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Decoupling Economic Growth from Carbon Emissions in the Yangtze River Economic Belt of China: From the Coordinated Regional Development Perspective

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Abstract: Decoupling economic growth from carbon emissions is crucial for combating the climate crisis and promoting green development. However, a uniform approach to climate mitigation exacerbates regional disharmony. As a microcosm of China's regional heterogeneity, the Yangtze River Economic Belt (YREB) is helpful in exploring regional collaborative climate governance. This paper uses the Thiel index, the Tapio decoupling model, and the Logarithmic Mean Divisia Index (LMDI) decomposition approach to explore the decoupling of economic growth from carbon emissions in YREB from 2005 to 2019. Results indicate that the carbon intensity difference is mainly from the difference within middle-rising provinces (MRP) and western less-developed provinces (WLP). YREB exhibits strong decoupling overall, but it is not sustained. The economic growth effect significantly promotes carbon emissions, which is more prominent in MRP. The energy intensity effect plays a vital role in restraining carbon emissions. The emission factor effect signals an improved energy structure in WLP. Regional coordination is needed to achieve green development; thus, provinces should set differentiated carbon emission reduction targets, and more potent tools are recommended in major carbon emitters.

Keywords: economic growth; carbon emission; decoupling; regional coordination

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1. Introduction

Climate change is considered to be the most serious crisis facing humanity in the next decade [1]. The increase in atmospheric carbon emissions concentration caused by fossil energy combustion is a major contributor responsible for the resulting climate change [2]. Climate governance, especially carbon emissions reduction, will ensure that the progress made over the past decades is not stalled by climate change and that the health and resilience of national economies are ensured [3]. Most countries have responded positively to global climate governance, e.g., the Clean Energy Act for the United States, the European Climate Act for the European Union, and the Climate Change Adaptation Act for Japan [4–6], and have achieved relatively significant results. In 2022, carbon emissions in the United States were reduced to the 1988 level, the European Union achieved a 27.47% reduction from the 1990 level, and Japan's carbon emissions were brought down to the 1990 level [7].

China has become the world's second-largest cumulative carbon emitter, accounting for 30.7% of global carbon emissions in 2022. China's achievement of its carbon emission reduction targets has become critical to global climate governance [7,8]. Since 1990, China has had an officially established climate policy. In 2007, China introduced its National Program for Addressing Climate Change, followed by the release of the National Plan for Addressing Climate Change (2014–2020) in 2014. In 2020, China solemnly promised to achieve a "carbon peak" before 2030 and "carbon neutrality" before 2060. Since then, carbon dioxide emission intensity has dropped by 4.6% (Data from the National Development and Reform Commission).

Following China's dual carbon targets, individual provinces have responded positively and proposed their own differentiated carbon reduction plans. The developed eastern provinces have made strategies such as encouraging cleaner production in enterprises a priority action plan [9,10]. Beijing implemented 167 cleaner production audit programs in 2023, effectively reducing pollutant emissions (Data from the official website of the Beijing Municipal Commission of Development and Reform.). The central rising regions have actively participated in the development of energy use rights and carbon emission trading markets [11]. Four industries were selected to carry out transaction pilots, and the first batch of pilot enterprises completed compliance (Data from the official website of the Henan Provincial People's Government.). The underdeveloped western regions are abundant in natural resources and implement clean energy projects [12]. Sichuan province has approved 32 wind power projects with a total installed capacity of more than 3.21 million kilowatts and an investment of more than CNY 22.4 billion (Data from the official website of the Sichuan Provincial People's Government.).

It should be noted that carbon emission reduction strategies should be based on the principle of equity and reflect common but differentiated responsibilities and respective capabilities [3]. It is not only necessary to control the total amount of carbon emissions, but also to achieve coordination and equity in carbon emission reduction actions among regions [13,14]. In order to evaluate the effectiveness of China's carbon emission reduction actions and promote coordinated regional development, this paper selects the Yangtze River Economic Belt (YREB) as the research object, using relevant data from 2005 to 2019, to explore implementation plans for decoupling economic growth and carbon emissions, aiming to provide a reference for designing reasonable carbon emission reduction policies and paths.

The YREB is an essential economic zone in China, providing an ideal setting to study economic growth and climate action coordination. In 2021, YREB accounted for 46.4% of the country's total economic volume and 43% of the resident population with 21.5% of the country's area, which is the national regional economic growth plateau (Data from the Statistical Bulletin of National Economic and Social Development of the People's Republic of China, 2021). Meanwhile, the region accounted for 35.9% of the country's total energy consumption and 32.1% of the country's total carbon emissions (Data from the China Energy Statistics Yearbook, 2020). The YREB has great potential and necessity in addressing climate change. Considering the significant differences in the economic development level and carbon emission reduction affordability in YREB will help to deeply explore the factors influencing the decoupling of economic growth and carbon emissions and scientifically design carbon emission reduction targets, policies and paths, laying a solid foundation for coordinated regional development.

The research content mainly includes three aspects. First, the Thiel index was used to identify the regional variation of carbon intensity, and it was found that the differences mainly originated within regions. Coastal developed provinces (CDP) had the least difference within their region, leading to the coordinated development of the whole YREB. Secondly, the spatiotemporal evolution of the decoupling relationship between carbon emissions and economic growth was analyzed by the Tapio decoupling model. The analysis revealed that the decoupling evolution from negative decoupling to decoupling was evident from 2005 to 2019. Except for Jiangsu province, Anhui province, and Jiangxi province, the remaining eight provinces in the YREB have achieved a strong decoupling. Thirdly, the Kaya Identity and the Logarithmic Mean Divisia Index (LMDI) were used to analyze the determinants of carbon emissions. The findings suggested a different role for the driving factors. The economic growth effect was the most influential factor promoting carbon emission, and the energy intensity effect was the most important factor restraining carbon emission. The emission factor effect turned from positive to negative, indicating an improvement in energy structure. The effect of population scale was negligible, but the opposite effect was observed in different provinces.

The marginal contribution of this study is mainly reflected as follows. First, it analyzes the evolution of regional differences and the decoupling between carbon emissions and economic growth, transitioning from discrepancy to convergence. This provides insights for coordinated development on a national scale and addresses the limitation in existing decoupling analysis literature that struggles to analyze regional intrinsic linkages. Second, using the LMDI decomposition model, we found that the economic growth effect and the energy intensity effect play a major role in carbon emissions decoupling. Furthermore, this paper delves into the economic development conditions for decoupling to a greater extent than previous studies. We observe that as the level of economic development decreases, the decline in the contribution of economic growth effect becomes more significant, which declines by 22% in less developed regions (WLP), much higher than the 11% in CDP and MRP. Third, leveraging empirical results, the paper puts forth practical policy recommendations tailored to the distinct resource endowments and economic development levels of each province. This enhances the credibility and practicality of the policy suggestions, providing a foundation for decision-making in achieving carbon emission reduction targets.

The remainder of the paper is organized as follows: Section 2 provides an overview of the pertinent literature. Section 3 shows the methodology and data sources. Section 4 presents the decoupling analysis and the determinants analysis of carbon emissions. Finally, we summarize the primary findings and provide policy recommendations in Section 5.

2. Literature Review

The relationship between economic growth and carbon emission is the focus of research on regional sustainable development. The most traditional theory for it is the Environmental Kuznets Curve [15], which was expanded by Panayotou [16] to characterize the relationship between per capita income and environmental quality and has proved its practicality in subsequent studies [17–20].

With the deepening of the research, conclusions on the validity of the EKC model have become diversified [21–23]. For example, Massagony and Budiono [24] demonstrated that the EKC hypothesis is not valid for Indonesia in the long run. However, after controlling for income, energy consumption, and policies, the validity of the EKC can be verified. Aslan et al. [25] indicated that the EKC hypothesis applies in the United States across all industries except the commercial and transportation sectors. Hasanov et al. [26] found that in Kazakhstan, economic growth is monotonically associated with an increase in carbon dioxide, and the EKC does not apply. Therefore, a significant question is whether carbon emissions increase with economic growth. The decoupling theory has been gradually applied to this study [27].

Decoupling is widely used in economics. For example, it can be used to measure the decoupling of economic growth from energy consumption [28–30], the decoupling of economic growth from household consumption [31,32], the decoupling of economic growth from fuel consumption [33,34], and the decoupling of economic development from environmental pollution [35,36].

In researching the decoupling of economic growth and carbon emissions, previous studies have primarily concentrated on examining the decoupling trend, investigating factors influencing decoupling, and scrutinizing regional and industrial variations in decoupling. For example, Amir et al. [37] studied the decoupling relationship between carbon emissions and economic growth in the industrial sector of Pakistan and found that the decoupling relationship is unstable by undergoing expansion negative decoupling and strong decoupling. Xie et al. [38] delved into the factors influencing the decoupling of China's economic growth and energy-related carbon emissions. Their findings indicated that, over the long term, an increase in the share of clean energy and enhanced government intervention had promoted decoupling. In the short term, a decline in incremental government intervention was the most influential factor affecting decoupling. Bianco et al. [39]

provided a comparative analysis of the decoupling status of the 27 EU countries and found that 21 of them had achieved strong decoupling, while the others were in weak decoupling. Lu et al. [40] investigated the decoupling status of 38 subdivided industrial sectors in Jiangsu province, revealing that the industries exhibited a weakly decoupled state, with heavy industries exerting a dominant influence on industrial carbon emissions.

