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Posted Date: 12 June 2025

doi: 10.20944/preprints202506.1054.v1

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Impact of Digitalization on Carbon Emissions in Guangdong's Manufacturing Sector: An Input-Output Perspective

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Abstract: As global pressure to reduce emissions intensifies, China is increasingly turning to digital technologies to drive sustainable industrial development, aiming to boost production while keeping carbon emissions in check. This study takes a micro-level approach by dividing the industry into 17 sectors and applying an Environmentally-extended input-output (EEIO) model combined with structural decomposition analysis (SDA) to quantify the impact of digital transformation on carbon emissions across sectors. The results indicate that: (1) Technological improvements driven by digitalization play a key role in reducing industrial carbon emissions; and (2) While high-carbon sectors show substantial emission reductions due to digital transformation, industries such as textiles—where digital adoption is more challenging—exhibit only limited improvements. These findings underscore the need to further advance technological upgrading and transformation in less digitally integrated sectors.

Keywords: digitalization; carbon emissions; downscale structural decomposition analysis; environmentally-extended input-output model; industry sectors

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1. Introduction

As one of the important pillars of the world economy, the manufacturing industry has great contribution to both the economy growth and the employment. However, this industry also one of the main source of the global GHG(Green House Gas) emissions(Murphy, 2024)[1]. The producing and the transportation of the Manufacturing are all depend on fossil fuels, which will produce lots of GHGs like CO_2. According to IEA's (International Energy Agency） report, manufacturing carbon emissions have already accounted for more than 30% of the global greenhouse gas emissions, especially in high energy consumption sector, like steel, chemical and building materials manufactures (IEA,2024) [2].

With the global warming and climate change, as well as the continuing progress of International Environmental Agreements, lowing carbon emissions has become an international consensus. Under this background how to achieve emission reduction in the industrial sector has become an important issue in promoting sustainable development. With the advent of the Industry 4.0 era, digital technology is used by more and more countries in daily life and producing activities, including the manufacturing sector. Industrial digitization is widely recognized as a key method to solve the problem of emission reduction and promote the sustainable development of the manufacturing industry (Tang, 2024)[3]. Industrial digitalization can not only optimize the production process and improve the efficiency of energy use, but also reduce the waste of resources and achieve the goal of carbon dioxide emission reduction through the introduction of the Internet of Things (IoT), big data analysis and other technological means in the manufacturing industry in the areas of product design, production and transportation (Wang, 2023) [4].

China, as the center of global manufacturing, also faces huge pressure to reduce carbon emissions while promoting economic development. China's carbon emissions experienced a long-term growth from 2002 to 2019, although the growth rate slowed down in 2020, carbon emissions still account for 30% of the global total (Guangyue Xu, 2022)[5]. To lower carbon emissions and foster sustainable development, China has made a plan for carbon peaking and carbon neutrality, the objective is to achieve the carbon peak by 2030, and carbon neutrality in 2060. These challenging targets call for extensive reforms and enhancements in both the industrial and energy sectors, especially within manufacturing. (The State Council of China, 2021) [6]. The "Made in China 2025" strategy also clearly emphasizes the integration and development of information technology and manufacturing technology, the development of intelligent manufacturing and green manufacturing, and the promotion of the transformation and upgrading of traditional manufacturing industries (Cui, 2022)[7]. The subsequent "New Quality Productive Forces" also proposes the construction of a "Digital China" and the use of digitalization and other science and technology to develop green productivity.

Under the guidance of this policy, China's manufacturing enterprises are actively adopting digital technology to achieve low-carbon development while improving productivity. Especially in energy-intensive industries, digital technologies are extensively used to optimize energy and reduce emissions. However, due to the different structures of enterprises and industries sectors, there are significant differences in the performance and effectiveness of digital transformation, which is a phenomenon required in-depth study.

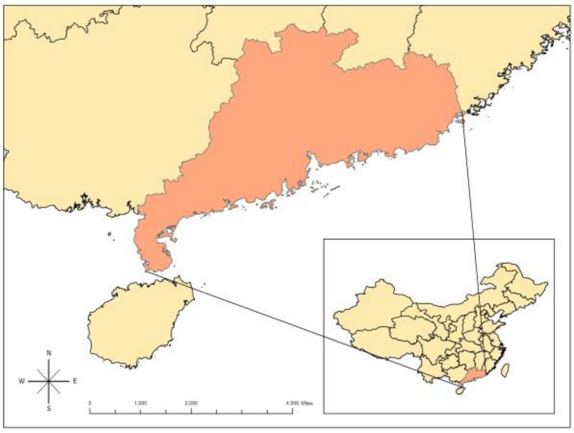

Figure 1. The location of Guangdong Province.

Guangdong is a major manufacturing province, accounting for nearly 4% of the world's manufacturing industry, and it has Shenzhen, the window of China's reform and opening up, which is not only a cluster of high-tech industries, but also a frontline of manufacturing innovation and development. Guangdong's manufacturing industry has responded positively to the policy call for "smart manufacturing" and "green development", vigorously promoting industrial digital transformation, and through the introduction of intelligent equipment and digital management systems, improving production efficiency and achieving carbon emission reduction targets in some industries. In 2023, the value added of Guangdong's manufacturing industry will reach RMB 443.979 billion, accounting for 32.7% of the GDP, the second largest in China, and accounting for 13.5% of the country's total. (Guangdong Provincial Bureau of Statistics)[8]. However, there are still differences in the breadth and depth of the application of digital technology in different industries and enterprises, which leads to different carbon emission reduction effects. As on of the pioneering region of the "dual-carbon" goal, the study of the carbon emission characteristics of Guangdong manufacturing enterprises is of great significance as a reference for low-carbon manufacturing in other regions of China.

Although there have already been some studies about the emission reduction effect of digitization, most of them mainly focus on the macro layer or a single industry, which lack a comparative analysis of the emission reduction effect of digitization among different industry sectors. Taking listed companies in the manufacturing industry of Guangzhou as the research object, this study uses the carbon emission data of different sectors in the manufacturing industry to measure the degree of digitization of enterprises through the digital input ratio, and further adopts the fixed effect model to analyze the extent of the impact of industrial digitization on the reduction of carbon emissions, as well as the difference of the impact of carbon emissions on different sectors of the manufacturing industry. Through the empirical study of Guangzhou's manufacturing industry, this thesis aims to provide policy recommendations for the digital manufacturing transformation in Shenzhen and other regions, and to contribute data support as well as the theoretical basis for the realization of the national "dual-carbon" goal.

