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Toward Sustainable Development: A Systematic Review of the Digital Economy's Role in Carbon Emissions (2021–2025) - Impacts, Influence Mechanisms, Spatial Effects, and Heterogeneity

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ABSTRACT

Global warming is impacting the ecological environment and threatening the sustainability of human survival and development. Developing the digital economy has become an urgent priority for countries addressing climate change. This study aims to explore the complex relationship between the digital economy and carbon emissions. Following the PRISMA 2020 guidelines, this study systematically analyzed 83 articles from the Scopus and Web of Science databases using bibliometric analysis. Utilizing CiteSpace, VOSviewer and ArcGIS tools, this review assessed publication trends, geographical distribution, country cooperation, co-citation authors, productive journals, theme evolution, and keyword analysis. The results reveal a growing trend in research on the digital economy and carbon emissions. The majority of research is conducted in China, India, Saudi Arabia, the United States, and Turkey. Among these, Chinese research influences the United States and India. Further thematic analysis reveals that research in this field has shifted from a singular focus to a more systematic, in-depth, and comprehensive one. Given the limitations of existing research focusing on single countries, especially China, this study also emphasizes that future research could focus on transnational carbon equity, transnational carbon spillover effects, the interaction between global climate governance and digital policy, and the global digital divide and consumption-side carbon emissions.

1. INTRODUCTION

While accelerated industrialization has boosted economic growth, it has also generated negative externalities such as increased carbon dioxide emissions [1]. Carbon dioxide is one of the main greenhouse gases, and the increase in its concentration caused by human activities is a primary source of climate change [2]. Driven by the significant pressures from global climate change, countries around the world have prioritized global climate governance. In 1992, the United Nations General Assembly adopted the United Nations Framework Convention on Climate Change, aiming to stabilize atmospheric greenhouse gas concentrations [3]. Subsequently, the 21st United Nations Climate Change Conference adopted the Paris Agreement in 2015, with the G20 pledging to hold global temperature rise to well below 2 °C and to work towards limiting the increase to 1.5 °C [4].

The digital economy has provided a new impetus for global economic growth. In the fourth industrial revolution, all countries have witnessed the advent of the digital economy [5]. Digital technology is a core production factor of digital economy, and digitization can empower green development and promote carbon neutrality [6-8]. Academic and policy communities have conducted extensive research on how to leverage digital economy to cope with challenges posed by climate change and achieve carbon emission reductions.

Currently, carbon neutrality and digital development have evolved into important national strategies, and governments worldwide formulate development policies derived from solid empirical evidence. Whereas, existing empirical research findings are inconsistent, implying that governments or organizations cannot rely on scattered papers for decision-making. Specifically, the digital economy has dual-sided impacts. Digital economy has advantages in improving energy efficiency, encouraging industrial upgrading, and increasing total factor productivity, thereby diminishing carbon emissions [8-10]. On the contrary, the operation of digital infrastructure is heavily supported by electricity. Digital industries such as computer and communication manufacturing powered by high electricity consumption, which definitely triggers the increase of carbon emissions [11, 12]. Most studies reach a consensus that digital economy indirectly curb carbon emissions, but mediating variables selected to explore such indirect effect vary. Furthermore, scholars hold differing views on the heterogeneity and spatial effects in their research on these influences.

Importantly, previous reviews fail to explore the underlying reasons for these inconsistent empirical conclusions. This review can effectively address the research confusion caused by existing scattered empirical evidence. Additionally, existing review papers do not cover the latest research and multi-dimensional analytical content, especially regarding research reviews on the digital economy and carbon emissions (see Table 1). Consequently, this review systematically synthesizes empirical evidence, identifies applicable scenarios for conclusions, and dissects the causes of contradictions. The research questions are shown as follows:

RQ (1) What is the overall status of research on the digital economy and carbon emissions from 2021 to 2025?

RQ (2) What are the prevailing perspectives on the role of digital economy in carbon emission regarding impact, mediating mechanisms, heterogeneity, and spatial effects?

RQ (3) What are the potential avenues for future research?

Table 1. Comparative analysis of previous literature reviews

Author	Database	Period	Coverage
Li et al. [13]	Scopus Web of Science (WoS)	2019–2023	Impact of the digital economy on CO_2 emissions; Impact channels.
Liu and Wang [14]	Web of Science (WoS)	2020–2024	Measurement of digital economy and carbon emission; Relationship; Mechanism.
Rosário and Dias [15]	Scopus	2000–2023	Conceptualization of the digital economy and sustainability; The relationship between digital economy and sustainability; Opportunities and challenges in the Digital Economy for Sustainability.

Compared to previous literature, this review delivers three targeted and innovative contributions:

First, this study integrates multiple classic theories to interpret the underlying reasons for contradictory conclusions in existing research regarding regional heterogeneity, spatial spillover effects, and nonlinear relationships. Obviously, it develops a holistic analytical framework for digital economy and carbon emissions.

Second, this study focuses on literature from 2021 to 2025, systematically reviewing it along four core dimensions: influencing relationships, mediating mechanisms, heterogeneity, and spatial effects. It accurately captures the cutting-edge research hotspots through thematic evolutionary trends and visually presents the current imbalance in the research landscape through bibliometric results such as the distribution of publications by country and source.

Third, given that nearly 80% of the included literature is from China, while empirical evidence from Europe, the United States, Africa, and the Middle East is scarce, this review argues that different economies need to adopt different digital development models, and that China's digital development strategy cannot be directly replicated.

2. RESEARCH METHODS

This study employed a combination of systematic literature review and bibliometric analysis to ensure the methodological rigor, transparency, and reproducibility.

