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Regional Comparison of Progress Toward Carbon Emissions Peak in China

Yu Luo *

Guangdong Provincial Academy of Environmental Science, Guangzhou, Guangdong, 510045, China

*** Corresponding author Email:** luoyu1229@163.com

Abstract: Accurately assessing the progress of carbon emissions peak actions at the national and regional levels is a crucial foundation for achieving China's carbon emissions peak target before 2030. This study first examines the relationship between carbon emissions peak and carbon emissions decoupling, and establishes their correspondence numerically by employing the Tapio decoupling model. Second, using provincial panel data from 2000 to 2019, it investigates the progress of the carbon emissions peak in China overall and in the Eastern, Central, and Western regions. The study finds that at the national level, China's overall CO_2 emissions have entered a near-peak plateau phase, where the growth rate of carbon emissions has significantly slowed and is much lower than GDP growth. However, an unstable rebound trend persists under the influence of macroeconomic policies. Regionally, the Eastern region has the most advanced progress toward the carbon emissions peak, followed by the Central region, with the Western region lagging. Moreover, the gaps among the three regions are gradually widening.

Keywords: Carbon Emissions Peak; Regional Differences; Decoupling.

1. Introduction

A common consensus has emerged globally on addressing the climate crisis for sustainable development. From the Kyoto Protocol to the Paris Agreement, international competition over global warming issues has intensified. To enhance China's contribution to the global carbon reduction target, President Xi Jinping pledged at the 75th Session of the United Nations General Assembly that China would strive to reach the carbon emissions peak before 2030. On one hand, as the world's largest carbon emitter, the timing of the global emissions peak and future mitigation pathway will largely depend on China's actions; on the other hand, a low-carbon transition is an inevitable requirement for China's own "new normal" of economic growth and for achieving high-quality development.

However, as a developing country, China has obvious disparities in economic strength and technological capacity among its Eastern, Central, and Western regions, and the progress of carbon peak actions in each region also differs. This means each region must tailor its peak planning to its own conditions under the principle of "common but differentiated responsibilities". Consequently, the following questions naturally arise: How can we accurately assess the progress of carbon peak actions at both the national and regional levels in China? To answer the question, this paper first examines the characteristics and connection between carbon emissions peak and carbon emissions decoupling, and establishes their correspondence by applying the Tapio decoupling model. Second, using the carbon emissions decoupling index as the research object and employing provincial panel data from 2000 to 2019, the paper conducts an in-depth analysis of the progress of carbon peak actions at both the national and regional levels.

The main contribution of this paper lies in its approach: previous research on carbon emissions peak often took total CO_2 emissions as the sole factor of interest. However, for China and other countries that have not yet reached a peak, achieving the carbon emissions peak involves not only pursuing a decline in total carbon emissions, but also maintaining sustainable economic growth. This requires shifting the relationship between economic growth and carbon emissions from the current "coupling" state to a "decoupling" state, while achieving economic growth while total CO_2 emissions continuously decline. Based on this perspective, this paper proposes using the carbon emissions decoupling index as the object of study for carbon peak, and systematically clarifies the correspondence between carbon emissions peak and decoupling. This innovation can provide insights not only for China but also for other countries that have not yet peaked, in exploring pathways to achieve the carbon emissions peak under ongoing economic growth.

2. Literature Review

Scholars have examined whether CO_2 can reach a peak and how to determine the peak state from different angles. Internationally, criteria for determining a CO_2 peak include: the region's historical CO_2 emissions have reached the highest level compared to the latest carbon accounting inventory [1]; after reaching a peak, CO_2 emissions may be allowed to rise for a short plateau period but must not exceed the peak value [2]; within five years after the CO_2 peak, the region's CO_2 emissions should decrease by at least 10% [3]; and the region publicly commits to continue supporting emissions reductions unconditionally in the future [4]. Currently, however, no clear method has been established for judging the carbon peak status at the national, regional, or provincial level in China.