In addition to studying the decoupling state and dynamic evolution trends between economic growth and carbon emissions, many scholars have also conducted in-depth research on the determinants of carbon emissions. The most frequent methodologies applied by researchers include regression analysis and decomposition approaches. Regression analysis mainly includes the symbolic regression method and ridge regression method. The factors that influenced carbon emissions that scholars considered in regression analysis include economic growth, urbanization, population scale, industrialization, technological innovation, energy intensity, and energy mix [41,42]. For example, Pan et al. [43] identified the key factors influencing carbon emissions in 34 OECD member countries as GDP, population scale, industrialization, technological innovation, and foreign direct investment. In another study, Zhang et al. [44] revealed that the primary factors affecting China's carbon emissions were economic growth, total fossil energy, and the urban population. Additionally, Pan and Zhang [41] highlighted GDP per capita as the most significant factor influencing carbon emissions in the United States.

Decomposition approaches are more abundant in analyzing the determinants of carbon emissions; they include the structural decomposition analysis (SDA), index decomposition analysis (IDA), and production-theory decomposition analysis (PDA), which are prevalent and often combined with decoupling analysis [45,46]. For example, Xu et al. [47] employed the SDA method to decompose the factors influencing carbon emissions in Jiangsu province. Fan et al. [48] decomposed the factors affecting carbon emissions in "Belt and Road Initiative countries" using the PDA method. Lima et al. [49] used the IDA method to decompose the factors affecting energy carbon emissions in Portugal, the UK, Brazil, and China.

In particular, LMDI, as the preferred IDA method, has been widely adopted by scholars due to its ability to decompose any ratio without residue [50] and scrutinize carbon emissions determinants in specific regions and industries [51]. For example, Koilakou et al. [52] compared the drivers of decoupling energy and carbon intensity in the U.S. and Germany. Hang et al. [53] analyzed the factors influencing the decoupling development of the manufacturing industry. Wang et al. [54] examined the decoupling of electricity generation and carbon emissions in China.

Across these studies, a consensus has emerged that energy intensity, energy efficiency, population scale, and economic scale are the dominant drivers of decoupling development in carbon emissions. However, the potential for carbon reduction varies significantly among different regions due to differences in geographic location, population distribution, and economic development [55]. For example, at the international scale, Diakoulaki and Mandaraka [56] examined the divergence of decoupling in the EU and found that the contribution of economic growth to the increase in carbon emissions was 140% in Ireland, compared to 20% in most countries. The contribution of the energy intensity effect is largest in countries dominated by energy-intensive industries. When comparing developed and developing countries, Wang et al. [57] scrutinized the distinctions in decoupling between China and the United States. The study identified that economic growth emerged as the primary factor influencing carbon emissions in China, while energy intensity played a more substantial role in the United States. Within a single country, Shen et al. [58] divided China into eastern, central, and western regions for their research. Their findings indicated that the energy structure predominantly determined carbon emissions, with a more pronounced impact on the central and western regions than on the eastern regions.

To sum up, a wealth of research has been carried out on the relationship between economic growth and carbon emissions, aiming to explore effective ways to mitigate global warming without sacrificing the economy. From the traditional environmental Kuznets curve to the current decoupling theory, relevant research focuses on the decoupling trend and determinants influencing decoupling. Using regression analysis and decomposition approaches, energy intensity, energy efficiency, population size and economic scale are considered to be the main factors influencing carbon emissions. However, a universal approach is not feasible. Differences in geographical location, population distribution and economic development levels lead to differences in carbon emission reduction affordability. It is urgent to consider the coordination and equity of carbon emission reduction actions among regions. The existing literature has not fully considered the differences in regional carbon emission affordability. Hence, this paper applies the Thiel index to analyze the differences and sources of carbon emission intensity in YREB. Further, the Tapio decoupling model and LMDI index are used to study the degree, trends, and determinants of carbon decoupling in YREB. Combined with the emission reduction policies of each province, the emission reduction effects and optimization paths are discussed to provide reference for achieving regionally coordinated emission reduction.

3. Methodology and Data

3.1. Thiel Index

The Thiel index, originally proposed as a metric for gauging the disparity or inconsistency between two time series, serves as a statistical measure of economic inequality. Its application has expanded to encompass the assessment of variations in trends across regions concerning economic, social, and environmental variables. A notable attribute of the Thiel index is its decomposability, allowing the total differences between regions to be dissected into two distinct components. Specifically, the Thiel index is adept at quantifying regional disparities, making it a valuable tool for our analysis. In this study, we employ the Thiel index to express regional differences in carbon intensity in the YREB, utilizing the following formula to capture and quantify these variations:

$$T = \sum\nolimits_{p}^{11} \left(\frac{CE_p}{CE} \times \ln \left(\frac{CE_p / CE}{RG_p / RG} \right) \right) \tag{1}$$

where T is the Thiel index describing the regional difference in carbon intensity, CE_p is the carbon emission index of province p, CE is the total carbon emission index of the YREB, RG_p is the real GDP of province p, and RG is the real GDP of the YREB. As a dimensionless value, the magnitude of the T value is positively correlated with variability, with larger values indicating greater variability and vice versa.

As in Table 1, the YREB is divided into the coastal developed provinces (CDP, downstream of YREB), middle-rising provinces (MRP, middle of YREB), and western less-developed provinces (WLP, upstream of YREB). This paper compares the regional differences in carbon intensity between them. The following formulas are used to measure the regional differences between regions and within regions, respectively.

$$T_{br} = \sum\nolimits_{q}^{3} \left(\frac{CE_q}{CE} \times \ln \left(\frac{CE_q / CE}{RG_q / RG} \right) \right) \tag{2}$$

$$T_{wr} = \sum\nolimits_{q}^{3} \frac{CE_q}{CE} \sum\nolimits_{p}^{11} \left(\frac{CE_{qp}}{CE_q} \ln \left(\frac{CE_{qp} / CE_q}{RG_{qp} / RG_q} \right) \right) \tag{3}$$

$$T = T_{br} + T_{wr} \tag{4}$$

where T_{br} is the Thiel index describing the difference in carbon intensity between regions, T_{wr} is the Thiel index describing the differences in carbon intensity within regions, CE_{qp} is the carbon emission index of province p in region q, CE_q is the total carbon emission index of region q, RG_{qp} is the real GDP of province p in region q, and RG_q is the real GDP of region q.

Table 1. Basic information about the research area.

Region	Province	Population (Ten Thousand)	Administrative Area (Ten Thousand km^2)	GDP Per Capita (CNY)
CDP	Shanghai	2424	0.63	134,982
	Jiangsu	8051	10.72	115,168
	Zhejiang	5737	10.56	98,643
MRP	Anhui	6324	14.01	47,711
	Hubei	5917	18.59	66,615
	Jiangxi	4648	16.69	47,433
	Hunan	6899	21.18	52,948
WLP	Chongqing	3102	8.24	65,932
	Sichuan	8341	48.61	48,883
	Yunnan	4830	39.41	37,135
	Guizhou	3600	17.62	41,243

Note: *CDP*, *MRP*, and *WLP* represent coastal developed provinces, middle-rising provinces, and western less-developed provinces, respectively.

3.2. Decoupling Model

The decoupling model serves to determine whether economic growth is accompanied by an increase in carbon emissions. Towards the close of the 20th century, the OECD incorporated decoupling theory into the examination of agricultural policy development, progressively extending its application to the realm of environmental economics. Decoupling, in essence, signifies that during the initial phases of industrial development, the aggregate material energy consumption aligns with the overall economic growth. However, at a certain stage, this relationship undergoes a reversal, leading to concurrent economic growth and a reduction in material energy consumption. Two decoupling models are used widely, the OECD model [59] and the Tapio model [60,61]. The Tapio model improved the existing decoupling model in analyzing CO_2 emissions from the transportation industry and expressed it in the form of an elastic index, shown in Formula (5). Compared with the OECD model, the Tapio decoupling index avoids the instability caused by the selection of the base period [62].

$$\varepsilon_{CG,it} = \frac{\Delta CE/CE}{\Delta RG/RG} = \frac{\left(CE_{i(t+1)} - CE_{it}\right)/CE_{it}}{\left(RG_{i(t+1)} - RG_{it}\right)/RG_{it}} \tag{5}$$

where $\varepsilon_{CG,it}$ is the decoupling factor, representing the decoupling index of economic growth from carbon emission. The subscripts i and t denote province and year, respectively. CE represents the carbon emissions, and RG is the real GDP. $\Delta CE = CE_{i(t+1)} - CE_{it}$ and $\Delta RG = RG_{i(t+1)} - RG_{it}$ indicate the changes in the percentage of carbon emission and economic growth, respectively. The classification of decoupling states is shown in Table 2 [63].

The decoupling of economic growth from carbon emissions in the provinces and cities of YREB is unstable. Therefore, the stability indicator δ_i is used to measure the stability of the decoupling state.

$$\delta_i = \frac{1}{T-1}\sum\left|\frac{\varepsilon_{CG,i(t+1)} - \varepsilon_{CG,it}}{\varepsilon_{CG,it}}\right| \tag{6}$$

where T represents the total study year. The smaller δ_i indicates a more stable decoupling state, while the larger δ_i indicates a less stable decoupling state.

3.3. Decomposition Analysis

Decomposition analysis is used to analyze the determinants of changes in the decoupling of economic growth from carbon emissions. The Kaya identity is the dominant analytical method for analyzing the drivers of carbon emissions [64].