2.1 Inclusion and exclusion criteria

This systematic literature review only includes peer-reviewed English journal articles and conference papers between 2021 and 2025, while all other types of literature have been excluded. The time frame is set as over 80% of global economies set clear carbon neutrality targets in 2021, pushing numerous empirical studies at the city, provincial, and transnational levels. Furthermore, choosing the five-year focused window avoids including a large number of outdated and low-quality studies, improving the review's timeliness.

This review is limited to empirical studies at the national, provincial, or prefecture-level administrative levels to systematically analyze the regional spillover effects and spatial heterogeneity of the digital economy. Studies of single industries or regions fall outside the scope of macro-regional analysis framework.

In addition, this review restricts its scope to research on the digital economy and carbon emissions. Research in other environmental fields such as air quality and population has been excluded to focus the research scope. Any articles that do not meet the criteria have been eliminated accordingly.

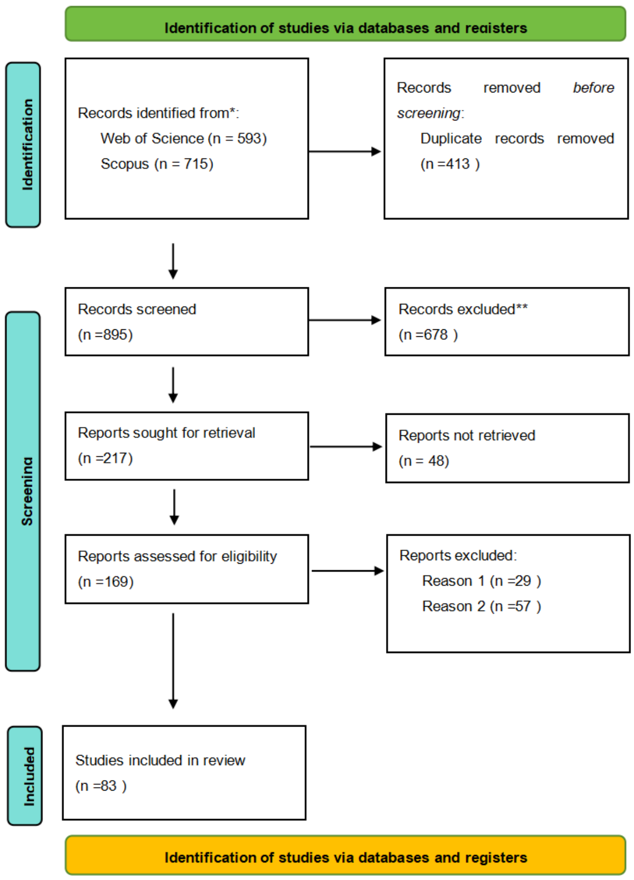

Figure 1. PRISMA flowchart

2.2 Data sources and research collection strategies

The study carried out a systematic literature review following the PRISMA 2020. Web of Science Core Collection and Scopus are the primary databases. To minimize the risk of missing relevant literature, this review employed backward citation tracking after database searching to capture relevant studies originally indexed in other databases such as Google Scholar, IEEE Xplore and ProQuest.

For comprehensive searching, this study applied advanced search. The following search string was used: (TITLE-ABS-KEY ("digital economy" OR digitization OR digitalization) AND ("carbon emissions" OR "CO2 emissions" OR "greenhouse gas" OR GHG OR "carbon dioxide") AND (threshold OR nonlinear OR "non-linear" OR "U-shaped" OR "inverted U" OR mediation OR mediator OR "mediating effect" OR mechanism OR "heterogeneity "OR "heterogeneous" OR "heterogenous")).

Figure 1 conducted a preliminary suitability check on all 895 selected articles. To ensure that the research focus of each study aligned with the research questions and objectives, 217 articles were eligible for further evaluation after reviewing titles and abstracts. During the retrieval process, 48 articles were unable to obtain full texts. Finally, after full-text reviewing and standardized quality appraisal via the MMAT and CASP critical appraisal checklists, 83 articles were included as the core research sample for this systematic literature review.

3. RESULTS

This section summarizes the results of the bibliometric analysis of the literature included in the core study.

3.1 Trend of publication

Of the 83 excerpted articles, 82 are from journal publications, with only one conference paper. Of the 83 articles included in the literature review, only one closely related paper was published in 2021, followed by four articles in 2022. Despite this, there is an upward trend in the number of publications on this topic, with 20 publications in 2023 and 32 publications in 2024. As for 2025, there were 26 publications as of August, and it is likely that more will be published in the following months, surpassing the 2024 record (see Figure 2). Therefore, the increasing trend in the number of publications signals that research on this topic is of value for both academic and policy communities.

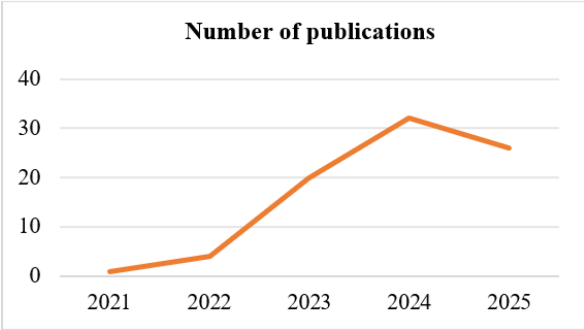

Figure 2. Number of publications per year

3.2 Geographic distribution analysis

The 83 publications incorporated in this review are from 25 countries. Figure 3 visualizes the countries that have published more than two eligible publications. China accounts for 69 of these publications, indicating research on the link between digital economy and carbon emissions has received significant attention from Chinese scholars. This imbalance fact is because that as the largest carbon emitter, China faces greater pressure to slow down carbon emissions [16]. Meanwhile, the digital economy has also been designated as one of the key strategies for achieving carbon neutrality in China. India, Saudi Arabia, the United States and Turkey are the second-tier contributors, with three publications respectively. Figure 3 also demonstrates that ongoing high-quality research is relatively scarce in North America and Oceania.

