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Exploring Industrial Restructuring Pathways Based on Regional Carbon Productivity Variations: A Case Study of Jiangsu and Zhejiang Regions in China

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Abstract. The reduction of carbon emissions has emerged as a critical issue that requires urgent attention in the Jiangsu and Zhejiang regions as environmental concerns continue to grow. This paper examined how to achieve carbon emission reduction through industrial restructuring. The influence rela-tionship between industrial restructuring and carbon emissions was investigated using the Kaya constant equation LMDI decomposition method, while the coefficient of variation (CV) method was utilized to explore practical ways of promoting carbon emission reduction through industrial re-structuring. Data on carbon emissions and the economy from 12 core cities and 24 industries in the Jiangsu and Zhejiang regions from 2010 to 2020 were analyzed. The key findings of this study in-dicate that economic growth remains the primary driver of local carbon emission growth, while industrial restructuring and carbon emission intensity changes exhibit both positive and negative effects on carbon emission growth. The inhibitory effect of industrial structure upgrading on carbon emission growth can be weakened by regional industrial isomorphism. Furthermore, regional dis-parities in carbon emission intensity exist among some industries in the Jiangsu and Zhejiang regions, and industrial restructuring based on carbon productivity variations has greater potential for emission reduction. The cities in these regions can encourage the development of industries with superior carbon productivity while regulating the growth of industries with inferior carbon productivity, allowing the optimal allocation of carbon emission credits from industries with lower productivity to those with higher efficiency, resulting in carbon emission reduction.

1. Introduction

Climate change has been one of the greatest challenges for the survival of human beings in the past century, and concerted efforts to address it have become a global consensus. China, due to its need for economic development, has been the world's largest emitter of carbon dioxide since 2007. Recent data shows that China's total car-bon emissions increased from 8,459.7 million tons in 2010 to 9,884 million tons in 2020, accounting for approximately 30% of the world's total carbon emissions, and this amount is increasing every year. Despite this, the Chinese government has been mak-ing considerable efforts to control the rising trend of CO_2 emissions. In September 2020, President Xi Jinping reiterated the country's commitment to tackling climate change[1], pledging that "China will increase its autonomous national contribution, adopt more vigorous policies and measures, and strive to peak CO_2 emissions by 2030. We will strive to achieve carbon neutrality by 2060." This double carbon target not only reflects China's confidence in pursuing sustainable development, but also emphasizes its role as a major world power in global environmental governance. Nevertheless, the situa-tion in China's environment remains grave, and reducing emissions and carbon levels have become critical tasks that require urgent attention.

Jiangsu and Zhejiang have long been considered one of China's most representa-tive and forward-looking regions in terms of economic and social development. It is a significant force supporting China's economy, possessing high economic strength and scientific and technological innovation. Unfortunately, the rapid economic growth in the region has also led to greater environmental problems: statistics show that the carbon emissions of these two provinces accounted for nearly 12% of China's total in 2019, despite only accounting for 2.2% of China's land area The total and per capita carbon emissions in the region are currently at a high level compared with other re-gions in China, seriously impeding the local green development and the promotion of the double-carbon goal. Given the increasing global pressure on China to reduce car-bon emissions, Jiangsu and Zhejiang have a responsibility to make the necessary emis-sions reductions. It is imperative to achieve the carbon emission reduction targets and reduce the amount of carbon dioxide that the region produces.

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After the Third Plenary Session of the 18th Central Committee, with advanced concepts such as "new normal" and "supply-side reform," Jiangsu and Zhejiang have started to eliminate backward production capacity, and actively develop low-carbon emission industries, such as services and finance. However, the region still suffers from a high concentration of energy-consuming and polluting industries, with many busi-nesses having unreasonable regional distributions. As such, adjusting the industrial structure reasonably has become the key challenge for the region: achieving carbon reduction targets while maintaining economic growth. By restructuring the region's industries, it is possible to improve the level of economic development while promot-ing carbon emission reduction effectively.

Carbon productivity, defined as the ratio of gross national or regional product to CO_2 emissions over the same period, is an inverse indicator of CO_2 emission intensity and reflects the economic benefits produced per unit of CO_2 emissions [2]. The concept of carbon productivity was first introduced by Kaya and Yokobori in 1993 [3]. While carbon intensity is an environmental perspective on the problem, carbon productivity is a manifestation of efficiency that considers emissions reduction from an economic perspective [4]. It can be compared to traditional labor or capital productivity. In re-gions like Jiangsu and Zhejiang, where economic growth and carbon emission reduc-tion are critical, improving carbon productivity is a better measure of an area's carbon emission reduction efforts than reducing carbon emission intensity. This concept pro-vides a clearer representation of the theory of low-carbon economy and the new de-velopment concept.

This paper discusses the regional division of labor and carbon productivity, and proposes an industrial restructuring approach to achieve carbon emission reduction in the Jiangsu and Zhejiang regions. Industry is a major contributor to the local GDP and therefore plays a vital role in the region's economy. Hence, it is necessary to maintain the complete industrial system, especially the regions' high-carbon industries. Indus-trial restructuring, in this case, should not entirely focus on "de-high carbonization" or "low-carbonization" but rather strike a balance between economic development and carbon emission reduction. Moreover, the vast territory of Jiangsu and Zhejiang im-plies that there are regional differences in resource endowment, geographical location, and environmental carrying capacity. Consequently, the carbon productivity of each industry in each region will inevitably vary.

Therefore, achieving carbon emission re-duction through industrial restructuring should consider the overarching goal of re-gional efficiency, whereby the carbon productivity of each region gradually converges to the ideal carbon productivity level.To achieve carbon emission reduction, industrial transformation and upgrading is an imperative path to promoting "carbon peaking" and "carbon neutrality." Devising new green low-carbon industries and improving the carbon productivity levels of each industry to achieve optimal allocation of carbon emission credits are equally crucial. Furthermore, there is a necessity for carbon emis-sion credit reduction, which can be achieved through the division of labor in industries. This approach enables carbon credits to flow from industries with lower productivity to those with higher productivity, and thus improves energy resource utilization effi-ciency. Consequently, this approach is a necessary path to achieving carbon emission reduction.