2. Literature Review

2.1. Industrial Digitalization and Industrial Transformation

According to the 2017 White Paper on China's Digital Economy, the digital economy is consists of both digital industrialization and industrial digitization [21]. Digital industrialization refers to the information industry, which primarily encompasses electronic information manufacturing and software services. In contrast, industrial digitization describes the improvements in output and efficiency achieved by integrating digital technology into traditional industries. In this process, the application of digital technologies not only improves production quantity and efficiency but also adds significant value to these sectors. This study focuses on the industrial digitization aspect, widely seen as a crucial means of transforming the manufacturing sector by converting traditional industries into cleaner, more advanced, and environmentally friendly high-tech industries.

In China, the transformation and upgrading of the manufacturing industry has been widely emphasized as a focus of economic development. Made in China 2025 states that it is necessary to integrate information technology and promote industrial upgrading around key sectors of manufacturing. The digitalization of Chinese enterprises often starts from the production side, which is mainly manifested in the data and visualization of the production process, the installation of detection devices for the production equipment of enterprises, and the monitoring of their energy consumption and emissions, so as to improve the production efficiency and better manage the energy use in the production of enterprises. Li Tianren (2024) pointed out that the integration of digital technology with industry changes enterprise production models, proceeds the sharing of information and the exchange of technical expertise, thereby driving the green transition and sustainable growth of traditional industries [9].

2.2. Influence Mechanism of Digital Technology on Carbon Emission in Manufacturing Industry

Empirical analysis shows that industrial digital technology can improve production efficiency, stimulate green innovation in enterprises, significantly reduce unit energy consumption, and thus reduce carbon emissions. Especially in energy-consuming industries, smart manufacturing technologies have been shown to have greater potential for carbon emission reduction (Li Tianren) [9] .

However, as each industry has its own characteristics in terms of production mode, the investment in digitization also varies, and its emission reduction effect will also vary as a result. Zhang's study (2021) points out that high-technology-intensive industries are more significant in achieving carbon emission reduction due to their complex production processes and better digitization foundation[10]. In contrast, labor-intensive industries and low-technology level industries have relatively limited emission reduction effects. These findings suggest that industry characteristics play an important moderating role in the relationship between digital transformation and carbon emissions.

 doi:10.20944/preprints202506.1054.v1

2.2. Comparison of Digitalization Research Methods

With scholars' research on enterprise digitization, many digitization measurement methods have also emerged, such as expert scoring method, text analysis method and digitization project input amount. One of the more mainstream method is the text analysis method, which is widely used in the measurement of the degree of enterprise digitization. It extracts the digitization keywords in the annual reports of enterprises, and analyzes the frequency of these words to derive the enterprise digitization index (Wu, 2021)[11]. However, this method is controversial in terms of accuracy, and it is difficult to take into account the actual investment of enterprises in digitization technology.

The other research method is the digitalization investment ratio. Enterprises' digital input is an important indicator of the degree of digitization, and Liu found in his study that enterprises with a high percentage of digital input are more inclined to adopt intelligent equipment and energy-saving technologies, thus achieving lower carbon emissions (Li， 2023)[12]. This study plans to analyze the degree of digitization of enterprises by using the digitization part of their intangible asset input species.

According to the definition of the Bureau of Statistics on the manufacturing industry, can be divided into a total of eighteen industry sectors, digitalization between different industries in different regions of the digitalization of the application of the difference is obvious, to the textile industry in Guangdong, the refining industry and the electronics industry, for example, many textile enterprises through the application of industrial Internet intelligent system "shuttle intelligent textile ", so that the digitization technology Many textile enterprises have applied the industrial Internet intelligent system "Shuttle Smart Spinning" to make digital technology cover the whole process from business to production. However, the textile industry in Guangdong is mainly dominated by small-scale and scattered micro enterprises, which makes it difficult to realize centralized large-scale production, and this has also caused the application of digitization to be not yet common (Zhou, 2025)[13]. And in the high carbon emission section, focusing on automated production of the refining sector, but also a wide range of digital twin technology applied to the production chain, relying on the whole domain data sharing and intelligent model, to build a series of digital scheduling command, intelligent material balance and other digital intelligence application scenarios (Huang, 2024)[14]. In addition to these two types of industries, there is also the original information technology accounted for a larger share of the electronics industry, such as electronic devices and communications equipment industry, is the basis of industrial digitization, a large number of 5G base station construction, Internet of Things management and so on infrastructure in the development of these industries continue to improve, but also these industries are the focus of government policy to support the object.

In summary, while the overall impact of industrial digitization on carbon emissions has been studied to some degree, literature still lacks a detailed differential analysis at both the regional and sector levels. Most studies focus on macro-level emission reduction effects, with insufficient exploration of the differences among specific regions or specific industries.

Based on the existing literature, this study aims to address the following research gaps:

1. It examines the relationship between digitalization investments and carbon emissions among listed manufacturing enterprises in Guangdong Province, thereby providing empirical evidence for regional-level carbon emission research.
2. It investigates the heterogeneity of carbon reduction effects across different industries during the digital transformation process, offering insights to optimize policy formulation and resource allocation.

3. Model Building

3.1. Digitalization Degree Calculation

For the calculation of the degree of digital transformation, this paper chooses the improved method of word frequency method by Li Yingmei. It is comparing the investment amount of digital projects disclosed in the special report on annual fund raising and the construction in progress and intangible assets (digital part) in the financial statements[12]. If keywords or relevant patents related to digital transformation technology, such as “software” and “network” are mentioned in the breakdown of the financial report, the item will be defined as digital technology intangible assets. Cumulative investment in digital transformation was derived and logged. The digitization data is derived from the publicly released financial statements of the companies.

3.2. Carbon Emission Accounting

The Environmentally-Extended Input-Output (EEIO) model is an extended environmental input-output model, which introduces environmental elements into the input-output model.