3.3 Country cooperation analysis

Figure 4 reflects the citation relationships between different countries in this research domain. The four countries plotted are the ones with the closest mutual citations in this field in recent years. China is at the very center of the network with the largest node, further illustrating China's central position in research on the relationship between the digital economy and carbon emissions. Furthermore, the connecting lines show a clear mutual citation relationship between Chinese research and the United States and India. Some Chinese studies also indirectly influence India through Saudi Arabian research.

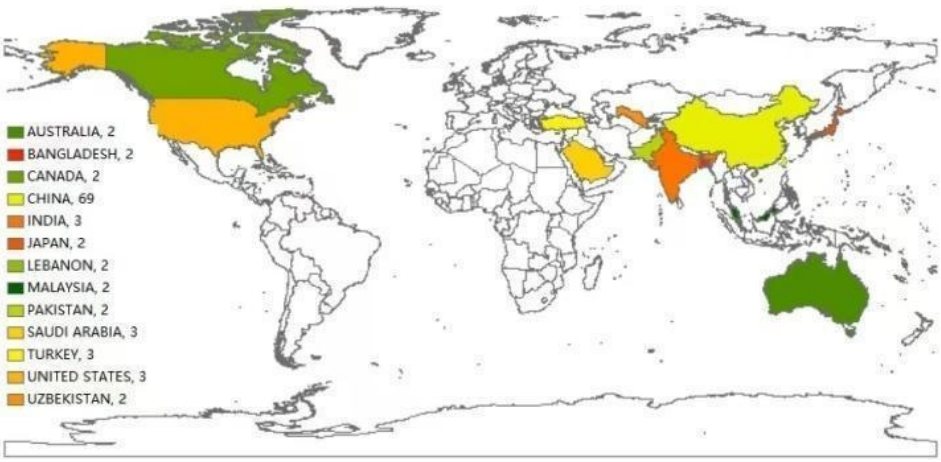

Figure 3. The geographic distribution of publications

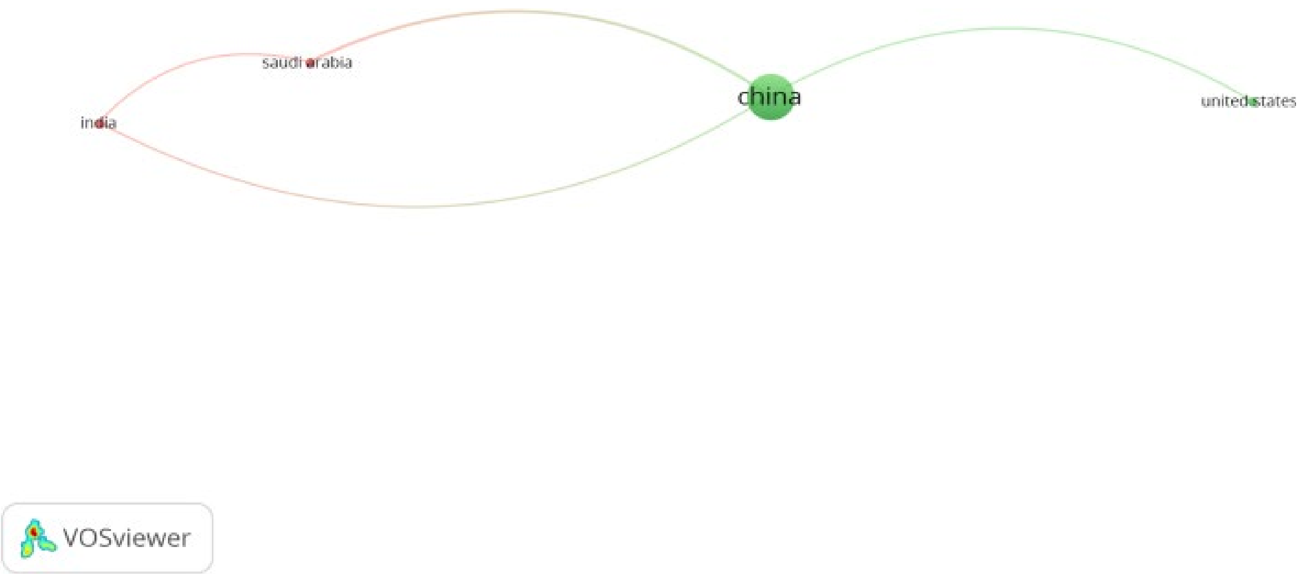

Figure 4. Collaborative network among countries

Table 2. Number of publications per source

Source	Documents	Percentage
Sustainability	13	15.7%
Frontiers in Environmental Science	7	8.4%
Journal of Cleaner Production	5	6.0%
Journal of Environmental Management	4	4.8%
Energy Strategy Reviews	3	3.6%
Scientific Reports	3	3.6%
Energy	2	2.4%
Energy Economics	2	2.4%
Energy Policy	2	2.4%
Environment, Development and Sustainability	2	2.4%
Environmental Science and Pollution Research	2	2.4%
Frontiers in Energy Research	2	2.4%
Humanities and Social Sciences Communications	2	2.4%
PLoS ONE	2	2.4%
Resources Policy	2	2.4%
Technological and Economic Development of Economy	2	2.4%

3.4 Productive journals analysis

The articles included in the study are from 44 sources. Table 2 shows the sources with at least two publications. Among them, there are 13 articles on Sustainability, accounting for 15.7%. Frontiers in Environmental Science has 7 articles, accounting for 8.4%. Journal of Cleaner Production has 5 articles accounting for 6.0%. Journal of Environmental Management has 4 articles accounting for 4.8%. Energy Strategy Reviews and Scientific Reports each have 3 articles, accounting for 3.6%. The remaining nine publication sources each have 2 articles (see Table 2).

