and ESS for a Carbon-Neutral Society. *Buildings* **2023**, *13*, 829. [CrossRef]
89. Saafi, M.A.; Ou, S.; He, X. *Quantifying the Sensitive Parameters of the New Energy Vehicles in China*; SAE International: Warrendale, PA, USA, 2023.
90. Khurshid, A.; Khan, K.; Saleem, S.F.; Cifuentes-Faura, J.; Cantemir Calin, A. Driving towards a sustainable future: Transport sector innovation, climate change and social welfare. *J. Clean. Prod.* **2023**, *427*, 139250. [CrossRef]
91. Aryanpur, V.; Balyk, O.; Daly, H.; Ó Gallachóir, B.; Glynn, J. Decarbonisation of passenger light-duty vehicles using spatially resolved TIMES-Ireland Model. *Appl. Energy* **2022**, *316*, 119078. [CrossRef]
92. Saafi, M.A.; Ou, S.; Jiang, Y.; Li, H.; He, X.; Lin, Z.; Gan, Y.; Lu, Z.; Dawson, S.T.M. Exploring the potential of hydrogen in decarbonizing China's light-duty vehicle market. *Int. J. Hydrogen Energy* **2022**, *47*, 36355–36371. [CrossRef]
93. Yousaf, A.U.; Hussain, M.; Schoenherr, T. Achieving carbon neutrality with smart supply chain management: A CE imperative for the petroleum industry. *Ind. Manag. Data Syst.* **2023**, *123*, 2551–2576. [CrossRef]
94. Guo, X.; Xia, A.; Zhang, W.; Huang, Y.; Zhu, X.; Zhu, X.; Liao, Q. Photoenzymatic decarboxylation: A promising way to produce sustainable aviation fuels and fine chemicals. *Bioresour. Technol.* **2023**, *367*, 128232. [CrossRef]
95. Thepsaskul, W.; Wongsapai, W.; Sirisrisakulchai, J.; Jaitiang, T.; Daroon, S.; Raksakulkan, V.; Muangjai, P.; Ritkrerkkrai, C.; Suttakul, P.; Wattakawigran, G. Potential Business Models of Carbon Capture and Storage (CCS) for the Oil Refining Industry in Thailand. *Energies* **2023**, *16*, 6955. [CrossRef]
96. Strunge, T.; Naims, H.; Ostovari, H.; Olfe-Kräutlein, B. Priorities for supporting emission reduction technologies in the cement sector—A multi-criteria decision analysis of CO_2 mineralisation. *J. Clean. Prod.* **2022**, *340*, 130712. [CrossRef]
97. Yu, X.; Tan, C. China's pathway to carbon neutrality for the iron and steel industry. *Glob. Environ. Chang.* **2022**, *76*, 102574. [CrossRef]
98. Zhang, S.; Yi, B.; Guo, F.; Zhu, P. Exploring selected pathways to low and zero CO_2 emissions in China's iron and steel industry and their impacts on resources and energy. *J. Clean. Prod.* **2022**, *340*, 130813. [CrossRef]
99. Lin, Y.; Ma, L.; Li, Z.; Ni, W. Coordinating energy and material efficiency strategies for decarbonizing China's iron and steel sector. *J. Clean. Prod.* **2023**, *425*, 139038. [CrossRef]
100. Iorio, V.S.; Farina, D.; Racca, S.; Dal Forno, L.; Concina, F. Advanced Analytic Tool Development for GHG Emissions Monitoring in Well Operations. In Proceedings of the Offshore Technology Conference, Houston, TX, USA, 1–4 May 2023.