Existing research methods mainly fall into two categories: future carbon emissions forecasting analysis and historical carbon emissions statistical analysis. Some scholars use econometric models or factor decomposition models to explore the relationship between CO_2 emissions and their driving factors, and to predict whether CO_2 will peak by conducting scenario analyses of future trends in the driving factors [5-7]. Others use input-output models or general equilibrium models to examine CO_2 emissions by sector or industry, thereby predicting the timing and magnitude of the CO_2 peak [8-10]. A smaller number of scholars use the Tapio decoupling model to measure the decoupling relationship between carbon emissions and economic growth, and combine this with historical CO_2 emission trends to determine the current carbon peak status of different regions [11-13].

In general, most studies to date have focused on predicting China's future CO_2 peak value and peak timing, while research on how to determine the current peak state is still relatively scarce. Furthermore, in terms of pathways to achieving the carbon peak, existing research mainly examines the impact of changes in a single driving factor such as energy structure [14], economic structure [9], or economic growth [8] on advancing the carbon peak, and has mostly focused on China as a whole or on specific industries [11, 15-17]; or on one industry [18-20]. There is relatively little attention to the regional level, which leaves space for the present study to explore regional differences.

3. Model Design and Data Sources

3.1. The Tapio Decoupling Model

Decoupling of carbon emissions in the context of resources and the environment refers to the phenomenon where the rates of change in carbon emissions and economic growth are not synchronized. Tapio [21] introduced an elasticity coefficient into the decoupling model, using the percentage increase or decrease in pollutant emissions resulting from a 1% change in GDP as the basis for analysis. Because its calculation is simple and the time span can be flexibly chosen, it has become a mainstream method for measuring the degree of decoupling between economic growth and carbon emissions [22]. The Tapio decoupling index is defined as the ratio of the percentage change in CO_2 emissions to the percentage change in GDP over a given period. Different decoupling states can be categorized based on the magnitude of the index and the signs of ΔCO_2 and ΔGDP, yielding eight types. Since this paper focuses on the relative change between economic growth and carbon emissions, and because the GDP of each Chinese province remained positive throughout the sample period, only three decoupling states are emphasized (Table 1).

Table 1. Three decoupling states under positive economic growth

Decoupling State	ΔGDP	ΔCO_2	Relationship	Decoupling Index Value
Expansive coupling	>0	>0	GDP growth rate < CO_2 growth rate	$[1, +\infty)$
Relative decoupling	>0	>0	GDP growth rate > CO_2 growth rate	$[0, 1)$
Absolute decoupling	>0	<0	GDP growth rate > 0, CO_2 growth rate < 0	$(-\infty, 0)$

Expansive coupling refers to a state where GDP growth and CO_2 emissions growth are both positive, with the CO_2 growth rate exceeding the GDP growth rate. Relative decoupling refers to a state where both GDP and CO_2 emissions are growing, but the CO_2 growth rate is lower than GDP growth rate. Absolute decoupling refers to a state where GDP is growing while total CO_2 emissions are declining, which is the most ideal condition for achieving the carbon emissions peak.

By definition, decoupling emphasizes long-term trends rather than short-term random fluctuations in carbon emissions. Therefore, unlike prior literature that often uses a one-year period (from t-1 to t) for calculating the decoupling index [11, 13, 22], this paper uses the ratio of the CO_2 change rate to the GDP change rate from t-1 to t+1 to reflect the decoupling status at time t. This setting overcomes the drawback that a one-year decoupling index is easily influenced by external shocks and can exhibit occasional volatility, and it more accurately reflects the sustained, stable relative change trend between economic growth and carbon emissions.