3.5 Top 10 cited publication analysis

Figure 5 displays the top 10 most cited publications. Chinese scholars contributed to 8 of these articles, demonstrating China's leading position within this research field. The observed finding is consistent with the results of country cooperation analysis. The three most cited papers all conclude that the digital economy delivers significant carbon mitigation impacts and spatial effects [17-19]. In addition, the three papers investigated the interaction mechanism between the two variables. The conclusions verified that the digital economy mainly optimizes carbon emissions through energy structure, industrial structure, and technological innovation [20-22]. The high citation volume of these three papers proves that their findings are viewed as a foundational pillar of the theoretical framework in this research field.

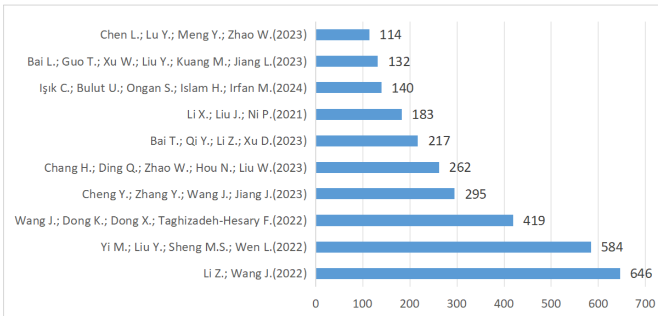

Figure 5. Top 10 global cited documents

3.6 Co-citation author analysis

Figure 6 displays the author co-citation network for literature examining the impact of the digital economy on carbon emissions. The names shown are authors with the highest frequency of appearance in the reference lists of the selected papers. Taghizadeh-Hesary F., Wang J., Alam K., Liu J., Khan Z., Zhang J., etc., are at the central in this network. These scholars primarily focus on the relationship and influence mechanisms between the digital economy and carbon emissions. Research demonstrates that the impact of the digital economy and related technologies on carbon emissions remains ambiguous [23-26]. Both positive and negative impacts have received considerable attention. Industrial structure, technological innovation, energy structure, and R&D investment have become important influencing paths in the research framework [26-28]. Subsequent studies widely draw upon the above theoretical framework.

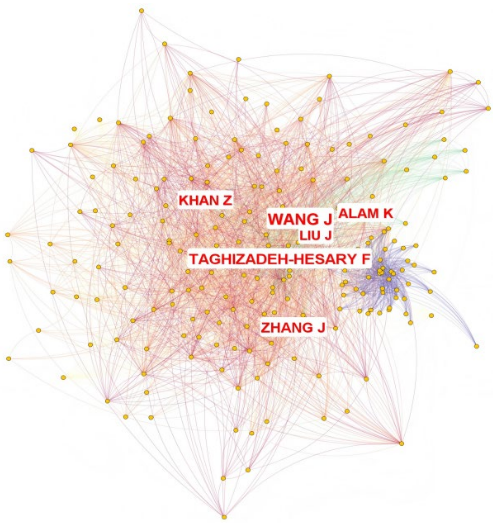

Figure 6. Author co-citation network

3.7 Theme evolution analysis

Based on CiteSpace, Figure 7 illustrates the evolution of the relationship between the digital economy and carbon emissions over the past five years. In 2021, research on this topic centered on carbon emissions and associated environmental issues in the digital context. Scholars mainly explored whether the digital economy impacted carbon emissions. In 2022, research delved into the interaction mechanisms linking digital and carbon emissions. Some new keywords emerged, including energy structure, spillover effect, emission control, and green technology. From 2023 to 2024, the research became more systematic. Scholars turned their attention to the comprehensive economic and environmental impacts, as well as industrial emissions. In 2025, the long-term goal of carbon neutrality became a focus. Researchers explored pathways through which the digital economy can contribute to achieving long-term carbon reduction goals, such as carbon cycle, carbon sequestration, and low-carbon development. Collectively, over the past five years, the impact of the digital economy on carbon emissions has shifted from a singular focus to a more systematic, in-depth, and comprehensive research framework.

3.8 Keywords analysis

Based on the selection criteria that keywords appear in at least six publications, this study employed VOSviewer software to retrieve 30 core keywords from 83 articles and 490 keywords. Figure 8 shows the frequency of these keywords using node size, and the thickness of connecting lines represents the strength of the relationship between keywords. According to the visual network map, the 30 keywords were classified into three clusters. Table 3 shows the occurrence, total link strength (TLS), cluster and ranking of each keyword. Among them, Carbon Emissions and Digital Economy ranked first and second respectively, with extremely high co-occurrence values. This is because these two keywords were included in the search characters and are also the core topics of this research review.