Table 2. Classification of decoupling states in the Tapio model.

Type	Decoupling State	Carbon Emission	Economic Growth	Decoupling Factor
Decoupling	strong decoupling	ΔCE < 0	ΔRG > 0	$\varepsilon < 0$
	weak decoupling	ΔCE > 0	ΔRG > 0	$0 < \varepsilon < 0.8$
	recessive decoupling	ΔCE < 0	ΔRG < 0	$\varepsilon > 1.2$
Coupling	growth link	ΔCE > 0	ΔRG > 0	$0.8 \leq \varepsilon \leq 1.2$
	recessive link	ΔCE < 0	ΔRG < 0	$0.8 \leq \varepsilon \leq 1.2$
Negative decoupling	expansive negative decoupling	ΔCE > 0	ΔRG > 0	$\varepsilon > 1.2$
	strong negative decoupling	ΔCE < 0	ΔRG < 0	$\varepsilon < 0$
	weak negative decoupling	ΔCE < 0	ΔRG < 0	$0 < \varepsilon < 0.8$

In terms of carbon emissions determinants, there is a consensus that economic growth depends on energy expenditure, which is the main producer of carbon emissions [65]. Meanwhile, both economic efficiency per unit of energy brought and clean energy utilization have a direct impact on the quantity of fossil energy burned. Thus, energy efficiency and energy structure are the significant factors of carbon emissions [66]. In addition, energy expenditure on the consumption side is also responsible for carbon emissions. Each additional person increases the demand for energy expenditure [67]. Therefore, the population scale has an impact on carbon emissions [68].

In this paper, carbon emission is decomposed into four factors by Kaya identity (as Formula (7)): emission factor of total energy use ($c = CE/Energy$), energy intensity ($e = Energy/GDP$), GDP per capita ($g = GDP/P$), and population (P). c is a comprehensive emission factor that is not specific to a certain energy type. The smaller the factor, the cleaner the energy structure. The Kaya identity can be illustrated below:

$$\begin{aligned} CE = & \left(\frac{CE}{Energy}\right) \times \left(\frac{Energy}{GDP}\right) \times \left(\frac{GDP}{Population}\right) \times Population \\ & = c \times e \times g \times P \end{aligned} \tag{7}$$

Among the SDA, IDA, and PDA methods, IDA is more advantageous than others since it can decompose any ratio [50]. LMDI is considered a preferred IDA method because of its absence of residue and its ability to handle zero values [69]. LMDI employs qualitative methods to decompose carbon emissions into drivers, then quantitatively assesses their contributions. It can analyze the contribution of the drivers obtained from the Kaya identity. By applying the LMDI decomposition approach, we can discuss the influence of objective factors on carbon emission trends [70,71]. The Kaya identity can be transformed into

$$\Delta CE = \Delta c + \Delta e + \Delta g + \Delta P \tag{8}$$

The x refers to c, e, g, and P, where:

$$\Delta x = \frac{CE_{t_2} - CE_{t_1}}{lnCE_{t_2} - lnCE_{t_1}} \times ln\frac{x_{t_2}}{x_{t_1}} \tag{9}$$

The effect of Kaya's decomposition factors on the decoupling index is the same as the effect on carbon emissions. According to the decoupling model (Formula (5)): $\varepsilon_{C,G} = \frac{\Delta CE/CE}{\Delta RG/RG} = \Delta CE \times \frac{RG}{CE \times \Delta RG}$. The $\frac{RG}{CE \times \Delta RG}$ part has the same influence on each Kaya decomposition factor, so when we discuss the relative influence of the Kaya decomposition factor on the decoupling index, the contribution of this part can be ignored.

3.4. Data Sources and Processing

Based on the description of the methodology above, the data required for this study include GDP, population, carbon emissions, and total energy consumption. This paper uses annual provincial data from 2005 to 2019. The GDP and population data come from China's National Bureau of Statistics. GDP was measured at the constant price of 2004 to ensure comparability across the years. The total energy consumption data come from China Energy Statistical Yearbook. It is noteworthy that to address data gaps in total energy consumption, information was cross-referenced and complemented by consulting various provincial statistical yearbooks, ensuring a comprehensive and reliable dataset for the analysis. The carbon emission data come from China Emission Accounts and Datasets (CEADs), as they are not directly available from existing statistics in China. CEADs calculated carbon emissions based on the 2006 IPCC sectoral approach [72,73]. Data at the regional level are aggregated from provincial data. Descriptive statistics are shown in Table 3.

Table 3. Descriptive statistics of variables.

Variables	Units	N	Mean	Sd	Min	Max
Carbon emissions (CE)	*Mt*	165	277	141	82	805
Real GDP (RG)	*Billion yuan*	165	1641	1225	189	6691
Total energy use ($Energy$)	*Million metric tce* (tce: tonnes coal equivalent.)	165	133	62	43	325
Emission factor (c)	*Mt/Million metric tce*	165	2.105	0.367	1.439	3.050
Energy intensity (e)	*Metric tce/Thousand yuan*	165	0.107	0.057	0.035	0.298
GDP per capita (g)	*Thousand yuan*	165	32	22	5	115
Population (P)	*Thousand*	165	53	18	19	85

4. Results and Discussions

4.1. Decoupling Analysis of Carbon Emissions

4.1.1. Regional Differences in Carbon Intensity

In this section, the Thiel index is applied to quantify the regional differences in carbon intensity in the YREB. A smaller Thiel index means more coordinated development. This paper calculated T, T_{br}, and T_{wr}, respectively. The results are shown in Figure 1.

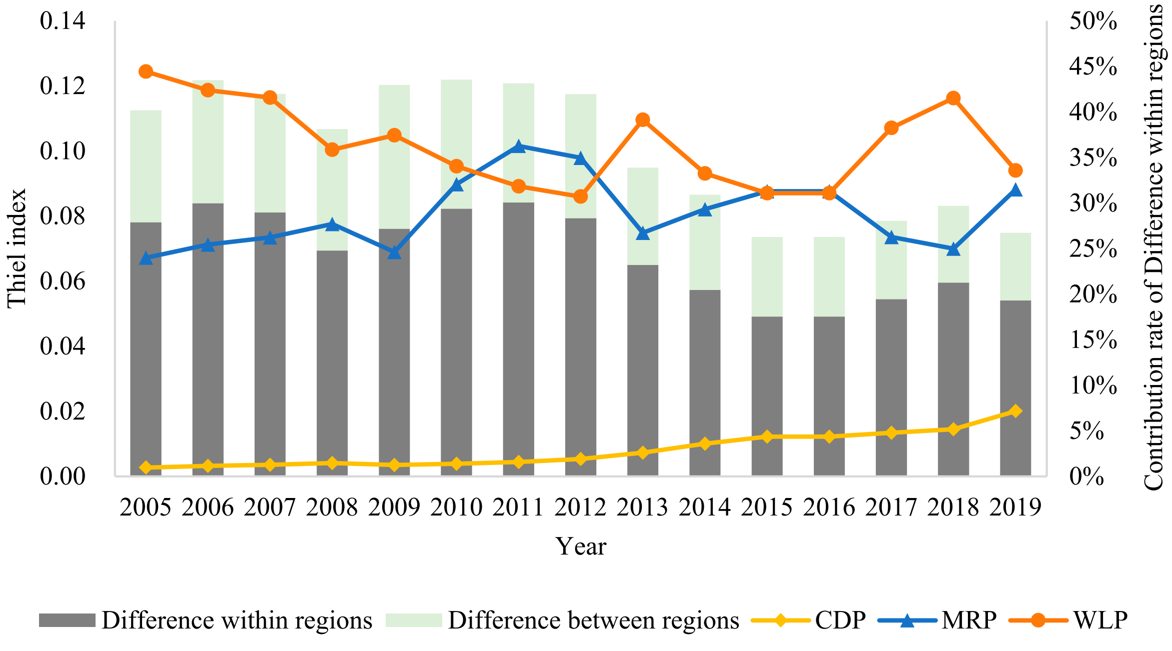

Figure 1. Regional differences in carbon intensity by Thiel index.

The difference in carbon intensity in the YREB decreases. The overall trend of the total Thiel Index T is rising and then declining, reaching its peak at 0.1219 in 2010, while in the last five years, the total Thiel Index T is close to 0.08. This indicated that regional development gradually moves towards coordination. The difference in carbon intensity is mainly from the difference within regions. The contribution rate within regions is 68.25% on average, with the highest value reaching 72.24% in 2019. The contribution between regions is only 31.75% on average, reaching its lowest point of 27.76% in 2019.

According to differences within regions, the CDP has the least difference in carbon intensity and the most unified regional development direction. The contribution rate of CDP is less than 10%. The contribution of the MRP surpasses that of the WLP in 2011, 2012, and 2015. Moreover, the contribution of the WLP exceeds that of the CDP and the MRP. This indicates that the difference in carbon intensity in the YREB mainly originates from the WLP.

The differences between regions may be caused by factor flow barriers [74]. In China, the marketization progress of the factor market significantly lags behind that of the product market. Local governments, in their pursuit of economic growth, engage in distorting factor prices. This distortion is a strategic move to ensure that local enterprises can secure land, capital, labor, and other factors at reduced costs. The market segmentation within factor markets, facilitated through direct price interventions or implicit preferential policies, distorts the relative prices of diverse factors. Consequently, it imposes limitations on the fluidity of factors across regions. Factor flow barriers distort the economic operation mechanism and hinder the optimal allocation of social resources, and thus, regional differences emerge.