2. Literature Review

2.1 A study of the factors that contribute to the rise of carbon emissions

The drivers of carbon emissions growth have received significant attention from scholars at home and abroad, with a wealth of research conducted on this issue. The mainstream method of driver decomposition is Kaya's constant equation decomposi-tion method, which was proposed by Kaya in 1989 to decompose carbon emissions into several factors multiplied by each other[5]. Subsequently, many scholars have re-searched this method, where determining weights include Laspeyres index, adaptive weight decomposition (AWD), arithmetic average index decomposition (AMDI), and logarithmic average index decomposition (LMDI) method. Ang compared the different methods of determining weights and concluded that LMDI is the most practical and ideal decomposition method[6]. This method is widely used by domestic and foreign scholars. For instance, Chunbo Ma[7] used the LMDI model to study the driving fac-tors affecting carbon emission growth in China from 1971 to 2003. Lin Boqiang et al [8] also used the LMDI model and STIRPA model to measure the factors influencing per capita carbon emissions in China and found that industrial structure, energy con-sumption structure, and energy intensity substantially impact China's carbon emis-sions, particularly industrial energy intensity. Wang Feng and Wu Lihua [9] used the LMDI method to decompose carbon emission growth from 1995 to 2007, resulting from the combined effect of 11 factors, introducing new variables such as the number of transportation modes and average annual household income. Other scholars, like Li Bo et al [10] found that efficiency and structural factors and labor force size demonstrated suppressive effects on China's agricultural carbon emissions. Similarly, Yang Qian [11] and other scholars noted that there are apparent regional differences in carbon emis-sions in China, with carbon emission intensity presenting larger regional differences than carbon emission per capita. Guo Chaoxian [12] analyzed carbon emission growth factors from different dimensions and levels, while Lin Boqiang [13] studied urbaniza-tion and carbon emissions together and concluded that the advancement of urbaniza-tion is a leading cause of energy consumption increase in China. Finally, Chen Shiyi [14] found that the reduction of energy intensity or the increase of energy productivity is the primary factor for accounting for the fluctuating decrease of CO_2 emission intensi-ty, and the adjustment of energy consumption structure and industrial structure is beneficial to reducing carbon emission intensity.

2.2 A study on the relationship between industrial restructuring and the impact of carbon emissions

Industrial structure is a crucial factor that reflects the interdependence and de-velopment status of each industry in a country or region, and serves as an important basis for formulating economic and social development plans. The adjustment of in-ter-industry structure should take into account the inter-industry linkage, economic stability, and consumption structure, and determine the inter-industry combination plan with one or more objectives, such as maintaining stable economic growth, opti-mizing consumption structure, reducing pollutant emissions, and energy consumption [15]. However, changes in inter-industry portfolio relationships may lead to changes in industrial scale and factor structures within the industry, and thus require considering the spatial allocation of production factors and forming a new regional division of la-bor layout to avoid a mismatch of production factors during the implementation of industrial structure changes [16]. The regional division of labor layout should depend on the comparative advantages of each industry in each region, and the implementa-tion of industrial clustering should be based on regions with high industrial efficiency, while industrial re-planning should focus on regions with low efficiency. Such measures can improve production efficiency and promote inter-regional industrial cooperation [17].

With the increasing seriousness of carbon emission problems, scholars have con-ducted extensive research on the relationship between carbon emissions and industrial structure. Liu Hongguang and Liu Weidong [18] found that reasonable adjustments in industrial structure can promote carbon emission reduction, which has the greatest ef-fect in the northeast and central regions of China. By constructing a theoretical model, Zhang Jie et al. [19] found that economic growth and carbon emission reduction can be achieved simultaneously through industrial restructuring, and the greater the adjust-ment, the greater the expected GDP increase and carbon emission reduction. Han and Qiang [20] also found that industrial restructuring, technological progress, and energy structure optimization are effective paths to achieve the goal of "energy saving and emission reduction." Zhang Hongyan [21] emphasized that both internal industrial upgrading and inter-industrial coordinated development are essential to achieve car-bon emission reduction, and that improving energy use efficiency in the tertiary in-dustry can accelerate this process. Sun Zhenqing et al [22] showed that advanced in-dustrial structures have a more significant effect on promoting carbon emission reduc-tion than industrial structure rationalization. Tang Weiqi et al. found that carbon poli-cies would cause industrial transfer and that intensity reduction targets would pro-mote the transfer of high energy-consuming industries to cluster in central and west-ern China [23]. Pang, Rui-Chi, and Li, Peng [24] also found that the gradient transfer behavior of energy-consuming industries is "pollution moving west."

The current research on industrial structure and carbon emissions suffers from three main limitations. Firstly, while many studies have established that industrial re-structuring can aid in reducing carbon emissions, most of these studies focus solely on the impact of structural changes on carbon emissions between industries that shift production resources from high-carbon to low-carbon industries. Moreover, the indus-trial upgrade is mainly due to the carbon emission reduction policies' backward pres-sure, making it difficult to reduce carbon emissions in the short term. Secondly, current research areas typically cover national, central or northeastern regions, with little fo-cus on areas such as Jiangsu and Zhejiang. Thirdly, existing literature is primarily con-centrated on particular regions or provinces, making it difficult to produce highly ac-tionable and easily formalized policy recommendations when implemented in a speci-fied city or industry.

To address these deficiencies, this paper will focus on Jiangsu and Zhejiang re-gions, selecting 24 industries and 12 major cities as the research targets. The paper will decompose the carbon emissions growth factors in the region using Kaya's constant LMDI decomposition method and examine the "12th Five-Year Plan" and "13th Five-Year Plan" periods. Subsequently, the coefficient of variation (CV) method will be employed to analyze the regional trends in carbon productivity of industrial sectors in the region and determine the carbon emission intensity patterns existing in each region. Differences in carbon productivity between regions will signal irregularities in the re-gional industrial division of labor, indicating the potential for the implementation of pathways such as carbon productivity enhancement and carbon emission allowance optimization. Finally, the results of these analyses will yield targeted recommendations for the industrial restructuring of individual local cities.