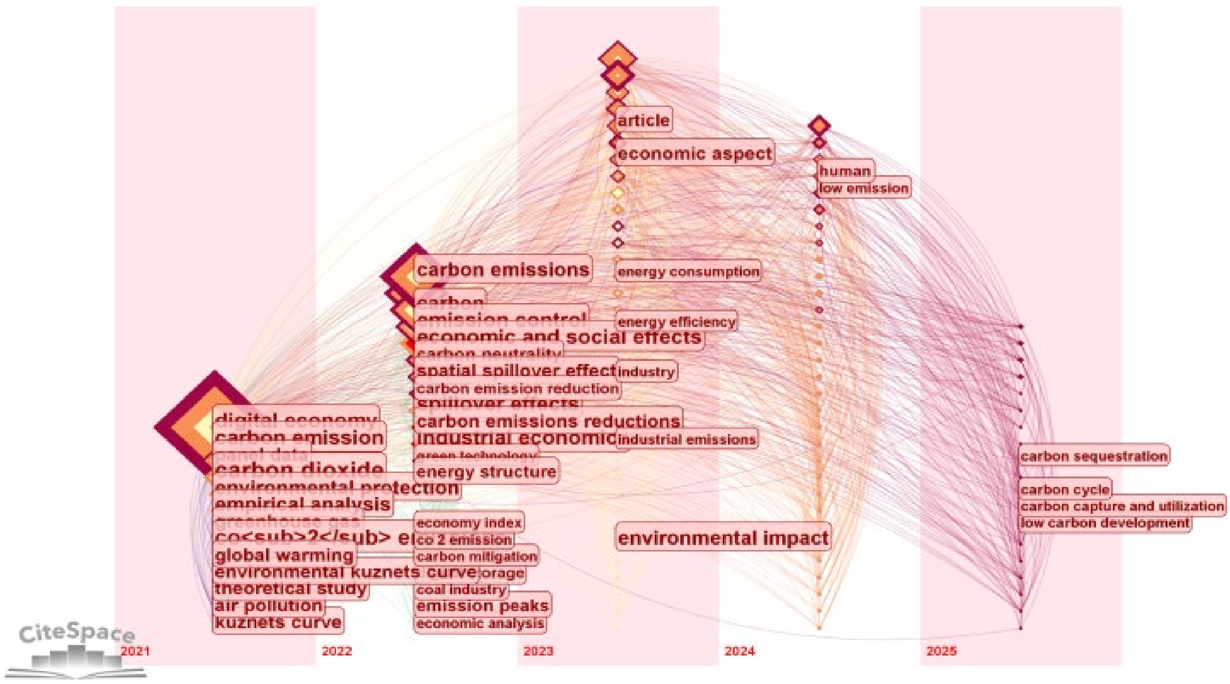

Figure 7. Thematic evolution in the field of digital economy and carbon emissions

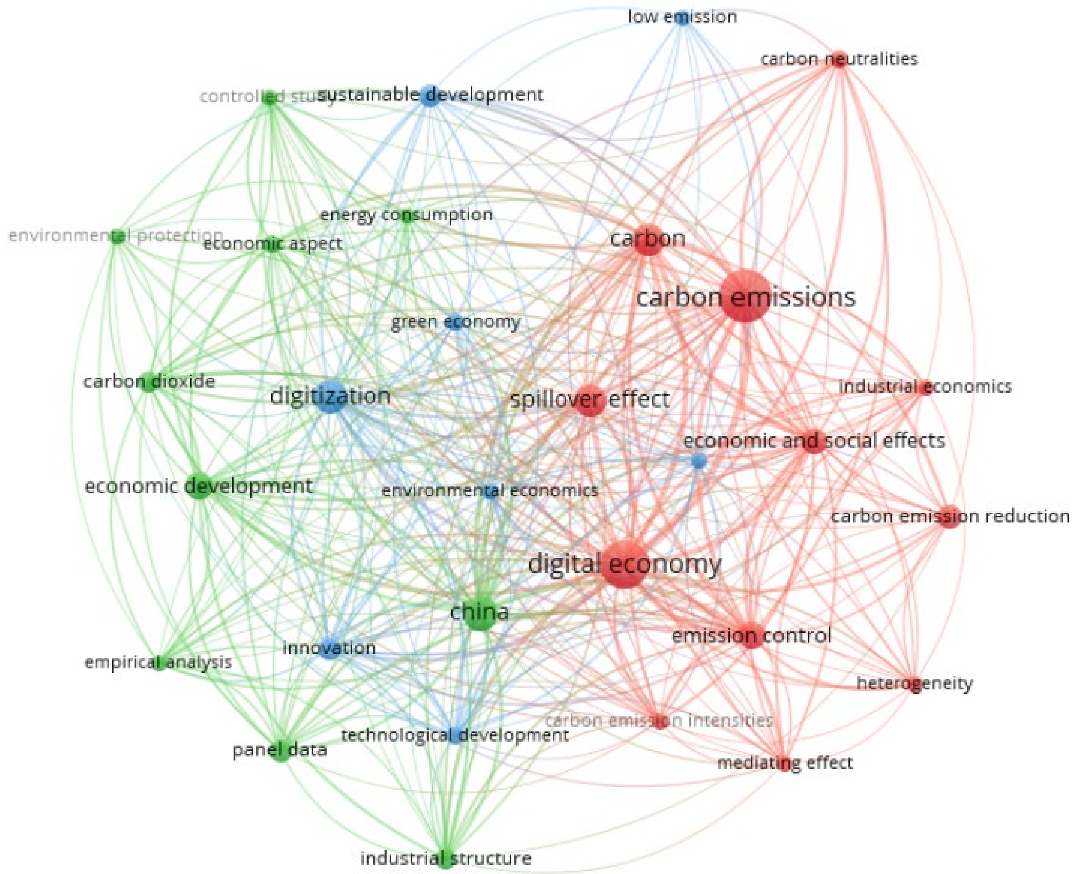

Figure 8. Co-occurrence of keywords in the literature

Table 3. Co-occurrences of keywords based on cluster and total link strength (TLS)