4.1.2. Decoupling Index and State of the YREB

Based on the decoupling index (See Appendix A), the section analyzed the development progress of carbon emission reduction in YREB (see Figure 2). Referring to the classification of decoupling states outlined in Table 2, given that economic growth consistently exceeds 0, four states emerge: expansive negative decoupling (END), representing negative decoupling; growth link (GL), indicating coupling; and decoupling, further categorized into weak decoupling (WD) and strong decoupling (SD). Obviously, the decoupling progress of CDP, MRP, and WLP are different. Table 4 illustrates the decoupling stability indicator of YREB. The paper analyzed the decoupling degree of these three regions in conjunction with Figure 2 and Table 4 to explore the differentiated low-carbon development progress of provinces in the YREB.

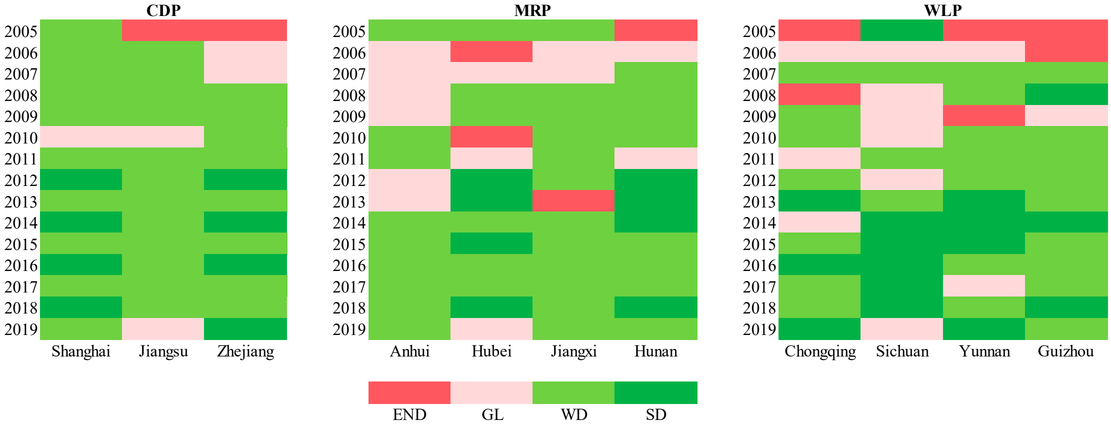

Figure 2. The degree of decoupling during 2005–2019 by regions. Note: END, Expansive negative decoupling (negative decoupling); GL, Growth link (coupling); WD, Weak decoupling (decoupling); SD, Strong decoupling (decoupling).

As illustrated in Figure 2 (CDP), all CDP exhibited decoupling of economic growth from carbon emissions, with a few exceptions. Shanghai city has the best decoupling effect, which is consistent with the findings of another study [75]. As shown in Table 4, Shanghai city exhibits a decoupling stability indicator of 2.57. Shanghai is renowned as the top city in China and a global financial center and transportation hub. International trade is responsible for carbon emissions in Shanghai city, while technological changes and international import changes are the keys to promoting decoupling [76]. Jiangsu province has the most stable decoupling state, with weak decoupling in 80% of the study period. Zhejiang province has four states: END, GL, WD, and SD. The decoupling stability indicator of Zhejiang province is 6.38, which is 4 times higher than that of Jiangsu province and 2.5 times higher than that of Shanghai city. In conclusion, the current priority of low-carbon development in the CDP is Jiangsu province, which has not been strong decoupling yet.

Table 4. The decoupling stability indicator in the YREB.

CDP		**MRP**		**WLP**	
Shanghai	2.57	Anhui	2.06	Chongqing	7.17
Jiangsu	1.63	Hubei	3.33	Sichuan	12.66
Zhejiang	6.38	Jiangxi	4.14	Yunnan	1.65
		Hunan	2.46	Guizhou	2.13

The decoupling progress among the MRP has significant differences. As shown in Figure 2 (MRP), Hubei province and Hunan province have achieved SD, while Anhui province and Jiangxi province have not. Anhui province was in growth link from 2006 to 2009 and 2012 to 2013, and in weak decoupling in the other years. Hubei province has spanned four different decoupling states and fluctuated. Jiangxi province was in END in 2013, and the degree of decoupling changed significantly. The decoupling stability indicator of Jiangxi province is 4.14, indicating the worst stability among the MRP. Hunan province was in a state of END in 2005 and achieved SD for the first time in 2012. In conclusion, the decoupling state of MRP is most stable throughout the YREB. The decoupling stability indicators of MRP are in the range of 2.06–4.14, lower than that of the CDP (1.63–6.38) and WLP (1.65–12.66). The analysis above indicates that MRP are progressively adapting their development approach in a resilient manner to diminish the reliance of economic growth on energy consumption. These findings align with research in the industrial sector [77], yet there exist disparities in comparison to studies conducted in the agricultural sector [78]. The agricultural sector in Jiangxi province exhibits SD and in Anhui province demonstrates END. It signifies a substantial reliance of Anhui's agricultural development on agricultural CO_2 emissions. This underscores the importance of vigorously promoting scientific and technological advancements in agriculture as a key strategy to facilitate carbon emission reduction.

The differences in carbon emissions within WLP account for about 35%. As shown in Figure 2 (WLP), in 2005, only Sichuan province was in a SD state, while Chongqing city, Yunnan province, and Guizhou province were in an END state. Yunnan province is the most stable among WLP, with a decoupling stability indicator of 1.65. The decoupling index of Sichuan province was -0.88 in 2018, 80 times that of 2017. In 2015, the decoupling index of Sichuan province was -0.68, 70 times that of 2014. In the two periods, the carbon emissions of Sichuan province decreased by a large amount compared with the previous year, resulting in a large fluctuation in the decoupling index. Sichuan province experienced its lowest degree of decoupling during the period from 2008 to 2010, with three consecutive years in a state of growth link. The reason is this was a period of economic development in Sichuan province, when it did not take carbon emissions seriously and lacked effective control means [79].

4.2. Decomposition Analysis of Carbon Emissions

4.2.1. Decomposition between Regions

The factors driving carbon emission in YREB are examined from 2005 to 2019 by the Kaya Identity and the LMDI decomposition approach (see Figure 3). As shown in Figure 3A, from 2005 to 2010, the carbon emission of the YREB increased by 1050 Mt, while it just increased by 387 Mt from 2010 to 2015 and 216 Mt from 2015 to 2019. Since 2011, the growth trajectory of carbon emissions has significantly flattened compared to the period from 2005 to 2010. This indicates that in recent years, YREB has actively pursued a sustained reduction in carbon emissions through economic restructuring and the elimination of outdated production capacity. The economic growth effect is the primary factor promoting carbon emissions, while the energy intensity effect is crucial in restraining it. This is primarily attributed to the reduction in economic activity and the heightened suppression of energy intensity. The coefficient of emission factor turns from positive to negative, indicating that the YREB produced lower carbon emissions with the equivalent energy use. The evidence supports the view that technological advances have likely contributed to energy efficiency improvements. The effect of population on carbon emissions is always positive and stable with a minor value. This suggests that the increase in population scale will contribute to carbon emissions, but the contribution is smaller than other factors. In conclusion, for the YREB as a whole, promoting decoupling and increasing the energy intensity of each economic sector will be the most effective way to control carbon emissions.