This paper's innovations include a more refined and targeted approach to re-search in different cities in Jiangsu and Zhejiang regions, providing more specific sug-gestions for industrial structure adjustment tailored to the industry level. This feature compensates for the lack of targeting in previous research results and makes the find-ings more representative and of increased practical significance, leading to further in-depth research on industrial structure and carbon emissions. Additionally, the pa-per comprehensively sorts out the contribution of industrial structure adjustment to carbon emission reduction in the 12th and 13th Five-Year Plan periods based on de-tailed industry samples during the decomposition of carbon emissions in Jiangsu and Zhejiang regions.

3. Methodology and Data Sources for the Research

3.1 Research Methodology

- 1.Methodology for calculating carbon emissions

After a thorough review of the literature on carbon emission reduction, this paper has decided to employ the carbon emission estimation method established by the United Nations department IPCC. This method is currently recognized and presents high levels of accuracy in measuring carbon emissions of different cities and industries in Jiangsu and Zhejiang [25]. Specifically, this method involves:

$$S=\sum_{i=1}^{n} C_i \times CC_i \times JC_i \times CTO_i \times \frac{44}{12} \quad (1)$$

where S is the total CO_2 emissions, C_i is the consumption of the i th energy source (million tons), CC_i is the carbon emission factor (kg/kJ), JC_i is the average low-level heat output of the i th energy source (kJ/kg) [26], and CTO_i is the propor-tion of the th energy source that is oxidized.

- 2.Kaya's constant equation and LMDI decomposition method

According to Guo Chaoxian's decomposition [27], the change in CO_2 emissions in Jiangsu and Zhejiang regions was divided into three driving factors for measuring the impact of industrial restructuring on carbon emission reduction in those regions: the scale effect, the intensity effect, and the structural effect. The scale effect is the impact of GDP growth on CO_2 emissions; the intensity effect is the impact of CO_2 emissions intensity; and the structure effect is the impact of industrial restructuring on CO_2 emissions. The breakdown expression of CO_2 emissions after suitably deforming Kaya's constant equation is as follows:

$$C^t=\sum_{j=1}^{j} \frac{C_j^t}{G_j^t} \times \frac{G_j^t}{G^t} \times G^t=\sum_{j=1}^{j} \alpha_j^t \times \delta_j^t \times G^t \quad (2)$$

In Equation(2), C^t represents the total CO_2 emissions within a municipality with j industries in period t, and C_j^t is the carbon dioxide emissions of industry j within the city in period t, G_j^t is the value added of industry j in the city in period t, and $\alpha_j^t = C_j^t / G_j^t$ is the carbon dioxide emission intensity of industry j in the city in period t [28], $\delta_j^t = G_j^t / G^t$ is the the value added of industry j in the city as a share of the city's GDP. The change in CO_2 emissions of a city from year t to year $t+1$ can be expressed as follows:

$$\triangle C = \triangle C_{scale} + \triangle C_{str} + \triangle C_{intern} \quad (3)$$

In the above equation, $\triangle C_{scale}$ denotes the change of carbon emission caused by the growth of total economy, that is, the scale effect that affects carbon emissions; $\triangle C_{str}$ represents the change of carbon emissions caused by the change of industrial structure, that is the structural effect of carbon emissions, changes in industrial structure are reflected in changes in the proportion of different industries. $\triangle C_{intern}$ represents the change of carbon emissions caused by the intensity of carbon emissions, that is the intensity effect of carbon emissions.The change of carbon emission intensity may be due to the progress of industrial production process or the improvement of energy use efficiency. Drawing on $Sunil$'s [29]definition of each effect formula, the effect of the $LMDI$ for each decomposition factor from year t to $t+1$ is calculated as follows:

$$\triangle C_{scale}=\sum_{j=1}^{j} L\left(C_J^{t+1}, C_J^t\right) \ln \left(\frac{G^{t+1}}{G^t}\right) \quad (4)$$

$$\triangle C_{str}=\sum_{j=1}^{j} L\left(C_J^{t+1}, C_J^t\right) \ln \left(\frac{\delta_j^{t+1}}{\delta_j^t}\right) \quad (5)$$

$$\triangle C_{intern}=\sum_{j=1}^{j} L\left(C_J^{t+1}, C_J^t\right) \ln \left(\frac{\alpha_j^{t+1}}{\alpha_j^t}\right) \quad (6)$$

$$L\left(C_J^{t+1}, C_J^t\right)\begin{cases}\left(C_j^{t+1}-C_j^t\right) /\left(\ln C_j^{t+1}-\ln C_j^t\right), C_j^{t+1} \neq C_j^t \\ C_j^{t+1}, C_j^{t+1}=C_j^t \neq 0 \\ 0, C_j^{t+1}=C_j^t=0\end{cases} \quad (7)$$

- 3.Coefficient of variation method

This paper employs the Coefficient of Variation (CV) method to measure regional differences in carbon emission intensity within different industries of the industrial sector in the Jiangsu and Zhejiang regions. The CV reflects the degree of data dispersion and is an absolute value [30]. Its magnitude is influenced not only by the degree of data dispersion but also by the average size of the variable values. Its advantage over variance and standard deviation lies in its ability to eliminate the bias of results caused by differing data magnitudes.The coefficient of variation method is a relative differences calculation method wherein larger values denote greater differences between variable observations. In this chapter, the method is primarily used to assess regional differences in carbon emission intensity across different industries. The formula for this calculation is as follows:

$$V_i=\frac{\sigma_i}{\overline{x}_i} \quad (8)$$

where V_i represents the coefficient of variation of carbon emission intensity of industry i, σ is the regional standard deviation of carbon emission intensity of industry i, and $\overline{x}_i$ represents the regional average of carbon emission intensity of industry i in different regions.The larger the value of V_i, the greater the regional variation of carbon emission intensity of industry i in different regions.