Keyword	Occurrences	Total Link Strength	Cluster	Rank by Occurrences
		Cluster 1		
Carbon	24	163	Red	6
Carbon Emission Intensities	6	58	Red	24
Carbon Emission Reduction	14	41	Red	10
Carbon Emissions	66	178	Red	1
Carbon Neutralities	8	54	Red	16
Digital Economy	54	261	Red	2
Economic and Social Effects	16	123	Red	9
Emission Control	19	137	Red	7
Heterogeneity	6	37	Red	25
Industrial Economics	6	51	Red	26
Mediating Effect	7	44	Red	20
Spillover Effect	26	85	Red	5
		Cluster 2		
Carbon Dioxide	11	69	Green	14
China	30	187	Green	3
Controlled Study	7	52	Green	21
Economic Aspect	8	61	Green	17
Economic Development	18	115	Green	8
Empirical Analysis	6	44	Green	27
Energy Consumption	6	37	Green	28
Environmental Protection	6	27	Green	29
Industrial Structure	11	67	Green	15
Panel Data	12	58	Green	11
		Cluster 3		
Digitization	28	103	Blue	4
Environmental Economics	7	48	Blue	22
Green Economy	8	44	Blue	18
Innovation	12	85	Blue	12
Low Emission	6	19	Blue	30
Sustainable Development	12	43	Blue	13
Technological Development	8	53	Blue	19
Technological Innovation	7	46	Blue	23

Cluster 1 (red) focuses on the relationship between the digital economy and carbon emissions, with a key examination of their correlation, mediating mechanisms, heterogeneity, and spatial spillover effects. Keywords include "Carbon," "Carbon Emission Intensities," "Carbon Emission Reduction," "Carbon Emissions," "Carbon Neutralities," "Digital Economy," "Economic and Social Effects," "Emission Control," "Heterogeneity," "Industrial Economics," "Mediating Effect," and "Spillover Effect." This cluster consists of two interconnected sub-themes. The first sub-theme centers on the impact of the digital economy on carbon emissions. Studies use linear and nonlinear models to verify the inverted U-shaped or purely negative correlation between the two [29-34]. The second sub-theme focuses on exploring mediating pathways, impact differences, and spatial effects, analyzing the impact of the digital economy on carbon emissions from the perspectives of technology, industry, and energy [20, 22, 27, 35-37]. Furthermore, the studies exhibit differences in their analyses of dissimilarity and spatial effects [18, 38, 39].

Cluster 2 (green) focuses on China's economic development and environmental protection. Keywords include "China," "Carbon Dioxide," "Controlled Study," "Economic Aspect," "Economic Development," "Empirical Analysis," "Energy Consumption," "Environmental Protection," "Industrial Structure," and "Panel Data." This cluster uses provincial and municipal panel data as its sample and employs econometric models to explore the impact of China's industrial structure, energy consumption, and economic development level on carbon emission reduction [40-42]. The clustering results are consistent with the national distribution results of the aforementioned literature, indicating that current research overly draws on Chinese city samples, especially in studies of dissimilarity [39, 43, 44].

Cluster 3 (blue) focuses on digitalization and the green economy, involving keywords relevant to technological innovation and sustainable development, including "Digitization," "Environmental Economics," "Green Economy," "Innovation," "Low Emission," "Sustainable Development," "Technological Development," and "Technological Innovation." Environmental economics and sustainable development theory are employed to analyze the supporting role of technological innovation in decarbonization [45, 46]. Existing research unanimously agrees that technological innovation is the core driving force for the digital economy to achieve low carbon emissions and green development [39, 47].

4. DISCUSSION

The digital economy has attracted much attention since its inception and has been widely discussed by scholars along with greening and decarbonization. The research areas were then divided into 4 categories as follows.

4.1 The relationship between digital economy and carbon emissions

Between 2021 and 2025, scholars studying the relationship between the digital economy and carbon emissions primarily draw conclusions from linear and nonlinear perspectives. Ecological modernization theory asserts that modernization could mitigate the environmental threats posed by economic expansion through technological innovation, industrial upgrading, and environmental regulations. Some scholars verify that the digital economy does indeed reduce carbon emissions by constructing linear models such as the SYS-GMM model [30, 45], the two-way fixed effects model [35, 48], and the extended STIRPAT model [49]. At the national level, analysis using panel regression models points out that digitalization is associated with a reduction in carbon emissions, with robust evidence in Central European countries, countries along the Belt and Road Initiative, and BRICS countries [31-34, 50]. In China, previous literature has explored the linkage between the digital economy and carbon emissions across Chinese provincial and prefecture-level city tiers, expanding analysis temporal scope over successive studies. At the provincial level, research covering 30 Chinese provinces demonstrates that the digital economy is beneficial for carbon emission control [51-53]. Consistent findings emerge in studies covering hundreds of Chinese cities [54, 55]. These studies typically employ linear models, ignoring the fact that the expansion of digital infrastructure may lead to a short-run escalation in carbon emissions, ultimately resulting in a negative correlation between digitalization and emissions.

Drawing on the Environmental Kuznets Curve (EKC), other researchers have utilized nonlinear models to confirm that the digital economy and carbon emissions exhibit an inverted U-shaped pattern [56]. The early stage of digital development requires substantial infrastructure, raising energy consumption and carbon emissions, and resulting in a short-term rebound effect [57, 58]. Nevertheless, mature digitalization could boost industrial productivity, increase energy efficiency, and achieve sustained carbon emissions [59-61]. Cross-country evidence also supports this nonlinear relationship, especially in the EU and the Mediterranean regions [62, 63]. Empirical studies from Chinese cities further verify this nonlinear effect [64-66]. Notably, some scholars propose that the relationship between the digital economy and carbon emissions is U-shaped. Although the digital economy initially cuts carbon emissions, this inhibitory effect gradually weakens [17]. This may be because in the mature stage of the digital economy, digital consumption and online services expand carbon footprints, triggering a rebound in carbon emissions.

