CREATION OF A MODERN MODEL OF REDUCTION OF CARBON TOXIC GASES IN INDUSTRY

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Abstract: In this scientific article, with the development of industry, the demand for reducing carbon dioxide toxic gases on the planet is increasing. In addition, various scientific studies have been conducted based on the increasing demand for determining the composition of toxic gases in the air and building a modern model of production sources that lead to their increase, thereby building new models in terms of environmentally harmful gases. By combining a two-way fixed effect model, a mediated effect model, and a panel threshold model, this research endeavors to explore the effect that the expansion of the digital economy has on the level of carbon emission intensity that is produced by industry. The research yielded the following primary conclusions. The digital economy effectively reduces the industrial carbon intensity via three distinct mechanisms: enhancements to the technological and innovative capacities of industries, improvements in energy efficiency, and enhancements to the country's overall industrial structure. This research offers a theoretical backing for advancements in the digital economy; the achievement of energy-saving and carbon-reducing sustainable development objectives; and the establishment of green, ecologically friendly, and recycling development strategies.

Keywords: environmentally harmful gases; digital economy; carbon emis-sion intensity; carbon sequestra-tion; mediation effect; panel threshold modeling; theoretically analyzes

Introduction. Significant carbon emissions resulting from human activities are a primary contributor to global climate change. The climate issue has led humanity off course from progressing towards sustainable development. One of the most significant pillars of the economy and an essential component in the general strategy regarding the reduction in greenhouse gases in various nations is the industrial sector. Efforts initiated by the entire country to realize the "dual-carbon target" and to pursue the harmonization of economic, social, and environmental benefits contain a decrease in emissions of carbon, along with the exploration of a long-term mechanism for improving the scale and efficiency of industrial production.

The growing assimilation of digital components into many economic domains has transformed the digital economy into a novel power engine capable of improving indusrties economic development quality and accomplishing environmentally friendly objectives. The digital economy showcases a nation's overall capability in the information technology age, contributing to significant transformations in production and lifestyle and serving as a crucial factor for the astonishing expansion of the national economy. From the micro standpoint, the profound integration of the digital sector, exemplified by e-commerce, with the physical economy has substantially increased enterprise information channels, transparency, and total factor productivity and decreased production and transaction costs. The interpenetration of digital factors and conventional economic elements of production at the macro level facilitates the efficient allocation and unrestricted circulation of production factors, thereby substantially augmenting social productivity and optimizing resource utilization.

There are two distinct research perspectives regarding the connection between the dynamics of the digital economy and the actual growth of atmospheric carbon dioxide across diverse businesses. Several academics have concluded that the extensive implementation of digital production factors contributes to the increase in carbon emissions. On this basis, they identified the generating sectors, transfer pathways, and economic development drivers of carbon emissions, thereby revealing the principles of the formation and change in carbon emissions. Scholars who have investigated the theoretical underpinnings of the current correlation between the degree of Internet-based economy development and carbon emissions have arrived at the finding that a steady trajectory of growth in the digital economy might culminate in resource conservation and decreasing emissions. As an illustration, examined the transmission mechanism and theoretical mechanism of the digital economy, an inevitable consequence of the new technological revolution, concerning the facilitation of carbon emission decrease at the levels of direct effect and spatial spillover effect.

Researchers have studied how technology developments in the digital economy, a relatively new industry, have influenced the decrease in carbon emissions from the industrial sector. Integrating the digital production elements with the manufacturing-based conventional tangible economy prevents economic development from becoming disconnected from physical industries. The integration presents necessary support for the enhancement of digital productivity and speeds up the transformation of the economic operation mechanism. Furthermore, certain research has revealed discrepancies in the influence of digital element inputs on manufacturing-related carbon footprints: domestic digital inputs significantly reduce carbon intensity, whereas imported digital inputs may raise carbon intensity.