3.2 Data sources

Based on data from the CEADs database, the industrial sector in Jiangsu and Zhejiang is responsible for approximately 90% of the total carbon emissions in the region. The mining, manufacturing, and electricity and gas production and supply industries are the primary sources of carbon emissions and are therefore key drivers of the overall carbon productivity pattern in the region.

Given this context and the availability of data, this paper focuses primarily on industrial sectors in the Jiangsu and Zhejiang regions. The industries are classified and presented in detail in the following Table 1:

Table 1. Division of industrial sectors emitting CO_2

Level 2 Classification	Level 3 Classification
Mining Industry	1. Coal mining and washing industry
	2. Oil and gas extraction industry
	3. Metal mining industry
	4. Non-metallic mining and other mineral extraction industry
Manufacturing Industry	5. Food and beverage manufacturing and tobacco processing industry
	6. Textile industry
	7. Textile, clothing, shoes, hats, leather and down products industry
	8. Wood processing and furniture manufacturing
	9. Paper printing and education, sports and entertainment products manufacturing
	10. Petroleum processing, coking and nuclear fuel processing industry
	11. Chemical industry
	12. Non-financial mineral products industry
	13. Metal smelting and rolling processing industry
	14. Metal products industry
	15. General and special equipment manufacturing
	16. Automotive and transportation equipment manufacturing
	17. Electrical machinery and equipment manufacturing
	18. Communications equipment, computers and other electronic equipment manufacturing
	19 instrumentation and cultural office machinery manufacturing
	20. Other manufacturing industries
	21. Comprehensive utilization of waste resources industry
	22. Metal products, machinery and equipment repair industry
Electricity, heat, gas and water production and supply industry	23. Electricity, heat production and supply industry
	24. Gas and water production and supply industry

As the most recent economic and carbon emissions data for Jiangsu and Zhejiang regions only spans until 2021, this study focuses on the time period of 2010 to 2020, corresponding to China's strategic development plan during the 12th and 13th Five-Year Plan periods. The study area encompasses 12 major cities in Jiangsu and Zhejiang: Hangzhou, Taizhou, Wenzhou, Zhoushan, Suzhou, Huzhou, Shaoxing, Wuxi, Nanjing, Changzhou, Jiaxing, and Ningbo. Overall carbon emission data was sourced from the CEADs database (https://www.ceads.net.cn) and the statistical yearbook of each city. Carbon emission data for each industry was calculated using Equation **(1)**. Value-added data for each industry was obtained from the input-output tables of each city.

4. Analysis of results

4.1 Analysis of the relationship between industrial restructuring and carbon emission growth: based on Kaya's constant equation and LMDI model

- 1."The 12th Five-Year Plan" Period

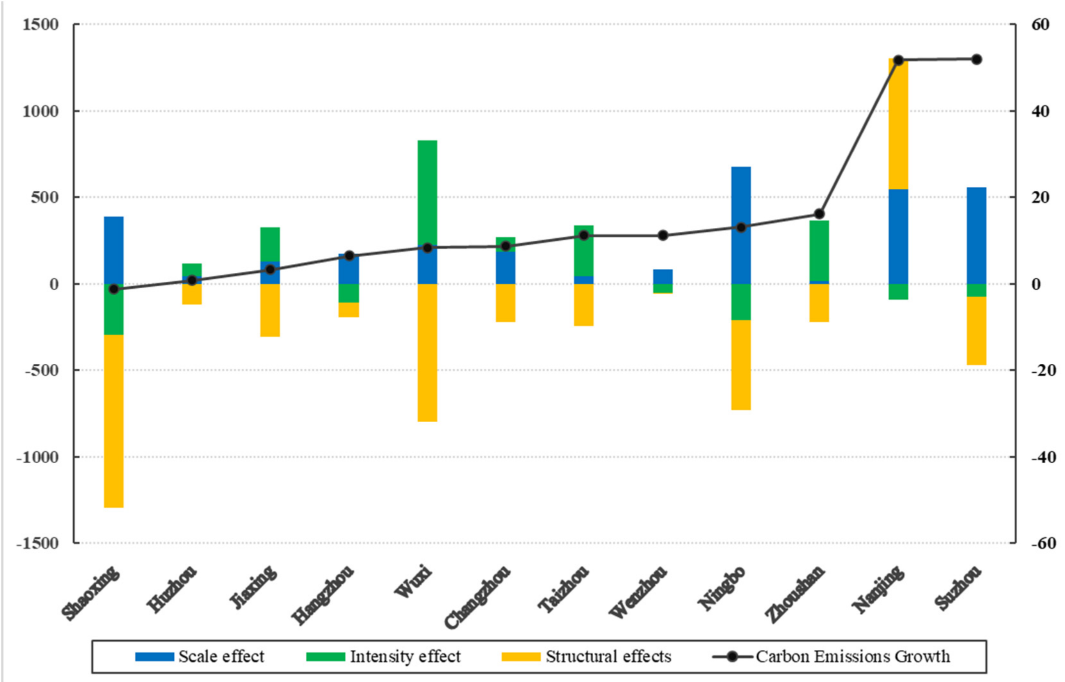

Figure 1. Decomposition of carbon emission growth drivers by city, 2010-2015

During the "12th Five-Year Plan" period, the total carbon dioxide emissions of some cities in Jiangsu and Zhejiang have decreased, such as Shaoxing City, while the other eleven cities maintain positive growth. Nanjing City and Suzhou City, characterized by higher industrialization levels, experience larger increases in carbon emissions due to economic development requirements, as shown in Figure 1. The intensity effect has differing impacts on carbon emissions across the various cities, with both positive and negative effects. Meanwhile, the structural effect of industrial restructuring displays a negative influence on carbon emission growth in most prefecture-level cities.