At the first step, this research constructs the technical coefficient matrix A_{ij}, where Z_{ij} is the intermediate input of sector i to sector j, and X_j represents the total output of sector j.

$$A_{ij} = \frac{Z_{ij}}{X_j} \tag{1}$$

Then, we construct the base total output X_0 and base carbon emission C_0. In this formula, Y is the final demand and F is the carbon emission factor, which is derived from the ratio between carbon emission and sectoral output.

$$X = (I - A)^{-1}Y \tag{2}$$

$$C = FX = F(I - A)^{-1}Y \tag{3}$$

This paper mainly focuses on the impact of digitization within the manufacturing sector, while the input-output table contains other industry sectors except manufacturing, in order to reduce the impact, so “agriculture, forestry, animal husbandry and fishery” and other sectors are merged into “other sectors”, and the remaining 17 sectors are studied individually. Since the carbon intensity of each sector varies, for example, the carbon emissions of the metal manufacturing sector are much higher than those of other sectors, the sectors are subdivided into high-carbon and non-high-carbon sectors according to whether the carbon intensity is greater than 0.1 High-carbon sectors include “Petroleum, coking products and processed nuclear fuel”, “Nonmetal Mineral Products” and “Smelting and Pressing”. and “Smelting and Pressing of Metals”.

3.3. Data Sources

In this study, the input-output data are from the 2017 Guangdong Province Input-Output Tables publicly released by China’s statistics department, which are published every five years, with 2017 being the most recent data available. Emissions from various sectors in Guangdong Province are mainly from the China Carbon Accounting Databases (CEADs), which provides statistics on carbon emissions from various sectors in Guangdong Province in 2017.

3.4. SDA Model

The structural decomposition analysis (SDA) method is often used in conjunction with input-output modeling, which is based on input-output tables and is widely used to examine the impact of drivers on carbon emissions (Hong, 2024)[15]. Using the SDA method, it is possible to analyze the role of different factors, including digitization, in reducing emissions, and to determine the contribution that digitization has made to the reduction of carbon emissions in the manufacturing sector in Guangdong Province, as well as the extent of the impact of different industries.

The SDA method usually takes two forms: weighted average method and bipolar decomposition method. In order to simplify the arithmetic steps, reduce the error, and get more reasonable results, this paper adopts the bipolar decomposition method to decompose the change ΔC of carbon emissions in the two periods of 2012 and 2017 into technological effect, structural effect, and scale effect, and to explore the role of the influence of different factors.

The basic form of the SDA model is:

$$S = BY \tag{4}$$

$$B = (I - A)^{-1} \tag{5}$$

From EEIO model we have:

$$C = FX = F(I - A)^{-1}Y \tag{6}$$

Setting 2012 as the base period (period 0) and 2017 as the comparison period (period 1):

$$C_0 = F_0B_0Y_0 \tag{7}$$

$$C_1 = F_1B_1Y_1 \tag{8}$$

Therefore the change in total carbon emissions is assumed to be:

$$\Delta C = C_0 - C_1 \tag{9}$$

Based on the polarized average method, the decomposed form of the impact of digitization on carbon emissions in different sectors of the manufacturing industry can be written as follows:

$$\Delta C = \tfrac{1}{2}\Delta F(B_0Y_0 + B_1Y_1) + \tfrac{1}{2}(F_1\Delta BY_0 + F_0\Delta BY_0) + \tfrac{1}{2}(F_0B_0 + F_1B_1)\Delta Y \tag{10}$$

Among the formula, ΔF reflects technological effects, that it the changes in carbon intensity per unit of production value, ΔB reflects structural change and ΔY reflects the scale change.

Tech effect, struct effect and scale effect can be written as follows:

$$\text{Tech Effect} = \frac{1}{2}\Delta F(B_0Y_0 + B_1Y_1) \tag{11}$$

$$\text{Struct Effect} = \frac{1}{2}(F_1\Delta BY_0 + F_0\Delta BY_0) \tag{12}$$

$$\text{Scale Effect} = \frac{1}{2}(F_0B_0 + F_1B_1)\Delta Y \tag{13}$$

Table 1. Result of SDA model.

	Tech Effect	Struct Effect	Scale Effect
Food and Tobacco Processing	-1523954.663	-40273.39793	1554247.136
Textile Industry	-6334503.097	2743807.047	4009767.908
Textile Clothing Shoes and Hats Leather Down and its products	-1265568.841	-211542.9817	940001.822
Woodwork and Furniture	-474611.8052	189779.7323	290159.3434
Paper, printing and stationery	-3456984.744	2259874.772	2784573.23
Petroleum, coking products and processed nuclear fuel	4350120.727	-3572788.784	1543157.142
Chemical products	-414517.3999	733783.2996	2764731.79
Nonmetal Mineral Products	-38760022.87	87124698.11	70779646.35
Smelting and Pressing of Metals	7675511.848	76891809.72	126129635.2
Metal Products	-1622959.736	335345.0404	1148140.695
Ordinary Machinery	-120892.5008	140086.1948	1218281.694
Equipment for Special Purposes	-622493.426	-232772.5191	593749.7327
Transportation Equipment	-768201.821	-166827.9607	595702.0655
Electric Equipment and Machinery	-1302721.86	-234572.8099	809394.5448
Telecommunications Equipment, Computers and Other Electronic equipment	-3414791.295	-1749447.061	2310817.422
Instrumentation Machinery	-415960.8536	129899.6814	210468.0162
Other manufacturing products and scrap waste	-58676734.6	47202190.78	8200623.011

The technology effect mainly measures the extent to which digitalization or other technological improvements reduce or increase carbon emissions per unit of output value, while the structure effect reflects the impact of changes in the input-output relationship between industries (like changes in the Leontief inverse matrix B) on carbon emissions. This effect mainly reflects the changes in carbon emissions due to industrial restructuring, including direct and indirect (pull and push) effects, and the scale effect reflects the impact of changes in final demand or economic scale on carbon emissions, i.e., the increase in carbon emissions brought about by the expansion of economic activities. Among them, we mainly analyze the technical effect, which is negative in most industries, indicating that with the introduction of technological advances (such as digital upgrading), most industries have

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achieved a reduction in carbon emissions per unit of output value, thus contributing to the reduction of overall carbon emissions. The absolute value of the technology effect for industries such as food is small, indicating that the carbon reduction effect of technological improvements in this industry is weak. It is particularly noteworthy that the technology effect of "other manufacturing industries" is -58,676,734.6, which may indicate that this industry has achieved significant results in technological upgrading, significantly reducing carbon emissions per unit of output value.

3.5. Scenario Simulation

In this paper, I use a scenario simulation approach to examine how a static input-output model affects the digitalization process in an industry subject to external shocks. In their investigation of the economic and carbon emission impacts associated with electric vehicle rollout, Guo et al. (2022) employed a similar simulation strategy to replicate carbon emission shocks arising from fluctuations in electric vehicle demand. Given the sustained growth of digitization and its influence on industrial energy consumption, the model is applied to analysis the impact of industrial digitalization on carbon emissions across various manufacturing sectors[16].