For the i-th province in period t, the decoupling index is thus defined as the ratio of the CO_2 change rate to the GDP change rate over the period from t-1 to t+1:

$$D_{i,t} = \frac{(CO_{2,i,t+1} - CO_{2,i,t-1})/CO_{2,i,t-1}}{(GDP_{i,t+1} - GDP_{i,t-1})/GDP_{i,t-1}} \tag{1}$$

3.2. Data Sources and Processing

The data used in this study come primarily from the National Bureau of Statistics of China, the statistical yearbooks of each province, and the China Energy Statistical Yearbook. Total CO_2 emissions for each province were calculated by the authors according to the IPCC Guidelines. Specifically, we multiplied the consumption of various fossil fuels (such as coal, coke, gasoline, diesel, kerosene, crude oil, and natural gas) by their respective CO_2 emission factors. GDP figures are converted to constant 2000 prices to ensure comparability.

4. Assessment and Analysis of Carbon Emissions Peak Progress

4.1. Judging the Progress of Carbon Emissions Peak

The carbon emissions peak is not defined by a single year in which emissions are maximized, but is instead a dynamic, evolving process. In this process, carbon emissions first enter a plateau phase, exhibiting short-term fluctuations, and then transition into a long-term steady decline. Therefore, the trajectory toward the carbon peak can be roughly divided into three stages: the pre-peak rising stage, the near-peak plateau stage, and the post-peak decline stage. The correspondence between the carbon emissions peak and the decoupling states can be summarized as follows:

• Pre-peak rising stage: The decoupling index is greater than 1. Economic growth and carbon emissions are in an expansive coupling state. At this stage, CO_2 emissions and GDP both increases, but the growth rate of CO_2 emissions is much higher than that of GDP. Achieving a carbon emissions peak under sustained economic growth is most difficult in this stage.

• Near-peak plateau stage: The decoupling index decreases to between 0 and 1. Economic growth and carbon emissions are in a relative decoupling state. At this stage, CO_2 emissions are still increasing, but their growth rate has significantly slowed and is lower than GDP growth. This provides a favorable condition for achieving the carbon emissions peak while maintaining sustainable economic growth.

• Post-peak decline stage: The decoupling index is below 0 for an extended period. Economic growth and carbon emissions are in an absolute decoupling state, meaning GDP continues to grow while total CO_2 emissions continuously decline. This is the most ideal state for achieving the carbon emissions peak.

From the above, it is evident that when the economy maintains continuous positive growth, the magnitude of the decoupling index directly reflects the progress of carbon peak actions in each region. A process in which the index value decreases from above toward zero indicates that the region is gradually approaching its carbon emissions peak target. When the index remains below zero for an extended period, it indicates that the region has already achieved its carbon emissions peak target.

4.2. Analysis of Carbon Emissions Peak Progress

Using the above framework, we calculate the carbon emissions decoupling index for China as a whole and for each region (Eastern, Central, and Western) using data from 2000-2019, to observe the evolution of each region's progress toward the carbon peak (Figure 1). Overall, the national decoupling index during the sample period exhibits an "M" shaped pattern of fluctuations and decline. This indicates that China is gradually approaching the carbon peak target, although there remain unstable rebound phenomena during the process.

From a temporal perspective, during the 10th Five-Year Plan period (2001-2005), China's national CO_2 emissions were in a rapid growth phase prior to reaching the emissions peak. This period marked China's accession to the World Trade Organization and a significant acceleration of industrialization; however, the extensive use of energy led to a continuous rise in the decoupling index, reflecting a deteriorating trend in carbon efficiency. During the 11th Five-Year Plan (2006-2010), mounting environmental pressures prompted the Chinese government to implement structural industrial reforms and set a target to reduce major pollutant emissions by 10%. These measures effectively curbed the growth rate of CO_2 emissions, which gradually slowed and entered a plateau. Nevertheless, at the end of this period, the global financial crisis triggered the introduction of a 4 trillion RMB economic stimulus plan, which temporarily boosted demand in energy-intensive industries, resulting in increased energy consumption and a modest rebound in the decoupling index. In the 12th Five-Year Plan period (2011-2015), the government launched a series of policies, including the establishment of a carbon emissions trading market, allocation systems for greenhouse gas emissions, and the development of low-carbon provinces and cities. These initiatives briefly drove national CO_2 emissions into a declining trajectory, yet the downward trend proved unsustainable. Entering the 13th Five-Year Plan (2016-2020), as the effectiveness of prior policies diminished, national CO_2 emissions returned to a phase of gradual increase, reflecting a prolonged plateau in emission levels.