This negative driving effect of the structural adjustment could be linked to the Jiangsu and Zhejiang 12th Five-Year Plan policies aimed at establishing a green and low-carbon industrial system, which include "appropriately reducing the scale of high-energy-consuming industries and controlling their growth rate," "eliminating and upgrading backward production capacity", and "reducing the scale of energy-consuming industries", "eliminating and upgrading backward production capacity", accelerating structural reform on the supply side, and vigorously developing strategic new industries. During this period, Jiangsu and Zhejiang cities intensified the transformation of high-carbon and high-pollution enterprises, developed modern service industries and strategic new industries, and promoted the optimization and upgrading of the industrial structure towards intensification and low-carbon. However, this shift led to a relative reduction in the output value proportion of local high-emission industries, resulting in a mostly negative structural effect on industrial restructuring that curbs the growth of local carbon emissions. This negative influence alone cannot alter the direction of total carbon emissions growth, with overall scale and intensity effects still promoting local carbon emissions.

This situation may arise from all Jiangsu and Zhejiang's prefecture-level cities' efforts to develop service industries and strategic new industries. Rapidly expanding a particular industry in a short time could result in inter-regional industrial isomorphism, hampering the professional development of their respective industries and destabilizing the overall layout of industries. Furthermore, industrial homogeneity can lead to increased competition and issues of overcapacity, waste of resources, and lower utilization efficiency, all of which impede the efficient allocation of production factors and reduction of local carbon emissions and carbon productivity improvement.

- 2.“The 13th Five-Year Plan“ Period

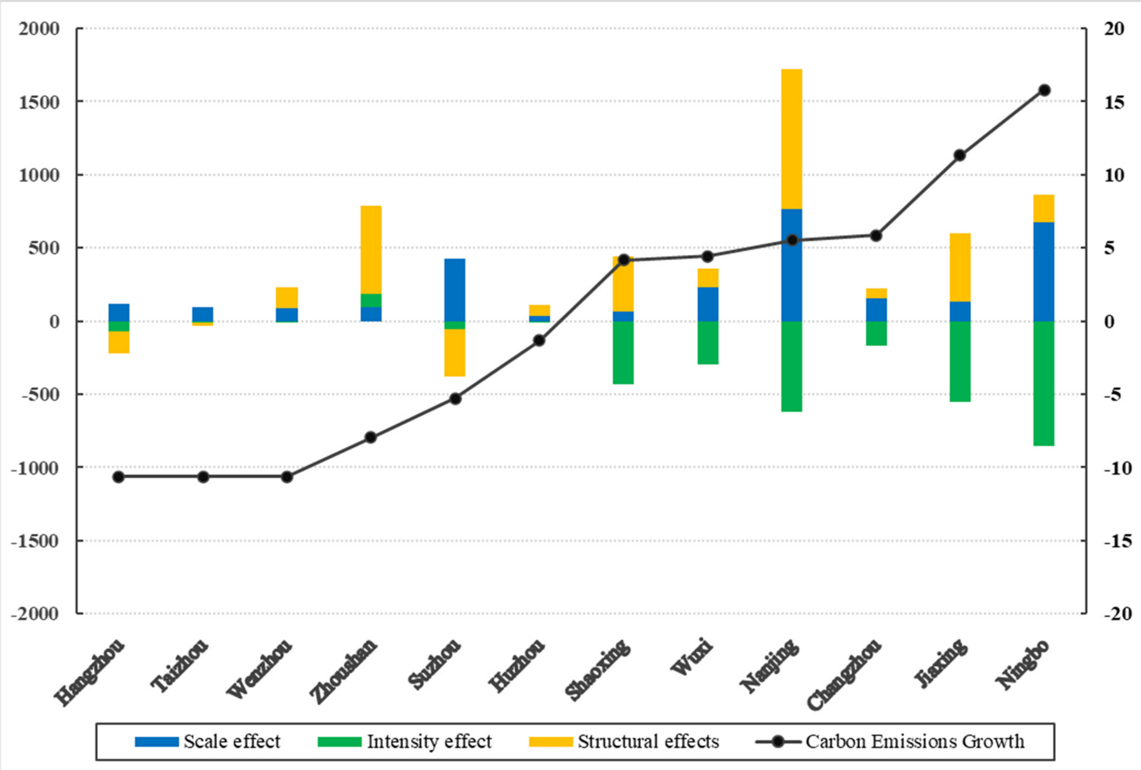

Figure 2. Decomposition of carbon emission growth drivers by city, 2016-2020

In contrast to the 12th Five-Year Plan period, from 2016 to 2020, the total carbon emissions of six prefecture-level cities in Jiangsu and Zhejiang, including Hangzhou, Taizhou, Wenzhou, Zhoushan, Suzhou, and Huzhou, have experienced negative growth. The analysis of the drivers of carbon emission growth in the 13th Five-Year Plan period is shown in Figure 2. The carbon reduction effect of major cities in Zhejiang Province was relatively significant, which may be related to the implementation of a number of energy conservation and emission reduction policies in Zhejiang during this period, primarily including the "Thirteenth Five-Year Plan for Industrial Pollution in Zhejiang Province" ,the "Comprehensive Work Plan for Energy Conservation and Emission Reduction in Zhejiang Province" . Additionally, the scale effect of economic growth on the growth of total carbon emissions in each city is slightly weaker than it was during the 12th Five-Year Plan period, indicating that each city's industrial and energy structures have been optimised as a result of the implementation of various industrial structure policies and low-carbon policies, and the relationship between economic growth and carbon dioxide emissions has been weaker than it was. During this period, the intensity effect plays a negative role in suppressing the growth of total carbon emissions in most cities. This could be attributed to progress in production processes, technology upgrades, or process optimization, leading to improved energy use efficiency. This advancement has consequently enhanced the carbon productivity of related industries. Meanwhile, the structural effect positively drives carbon emission growth in most cities, although its promoting effect is not significant. The growth rate of carbon emissions in most cities is lower than in the "Twelfth Five-Year Plan" period, with many cities even experiencing negative growth rates. This trend may be due to technological progress and process optimization in various industries in Jiangsu and Zhejiang, reducing the carbon emission intensity of the industries and having a strong negative impact on carbon emissions. Consequently, carbon emissions have been lowered.