4.2 Intermediary mechanisms of digital economy's impact on carbon emissions

Endogenous growth theory posits that knowledge, technology, and human capital are the three core drivers of economic growth [67]. With the nature of non-rivalrous and diffusive, technological knowledge is capable of improving production efficiency and refining production modes. Theoretically, the digital economy mitigates carbon emissions by promoting green technology innovation. On the one hand, supported by digital technologies such as artificial intelligence, the digital economy drives green technology innovation and further achieves carbon reduction [22, 36, 37, 68]. On the other hand, the application of digital technologies in production reduces energy consumption and improves energy efficiency, thereby controlling carbon emissions [20, 69].

Schumpeter's innovation theory claims that innovation is the core driving force of economic development [70]. The development of digital technologies fosters low-carbon industries, reduces the proportion of energy-intensive industries, and ultimately lower carbon emissions. Accordingly, the digital economy can achieve carbon emission reduction by promoting industrial upgrading [21, 71].

Sustainable development theory pushes traditional high-carbon-emission enterprises to achieve digital transformation. Energy consumption is shifting from being primarily based on fossil fuels to renewable energy. Furthermore, digital technologies have accelerated the development of new energy sources such as solar and photovoltaic power, improving the production efficiency of clean energy and thus curbing carbon emissions. Therefore, optimizing the energy structure is an important influencing mechanism [20, 72, 73]. However, it is undeniable that the energy rebound effect indicates that the improved energy efficiency brought about by the digital economy may also lead to an increase in carbon emissions [74].

The digital economy can also achieve carbon emission reduction via optimizing resource allocation efficiency. Transaction cost theory holds that information asymmetry and barriers to factor mobility lead to resource misallocation, resulting in excessive energy consumption. Relying on digital platforms and big data technologies, the digital economy cuts transaction costs, achieves precise matching of production factors, curtails unnecessary energy consumption, and thus mitigates carbon emissions [20, 75]. Additionally, economic agglomeration is also an intermediary channel for the digital economy to abate carbon emissions. New economic geography posits that factor agglomeration can generate economies of scale [75]. Digital technologies break down geographical barriers, accelerating the agglomeration of production factors and forming digital industrial clusters. The clusters allow for the sharing of technology and other production factors, thereby minimizing the overall scale of carbon emissions [75]. Table 4 summarizes the main influencing mechanisms.

Table 4. Main influencing mechanisms

Influencing Mechanisms	Supporting Studies
Green technology innovation	Asif et al. [22]; Li et al. [36]; Li and Zhou [37]; Wang et al. [68].
Industrial structure upgrades	Chen and Liu [21]; Jiang et al. [71].
Energy structure optimization	Ding et al. [20]; Li et al. [72]; Sheraz et al. [73].
Energy efficiency improvements	Ding et al. [20]; Chen et al. [69].
Resource allocation optimization	Ding et al. [20]; An et al. [75].
Economic agglomeration	An et al. [75].

4.3 Heterogeneity analysis

Existing research uncovers that the impact and intensity of the digital economy on carbon emissions depend on factors such as geographical location, urban tier, and economic development level. Whereas, research on geographical heterogeneity is overwhelmingly concentrated in China. The fact is because China's regional development is significantly unbalanced, while countries in Europe and North America feature high degree of regional homogeneity. Beyond this, Chinese scholars focus on regional digital development, while other scholars emphasize cross-country comparisons. The debate mainly falls into three strands. First, carbon emission reduction effects in eastern and coastal cities of China are better than in central and western inland cities [76-79]. Second, emission reduction in central and western and northern regions is stronger than in eastern and southern regions [43, 44]. Third, the digital economy mitigates carbon emission in the east and west, yet promote emission in the central region; and the west shows a pattern of initial increase followed by decrease [52, 65]. Such conflicting findings mainly arise from the different composite digital economy measurement indicators, carbon emission measurement methods, research time frames, and econometric models chosen by researchers.

Regarding the impact of urban resources and urban tier on the carbon emissions mitigation effects, scholars have reached consensus. First, non-resource-dependent cities are more likely to suppress carbon emissions through the digital economy [80]. Second, provincial capitals and central cities, relying on their economic strength and policy advantages, attract significant inflows of capital, talent, and technology, resulting in better emission reduction effects than non-central prefecture-level cities [39, 78, 81].

In studies on the heterogeneity of economic development levels, researchers unanimously agree that digitalization has the greatest impact on environmental improvement in high-income countries and developed cities [34, 82, 83]. The reason lies in that they can achieve more effective carbon emission reductions by utilizing advanced digital infrastructure and technologies.

4.4 Spatial effects

Using spatial econometric methods, scholars argue that the digital economy not only affects local carbon emissions but also those of surrounding regions. However, existing research remains controversial regarding whether such impact is positive or negative. Some scholars contend that the digital economy generates positive spillover effects [17-19, 52]. Marked by timelessness, borderlessness and sharing, digital economy development increases the intensity of cross-regional economic activities [84]. A region's digital economy may promote the digital development of surrounding regions through economic interaction and information exchange [85]. Furthermore, free flows of technology and knowledge improve the region's technological level and energy efficiency, thereby mitigating carbon emissions [86].