The scholarly scientific investigations on Internet-based economy and carbon dioxide emissions offer relevant theoretical backing for this paper. Currently, research within an area primarily focuses on national or provincial carbon emissions, whereas this paper undertakes a theoretical and empirical investigation into carbon emissions at the industry level. Given this, the following are this article's primary contributions: (1)

This article develops an evaluation index system for country's inter-provincial industrial digital economy and uses the entropy approach to assess the progress of each province; it uses a two-way fixed effect model, a mediated effect model, and a threshold panel model to measure the link between digital economy growth and industrial carbon emission intensity in industries. (2) This research examines the diversity of effects that digital policies have on different aspects, such as the level of integration between informatization and industrialization development. Additionally, it theoretically analyzes how digitization affects industrial carbon emissions and the mechanisms behind this impact.

Theoretical Exposition and Hypothesis. Digital transformation is a powerful force that enhances collaboration and improves resource allocation in the industrial and supply chains. It is an excellent method for promoting environmentally friendly, low-carbon, and sustainable development in the industry. Nevertheless, scholars must address the specific mechanisms via which the Internet-based economy impacts industrial carbon intensity. This section examines how the digital economy impacts the decrease in industrial carbon production. It explores the direct impact, mediating impact, and threshold effect of the digital economy on carbon footprint reduction. Ultimately, this section formulates rational research hypotheses to set objectives and provide direction for the research subject of this dissertation.

The profound integration of digital resources and industry has the potential to facilitate a decrease in carbon emissions through the improvement of industrial manufacturing procedures and environmental detection and management. The digital economy could improve industrial production by simplifying processes, improving efficiency, and intelligently controlling production equipment to optimize operational efficiency, enhance quality, increase efficiency, and decrease energy consumption and hazardous emissions. Industrial equipment is a significant contributor to energy consumption during manufacturing and emits substantial quantities of greenhouse gases during operation. The digital economy can decrease enterprises' production energy utilization by enhancing equipment operational effectiveness. Utilizing advanced production processes and equipment like the circular economy and clean production technology can effectively lower industrial carbon emissions. Digital governance theory proposes that advancements in digital technology offer new opportunities for strengthening and enhancing the methods and effectiveness of government administration.

Furthermore, technologies like intelligent manufacturing and big data (computing) can systematically and effectively monitor environmentally relevant information and data such as air quality and carbon emissions, offering additional insights for decision-making in industrial eco-friendly initiatives. The government is enhancing its regulatory capacity over resources and the environment. The digital economy and industry are being closely integrated to support policies aimed at reducing industrial carbon emissions, particularly in high energy-consuming sectors like nonferrous metals, building materials, electric power, iron and steel, and the chemical industry.

From the macro viewpoint, the focus of economic development might be shifted from high-carbon to low-carbon industries by the digital economy, which would enable the industrial structure to be upgraded overall through industrialization and the commercial use of digital technology. At the micro level, digital technology can enhance energy efficiency and facilitate energy conversion, resulting in decreased energy wastage in manufacturing and trading operations and mitigating environmental pollution. Furthermore, the digital economy is essential for navigating the latest technological revolution, and science, technology, and innovation can achieve low-carbon objectives by reducing carbon at the source and during the production process. Therefore, this research will analyze the influence mechanisms through three channels: industrial structure effect, energy utilization effect, and technical innovation effect.

-Upgrading the industrial structure involves the dynamic stage of development in which production factors circulate in low-efficiency and high-efficiency sectors, facilitating the economy's entry into a virtuous circle. The digital economy's advancement integrates data into various production factors, permeating multiple economic sectors. This optimization not only enhances the conventional industrial structure but also facilitates the merging of diverse industrial sectors, leading to the appearance of novel business models. From the standpoint of digital industrialization, information industries such as the Internet, software, and telecommunications sectors, along with the electronic information manufacturing sector, have continued to grow in size within the industrial system due to increased labor productivity. The result has generated novel possibilities for digital dividends, elevated emerging sectors to the forefront of the social economy, and established a crucial basis for a stable economic cycle. Concerning the degree of industrial digitization, the permeability of the information-based production factors incorporating digital technology allows it to interact with and enhance other industries, leveraging each other's strengths and integrating deeply. The process of integration aids traditional enterprises in consolidating essential resources, boosting the quality and efficiency of industries, driving the transition from an industrial structure centered on industry to one that is service-oriented, and serving as a new catalyst for the transition and upgrade of traditional sectors.