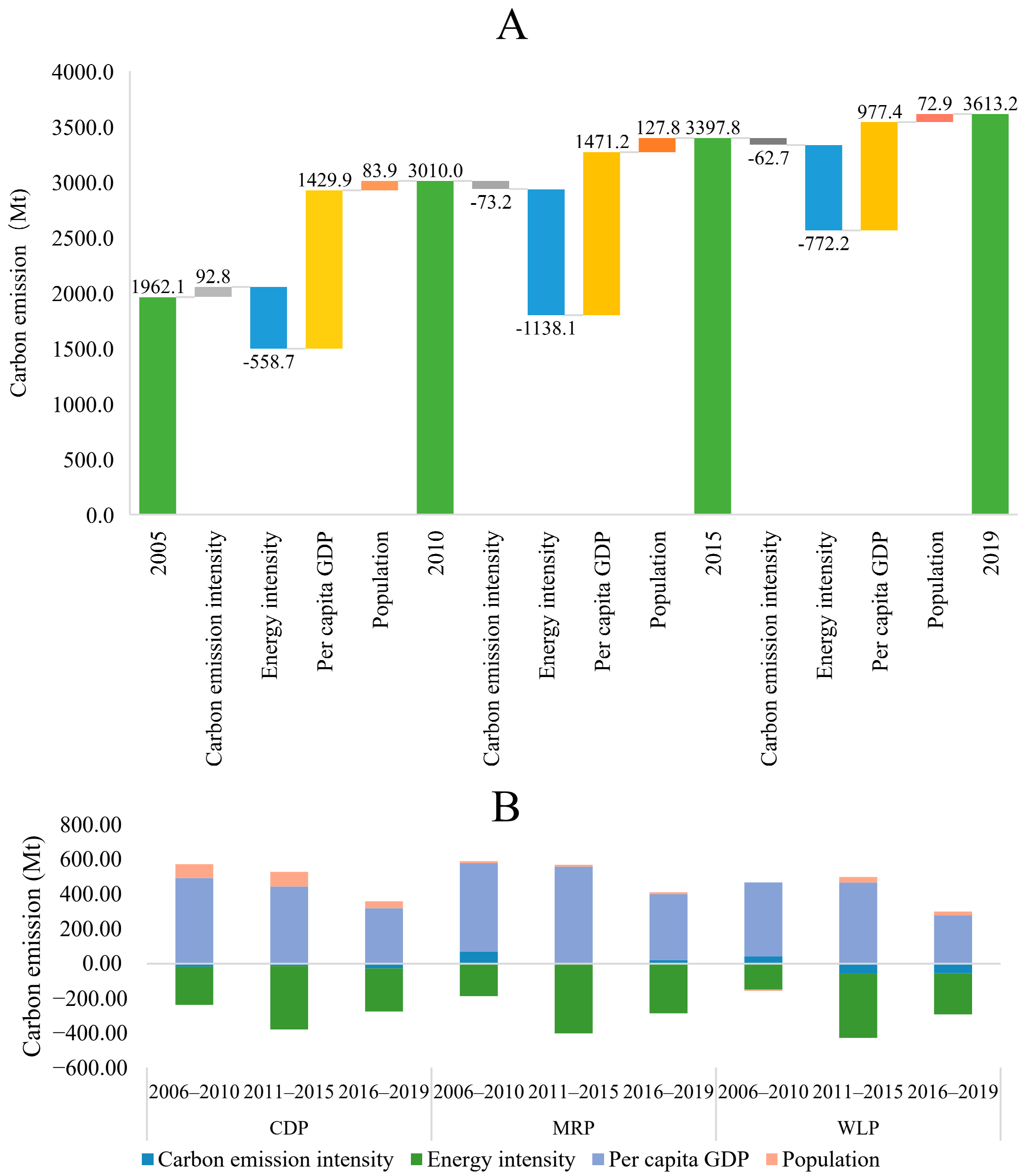

Figure 3. LMDI decomposition results during 2005–2019 in YREB. (**A**) By drivers and periods; (**B**) by regions, drivers, and periods.

Figure 3B illustrates the impact on carbon emission of different driving factors in CDP, MRP, and WLP. For CDP, the economic growth effect is the predominant factor driving carbon emissions, contributing 61% to 50%. Simultaneously, the energy intensity effect plays a crucial role in curbing carbon emissions, with its contribution escalating from 27% to 39%. The emission factor inhibited carbon emission throughout the study period. The population-scale effect promoted carbon emissions with a decreasing contribution. This suggests that economically developed provinces have shifted their development focus towards the quality of economic growth. Simultaneously, the growing population in first-tier cities, while exhibiting a declining trend in carbon emissions per capita, continues to exert a substantial influence on the overall increase in carbon emissions.

For MRP, the economic growth effect takes the lead in promoting carbon emissions, with its contribution decreasing from 65% to 54%. The energy intensity effect serves as a significant factor in restricting carbon emissions, contributing 24% to 41%. The emission factor effect inhibited carbon emission (contributing 0.01%) from 2011 to 2015 and promoted it during other periods. The population-scale effect promotes the growth of carbon emissions, contributing 1%.

For WLP, the economic growth effect stands out as the primary driver of carbon emissions, and the contribution is decreasing from 68% to 46%. The energy intensity effect proves to be the most significant factor in constraining carbon emissions, contributing 24% to 40%. The emission factor effect promoted carbon emission (contributing 6%) from 2006 to 2010 and inhibited it during other periods. The population-scale effect suppressed carbon emissions from 2006 to 2010 and promoted carbon emissions post-2010 (contributing 3%).

We examined the rationales underlying the influence of each factor. Regarding the economic growth effect, the contribution to increased carbon emissions is diminishing across all regions. This trend suggests a gradual decoupling of economic growth from carbon emissions, aligning with the results obtained from the decoupling index analysis. In terms of the emission factor effect, it is constantly negative in CDP, while in other regions, it is trending from positive to negative. This indicates that CDP have a cleaner energy structure than MRP and WLP. In terms of the population-scale effect, the CDP population scale has a greater contribution to carbon emissions compared to MRP and WLP. It is due to the significant population pressure in CDP. The average per capita parkland area in CDP in 2019 was 12.58 m^2 per person, lower than in MRP (13.28 m^2 per person) and WLP (14.73 m^2 per person).

4.2.2. Decomposition within Regions

1. Coastal developed provinces

Figure 4A illustrates the decomposition results for carbon emissions in CDP. The carbon emissions increased from 568 Mt in 2005 to 1378 Mt in 2019. The positive factors involve the economic growth effect and the population-scale effect. The economic growth effect contributed 60% to the carbon emission increase in 2006–2010. However, the impact of the economic growth effect was diminishing, and the contribution decreased to 50% in 2011–2015 and 2016–2019. Rapid economic growth generates the negative environmental externalities of increasing carbon emissions, and the negative externality decreases with the transition to green development. The negative factors involve the emission factor effect and energy intensity effect. The emission factor effect is negative and may mean the improvement of energy structure. The energy intensity effect is the most significant deceleration factor and contributed 40% to carbon emission reduction in 2011–2015. With technological progress and increased investment in energy conservation, the inhibitory effect on carbon emissions has increased. The contribution of the emission factor effect and the population-scale effect to carbon emission increase was about 10%, respectively.

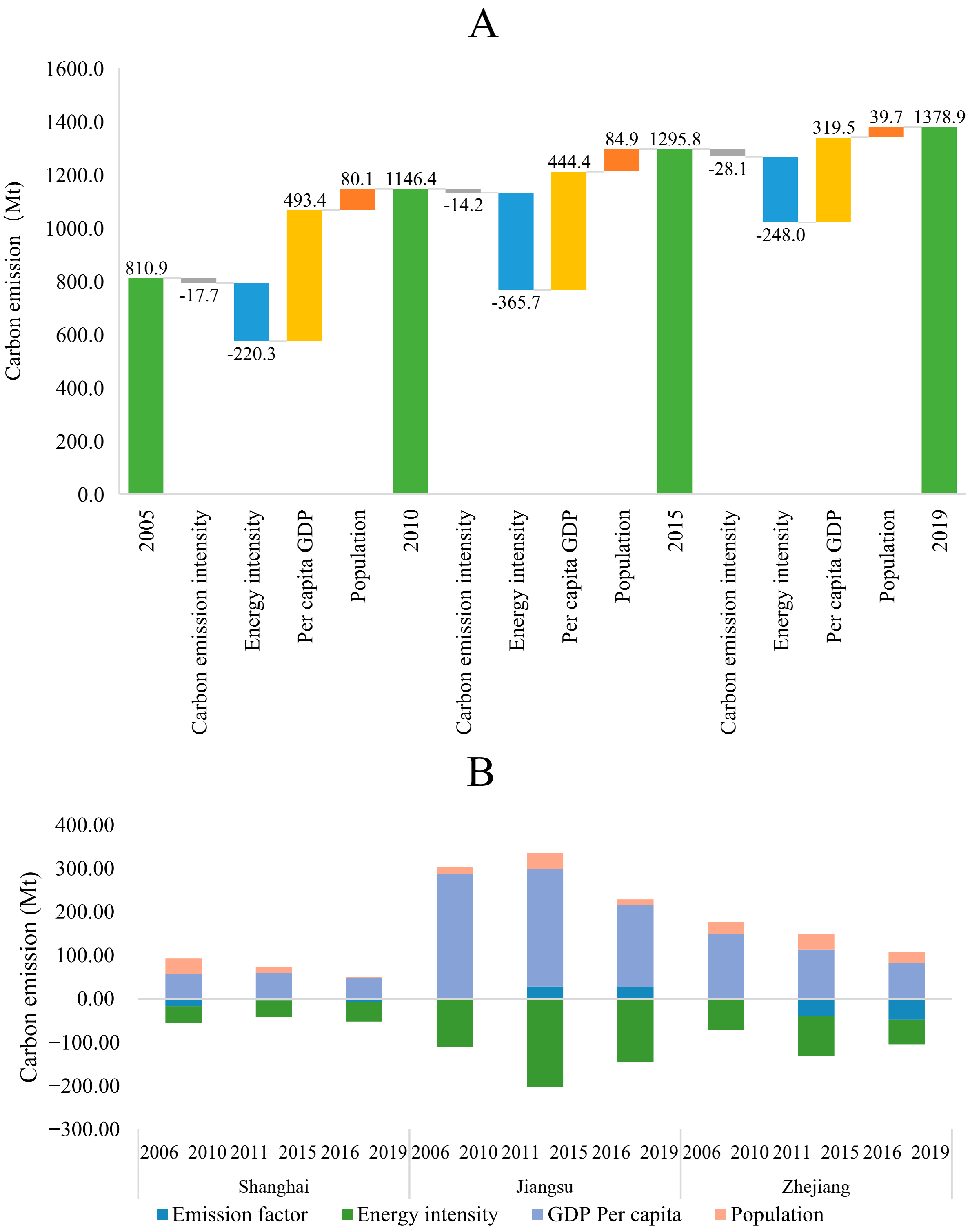

Figure 4. LMDI decomposition results during 2005–2019 in CDP. (**A**) By drivers and periods; (**B**) by provinces, drivers, and periods.