Some scholars claim that the digital economy negatively impact carbon emissions in surrounding areas. The divergence derives from two dominant rationales. First, to develop the digital economy, a region may relocate some highly polluting enterprises to neighboring areas [87]. Second, the benefits of regional digital economy development stimulate surrounding areas to build digital economy infrastructure and further develop the digital economy. However, the early stage of the digital economy relies on massive energy consumption, leading to a continuous increase in carbon emissions [21, 71].

Several studies identify that the impact of the digital economy on CO_2 emissions in surrounding areas exhibits a non-linear characteristic. Some studies claim that a country's digital economy has an inverted U-shaped effect on carbon emissions in neighboring countries, initially promoting growth before increasing emissions [58, 64]. A different view argues that the impact of the digital economy on carbon emissions in surrounding cities initially decreases before increasing emissions [24].

The controversy primarily stems from the different standards chosen by scholars when constructing spatial weight matrices, among which geographical distance matrices and economic distance matrices are the main tools. These two tools capture different paths of factor flows and industrial transfers, directly leading to differences in spillover effects. Beyond the standards chosen, disparities in sample size and timeframe also result in different spillover effects, particularly between cross-border and domestic samples. Various settings of spatial econometric models, such as the static spatial Durbin model, dynamic threshold spatial model, and multi-scale geographically weighted regression, also yield inconsistent conclusions. Furthermore, the lack of uniformity between digital economy and carbon emission measurement indicators also contributes to the controversy in scholarly research.

5. FUTURE RESEARCH

5.1 Transnational carbon fairness

Developed countries, positioned upstream in the global value chain, curb carbon emissions through industrial digitalization. On the contrary, developing countries locked in downstream may witness rising carbon emissions due to digital expansion. This leads to a severe mismatch between global digitalization benefits and carbon costs. Existing research focuses on carbon emissions from individual countries, rarely linking trade benefits to implicit carbon costs or conducting transnational carbon fairness comparisons.

5.2 Transnational carbon spillover effects

Cross-border data storage and cross-border computing power interconnection allow carbon emission to be transferred from data-consuming countries to data-receiving countries. Existing literature studies spatial spillovers between regions, neglecting carbon transmission in cyberspace. Therefore, transnational carbon spillover effects could be a future research direction.

5.3 The interaction between global climate governance and digital policy

The interaction between digital trade rules and carbon border taxes (CBAM), and the role of digital environmental regulation in global carbon greening, have not been extensively studied by scholars.

5.4 Global digital divide and differences in digital governance

A gap in digital infrastructure exists between high-income and low-income economies, forming a digital divide. Current research has not yet incorporated the digital divide as a core threshold variable. Furthermore, the varying carbon reduction effects resulting from differences in national digital governance systems require further investigation.

5.5 Consumption-side carbon emissions

Most research focuses on carbon emissions generated at the production end, neglecting carbon emissions from digitalization at the consumption end. For example, online consumption has led to new carbon emissions from express delivery packaging and logistics. Digital credit has intensified over-consumption, raising concerns about a potential rebound in carbon emissions.

6. CONCLUSION

Currently, there is controversy regarding the relationship, impact mechanism, spatial effects, and regional heterogeneity between the digital economy and carbon emissions. Existing empirical evidence is fragmented and lacks a holistic integrated judgment. Therefore, this paper follows PRISMA 2020 and combines bibliometrics to systematically review 83 articles included in Scopus and Web of Science from 2021 to 2025, clarifying the overall picture of existing research in this field and pointing out key directions for the future.

Bibliometric analysis reveals an upward trend in research on the digital economy and carbon emissions, with the current center of expertise concentrated in China. This finding calls for cross-border knowledge exchange and research among scholars.

The mainstream perspectives within the field are as follows: (1) The digital economy has an overall inhibitory effect on CO_2 emissions. However, existing research is mainly divided into two viewpoints. One viewpoint believes that the digital economy and carbon emissions are linearly negatively correlated, while the other viewpoint believes that the two have an inverted U-shaped nonlinear relationship of first promoting and then inhibiting. (2) The impact of the digital economy on carbon emissions is mainly achieved through green technology innovation, industrial structure upgrading, energy structure optimization and energy efficiency improvement, economic agglomeration, and resource allocation optimization. (3) The impact varies depending on factors such as regional location, city level and type, and economic development level. Existing regional heterogeneity studies are highly controversial, and related empirical studies suffer from severe Chinese sample bias and limited external validity. (4) Spatial effects are uncertain. Some scholars believe this impact is negative, some believe it is positive, and others believe it exhibits nonlinear characteristics in neighboring regions.

It should be noted that due to the lack of empirical research on the multiple relationships between the digital economy and carbon emissions in regions such as Europe, America, Africa, the Middle East, and Latin America, the heterogeneity patterns obtained based on Chinese samples cannot be directly generalized globally. In particular, due to significant differences in the digital industry systems, policies, and resource endowments of different economies, caution is needed when replicating other countries' digital strategies to achieve carbon emission reduction. The conclusions drawn from Chinese city samples have obvious limitations in external validity. In addition, the development of the digital economy in Chinese cities varies significantly, and governments need to implement differentiated low-carbon governance plans at different levels. Furthermore, there are spatial spillover effects between regions, so governments need to formulate cross-regional digital carbon compensation and coordination mechanisms to achieve integrated development of the regional digital economy.

Based on the analysis of existing research, this study proposes several future research directions: transnational carbon equity; transnational carbon spillover effects; the interaction between global climate governance and digital policy; the global digital divide and differences in digital governance; Consumption-side carbon emissions.

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