At the regional level, the trends in the decoupling index across the Eastern, Central, and Western regions generally align with the national pattern; however, significant differences exist in terms of volatility and the pace of progress. The Eastern region exhibits relatively stable fluctuations in its decoupling index, while the Western region experiences greater volatility and more pronounced rebound effects. In terms of absolute decoupling index values, the Eastern region is the most advanced in progressing toward the carbon emissions peak, followed by the Central region, with the Western region lagging. Moreover, the divergence among the three regions has shown a tendency to widen over time, reflecting underlying disparities in regional development strategies, resource endowments, and technological capabilities. This pattern may be related to China's strategy of differentiated regional development and to differences in resource endowment and technological capacity across regions. In addition, in recent years some high-energy-consuming, low value-added industries have gradually relocated from the Eastern region to the Central and Western regions. Consequently, as the Central and Western regions develop their economies, they generate more CO_2 emissions, resulting in a tighter coupling between economic growth and carbon emissions. Therefore, the rebound effect on carbon emissions from economic stimulus measures is more pronounced in the Central and Western regions.

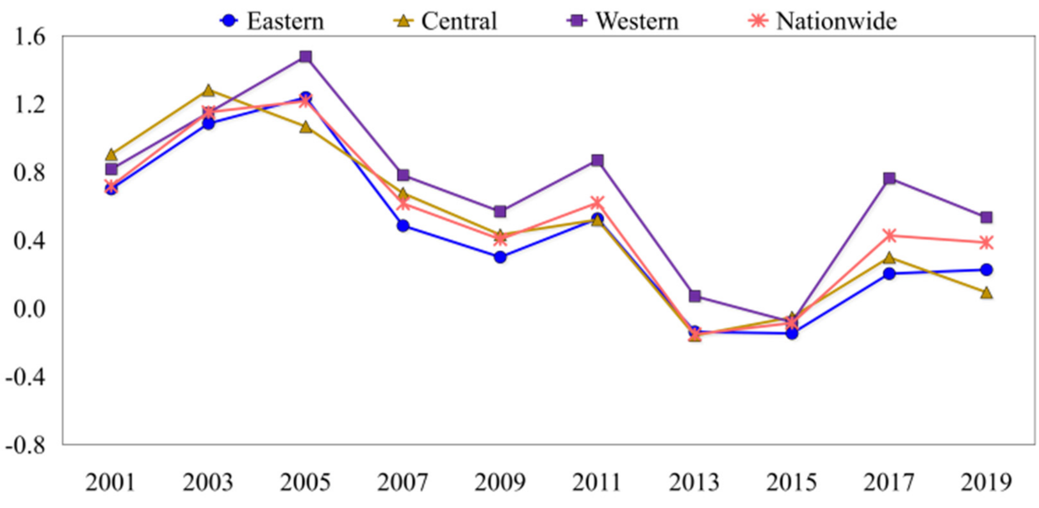

Figure 1. Trends in the progression toward the carbon emissions peak in Eastern, Central, and Western China

5. Conclusion

Under the premise of sustainable economic growth, this paper discusses the correspondence between carbon emissions peak and carbon emissions decoupling, and establishes their numerical relationship using the Tapio decoupling model. On this basis, using the carbon emissions decoupling index as the object of study and employing provincial panel data from 2000-2019, the study provides a detailed analysis of the progress of carbon peak actions at both the national and regional levels in China. The empirical results indicate that, at present, China's overall CO_2 emissions have entered a near-peak plateau stage; however, influenced by macroeconomic policies, there are still unstable rebound trends. Regionally, the Eastern region is relatively advanced in its carbon peak progress, the Central region is second, and the Western region is relatively behind. Moreover, as time progresses, the gap among the three regions is tending to widen.

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