Figure 4B illustrates the impact on carbon emission of different driving factors in Shanghai city, Jiangsu province, and Zhejiang province. For Jiangsu province, the contribution of economic growth effect exceeded 50% in the study period, and the population-scale effect contributed less than 10% to carbon emissions. The contribution of the emission factor effect and energy intensity effect is increasing. For Shanghai city, the economic growth effect is the main driving factor (contributing from 39% to 51%), while energy intensity is the main inhibiting factor (contributing from 26% to 43%). The contribution of the population-scale effect is decreasing from 23% to 1%. For Zhejiang province, the contribution of the emission factor effect was only 0.1% in 2006–2010 and increased to 22% in 2016–2019. The energy intensity effect is the most significant factor restraining carbon emissions. The contribution of the economic growth effect was decreasing from 59% to 39%. The contribution of the population-scale effect remained at about 12%.

The results of this study not only align with existing research, such as Huang et al. [75]'s examination of carbon emission growth factors in the Yangtze River Delta region (Shanghai city, Jiangsu province, and Zhejiang province) using the LMDI method, but also introduce novel perspectives. In concordance with prior findings, both studies emphasize economic growth as a primary driver of carbon emissions, highlighting energy intensity as a key deceleration factor. However, our study goes beyond these agreements by shedding light on the sustained significance of economic growth in contributing to carbon emission. Despite the fact that all provinces have proposed strict green development goals and achieved good results, there is the lingering issue of economic growth's strong reliance on energy consumption.

Analyzing the different roles of influencing factors, it is evident that Jiangsu province had higher total carbon emissions than Zhejiang province and Shanghai city during the study period. This can be attributed to two main factors. Firstly, Jiangsu province boasts the highest GDP among the four provinces, reaching CNY 9.96 trillion in 2019, surpassing Zhejiang province by CNY 3.73 trillion, equivalent to Shanghai's GDP in the same year. Additionally, the total energy consumption of Jiangsu province far exceeds that of Shanghai city and Zhejiang province. In 2019, the total energy consumption of Jiangsu province was 2.8 times that of Shanghai city and 1.5 times that of Zhejiang province.

In terms of the emission factor effect, only Jiangsu province is positive among the three provinces. It should be noted that the emission factor effect promoted the carbon emissions in Jiangsu province from 2011 to 2019. It indicates that Jiangsu province should pay primary attention to adjusting the energy consumption structure. Similarly, the increase in the contribution of the emission factor effect in Zhejiang province is due to the improvement of energy structure, with the proportion of clean energy sources in total energy consumption in Zhejiang province increasing from 20% in 2006 to 35% in 2019. The increase in clean energy consumption leads to the improvement of energy structure, which generates a more significant inhibitory impact of the emission factor effect in Zhejiang province.

In conclusion, the province with priority for carbon emission reduction in CDP is Jiangsu province. It is crucial to closely monitor both the overall energy consumption and the specific energy consumption structure within Jiangsu province. Effectively managing traditional energy consumption and elevating the share of clean energy sources in total energy consumption stand out as the most impactful strategies for curbing carbon emissions in Jiangsu province.

2. Middle-rising provinces

Figure 5A illustrates the decomposition results for carbon emissions in MRP. The total in carbon emissions of the MRP is lower than that of the CDP, but the increment is higher than that of the CDP. The economic growth effect is the most influential factor promoting carbon emission in the MRP, and the promoting effect increases first and then decreases. This suggests that economic growth in MRP is gradually decoupling from carbon emissions, which is consistent with the results of the decoupling analysis. The energy intensity effect is the most important factor restraining carbon emissions. The emission factor effect promoted carbon emission in 2005–2010, inhibited carbon emission in 2010–2015 (only 0.1), and then promoted carbon emission from 2015 to 2019. Compared with the CDP, it indicates that the energy structure of the MRP needs to increase the use of clean energy. The population-scale effect plays a role in promoting carbon emissions, but it is only about 10, indicating that the population scale of the MRP has a small impact on carbon emissions.

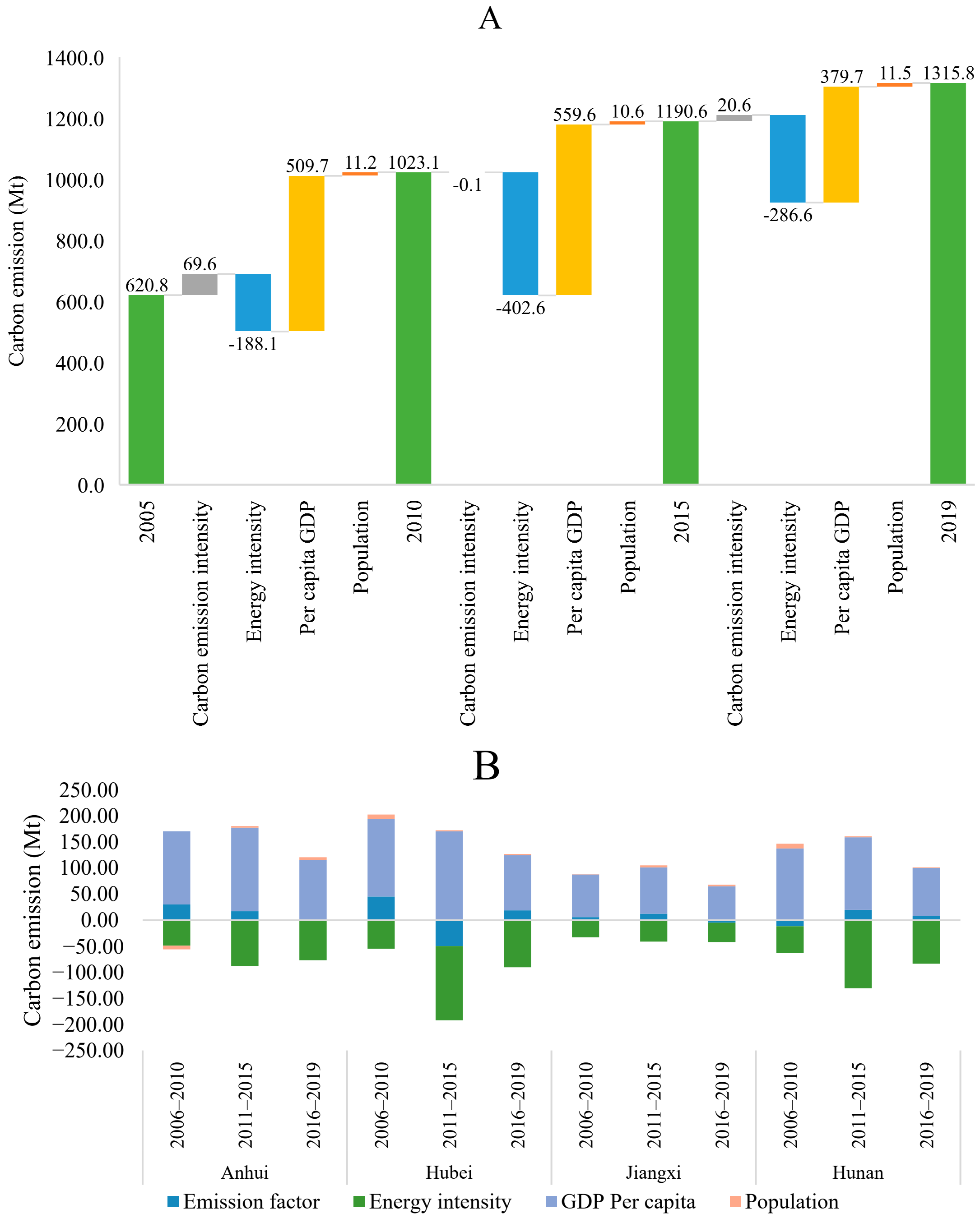

Figure 5. LMDI decomposition results during 2005–2019 in MRP. (**A**) By drivers and periods; (**B**) by provinces, drivers, and periods.

Figure 5B illustrates the impact on carbon emission of different driving factors in Anhui province, Hubei province, Jiangxi province, and Hunan province. For Anhui province, the economic growth effect dominates, contributing about 60%, while the energy intensity effect follows, rising from 21% to 38%. The population-scale effect inhibited carbon emissions during 2006–2010 and promoted it later with an increasing contribution. For Hubei province, the contribution of energy intensity to carbon emission suppression increased from 21% to 41%, slightly lower than the promotion of economic growth (48%) during 2016–2019. The population-scale effect consistently promoted carbon emissions, but contributed only from 0.49% to 3.39%. In Jiangxi province, the economic growth effect's significant contribution decreased from 67% to 59%. The energy intensity effect's inhibitory effect rose to 33%, and the population-scale effect consistently promoted, contributing from

0.42% to 2.67%. For Hunan province, the economic growth effect remained the primary contributor (47% to 65%), and energy intensity's inhibitory effect rose from 24% to 45%. These results are consistent with previous studies [80].

Examining the rationales underlying the influence of each factor, the suppressive effect of the emission factor effect is enhanced in Anhui province and Jiangxi province, while the contrary is observed in Hunan province. This is attributed to the rising share of clean energy sources in the overall energy consumption in Jiangxi province, increasing from 15% in 2007 to 30% in 2019. Similarly, it suggests that the energy structure of Anhui province has been improved from 2006 to 2019. In 2019, the proportion of clean energy sources in total energy consumption in Anhui province is 35%. Conversely, energy restructuring in Hunan province is proceeding slowly. The same energy consumption will generate more GDP as Hunan province increases its technological progress and investment in energy efficiency. In contrast, Hunan province spent CNY 24.2 billion on energy conservation and environmental protection in 2019, compared with CNY 19.4 billion in Jiangxi province. The share of clean energy sources in total energy consumption was only 21% in Hunan province and 30% in Jiangxi province. Regarding the energy intensity effect, its contribution in Hubei province is significantly enhanced. This increase can be primarily attributed to a rise in expenditure on energy conservation and environmental protection, reaching CNY 31.2 billion in 2019—eight times higher than the CNY 3.7 billion recorded in 2007.