4.2 Analysis of Regional Differences in Carbon Emission Intensity of Industrial Industries in Jiangsu and Zhejiang

Currently, both national and regional industrial planning focus on vigorously supporting low-carbon industries [31]. This includes transferring as many production materials as possible from industries with higher carbon emissions to industries with lower carbon emissions. However, such industrial planning is often mandatory and fails to consider the resource endowment and environmental ecology of each region when making structural adjustments. This lack of consideration is not only detrimental to the coordinated development of the regional industrial layout, but also may lead to increased competition and waste of resources within the industry. As a result, it is not conducive to improving the carbon productivity of the overall industrial layout.In this section, we use coefficient of variation(CV) to examine the differences in carbon emission intensity among 24 industrial industries in different cities in the Jiangsu and Zhejiang regions. During the statistical process, we noted that coal mining and washing industry, oil and gas mining industry, and metal products, machinery, and equipment repair industry data were missing in all or some years. If we forced statistics, the accuracy and representativeness of the analysis results would be affected. Therefore, we excluded these three industries in the industry analysis in this section, limiting the analysis to the remaining 21 industries.As a result, we examine the regional division of labor from the perspective of carbon emission intensity. The statistical results can be seen in Table 2.

The calculation results in Table 2 reveal several significant findings. Firstly, the coefficient of variation of carbon emission intensity of 21 industrial sectors in Jiangsu and Zhejiang in 2010 ranged from 60.15% to 308.15%, with a difference of 248% between the minimum and maximum values. In 2020, this range increased to 65.15% to 326.05%, indicating a 261% difference between the minimum and maximum values. The increase in the range of the CV reflects that the industrial structure of the region has not been adjusted reasonably according to the carbon productivity difference of each industry, leaving a vast potential for reducing carbon emissions through industrial planning by taking carbon productivity differences into account.

Secondly, in 2020, the CV of carbon emission intensity of industries such as metal mining, paper printing, education, sports and recreation goods manufacturing, electrical machinery and equipment manufacturing, automobile and transportation equipment manufacturing, other manufacturing, comprehensive utilization of waste resources, and gas and water production and supply industries in Jiangsu and Zhejiang cities exceeded 200%. This indicates a considerable difference in carbon emission intensity among the mentioned industries in different cities at the current stage, which can be alleviated by adjusting industrial scale according to the regional differences in carbon productivity of the industries. Specifically, the industrial scale of industries with lower carbon emission intensity can be increased, while the industrial scale in areas with higher carbon emission intensity can be decreased, leading to a reduction in the overall carbon emission intensity of the industry and improving the carbon productivity of the industry in the region.

Thirdly, during 2010-2020, the coefficient of variation of carbon emission intensity of 13 industrial industries in Jiangsu and Zhejiang, including metal mining, non-metallic mineral and other mineral extraction, wood processing and furniture manufacturing, paper printing, and manufacturing of cultural, educational, sports, and entertainment products and non-metallic mineral products, increased. This suggests that some regions are developing industries that do not match the local resource endowment, resulting in significant misallocation of production resources and an increase in carbon emission intensity. These developments are not conducive to improving the industry's carbon productivity or reducing carbon emissions. Regions engaging in industrial development in these industries should carefully examine local natural resources, technological capital, and human environment to determine the degree of suitability for the industry's development. Then, new industrial planning can be put in place to reduce local carbon emissions by improving the carbon productivity of the industry.

Table 2. Table of regional differences in carbon emission intensity of industries in 2010 and 2020

Industry Code	Standard Deviation (2010)	Average intensity (tons per million yuan) (2010)	CV(%) (2010)	Standard Deviation (2010)	Average intensity (tons per million yuan) (2010)	CV(%) 2020
3	0.07	0.03	226.56	0.28	0.09	326.05
4	1.35	1.17	114.8	0.55	0.29	191.6
5	0.89	0.82	109.22	0.11	0.13	89.27
6	2.73	2.28	119.6	0.55	0.61	89.81
7	0.97	0.58	166.2	0.09	0.08	115
8	0.52	0.4	129.87	0.47	0.28	171.23
9	1.88	2.13	88.07	2.56	1.27	201.12
10	8.13	3.59	226.56	13.67	7.97	171.57
11	7.92	4.26	186.19	2.32	1.63	142.76
12	7.59	6.52	116.42	3.09	2.45	126.26
13	3.16	3.96	79.71	3.29	3.28	100.22
14	0.41	0.57	71.28	0.53	0.39	135.78
15	0.15	0.26	60.15	0.06	0.07	95.56
16	0.23	0.19	116.58	11.54	3.58	322.75
17	0.22	0.17	127.65	0.56	0.22	249.19
18	0.19	0.15	125.95	0.06	0.04	129.5
19	0.06	0.06	99.72	0.04	0.02	147.88
20	0.42	0.28	149.69	4.5	1.45	310.15
21	3.34	1.32	253.47	6.49	2.66	244.17
23	45.75	46.29	98.84	12.25	18.8	65.15
24	2.82	0.92	308.15	0.95	0.32	295.19

4.3 Regional industry type classification based on carbon productivity advantage

Industrial restructuring that disregards each region's resource endowment, tech-nical humanities, and ecological environment is not only unlikely to reduce regional carbon emissions, but may also result in resource overuse and pollution that exacer-bates resource-related environmental issues. It will also have a negative impact on the industrial structure itself, such as the emergence of regional industrial isomorphism, which will increase competition and reduce efficiency. The emergence of regional industrial isomorphism will result in more competition within the same industry in a constrained area, which will intensify the conflict between resource scarcity and over-capacity and be detrimental to the healthy growth of low-carbon industries. Addition-ally, if we do not take into account the local resource endowment and arbitrarily re-strict or eliminate the high carbon emission industries in all Jiangsu and Zhejiang cities, it will cause the production resources with the highest suitability to flow outward and into the industries with the lowest suitability to the local resource endowment. Clearly, such industrial planning is not ideal. For instance, high energy-consuming industries like mining and oil extraction are among the key industries of concern during the pro-cess of national and regional industrial restructuring, but the carbon emission intensity of the resource-intensive metal mining industry will be 0.03 tonnes per million yuan i in 2010 and 0.09 tonnes per million yuan in 2020, respectively, the resource-intensive metal mining industry's carbon emission intensity is substantially lower than the av-erage for other industries. In the development of the metal mining industry in Jiangsu and Zhejiang, if a "one-size-fits-all" structural adjustment policy is adopted arbitrarily for all regions, it will not only be harmful to local economic development but may also result in a decline in the overall carbon productivity of the industrial chain in the area.