In the base scenario, the digitization degree is kept constant, and the base carbon emission is C_0.

$$C_0 = FX_0 = F(I - A)^{-1}Y \tag{14}$$

In Scenario A, digitization decreases by 5%. In this scenario, the adjusted gross output$X_1$and carbon emissions$C_1$are expressed as the following model:

$$X_1 = (I - A')^{-1}Y \tag{15}$$

$$C_1 = F_1X_1 \tag{16}$$

In Scenario B, digitization is increased by 5%. In this scenario, the adjusted gross output $X_2$and carbon emissions$C_2$are expressed as the following model:

$$X_2 = (I - A'')^{-1}Y \tag{17}$$

$$C_2 = F_2X_2 \tag{18}$$

Adjusting the carbon emission coefficient after the change of digitization degree, it is assumed that if digitization improves energy efficiency, the carbon emission coefficient will also be reduced by a certain percentage:

$$F_i' = F_i(1 - D_i') \tag{19}$$

Adjustment of the technical coefficient matrix to simulate digitally optimized production structures and reduce carbon emissions according to the R_{ij} （adjustment rate of 5%）:

$$A_{ij}' = A_{ij}\left(1 - R_{ij}\right) \tag{20}$$

Recalculate total output and carbon emissions according to the model. And then analysis the carbon emissions gap.

Emission reductions of each sectors,:

$$\Delta C_i = C_{0,i} - C_{1,i} \tag{21}$$

Sectoral contribution rates, which is used to measure the relative contribution of each sector to the total emission reductions.:

$$\text{Contribution rate}_i = \frac{\Delta C_i}{\Delta C} \tag{22}$$

3.6. Data Sources

In the study, the input-output data selected are from the 2017 Guangdong Province Input-Output Tables publicly released by China's statistics department, which are published every five years, with 2017 being the most current data available. Emissions from various sectors in Guangdong Province are mainly from the China Carbon Accounting Databases (CEADs), which provides statistics on carbon emissions from various sectors in Guangdong Province in 2017.

3.7. Result

Table 2. The result of EEIO Scenario Simulation of High Carbon Sector.

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High Carbon Sector			
Sectors	**Carbon Emission Factor (tons/ten thousand yuan)**	**Emission Reduction(tons)**	**Contribution Rate**
Petroleum, coking products and processed nuclear fuel	0.1835	4004624	1.11%
Nonmetal Mineral Products	0.9804	50613240	14.05%
Smelting and Pressing of Metals	0.7129	114984400	31.91%

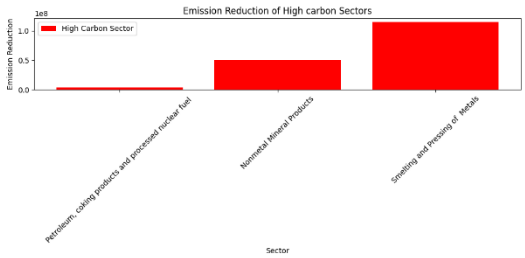

Figure 2. Emission Reduction of High Carbon Sectors.

Table 3. The result of EEIO Scenario Simulation of High Carbon Sector.

Non-high Carbon Sector			
Sectors	**Carbon Emission Factor (tons/ten thousand yuan)**	**Emission Reduction(tons)**	**Contribution Rate**
Food and Tobacco Processing	0.0141	445695	0.12%
Textile Industry	0.0548	1440923	0.40%
Textile Clothing Shoes and Hats Leather Down and its products	0.0090	180762	0.05%
Woodwork and Furniture	0.0063	100477	0.03%
Paper, printing and stationery	0.0513	1965939	0.55%
Chemical products	0.0144	1885076	0.52%
Metal Products	0.0153	456614	0.13%
Ordinary Machinery	0.0304	723410	0.20%
Equipment for Special Purposes	0.0062	90056	0.03%
Transportation Equipment	0.0065	164325	0.05%
Electric Equipment and Machinery	0.0086	338039	0.09%
Telecommunications Equipment, Computers and Other Electronic equipment	0.0035	648109	0.18%
Instrumentation Machinery	0.0133	101559	0.03%
Other manufacturing products	0.0272	582708	0.16%

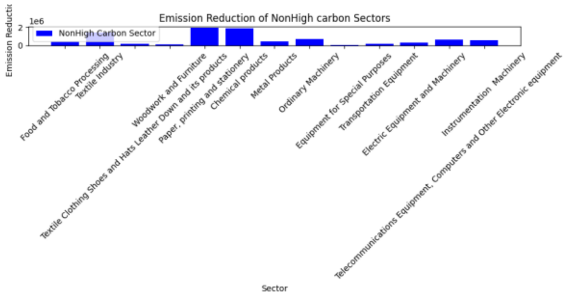

Figure 3. Emission Reduction of None-High Carbon Sectors.

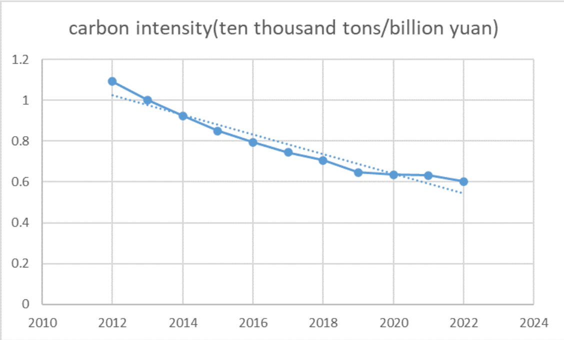

Figure 4. Carbon Intensity of Guangdong from 2012 to 2022.

According to the results, digitization in high-carbon sectors has a more significant impact and contribution to carbon emission reduction, while in non-high-carbon sectors, the contribution value is relatively small. On the one hand, the carbon emission base of high-carbon sectors is larger and the reduction effect is significant; on the other hand, the production of high-carbon enterprises under this classification is more concentrated and it is easier to carry out digitalization.

Among the high-carbon industries, the metal smelting and rolling industry has a carbon emission reduction of 114,984,400 tons, and the contribution of digitization to the reduction of carbon emissions is 31.90%, which occupies a dominant role in the overall carbon emission reduction. The smelting and rolling industry, on the other hand, has a high carbon emission intensity and usually involves energy-intensive production processes. This suggests that the digital transformation of this industry is relatively successful in reducing carbon emissions, not only in terms of having a significant impact on emissions reduction, but also in terms of leading the trend of carbon emissions for the industry as a whole.