Country's three primary industries consume varying amounts of different types of energy and produce differing levels of carbon emissions. The primary sector, encompassing animal farming, forestry, agriculture, and fisheries, and the tertiary sector, primarily consisting of the service industry, demands lower energy use and produces fewer carbon dioxide emissions. Industry dominates the secondary sector, consuming significant amounts of energy inefficiently and generating high levels of greenhouse gases. The swift advancement of digital productivity in country can optimize the state of resource allocation among industries and facilitate the shift in the national economic emphasis from the primary to tertiary industry. The proper allocation of industrial weights can control the ratio of high-energy-consuming industries. Integrated development among various industrial sectors can facilitate the movement of resources, synchronize high and low-energy-consuming industries, and ultimately lead to an overall emission reduction.

Industry must prioritize energy efficiency improvements to establish a new paradigm of sustainable economic growth. The digital economy possesses the capacity to reduce industrial fossil energy usage and carbon emissions by improving several processes of industrial energy production, consumption, and storage. The advent of digital technologies such as the Sharing Economy, Blockchain, Internet of Things Engineering, and New Industrial Retail has led to increased intelligence, efficiency, and environmental friendliness in energy production and development. The digital economy speeds up clean energy advancement; enhances energy extraction efficiency enables continuous tracking and evaluation of energy storage, transmission, and distribution; reduces unnecessary energy losses; and enhances energy utilization efficiency. IoT, big data, artificial intelligence, and other technologies can assist energy managers in monitoring energy system operations and consumption. The digital economy helps develop more environmentally friendly and scientifically informed management strategies, enhance industrial energy system efficiency, and lower carbon emission levels. For instance, digital technology in smart grid construction enables precise monitoring and control of energy use, enhances energy usage efficiency, prevents the wastage of resource endowments, and reduces carbon-rich gas emissions.

Enhancements in the industrial resource utilization ratio reduce the amount of industrial energy utilized per unit of GDP, and the less energy used, the fewer greenhouse gases are generated for the identical output. The swift growth of the digital economy has used effective ways to enhance energy structures, which in turn has led to a rise in the proportion of high-efficiency energy used and a decrease in carbon production.

The digital economy is a major motor for the present revolution in productivity and the modernization and enhancement of sectors, offering fresh momentum for advancing global scientific and technical innovation and restructuring the global competition landscape. The emerging economy has the potential to decrease time and transaction costs in scientific and technological innovation for industrial enterprises; accelerate the learning effect; enhance innovation capacity; improve innovation levels; and integrate digitalization into innovation development, acting as a catalyst for innovation-led development. Technologies like “Internet Plus”, IOT, and the Industrial Internet have significantly improved the exchange of information elements among enterprises, reduced information asymmetry, and expanded opportunities for scientific and technological innovation and collaboration.

Furthermore, STI’s impact on reducing industrial carbon emissions is seen in both conventional and sustainable energy sources. The implementation of scientific and technological advancements in conventional sectors has substantially enhanced the efficacy of conventional energy utilization and facilitated the adoption of renewable energy by industrial enterprises. The Industrial Internet can utilize 5G high-speed networks to efficiently connect all elements of industrial manufacturing, the entire industrial chain, and information. This optimization can improve production and management processes, enhance production and management efficiency, reduce unnecessary loss of traditional resources, and increase energy efficiency. Scientific and technological innovation, driven by energy and digital transformation, enables the advancement of clean energy technology, particularly renewable energy. The exploitation and utilization of clean resources are crucial for industrial enterprises to achieve green development.