To ensure effective planning of the industrial structure, it is essential to conduct reasonable planning based on the resource endowment and ecological carrying capac-ity of each region. This paper presents a comparative analysis of regional carbon productivity levels for each industrial sector in Jiangsu and Zhejiang in 2010 and 2020. We have classified each relevant industry based on our findings, and the scientific ba-sis for such classification is presented in Table 3. The table provides an empirical framework for the formulation of industrial policies and carbon reduction policies for each city in the region.

Table 3. Comparison table of regional carbon productivity advantaged, carbon productivity disadvantaged and carbon productivity reversed industries

Carbon productivity advantageous type				**Carbon productivity disadvantageous type**			
Region	**Industry Code**	**Carbon Emission Intensity in 2010 (tons per million yuan)**	**Carbon emission intensity in 2020 (tons per million yuan)**	**Region**	**Industry Code**	**Carbon Emission Intensity in 2010 (tons per million yuan)**	**Carbon emission intensity in 2020 (tons per million yuan)**
Suzhou	4	0.06	0.01	Hangzhou	4	2.64	1.91
Hangzhou	5	0.11	0.05	Jiaxing	5	0.44	0.28
Chang zhou	6	0.31	0.20	Hangzhou	6	2.18	1.50
Ningbo	7	0.16	0.01	Jiaxing	7	0.35	0.22
Nanjing	8	0.05	0.02	Wenzhou	8	0.51	0.63
Huzhou	8	0.19	0.04	Jiaxing	8	0.19	0.56
Nanjing	9	0.20	0.04	Hangzhou	9	1.74	1.28
Chang zhou	9	0.30	0.15	Suzhou	9	2.22	1.14
Hangzhou	10	0.22	0.22	Ningbo	10	27.72	27.50
Suzhou	10	0.06	0.01	Wuxi	10	2.45	39.08
Ningbo	11	0.43	0.60	Jiaxing	11	1.68	5.70
Chang zhou	11	0.65	0.11	Wuxi	11	4.76	1.27
Taizhou	12	0.65	0.42	Changzhou	12	5.36	2.70
Suzhou	12	0.43	0.17	Jiaxing	12	3.94	3.25
Shaoxing	13	0.74	0.20	Hangzhou	13	9.65	9.94
Nanjing	13	1.57	0.65	Ningbo	13	8.94	6.21
Ningbo	14	0.32	0.06	Hangzhou	14	0.64	0.55
Nanjing	14	0.12	0.04	Wenzhou	14	0.62	0.55
Ningbo	15	0.23	0.02	Jiaxing	15	0.23	0.18

Hang zhou	16	0.11	0.08	Shaoxing	16	0.31	0.25
Suzhou	16	0.03	0.01	Wenzhou	16	0.31	0.23
Ningbo	17	0.08	0.01	Jiaxing	17	0.22	0.18
Suzhou	17	0.03	0.01	Wenzhou	17	0.16	0.11
Hang zhou	18	0.03	0.02	Wenzhou	18	0.32	0.17
Jiaxing	19	0.03	0.03	Wenzhou	19	0.20	0.12
Nan jing	20	0.06	0.02	Wenzhou	20	0.48	0.36
Nan jing	20	0.06	0.02	Wuxi	20	0.60	0.39
Ningbo	21	0.24	0.12	Huzhou	21	0.56	0.23
Suzhou	21	0.35	0.27	Nanjing	21	0.57	0.25
Wen zhou	23	5.69	5.04	Ningbo	23	43.22	28.04
Hang zhou	23	25.25	14.37	Jiaxing	23	37.83	50.25
Chang zhou	24	0.01	0.02	Wenzhou	24	0.16	0.21

Continued from the above table:

Carbon productivity reversal type					**Carbon productivity reversal type**				
Region	**Industry Code**	**Carbon Emission Intensity in 2010 (tons per million yuan)**	**Carbon emission intensity in 2020 (tons per million yuan)**	**Status**	**Region**	**Industry Code**	**Carbon Emission Intensity in 2010 (tons per million yuan)**	**Carbon emission intensity in 2020 (tons per million yuan)**	**Status**
Ning bo	4	2.53	0.26	B	Hu zhou	14	1.67	0.20	B
Shao xing	5	3.08	0.23	B	Jia xing	14	0.37	1.87	W
Wuxi	6	3.51	0.30	B	Su zhou	15	0.18	0.01	B
Wuxi	7	3.45	0.01	B	Hu zhou	16	0.82	0.10	B
Shao xing	8	1.90	0.01	B	Nan jing	16	0.10	38.37	W
Tai zhou	8	0.01	1.53	W	Wuxi	17	0.79	0.03	B
Shao xing	9	5.54	0.13	B	Nan jing	17	0.03	1.89	W
Jia xing	9	2.87	8.89	W	Wuxi	18	0.19	0.01	B
Wen zhou	10	4.22	0.93	B	Hang zhou	19	0.13	0.02	B
Nan Jing	10	1.58	16.60	W	Ning bo	20	1.38	0.02	B
Hu zhou	11	4.17	0.58	B	Hang zhou	20	0.12	15.01	W
Nan jing	11	0.79	6.78	W	Wuxi	21	11.35	0.13	B
Nan jing	12	4.66	1.68	B	Shao xing	21	0.97	2.56	W
Hang zhou	12	10.29	11.15	W	Hu zhou	23	64.21	15.11	B
Hu zhou	13	2.07	0.61	B	Shao xing	23	2.82	21.17	W
Wuxi	13	4.01	4.48	W	Jia xing	24	9.43	0.03	B
Note: Better is denoted by the letter "B" in the table, whereas Worse is denoted by the letter "W".									