The nonmetal mineral production industry has a carbon reduction of 50,613,240 tons in the simulation, with a digital reduction contribution of 14.05%. This industry involves the production of building materials like cement, and these processes are often accompanied by a large amount of carbon emissions, so it has a high carbon emission intensity of up to 0.98. However, the contribution rate is relatively low compared with that of metal smelting, which proves that its digitization degree needs to be improved and there is still a large space for development. Especially in the cement industry, as one of the world's largest sources of carbon emissions, it is still difficult to reduce emissions, but through the continuous introduction of digital technology and the use of green building materials, it will further reduce the level of emissions.

As for non-high-carbon industries, including the food processing and textile industries, the carbon intensity of these industries is usually lower relative to high-carbon industries, and the contribution of digitization to carbon emission reductions is more insignificant. In the food industry and the textile industry, the carbon emission intensity is 0.0141 and 0.0548 in industry, with carbon emission reductions of 447,890.1 tons and 144,092,323 tons, contributing 0.12% and 0.4% respectively. Both industries have a relatively distribution and are difficult to achieve large-scale application of digital technology and centralized production, which restricts the role of digital technology to a certain extent. However, compared to the food industry, the textile industry involves a large number of dyeing and weaving processes, which consume a large amount of energy and have high carbon emissions. With the introduction of digital technologies such as automated production lines, smart logistics and data-driven energy management, there has been a significant reduction in emissions in the industry. However, the reduction is relatively more limited compared to high carbon industries. In industries such as furniture production and instrument and equipment production, the contribution rates are at low values, which proves that digitalization still needs to be further developed in these industries.

From the comparative analysis of high-carbon and non-high-carbon industries, although high-carbon industries face greater emission reduction challenges, their carbon emission reduction and contribution rate tend to be larger due to their higher carbon emission factors and the effectiveness

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of emission reduction measures. Non-high-carbon industries, on the other hand, have relatively low abatement potential, despite their low carbon emission intensity and relatively small contribution rate.

Conclusion and Policies According to the results, digitization in high-carbon sectors has a more significant impact and contribution to carbon emission reduction, while in non-high-carbon sectors, the contribution value is relatively small. On the one hand, the carbon emission base of high-carbon sectors is larger and the reduction effect is significant; on the other hand, the production of high-carbon enterprises under this classification is more concentrated and it is easier to carry out digitalization.

From the comparative analysis of high-carbon and non-high-carbon industries, although high-carbon industries face greater emission reduction challenges, their carbon emission reduction and contribution rate tend to be larger due to their higher carbon emission factors and the effectiveness of emission reduction measures. Non-high-carbon industries, on the other hand, have relatively low abatement potential, despite their low carbon emission intensity and relatively small contribution rate.

4. Conclusion and Policies

4.1. Research Conclusions and Policy Recommendations

Digitalization is a major direction for the further development of the manufacturing industry, and it is very necessary to achieve energy saving, emission reduction and production efficiency improvement. However, in order to achieve a more efficient digital transformation, specific problems should also be analyzed, and corresponding development goals and support policies should be formulated for the characteristics of different industries. In this paper, by using the EEIO model, we analyze the positive influence of digital transformation on carbon emissions and industry output value of manufacturing industries in Guangdong Province in 2012 and 2017, and quantitatively calculate the contribution rate of the two years for separate comparisons, to observe the emission reduction and output value increase of each industry as the digitalization process continues to develop.

(1) The impact of digital transformation on high-carbon enterprises is particularly significant.

Carbon emissions from manufacturing industries in Guangdong Province are mainly concentrated in the metal smelting and rolling processing and non-metal mineral products industries, and the contribution of digitization to the reduction of carbon emissions in these two industries reached 31.91% and 14.05% respectively in 2017, far exceeding that of other industries. On the one hand, this shows that the traditional heavy industry is still the main source of carbon emissions in the manufacturing industry of Guangdong Province, and on the other hand, it also shows that the introduction of digitalization technology has greatly improved the carbon emissions of this type of industry. We should pay more attention to the digitalization of these industries, carry out further industrial upgrading, optimize the production structure, and provide policy support and subsidies for the digitalization of these industries.

(2) Highly digitalized industries (such as the electronic equipment manufacturing industry) have relatively small reductions in carbon emissions, but have a greater contribution to the growth of output value.

Electronic equipment manufacturing industry itself energy-saving effect is obvious, usually using more advanced production technology and automation system, energy efficiency level is already higher, so after the digital transformation, the carbon emissions per unit of output value is not reduced; at the same time, this type of industry has a large potential for growth in output value, digital technology can significantly improve the production efficiency, optimize the management process, so that the industry's output value has been greatly improved; has certain industrial positioning advantages, such as the chemical industry in Guangdong, the industry has a large contribution to the growth of output value. Positioning advantages, such as Guangdong's chemical industry to pharmaceutical production, its products and processes are more in line with the high digital standards, so its performance in the low-carbon transition is more excellent.

(3) Textile and other industries are less affected by digitization.

Due to the industry's own production characteristics, it is difficult to centralize production and standardize operations, and the textile industry faces greater challenges in introducing advanced digital management, automated equipment or smart manufacturing systems, resulting in a lower overall level of digitization. At the same time, digitalization can usually improve production efficiency, optimize resource allocation, and thus reduce carbon emissions per unit of output. For industries with a low level of digitization, this effect is weaker and the reduction in carbon emissions is relatively small.

First, digitalization is an inevitable choice for industries to adapt to sustainable development. Enterprises should actively take advantage of this opportunities by integrating digital transformation into both strategic planning and production processes. Greater importance should be placed on upgrading production systems through digital technologies, putting digitalization into long-term strategies. Simultaneously, governmental support is also essential. Continued investment in industrial digital infrastructure and policy incentives for the digital upgrading of enterprises will play a c critical role in promoting the sustainable evolution.

For high-carbon industries, the integration of digitalization and green low-carbon technologies should be strengthened. Focus on supporting high-carbon industries such as metal smelting and non-metallic mineral products to adopt more big data and IoT to assist production, improve energy efficiency, optimize efficiency, and reduce carbon emissions and waste pollution. Establish a digital platform to provide a communication platform for advanced digital technologies such as IoT and 5G, making these technologies more accessible to enterprises for business development, while promoting further enhancement of the technologies in practice. In particular, they can be applied to capacity enhancement, such as real-time monitoring and control systems at the production line. Enterprises should also take action to learn and acquire new technologies, improve their internal digitalization level, and look for technologies that are more suitable for the development of the enterprise, so as to achieve the goal of emission reduction and comply with the economic trend of sustainable development.