101. Wang, S.; Altiparmak, S.O. Framing climate strategy of the oil industry of China: A tailored approach to ecological modernization. *Chin. J. Popul. Resour. Environ.* **2022**, *20*, 324–331. [CrossRef]
102. Yi, J.; Hou, Y.; Zhang, Z.Z. The impact of foreign direct investment (FDI) on China's manufacturing carbon emissions. *Innov. Green Dev.* **2023**, *2*, 100086. [CrossRef]
103. Xu, X.; Cui, X.; Zhang, Y.; Chen, X.; Li, W. Carbon neutrality and green technology innovation efficiency in Chinese textile industry. *J. Clean. Prod.* **2023**, *395*, 136453. [CrossRef]
104. Rasheed, R.; Tahir, F.; Afzaal, M.; Ahmad, S.R. Decomposition analytics of carbon emissions by cement manufacturing—A way forward towards carbon neutrality in a developing country. *Environ. Sci. Pollut. Res.* **2022**, *29*, 49429–49438. [CrossRef]
105. Li, Z.; Hanaoka, T. Plant-level mitigation strategies could enable carbon neutrality by 2060 and reduce non-CO_2 emissions in China's iron and steel sector. *One Earth* **2022**, *5*, 932–943. [CrossRef]
106. Dong, J.; Cai, B.; Zhang, S.; Wang, J.; Yue, H.; Wang, C.; Mao, X.; Cong, J.; Guo, F. Closing the Gap between Carbon Neutrality Targets and Action: Technology Solutions for China's Key Energy-Intensive Sectors. *Environ. Sci. Technol.* **2023**, *57*, 4396–4405. [CrossRef]

107. Zhang, C.; He, B.; Li, G. *Potential Energy Recovery of Robotic Extractors for Low Carbon Footprint*; Yang, H., Zou, J., Yang, G., Ouyang, X., Liu, H., Yin, Z., Liu, L., Wang, Z., Eds.; Springer Science and Business Media Deutschland GmbH: Berlin, Germany, 2023; pp. 533–542.
108. Dadi, D.; Introna, V.; Santolamazza, A. *Strategies and Key Factors to Achieve Carbon Neutrality for an Industrial Company: A Systematic Literature Review*; AIDI—Italian Association of Industrial Operations Professors: Rome, Italy, 2022.
109. Zhu, J.; Zhang, X.; Hua, W.; Ji, J.; Lv, X. Current status and development of research on phase change materials in agricultural greenhouses: A review. *J. Energy Storage* **2023**, *66*, 107104. [CrossRef]
110. Chen, M.; Cui, Y.; Jiang, S.; Forsell, N. Toward carbon neutrality before 2060: Trajectory and technical mitigation potential of non-CO_2 greenhouse gas emissions from Chinese agriculture. *J. Clean. Prod.* **2022**, *368*, 133186. [CrossRef]
111. Kato, S.; Lee, S.; He, Y.; Yoshioka, T.; Morotomi, T.; Chewpreecha, U. Impact of Carbon Neutrality on the Economy and Industry Assuming Japan's Achievement of 2030 Power Mix Plan: A 2050 Perspective Based on the E3ME Macro-Econometric Model. *Energies* **2023**, *16*, 6661. [CrossRef]
112. Anderson, B.; Cammeraat, E.; Dechezleprêtre, A.; Dressler, L.; Gonne, N.; Lalanne, G.; Martins Guilhoto, J.; Theodoropoulos, K. Designing policy packages for a climate-neutral industry: A case study from the Netherlands. *Ecol. Econ.* **2023**, *205*, 107720. [CrossRef]
113. Du, X. Thoughts on strategies and paths to achieve carbon peaking and carbon neutrality in China. *Front. Energy* **2023**, *17*, 324–331. [CrossRef]
114. Guo, N. Legal pathways of decarbonization in China: The emissions trading perspective. In *Handbook of Energy Law in the Low-Carbon Transition*; De Gruyter: Berlin, Germany, 2023; pp. 401–412.