The first category, carbon productivity advantage type, refers to the regional resource endowment is suitable for the development of a certain industry, the carbon productivity of this industry is at a high level in Jiangsu and Zhejiang, and has maintained the carbon productivity advantage, such as Changzhou textile industry in 2010, carbon productivity is 7 times that of Hangzhou, in 2020 is still 7.5 times that of Hangzhou, wood processing and furniture manufacturing industry in Nanjing in 2010, carbon productivity is 10 times that of Jiaxing, in 2020 the industry carbon productivity is 30 times that of Jiaxing, indicating that Changzhou's resource endowment is very suitable for the development of the textile industry, and Changzhou should continue to support the local textile industry, and Nanjing should also encourage the local wood processing and furniture manufacturing industry.

The second category, carbon productivity disadvantage type, pertains to industries that have a low carbon productivity rate due to the unsuitable regional resource endowment. For instance, Jiaxing's chemical industry had a carbon emission intensity rate 4 times higher than Ningbo's in 2010, which may increase to a staggering nine times higher in 2020. Similarly, the carbon emission intensity rate of Ningbo's metal smelting and rolling processing industry was notably higher, 5.7 times more than that of Nanjing, in 2010. This rate is expected to increase to 9.5 times by 2020. Hence, it is crucial that Ningbo and Jiaxing should takes strict measures, such as limiting local metal smelting and rolling industry chemical industry , to mitigate environmental threats and promote sustainable development.

The third category, carbon productivity reversal type, refers to the industries that initially have lower carbon productivity rates but gradually become advantageous due to technological advancements or external factors. For example, Suzhou's general and special equipment manufacturing industry had a carbon emission intensity rate 8 times higher than Ningbo's in 2010. However, the rate significantly declined to 0.9 times by 2020 after a decade of consistent progress. Suzhou's carbon productivity in this industry has now exceeded Ningbo's, making it one of the most suitable regions for its development.

In conclusion, understanding the carbon productivity for industries in a region is critical when formulating sustainable industrial policy. The classification offers comprehensive insights into identifying areas for development and economic growth while addressing environmental challenges. The policies must align with the resource endowment to achieve optimal carbon productivity rates, promote sustainable development and economic growth while safeguarding the environment.

Based on the aforementioned findings, it is recommended that concerned departments develop more effective industrial policies and carbon emission reduction policies. Specifically, cities located in Jiangsu and Zhejiang provinces can facilitate and endorse the growth of industries with superior carbon productivity while regulating the progress of industries that are inferior in this regard. This approach will ensure that carbon emission credits are allocated from industries with lower carbon productivity to those with higher efficiency, thereby enhancing the optimal utilization of energy resources and achieving carbon emission reduction. Consequently, these measures will result in a low-carbon economy and a green economy, promoting economic growth at the local level while simultaneously reducing regional carbon emissions.

5. Conclusions and Recommendations

The key findings of this pepaer can be summarized as follows:

1. During the 12th and 13th Five-Year Plan periods, local carbon emissions were primarily driven by the positive scale effect resulting from economic growth, while the intensity and structure effects exhibited both favorable and unfavorable impacts on carbon emission growth.

2. The adverse driving effect of industrial structure upgrading on carbon emission growth can be weakened by regional industrial isomorphism. For instance, during the 12th Five-Year Plan period, Jiangsu and Zhejiang regions introduced service and new industries to substitute for high-carbon industries, leading to industrial isomorphism among municipalities and reducing the negative driving influence of carbon emissions due to technological advancement. The intensity effect exhibited the opposing positive driving influence.

3. The carbon emission intensity of certain industries in the Jiangsu and Zhejiang regions displays significant variation amongst different cities, and the overall carbon productivity remains relatively low. A rationalized industrial division of labor based on carbon productivity would offer greater potential for emission reduction by increasing the scale of low carbon emission intensity industries in certain regions while minimizing the scale of high carbon emission intensity industries in other areas, ultimately leading to carbon emission reduction through the advancement of industrial carbon productivity.

4.The municipalities in Jiangsu and Zhejiang can incentivize the development of industries with superior carbon productivity and suitably restrict the growth of industries with inferior carbon productivity, allowing the efficient allocation of carbon emission credits from low carbon productivity industries to those with higher productivity. Consequently, carbon emission reduction can be attained through optimal allocation of carbon emission credits.

In light of the present situation of carbon emission reduction and industrial structure in the Jiangsu and Zhejiang regions, this study puts forward the following recommendations based on the research findings:

1. The governments of the two regions must persist in upgrading the industrial structure, cement the leading position of tertiary industries, and increase the development of low energy consumption and high output value industries such as modern service industries, digital trade, and emerging industries. Nevertheless, while developing these low-carbon industries, a careful industrial positioning of each region must accordingly be planned as per the development characteristics of each city[32]. Furthermore, inter-regional cooperation and communication must be reinforced to prevent excessive regional industrial isomorphism.

2. While formulating industrial planning, the two regions should consider the degree of adaptation of industries to local resource endowments and ecological carrying capacity, and should not forcibly demolish the industrial pattern that is initially congruous with the local development characteristics for the purpose of achieving

low-carbon targets. The carbon productivity level of each industry should undergo continuous improvement through industrial intensification and specialization, thereby promoting the low-carbon development of the economy.

3. The governments of Jiangsu and Zhejiang must implement a regional differentiated development strategy in the industrial layout, whereby the low-carbon or high-carbon industries are established only in areas where resource endowment and ecological carrying capacity are relatively suitable for the industry. The practice of universalizing the industries must be avoided whenever possible. Even though an industry is high in carbon emission, it must be supported if it aligns with the development indexes of the region and if it generates high economic benefits. Different regions should attempt to formulate industrial planning in line with the carbon productivity level of each industry within the area and recommend vigorous support to the industries with advantageous carbon productivity, while reducing the proportion of industries with inferior carbon productivity, ultimately leading to effective allocation of carbon credits.

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