In general, MRP have achieved some results in controlling carbon emissions by increasing spending on energy efficiency and environmental protection. The following major measures for carbon emission reduction should focus on how to accelerate the adjustment of energy structure.

3. Western less-developed provinces

Figure 6A illustrates the decomposition results for carbon emissions in WLP. The carbon emissions of WLP increased from 530 Mt in 2005 to 918 Mt in 2019. The total carbon emissions and carbon emission increment of WLP are lower than those of CDP and MRP. The effect of economic growth is the most influential factor promoting carbon emission in the WLP, with the promotional impact initially increasing and then decreasing. This suggests that economic growth in WLP is gradually decoupling from carbon emissions, aligning with the results of the decoupling analysis. The energy intensity effect remains the most crucial factor in restraining carbon emissions. The population-scale effect in WLP suppressed carbon emissions during 2005–2010 and began to promote it post-2010. The emission factor effect promoted carbon emissions during 2005–2010 and began to inhibit it post-2010. It shows that the energy structure of WLP has improved.

Figure 6B illustrates the impact on carbon emission of different driving factors in Chongqing city, Yunnan province, Sichuan province, and Guizhou province. For Chongqing city, the economic growth effect drives carbon emissions significantly (contributing from 64% to 40%), while energy intensity effect increasingly inhibits it (from 23% to 47%). It illustrates that energy efficiency in Chongqing city has improved with technological progress. The emission factor effect initially promotes emissions (2006–2010) but later inhibits it, with a growing effect (from 0.95% to 6.52%). Sichuan's economic growth effect promotes carbon emissions (from 60% to 42%), countered by an increasingly influential energy intensity effect (from 21% to 44%). The emission factor effect promoted carbon emission (contributing 16%) in 2006–2010 and inhibited it during other periods, and the inhibition effect increased from 1% to 15%. The population-scale effect shifts from suppression to promotion. In Yunnan province, the economic growth effect dominates carbon emissions (from 41% to 67%), while the energy intensity effect increasingly restrains it (from 22% to 46%). The emission factor initially promotes, then inhibits it, and the population-scale effect shifts from suppression to promotion. Guizhou province sees rising influence of the economic growth effect (71% in 2016–2019). Emission factor effects vary across periods, and the population-scale effect contributes to carbon emission growth (from 1% to 4%). These results are consistent with previous study [81].

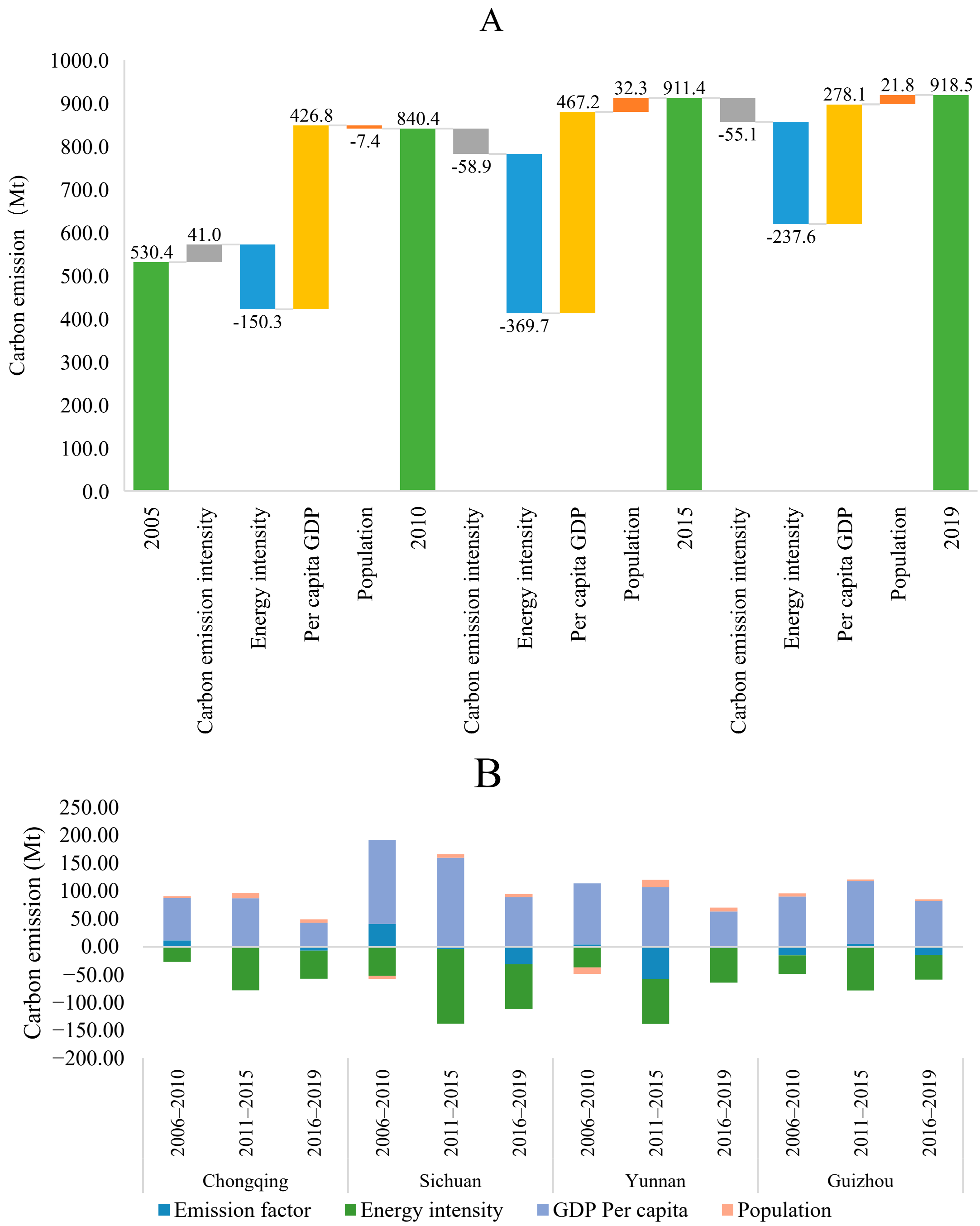

Figure 6. LMDI decomposition results during 2005–2019 in WLP. (**A**) By drivers and periods; (**B**) by provinces, drivers, and periods.

Examining the rationales underlying the influence of each factor, in terms of emission factor effects, the inhibitory effect of emission factor effects on carbon emissions has been increasing in Chongqing city and Sichuan province, while the contrary has been observed in Yunnan province. This is mainly due to the increase in the proportion of clean energy sources in total energy consumption in Chongqing city, from 19% in 2007 to 32% in 2019. Similarly, this shows that the measures to adjust the energy structure of Sichuan province are effective. As a high-quality clean energy base in China, Sichuan province has been actively promoting its development as a national clean energy demonstration province since the 13th Five-Year Plan. Clean energy consumption in Sichuan province increased to

32% of total energy consumption in 2019. However, in 2019, clean energy sources accounted for only 20% of total energy consumption in Yunnan province.

Regarding the economic growth effect, Guizhou province exhibits a significantly higher contribution to carbon emissions compared to other provinces and cities. It shows that the economic development of Guizhou province depends on energy consumption. Guizhou province is in the southwestern inland with large reserves of mineral resources and a complete species of mineral resources. Mineral resources are an important component of Guizhou's GDP. In 2019, the added value of industry above the scale in the province increased by 9.6% compared with the previous year, and by category, the added value of the mining industry increased by 13.7%, which is ranked first (data from the Statistical Bulletin of National Economic and Social Development of Guizhou province in 2019).

In general, WLP carbon reduction mainly depends on Yunnan province and Guizhou province. Yunnan province should pay attention to energy efficiency and energy structure, and actively increase the proportion of clean energy sources in total energy consumption. Guizhou province is still significantly dependent on industry, despite its current GDP dominated by tertiary industries.

4.3. Discussions

This section analyzes the distinct performances of the emission factor effect, the energy intensity effect, and the economic growth effect, and discusses the role of carbon emission reduction policies in YREB.

Emission factor effect. The emission factor effects in Sichuan province and Zhejiang province demonstrate outstanding performance in carbon emissions suppression, contributing 15.24% and 22.62%, respectively. The success in these provinces can be attributed to their shared emphasis on the role of technology in energy structure adjustment policies. In 2017, Sichuan province introduced the "13th Five-Year Plan for Energy Development in Sichuan", focusing on scientific and technological innovation, institutional mechanism revolution, and prioritizing the development of clean and low-carbon energy for adjusting the energy structure. In 2016, Zhejiang province identified optimizing energy structure adjustment as a key task in the "Thirteenth Five-Year Plan for Ecological Environmental Protection in Zhejiang province", proposing initiatives such as "electric energy substitution" and "coal to gas". Through these measures, the implementation of coal consumption reduction and substitution actions has gained momentum, while simultaneously establishing a market-oriented and enterprise-focused environmental protection science and technology innovation system.