Figure 1illustrates the impact of the digital economy on industrial carbon intensity. This picture supplies a succinct explanation of the theoretical mechanism explaining how the Internet-based economy decreases industrial carbon-rich gas emissions using three channels: the technical innovation effect, the energy consumption effect, and the industrial structure effect.

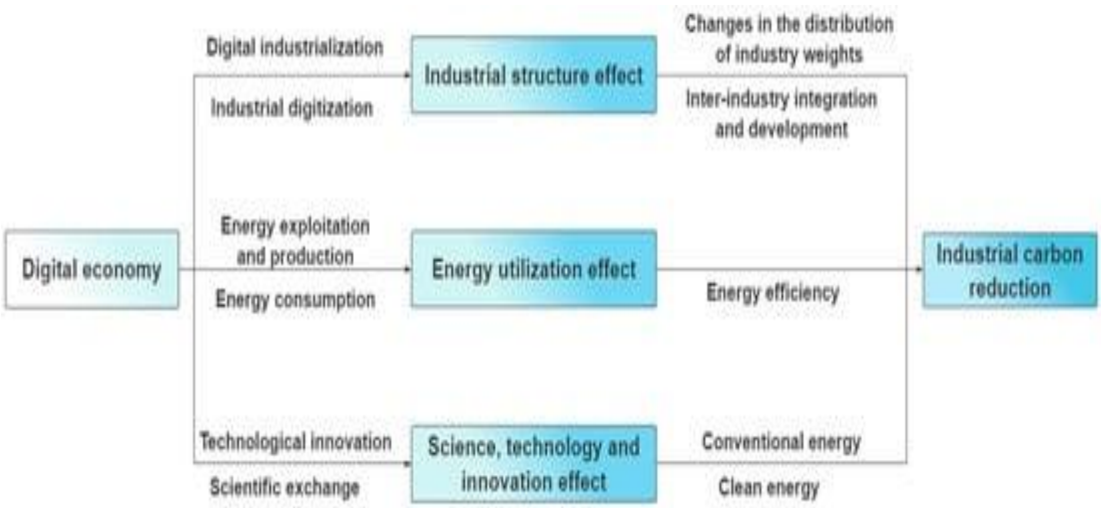

Figure 1. Mechanisms of the digital economy affecting industrial carbon emissions.

The swift progress of digital techniques, including the DC (data center) and industries like software, resulted in the extensive utilization of informational production factors in several businesses. Integrating digital technologies with the real economy might greatly decrease industrial carbon emissions. However, economic phenomena, such as "high-carbon lock-in", in the industrial economy might make sense of the swift expansion of the digital economy, including big data and the industrial Internet, on the industry's carbon production reduction exhibiting nonlinear features. The rapid growth of digital infrastructure could lead to a "Jevons paradox": the rapid progress of digital technology has led to more usage of natural resources, causing decreased pricing for subsequent items, hence boosting demand and consumption of natural resources. Similarly, the digital transformation of industries might result in an "energy rebound effect". The digital economy's advancement enhances equipment operation efficiency and empowers industrial enterprises to boost quality and productivity. Additionally, it leads to the heightened usage of energy and expanded industrial production scale, thereby undermining the future growth prospects of the digital economy and reducing manufacturing carbon-rich gas production.

Model Construction and Variable Selection.Scientific models are necessary to provide support for rational research assumptions. Thus, this section presents a logical economic model to empirically examine the study assumptions mentioned before. Furthermore, this section provides a comprehensive explanation of the precise definitions of the variables, including the dependent variables, the explanatory variables and the control variables. This step could help other researchers gain a deeper understanding of the dissertation study's subject matter. Additionally, this section offers data sources that are scientifically solid.