115. Xiao, L.; Guan, Y.; Guo, Y.; Xue, R.; Li, J.; Shan, Y. Emission accounting and drivers in 2004 EU accession countries. *Appl Energy* **2022**, *314*, 118964. [CrossRef]
116. Bai, S.; Zhou, J.; Yang, M.; Yang, Z.; Cui, Y. Under the different sectors: The relationship between low-carbon economic development, health and GDP. *Front. Public Health* **2023**, *11*, 1181623. [CrossRef]
117. Chen, L.; Msigwa, G.; Yang, M.; Osman, A.I.; Fawzy, S.; Rooney, D.W.; Yap, P.S. Strategies to achieve a carbon neutral society: A review. *Environ. Chem. Lett.* **2022**, *20*, 2277–2310. [CrossRef]
118. Numan, U.; Ma, B.; Aslam, M.; Bedru, H.D.; Jiang, C.; Sadiq, M. Role of economic complexity and energy sector in moving towards sustainability in the exporting economies. *Energy Strategy Rev.* **2023**, *45*, 101038. [CrossRef]
119. Hakovirta, M.; Kovanen, K.; Martikainen, S.; Manninen, J.; Harlin, A. Corporate net zero strategy—Opportunities in start-up driven climate innovation. *Bus. Strategy Environ.* **2023**, *32*, 3139–3150. [CrossRef]
120. Wang, P.; Liang, S. Environmental Regulations and Energy Efficiency: The Mediating Role of Climate Change and Technological Innovation. *Front. Environ. Sci.* **2022**, *10*, 909082. [CrossRef]
121. Saqib, N.; Radulescu, M.; Usman, M.; Balsalobre-Lorente, D.; Cilan, T. Environmental technology, economic complexity, renewable electricity, environmental taxes and CO_2 emissions: Implications for low-carbon future in G-10 bloc. *Heliyon* **2023**, *9*, e16457. [CrossRef] [PubMed]
122. Stepnov, I.M.; Kovalchuk, J.A.; Kolesnikova, T.V. Protectionism and Technological Development: The Green Agenda. In *Environmental Footprints and Eco-Design of Products and Processes*; Springer: Berlin, Germany, 2023; pp. 85–94.
123. Popova, I.; Kolmar, O. Russia's low carbon development policy: Opportunities and constraints in the new economic and political reality. *Int. Organ. Res. J.* **2023**, *18*, 62–95. [CrossRef]
124. Yao, L.; Tan, S.; Xu, Z. Towards carbon neutrality: What has been done and what needs to be done for carbon emission reduction? *Environ. Sci. Pollut. Res.* **2023**, *30*, 20570–20589. [CrossRef]
125. Zhang, Y. Artificial intelligence carbon neutrality strategy in sports event management based on STIRPAT-GRU and transfer learning. *Front. Ecol. Evol.* **2023**, *11*, 1275703. [CrossRef]
126. Heggelund, G.M. China's climate and energy policy: At a turning point? *Int. Environ. Agreem. Politics Law. Econ.* **2021**, *21*, 9–23. [CrossRef]
127. Safonov, G.; Kozeltsev, M.; Stetsenko, A.; Dorina, A.; Saphonova, Y.; Semakina, A.; Sizonov, A.; Safonov, M. Perspectives of Decarbonization of World Economy in the Context of Implementation of the UN Paris Climate Agreement. *Int. Organ. Res. J.* **2022**, *17*, 38–61. [CrossRef]
128. Fu, J.; Zhang, D.; Lei, M. *Climate Mitigation and Adaptation in China: Policy, Technology and Market*; Springer Nature: Berlin, Germany, 2021; pp. 1–285.
129. Wang, C.; Cong, J.; Wang, K.; Qi, Y.; Cai, W.; Li, Y.; Fu, S.; Wang, W.; Wei, Y.; Zheng, X.; et al. Research on China's technology lists for addressing climate change. *Chin. J. Popul. Resour. Environ.* **2021**, *19*, 151–161. [CrossRef]
130. He, J.; Li, Z.; Zhang, X.; Wang, H.; Dong, W.; Du, E.; Chang, S.; Ou, X.; Guo, S.; Tian, Z.; et al. Towards carbon neutrality: A study on China's long-term low-carbon transition pathways and strategies. *Environ. Sci. Ecotechnol.* **2022**, *9*, 100134. [CrossRef]
131. Aria, M.; Cuccurullo, C. bibliometrix: An R-tool for comprehensive science mapping analysis. *J. Informetr.* **2017**, *11*, 959–975. [CrossRef]
132. Boyack, K.W.; Klavans, R. Co-citation analysis, bibliographic coupling, and direct citation: Which citation approach represents the research front most accurately? *J. Am. Soc. Inf. Sci. Technol.* **2010**, *61*, 2389–2404. [CrossRef]

133. Van Eck, N.J.; Waltman, L. *VOSviewer Manual*; Leiden University's Centre: Leiden, The Netherlands, 2020; Available online: https://www.vosviewer.com/documentation/Manual_VOSviewer_1.6.15.pdf (accessed on 6 April 2024).
134. Van Eck, N.J.; Waltman, L. *VOSviewer Manual*; Leiden University's Centre: Leiden, The Netherlands, 2023; Available online: https://www.vosviewer.com/documentation/Manual_VOSviewer_1.6.19.pdf (accessed on 6 April 2024).

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