However, for Jiangsu province, the emission factor effect is still promoting carbon emissions, and the energy structure adjustment is lagging behind. Jiangsu province has consistently grappled with issues of high energy consumption and challenges in restructuring its energy landscape, despite ongoing planning efforts. In 2022, Jiangsu province took measures to address these concerns by issuing a "Notice on the Implementation of Financial Policies Linked to the Effectiveness of Pollution Reduction and Carbon Reduction" to reward cities that have exceeded their emission reduction targets. It also issued the "Implementation Opinions of the Jiangsu provincial Government on Accelerating the Establishment of a Sound Green, Low-Carbon and Cyclic Development Economic System" to further emphasize the optimization of the energy structure, and formulated a specific plan. To enhance its efforts, Jiangsu province could draw insights from the successful experiences of other provinces, emphasizing the importance of scientific and technological innovation in green development. Formulating a detailed pollutant emission index system and rigorously requiring municipalities to carry out and complete thorough midterm inspections would be crucial steps to expedite the pace of energy structure adjustment.

Energy intensity effect. Hubei province and Yunnan province exhibit a significantly stronger contribution of the energy intensity effect to the suppression of carbon emissions, exceeding 20%. This notable performance can be attributed to reinforced environmental protection investment policies. Energy intensity measures the efficiency of energy use, assessing the amount of energy consumed per unit of economic activity. Technological advances and increased investment in environmental protection can enhance energy-use efficiency, consequently reducing the energy required per unit of economic activity and aligning with the objective of mitigating carbon emission. In 2017, Yunnan province outlined its commitment to the advancement of an ecological civilization in the "Yunnan Ecological Civilization Construction Leading Plan (2021–2025)", emphasizing the synergistic promotion of green investment, green consumption, and green technology exchanges and cooperation. Similarly, in 2018, Hubei province unveiled the "Hubei province Energy Saving and New Energy Vehicle Industry Development Plan", underscoring the need to intensify research and development efforts and promote the adoption of new energy vehicles.

Economic growth effect. Zhejiang province stands out as the only region where the contribution of the economic growth effect to carbon emissions has decreased to below 40%. This indicates that Zhejiang province has reduced its dependence on carbon emissions for economic growth and enhanced its green production capacity. The reason for the remarkable performance may be that the 13th Five-Year Plan for Ecological Environmental Protection of Zhejiang province has made it the main goal to significantly improve the level of green production. The achievement of this goal is pursued through two main approaches: first, by specifying emission target goals for each district and city, and second, by implementing initiatives like the low-sulfur and low-ash coal allocation projects.

5. Conclusions and Policy Suggestions

5.1. Conclusions

It is of great practical significance to explore the coordinated regional development path between China's high-quality economic development and climate governance.

This study chooses the YREB, a microcosm of China's economic development, as a typical case to study determinants of change in the decoupling of economic growth from carbon emissions. The research results show that the regional differences in carbon intensity in the YREB are gradually decreasing, and the decoupling level of economic growth from carbon emission is gradually increasing, with 70% of provinces and cities having reached a strong decoupling state. Based on the LMDI decomposition model, this paper confirms that the decrease in carbon emissions is mainly due to the weakening of economic activities and the increased suppression of energy intensity.

The Thiel index is used to identify regional differences in carbon intensity in the YREB. The difference within the region is the dominant factor (contributing about 70%). By region, the difference within the region mainly originates from WLP (40% of 70%), and CDP have the least difference within the region, leading to the coordinated development of the whole YREB.

Tapio decoupling model analysis shows that the decoupling evolution from negative decoupling to decoupling is evident in the YREB from 2005 to 2019. CDP are in the largest proportion of decoupling and MRP have the most stable degree of decoupling, with a decoupling stability coefficient of 2.06–4.14. Except for Jiangsu province, Anhui province, and Jiangxi province, all other eight YREB provinces have reached strong decoupling.

The Kaya Identity and LMDI are used to assess the determinants of change in the decoupling of economic growth from carbon emissions of the YREB from 2005 to 2019. The economic growth effect is the most significant factor contributing to carbon emissions. But the contribution is decreasing, and it indicates that economic growth is gradually decoupling from carbon emissions, which is consistent with the findings of the decoupling analysis. The energy intensity effect is the most significant factor restraining carbon emissions, and the contribution is increasing. The effect of the emission factor on carbon emission turns from positive to negative, indicating the improvement of energy structure in the YREB, with the increase in the proportion of clean energy consumption. By region, the emission factor effect of CDP is always negative; however, in MRP and WLP, it turns from positive to negative, indicating that MRP and WLP need to pay more attention to the energy structure. The effect of population scale is negligible.

5.2. Policy Implications

Based on the aforementioned conclusions and considering the resource endowment of the YREB and the planning for ecological civilization development, the following policy recommendations are proposed.

First, government should develop differentiated carbon emission reduction programs. Tailored carbon emission reduction programs should be developed based on the successful experiences of Shanghai city and Hunan province, which may be attributed to their stringent implementation of energy-saving and emission reduction targets. For instance, Hunan province issued the "13th Five-Year Plan for Environmental Protection" in December 2016, emphasizing tasks such as controlling total energy consumption, optimizing energy structure, and utilizing clean energy. It also established the strictest environmental protection index system. Therefore, it is imperative to articulate clear implementation plans and roadmaps for carbon peak and carbon-neutral targets, refining initiatives for key industries and regions in alignment with the progress of decoupling economic growth and carbon emissions in each province. Carbon emission reduction should be carried out based on each province's strengths.

Second, we need more specific and effective tools to reduce carbon emissions. The provinces with large carbon emissions, such as Jiangsu province (ranking first with 804.59 Mt of carbon emissions in 2019) and Anhui province (ranking second with 408.06 Mt of carbon emissions in 2019), have not yet achieved strong decoupling of economic growth from carbon emission. They should be encouraged to decouple and implement carbon emission reduction targets. Jiangsu province should persist in implementing the "dual-control" system for total energy consumption and intensity, promoting clean energy, and focusing on the development of green, low-carbon, and recycling industries. Anhui province should strictly control total energy consumption, increase the share of renewable and new energy sources, and lead the development of strategic emerging industries through technological innovation.

Third, the current emission factor effect is still relatively minor compared to the energy intensity effect. There will be enough space for reducing carbon emissions by improving energy structure in the future. The recommendation is to accelerate clean energy technology innovation and promote energy transformation, including implementing clean coal substitution and promoting the replacement of coal and oil with electricity in both industrial and transportation sectors. Additionally, there is a need to scale up clean energy power generation and encourage the widespread application of solar energy through high-efficiency conversion methods. Further efforts should be directed towards the expansion of offshore wind power, meticulous planning of biomass direct-fired power generation, and the secure and systematic development of nuclear power.

Certain limitations in the study warrant consideration. Firstly, the employed analytical methods and models might not sufficiently capture the intricate dynamics involved in decoupling economic growth from carbon emissions. Secondly, the research is confined to specific regions in China, and given the policy and economic variations across different regions, generalizing findings to a macro level should be approached with caution. To address these shortcomings, it is suggested that future research embrace more intricate and comprehensive models, combined with more data, to more precisely elucidate the intricate relationship between carbon emissions and economic growth.

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

Appendix A

Table A1. The decoupling index of YREB from 2005 to 2019.

Year	Shanghai	Jiangsu	Zhejiang	Anhui	Hubei	Jiangxi	Hunan	Chongqing	Sichuan	Yunnan	Guizhou
2005	0.598	1.869	1.345	0.169	0.299	0.659	3.475	1.660	−0.224	9.979	1.484
2006	0.310	0.760	0.961	0.968	1.544	0.973	1.080	0.822	0.858	1.002	1.400
2007	0.379	0.423	0.834	0.883	0.827	1.157	0.657	0.634	0.680	0.497	0.113
2008	0.199	0.468	0.147	1.099	0.126	0.181	0.103	1.871	0.944	0.139	−0.470
2009	0.060	0.309	0.280	0.899	0.632	0.666	0.398	0.358	0.988	1.253	1.077
2010	0.900	1.133	0.562	0.554	1.622	0.465	0.662	0.539	1.041	0.457	0.340
2011	0.369	0.726	0.664	0.623	1.114	0.628	0.886	0.889	0.092	0.362	0.764
2012	−0.368	0.305	−0.063	0.908	−0.174	0.045	−0.020	0.222	0.821	0.245	0.773
2013	0.756	0.783	0.053	0.981	−1.510	2.139	−0.341	−1.067	0.399	−0.161	0.113
2014	−0.910	0.027	−0.124	0.199	0.022	0.268	−0.094	0.847	−0.010	−0.516	−0.113
2015	0.081	0.220	0.002	0.020	−0.074	0.475	0.584	0.073	−0.688	−0.932	0.082
2016	−0.046	0.380	−0.150	0.382	0.062	0.169	0.665	−0.433	−0.512	0.216	0.782
2017	0.106	0.277	0.342	0.188	0.421	0.578	0.632	0.272	−0.010	0.806	0.281
2018	−0.413	0.121	0.156	0.548	−0.088	0.428	−0.701	0.006	−0.883	0.731	−0.204
2019	0.199	0.899	−0.281	0.312	0.988	0.329	0.201	−0.430	0.860	−1.492	0.397

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