Two-Way Fixed Effect Model: Based on the Hausman test *p*-value of less than 0.01, this research rejects the random effect model hypothesis and establishes a two-way fixed effect model to investigate how the expansion of the digital economy affects industrial carbon emission intensity:

$$CE_{it} = \alpha_0 + \alpha_1 Dige_{it} + X_{it} + u_i + v_t + \varepsilon_{it} \quad (1)$$

CEit represents the industrial carbon intensity, with i representing the province and t representing the year. Digeit represents the status of digital economy development in the ith province (region, city) during the tth year. Xit is each control variable, and ui, vt and εitεit represent the province-fixed effects, time-fixed effects, and random error terms, respectively. α0 is the intercept term. α1 represents the digital economy regression coefficient, which is the key estimated coefficient in this paper.

Mediation Effect Model: This research constructs a mediating effect model using benchmark regression to verify the mechanism of carbon emission reduction and assess the mediating impact of industrial structure renovation, improvement in energy use efficiency, and scientific and technological innovation capacity.

$$M_{it} = \alpha_0 + \beta Dige_{it} + X_{it} + u_i + v_t + \varepsilon_{it} \quad (2)$$

$$CE_{it} = \alpha_0 + \gamma_1 Dige_{it} + \gamma_2 M_{it} + X_{it} + u_i + v_t + \varepsilon_{it} \quad (3)$$

Mit symbolizes the mediator variable, including industrial structure, science andtechnology innovation, and energy efficiency. β,γ1, and γ2 denote parameter vectors to be estimated, and the symbols of the other variables are the same as in Equation (1).

Threshold Model: This paper aims to further investigate the effect of the explanatory variable development level on carbon emission using Equation (1). Drawing on Hansen's (1999) research, a regression model is constructed utilizing a logarithmic estimation of industrial businesses' R&D projects exceeding enormous scales as a certain threshold variable. The objective is to determine if the association between the digital economy and industrial carbon emission reductions demonstrates nonlinear characteristics.

When a single threshold effect is present, the regression model is as follows:

$$CE_{it} = \alpha_0 + \alpha_1 Dige_{it} I(Dige \leq \lambda_1) + \alpha_2 Dige_{it} I(Dige > \lambda_2) + X_{it} + u_i + v_t + \varepsilon_{it} \quad (4)$$

When a double threshold effect is present, the regression model is as follows:

$$CE_{it} = \alpha_0 + \alpha_1 Dige_{it} I(Dige \leq \lambda_2) + \alpha_2 Dige_{it} I(\lambda_2 < Dige \leq \lambda_3) + \alpha_3 Dige_{it} I(Dige > \lambda_3) + X_{it} + u_i + v_t + \varepsilon_{it} \quad (5)$$

The intensity of carbon emissions (CEs) represents the quantity of CO_2 emissions generated per unit of output. In contrast to a metric that solely examines carbon emissions, carbon intensity incorporates the national economy and fluctuations in carbon emissions to offer a more accurate evaluation of industrial carbon emissions within each province. Industrial carbon emissions were calculated by selecting eight energy sources utilizing industrial consumption data from the industry Energy Statistics Yearbook. The energy sources comprise natural gas, crude coal, gasoline, electricity, fuel oil, crude oil, liquefied petroleum gas, and diesel fuel. The following is the calculating formula.

$$C = \sum_{i=1}^{8} C_i = \sum_{i=1}^{7} \lambda_i * E_i + \lambda_8 (\gamma * E_8) \quad (6)$$

C denotes the total industrial carbon emissions. "i = 1, 2, …, 8" denotes the eight major energy sources , respectively. C_i represents the carbon emissions of the ith energy source; E_i represents the total consumption of eight industrial energy sources;

λ_1–λ_7 represent the carbon emission coefficients of the first seven energy sources, respectively; and λ_8 is the coefficient of GHG emissions of the coal-power fuel chain. γ represents coal-powered electricity's share of overall generation.

This research utilizes a variety of control variables, degree of openness to the outside environment (lnOpen), fiscal decentralization, and environmental protection expenditures (lnEpe) to remove any influence of non-research variables on the empirical results to better examine the economic connection between industrial carbon emissions and digital economic development. Logarithmic values are assigned to environmental regulation, the level of openness to the outside environment, and administration expenditure on environmental protection.