Meanwhile, the digital upgrades of the low-carbon industry should not be neglected, specifically, the production capacity of the low-carbon industry should be further upgraded, and its influence in the whole industrial chain should be expanded, so as to play a leading role in the low-carbon industry. Utilize new digital technology to enhance the production efficiency and added value of products in low-carbon industries, and at the same time encourage and attract talents to participate in the research and development and promotion of these new technologies, so as to land and apply advanced technologies in low-carbon industries and form a demonstration effect, thus driving the green upgrading and low-carbon transformation of the entire industrial chain. Promote the linkage policy of digitization and carbon emission, combining digitization and carbon emission together.

4.2. Research Limitations and Future Outlook

As the latest version of the 2022 input-output table has not yet been released, this study uses the make 2012 and 2017 input-output table, which fails to cover the latest digitalization change trends. In the future, the key aspects of digitization can be tracked dynamically with the latest data of 2022.

This study mainly conducts static input-output analysis and lacks comparison of changes in digitization in dynamic time. In the future, dynamic input-output models can be used, or linear regression models can be used to assist the study to explore the long-term impact of digitization on the industry's carbon emissions and output value.

Supplementary Materials: The following supporting information can be downloaded at the website of this paper posted on Preprints.org: https://www.ceads.net.cn/; https://www.szse.cn/disclosure/index.html; https://www.csmar.com/channels/31.html

 doi:10.20944/preprints202506.1054.v1

Author Contributions: Conceptualization, writing—review and editing, Jiao Jingren and Mizunoya Takeshi; Methodology, software, validation, formal analysis, investigation, resources, data curation, writing—original draft preparation, visualization, Jiao Jingren; supervision, project administration, funding acquisition, Helmut Yabar. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding

Data Availability Statement: We encourage all authors of articles published in MDPI journals to share their research data. In this section, please provide details regarding where data supporting reported results can be found, including links to publicly archived datasets analyzed or generated during the study. Where no new data were created, or where data is unavailable due to privacy or ethical restrictions, a statement is still required. Suggested Data Availability Statements are available in section "MDPI Research Data Policies" at https://www.mdpi.com/ethics.

Acknowledgments: In this section, you can acknowledge any support given which is not covered by the author contribution or funding sections. This may include administrative and technical support, or donations in kind (e.g., materials used for experiments).

Conflicts of Interest: The authors declare no conflicts of interest.

Abbreviations

The following abbreviations are used in this manuscript:

GHG	Green House Gas
IEA	International Energy Agency
CEAD	China Emission Accounts and Datasets
SDA	Structural Decomposition Analysis
EEIO	Environmentally-Extended Input-Output

Appendix A

Appendix A.1

Table A1. Input-Output Tables for Guangdong Province, 2012 .

Other Sectors	Food and Tobacco Processing	Textile Industry	Textile Clothing Shoes and Hats Leather Down and its products	Woodwork and Furniture	Paper, printing and stationery	Petroleum, coking products and processed nuclear fuel	Chemical products	Nonmetal Mineral Products
10803122	18012718	160725	1766808	1638052	8600214	20456886	18243129	16869512.29
18012718	19043203	27310	578836	87707	357365	682	1021115	13467.83646
160725	20953	10331840	10627747	263206	739157	9326	442654	67565.12628
1766808	39917	140111	18050970	778543	499295	8644	213069	82736.45562
1638052	37487	11335	4226	6587696	393768	2550	25586	259973.9377
8600214	1220447	106319	690825	458024	15905058	14367	1453168	707554.5118
20456886	80183	61209	109154	387220	449664	8886934	4171999	1261996.291
18243129	1806391	3001232	5000307	1314942	7776336	1974371	55634866	3185942.552
16869512	272896	217	19544	620168	125176	4165	286628	9915032.929
8699518	10824	15355	76947	739963	13360826	0	687319	579556.0654
8003489	619058	116454	153327	1368905	548764	5803	1245068	295300.3958
1173533	34541	45809	117922	63430	147947	796	760041	118157.8579
3346361	285026	65846	530360	40207	297965	22466	2110491	158300.747
1755843	2910	2227	6201	1780	5008	421	5554	7675.104688

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5435455	5594	1645	19150	24592	772354	240	202421	34932.76037
20359795	6397	5978	8788	46341	4430097	880	202954	35226.08003
3695275	1795	141	148	1129	16270	401	6839	44127.78412
665073.0294	9150.861	6017.922	26891.98	421.1396	44896.08	4.3191	4866.764	4298.034431

Nonmetal Mineral Products	Smelting and Pressing of Metals	Metal Products	Ordinary Machinery	Equipment for Special Purposes	Transportation Equipment	Electric Equipment and Machinery	Telecommunications Equipment,	Instrumentation Machinery
16869512.29	8699518	8003489	1173533	3346361	1755843	5435455	20359795	3695275
13467.83646	7481.968	23296.52	8780.34	8050.552	6058.593	27384.83	33155.64	1774.914
67565.12628	15639.41	31904.42	19638.51	5922.402	115082.6	10917.5	28530.14	1503.439
82736.45562	65391.51	160097.2	38331.02	103488.8	142914	77939.83	49866.2	17747.82
259973.9377	18107.97	253948.2	41898.98	20639.17	52255.25	83468.02	161478.3	3691.901
707554.5118	83730.83	565247.3	323890.3	62914.86	228018.5	1845824	538909.1	50901.28
1261996.291	983370.3	515997.2	153708.8	31829.55	102921.9	158789.4	195668.5	8386.591
3185942.552	1349378	2773798	1315258	1395942	2048274	6096270	2933351	141673.6
9915032.929	287258.4	181457.9	285560	41350.8	126221.3	1331555	2829368	144901.2
579556.0654	26809814	18937751	3956352	2064960	4048100	20743179	4055704	645034.8
295300.3958	54483.46	11017134	1539455	684332.2	261097.3	2843489	1312469	132774.7
118157.8579	215920.6	291790	8427733	999006.1	1511473	4935654	1557527	153509
158300.747	26449	226599.1	391294.6	4374516	258538.1	1704138	1830711	70226.54
7675.104688	2071.779	21643.84	3669.804	268989.7	27916297	7332.644	1711.752	764.4908
34932.76037	153899.8	193199.3	2097231	1046769	1152965	19586183	7611000	696607.7
35226.08003	5054.854	116142.3	6789660	2037272	1761126	15727202	1.65E+08	2343635
44127.78412	591.7538	9951.925	135573.3	172722.7	34520.32	168553.3	226515.1	867952.5
4298.034431	10.48424	36238.16	1167.404	28.1403	32622.88	22939.39	27411.01	1223.708