This article employed technological innovation level, industrial structure transformation, and energy use efficiency as mediating variables to enhance the examination of the underlying and fundamental factors that contribute to assessing the effect of the explanatory variable on carbon discharge reduction in industries.

Empirical Evidence and Analysis. *Descriptive Statistics Analysis***:** The average industrial carbon intensity is 4.30, with a highest value of 6.0724 and a lowest value of 1.7400. This empirical result suggests that the intensity of carbon emissions varies significantly across various provinces. The explanatory variable's median is 0.0873, and the mean value is 0.13. The skewness value of the digital economy is 1.9892, and its data show a right-skewed distribution. The multitude of the distribution of the explanatory variables is smaller than the median, and the median is smaller than the mean value. A descriptive statistical analysis of the control and mediating variables revealed that the levels of each variable were within the normal range, with no outliers. This enables the subsequent phase of the thesis's analysis and research.

This paper computes the average values of industrial carbon intensity and the digital economy for each province from 2013 to 2021. As illustrated in **Figure 2**, a time-series depiction of the digital economy against the carbon intensity is generated in this paper. From 2013 to 2021, the digital economy has experienced progressive growth, while the carbon intensity has shown a gradual decline. This study concludes that industrial carbon emissions may be hindered by the digital economy based on an analysis of the patterns of both phenomena.

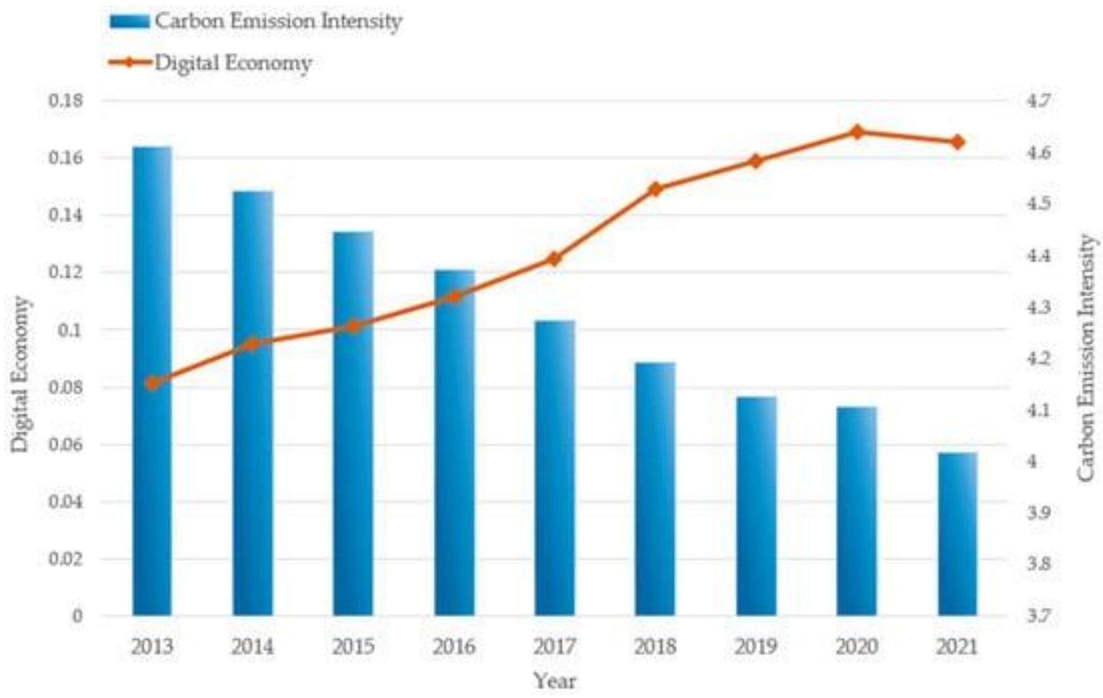

Figure 2. Time-series diagram of the digital economy and carbon emission intensity.

The swift growth of the Internet-connected economy has aided the decrease in industrial carbon emission intensity. However, this novel economic model will also be impacted by industrial carbon emission intensity, indicating a reciprocal relationship between the two. Furthermore, this research utilizes the auxiliary variable to address the endogeneity issue resulting from omitted variables due to the limited control variables chosen.

The integration of informatization and industrialization involves a comprehensive combination at a high level, where both processes merge and progress together, mutually enhancing each other in an upward spiral development path, paving the way for a new industrialization approach. The increasing convergence of information technology and industrialization has opened up new possibilities for industry to investigate green development in search of a new model for global sustainable development. The emergence and utilization of new information technologies have brought about substantial modifications in conventional production management techniques and corporate operating models. The third industrial revolution has enabled the incorporation and enlargement of information technology and traditional industry, resulting in significant progress in state-of-the-art science and technology.

This article will categorize thirty provinces based on the degree of information technology–industrialization integration in 2020 to examine the implication of digital economy development on industrial CO_2 discharges. The regression coefficient of the explanatory variable on the intensity of industrial carbon emissions is significantly negative at a 1% level in regions where digital technology is well integrated and diffused throughout the industrial sector. This outcome indicates that the R&D and iterative upgrades to information technology in industrial fields may successfully lower industrial carbon emission intensity in each province. The initial term regression coefficient of the core explanatory variable on industrial carbon emission intensity in underdeveloped regions with limited industrialization and information integration is positive but not statistically significant. The creation and operation of digital infrastructures consume significant quantities of energy in the early stages of the digital economy, leading to increased industrial carbon intensity. In this stage, the digital economy's economies of scale and scope have not yet been completely developed, and the synergistic progress of economic, social, and ecological benefits cannot be achieved.

Discussion.It is known from existing studies that the economic activities of human societies are the main cause of global carbon emissions. Based on the Sustainable Development Goals of the 2030 Agenda for Sustainable Development, this paper selects the digital economy and industrial carbon production intensity as research objects to explore the facilitating function of the digital economy on greenhouse gas reduction. This article collates and summarizes the relevant literature to conclude that industrial structure, science and technology, and energy use are the three main channels of action through which the emerging economy empowers carbon-rich gas reduction. This is supported by the empirical findings presented in this paper regarding mediation effects. While most of the literature takes regional heterogeneity as a research precaution for further analyses of digital economy-enabled carbon mitigation, this paper chooses heterogeneity in big data policy effects and heterogeneity in the degree of development of digitalization and industrialization convergence as the focus of the study. Such research makes it possible to more thoroughly examine how various stages of the expansion of the digital economy impact industrial carbon intensity.

The Internet-based economy is an unavoidable outcome of the ongoing scientific and technological revolution. Digital production factors play a vital role in driving productivity growth and shaping the evolution and advancement of economic structures. To achieve the objective of sustainable development, humans should focus on fully studying the brand-new channels of carbon footprint reduction empowered by the emerging economy within the realm of the digital sector and its spatial spillover effects in the era of information.

Heterogeneity investigations revealed that the rapid progress of a new information-driven economy has diverse impacts on the quantity of industrial carbon emissions. The impact is more pronounced in regions that have developed comprehensive big data demonstration areas and advanced levels of industrialization–information integration development.

Intending to promote a sustainable and environmentally friendly world and enhance the overall ecological conditions on a worldwide scale, it is crucial to strongly support the progress of the digital economy. Nevertheless, there are areas for improvement in this research. For instance, the digital industrialization dimension of the digital economy indicator system needs more data regarding indicators such as the radio and television industry. In addition, this study needs to completely integrate data from emerging industries, including the industrial Internet and cloud computing, as a result of the limited availability of data. Consequently, it is imperative to expand the time frame and increase the sample size to enhance the enduring influence of the digital economy on industrial carbon production research in future papers.

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