Other manufacturing products and scrap waste	Final Demand	Total Output	f
665073.0294	456151960.9	6.84E+08	0.574927
441.1856918	31536557.12	61543528.11	0.027075
31006.59189	9581156.728	25438350.13	0.136994
2716.082201	44061213.67	62016113.22	0.022447
628.0850725	17326181.34	23358394.78	0.015434
23851.76764	50607783.67	73150707.43	0.076928
44762.41906	31911744.67	37910257.4	0.136139
407096.08	53051392.37	119158413.9	0.015494
2055.536838	13649353.09	39625898.36	1.26907
277813.3173	19453405.62	54742578.09	0.694522
418374.9577	28975871.39	54904166.08	0.030532
6620.149463	35237188.28	38150809.13	0.031665
1201.095382	16941474.39	21995769.23	0.016134
102.498793	49319477.64	59469797.15	0.01284
20265.6197	93466951.55	109239365.9	0.015522
785942.6968	173076390.7	250432581.4	0.007809
237.6688498	12438687.68	8262611.774	0.027727
165208.4433	2508628.703	3250298.839	1. 429921

Table A2. Input-Output Tables for Guangdong Province, 2017.

Other Sectors	Food and Tobacco Processing	Textile Industry	Textile Clothing Shoes and	Woodwork and Furniture	Paper, printing	Petroleum, coking products	Chemical products	Nonmetal Mineral Products

			Hats Leather Down and its products		and stationery	and processed nuclear fuel		
403850902	32881164	6182629	13367711	9604617	14418026	10203591	26099463	18626789.14
21166471	18908530	68009	1076044	104889	74807	61773	492539	236314.1759
414644	43624	14328827	22291025	871632	1753946	2587	511610	234403.9337
2330402	45779	585540	13553300	368823	716691	21840	518664	126473.7718
2208440	185635	160240	77978	9612795	1260307	169	533144	805449.1197
11154357	1207992	480297	1595982	1364631	25996301	20414	3005962	1397380.122
13946671	52403	60599	101475	135636	135310	5564807	4397845	875324.0842
23860532	1753251	2765344	10343186	3224009	8050132	208878	69036210	6043620.967
47306877	250711	55821	108176	325654	525196	680	1265490	13768527.63
820860	6191	13598	113777	993932	6310342	1911	2899753	1452761.837
10331336	1080390	220933	896113	1470489	1167312	4334	983823	843028.5798
1374191	27827	84484	21520	319439	190835	9551	126551	995418.3862
1099417	14437	25535	592969	190737	610378	23409	414208	93354.8344
1326550	1452	2864	3299	2172	4206	2814	4237	6138.5632
7504159	6388	11592	23436	61703	404051	1125	81821	60632.6828
7002694	5908	4714	17536	8174	3646468	1693	889349	256708.1426
3946537	1537	1157	59	64	35783	4076	8269	193674.9267
7201298.578	14772.25	4067.437	209323	4992.34	5570702	23.9232	2863200	318935.8704

Smelting and Pressing of Metals	Metal Products	Ordinary Machinery	Equipment for Special Purposes	Transportation Equipment	Electric Equipment and Machinery	Telecommunications Equipment, Computers and Other Electronic equipment	Instrumentation Machinery
8743253	10034218	5514641	5153966	11547822	17124506	28137998	1285732
16802.13	127132.3	94000.96	53675.43	81144.97	175647.9	699731.7	33560.36
7392.89	116434.4	61192.54	87548.48	59236.44	160289.1	287112.7	20534.07
73438.58	106289.2	50047.75	95100.35	273346.1	96327.15	199132.6	19928.8
666773.3	745352.1	163076.9	193029.9	298832.2	409444	372886.4	7762.236
74528.38	1329107	447348.9	428409.6	243500.4	1732980	2713651	103827.6
234606	454396.3	107177.8	75051.64	157488.8	171692.1	129245	8213.921
686881.2	4162191	1585620	1978111	3431477	9789363	9969751	173094.2
115175.2	1037865	953070.6	292118.7	46670.22	1265257	11618395	420878.8
35176008	33206339	8782648	7096128	10985506	26112504	7911635	396227.7
112875	12781977	3816035	1734535	1591709	8912062	2507639	165380.8
45614.37	3539878	12579541	3083253	3617492	3940170	2501799	360517
13223.82	52358.78	534028	4056368	147706.8	945081.7	4934084	190492.6
4259.311	61765.82	19732.8	13243.07	35474360	728288.8	327829.9	1017.049
124063.7	199962	3122934	1776934	1402260	24315263	8082311	300583.1
11730.04	222410.2	3167150	1733787	779849.9	10136994	2.25E+08	3165307
5744.282	815.1082	499080.9	801303.6	63783.77	280041.2	1430413	1624292
2267158	244364.6	19387.07	9735.512	634694.2	47758.05	24288.34	911.2901

Other manufacturing products and scrap waste	Final Demand	Total Output	f
948777.8926	814793447.5	1140800857.8622	0.3806171

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5716.1697	67248633.1	74115326.75	0.014123
157415.7289	19454301.41	31625292.63	0.054789
183826.944	83975304.81	84192618.54	0.008951
23168.1139	32268566.2	37019037.26	0.006312
161849.3282	63441911.78	89990616.19	0.051325
68575.0155	15410153.83	23955106.64	0.183462
700132.5177	84802630.59	146100301.7	0.014438
10924.6678	25872441.34	59375197.87	0.980368
2035936.961	27966274.04	60012916.32	0.712886
63691.6807	47025205.4	86269872.22	0.015279
26881.2829	50777884.7	53066298.79	0.030402
12684.9635	49539268.61	39005228.58	0.006194
258.5803	81457080	89695566.21	0.00645
114156.6272	124722964.4	136206346.7	0.008589
562737.8609	279534496.5	382487753.7	0.003482
68655.8619	16639027.43	11126103.64	0.013292
1919490.334	12013111.99	16806188.55	0.027218

Table A3. Carbon Emission Intensity of Guangdong Province, 2012-2022.

year	Carbon emissions (million tons CO2e)	GDP（billion dollars)	Carbon emission intensity (tons/billion dollars)
2012	62253.41	57007.7	1.092018
2013	62637.52	62503.4	1.002146
2014	63078.54	68173	0.925272
2015	63485.74	74732.4	0.849508
2016	65295.89	82163.2	0.79471
2017	68253.42	91648.7	0.744729
2018	70549.51	99945.2	0.705882
2019	69855.48	107987	0.646888
2020	70717.62	111152	0.636224

References

1. Raymond Murphy, What is undermining climate change mitigation? How fossil-fuelled practices challenge low-carbon transitions, Energy Research & Social Science, Volume 108,2024,103390,ISSN 2214-6296,https://doi.org/10.1016/j.erss.2023.103390.
2. IEA (2024), CO2 Emissions in 2023, IEA, Paris https://www.iea.org/reports/co2-emissions-in-2023,Licence: CC BY 4.0
3. Yuhong Tang, Qi Zhao, Yuheng Ren, Nexus among government digital development, resource dependence, and carbon emissions in China,Resources Policy, Volume 95, 2024, 105186, ISSN 0301-4207,https://doi.org/10.1016/j.resourpol.2024.105186.
4. Shanyong Wang, Rongwei Zhang, Yejun Yang, Jiusong Chen, Shu Yang, Has enterprise digital transformation facilitated the carbon performance in Industry 4.0 era? Evidence from Chinese industrial enterprises, Computers & Industrial Engineering, Volume 184, 2023, 109576, ISSN 0360-8352, https://doi.org/10.1016/j.cie.2023.109576.
5. Guangyue Xu, Haoyun Dong, Zhenci Xu, Nishan Bhattarai, China can reach carbon neutrality before 2050 by improving economic development quality, Energy, Volume 243,2022,123087,ISSN 0360-5442,https://doi.org/10.1016/j.energy.2021.123087.
6. The State Council of China, ACTION PLAN FOR CARBON DIOXIDE PEAKING BEFORE 2030[EB/OL](2021-10-24) [2025-3-28], https://en.ndrc.gov.cn/policies/202110/t20211027_1301020.html.
7. 崔慧明,陈林.“中国制造 2025”战略之“智能制造”[J].科技经济市场,2022,(04):7-9.

doi:10.20944/preprints202506.1054.v1

8. 广东省统计局广东省第五次全国经济普查领导小组办公室.广东省第五次全国经济普查公报(第一号)[N].南方日报,2025-03-13(A07).
9. Li Tianren, Huang Sufeng, Does digital-industrial technology integration reduce corporate carbon emissions?, Environmental Research, Volume 257,2024,119313,ISSN 0013-9351,https://doi.org/10.1016/j.envres.2024.119313.
10. Zhiwei Guo, Tao Li, Bowen Shi, Hongchao Zhang, Economic impacts and carbon emissions of electric vehicles roll-out towards 2025 goal of China: An integrated input-output and computable general equilibrium study, Sustainable Production and Consumption, Volume 31, 2022,Pages 165-174,ISSN 2352-5509,https://doi.org/10.1016/j.spc.2022.02.009.
11. 吴非,胡慧芷,林慧妍,等. 企业数字化转型与资本市场表现——来自股票流动性的经验证据[J]. 管理世界,2021,37(7):130-144. DOI:10.3969/j.issn.1002-5502.2021.07.010.
12. 李瑛玫,焦婉茹,杨忠海. 企业数字化转型与审计师风险决策[J]. 财会月刊,2023,44(19):111-119. DOI:10.19641/j.cnki.42-1290/f.2023.19.015.
13. 周璟华,何婉虹,刘嘉煜.广东现代化产业体系的构建路径[J].四川省情,2025,(01):56-58.
14. 黄利春.广东制造业集群数字化转型发展的路径研究[J].科技与金融,2024,(07):13-19.
15. Jingke Hong, He Huang, Xianzhu Wang, Bertie Dockerill, Jiexu Ye, Shihan Zhang, Structural effects of provincial digital economy on carbon emissions within China: A multi-region input-output based structural decomposition analysis, Science of The Total Environment, Volume 934,2024,173140,ISSN 0048-9697,https://doi.org/10.1016/j.scitotenv.2024.173140.
16. Zhiwei Guo, Tao Li, Bowen Shi, Hongchao Zhang, Economic impacts and carbon emissions of electric vehicles roll-out towards 2025 goal of China: An integrated input-output and computable general equilibrium study, Sustainable Production and Consumption, Volume 31, 2022, Pages 165-174, ISSN 2352-5509,https://doi.org/10.1016/j.spc.2022.02.009.
17. Yuanjie Li, Na Li, Zibiao Li, Evolution of carbon emissions in China's digital economy: An empirical analysis from an entire industry chain perspective, Journal of Cleaner Production, Volume 414,2023,137419,ISSN 0959-6526,https://doi.org/10.1016/j.jclepro.2023.137419.
18. Bin Dou, SongLin Guo, XiaoChen Chang, Yong Wang, Corporate digital transformation and labor structure upgrading, International Review of Financial Analysis, Volume 90, 2023, 102904, ISSN 1057-5219, https://doi.org/10.1016/j.irfa.2023.102904.
19. Tingting Bai, Yong Qi, Zihao Li, Dong Xu, Digital economy, industrial transformation and upgrading, and spatial transfer of carbon emissions: The paths for low-carbon transformation of Chinese cities, Journal of Environmental Management, Volume 344, 2023, 118528, ISSN 0301-4797, https://doi.org/10.1016/j.jenvman.2023.118528.

doi:10.20944/preprints202506.1054.v1

20. Minglong Zhang, Yin Liu, Influence of digital finance and green technology innovation on China's carbon emission efficiency: Empirical analysis based on spatial metrology, Science of The Total Environment, Volume 838, Part 3, 2022, 156463, ISSN 0048-9697, https://doi.org/10.1016/j.scitotenv.2022.156463.
21. China Academy of Information and Communications Technology, CHINA DIGITAL ECONOMY DEVELOPMENT WHITE PAPER[EB/OL] (2017-07-13)[2025-3-28], https://www.cac.gov.cn/files/pdf/baipishu/shuzijingjifazhan.pdf