Regional Heterogeneity of Carbon Emissions and Peaking Path of Carbon Emissions in the Bohai Rim Region

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Taking the Bohai Rim region as the research object and based on the relevant data of energy consumption, GDP, and energy structure from 2000 to 2019, the total carbon emissions of the provinces and cities from 2020 to 2050 were predicted. The carbon peak situation of each province and municipality in the Bohai Rim region was also analyzed. A comparative analysis of the peaks among the provinces and cities has been carried out. The results show the following: (1) it is predicted that Beijing will reach its carbon peak before 2025. Tianjin is predicted to reach its carbon peak before 2030. Renewable energy development and utilization technologies in the two municipalities are crucial to achieving carbon peaks when energy intensity is already low. (2) Shandong and Shanxi have a heavy energy structure, are coal-minded, and have high energy intensity, while the replacement rate of renewable energy is relatively low. Shandong and Shanxi are predicted to reach carbon peaks around 2030. Liaoning also has the problem of heavy industrial structure, and it is predicted to reach the carbon peak before 2027. (3) Hebei itself relies on Beijing, and its renewable energy utilization technology is relatively advanced. It is predicted to reach the carbon peak before 2026. The energy intensity of Inner Mongolia has decreased rapidly, and it is predicted to reach the carbon peak before 2029. Therefore, according to the forecast results and the analysis of the similarities and differences among the provinces and cities, some specific suggestions for the optimization of the energy structure and the development of renewable energy in each province and city have been proposed in order to promote the comprehensive realization of the regional carbon peak goal in the Bohai Rim region.

1. Introduction

China is the world’s second largest economy and one of the world’s largest energy consumers. For a long time, one of the important reasons for China’s severe carbon emission problem is the energy consumption structure dominated by coal. China’s commitment to carbon peaks and carbon emission reductions has brought huge transformation pressures and challenges to the domestic energy structure. On September 22, 2020, the Chinese government delivered an important speech at the general debate of the 75th UN General Assembly. The Chinese government pointed out that “China will increase its nationally determined contributions and adopt more powerful policies and measures. Carbon dioxide emissions will strive to reach a peak before 2030 and strive to achieve carbon neutrality by 2060.” The adjustment of the energy structure is a huge practical problem facing China, including the coordinated development of economy, energy, and technology. The improvement of China’s energy structure, the effective replacement of traditional energy by new energy, the technical requirements for energy structure adjustment, and the direction of economic development all directly affect the target of peak carbon emissions.

The Bohai Rim region is an important coastal economic circle in China. The land area accounts for about 60% of China’s total area, and the gross national product accounts for about 40% of the country. After 2015, the energy consumption in the Bohai Rim region accounted for about 43%
of China’s total, and carbon emissions accounted for about 52% of China’s total carbon emissions. The development of this region directly affects China’s overall economic growth, energy consumption, and technological development. The coordinated development of the Bohai Rim region has promoted the rapid development of China’s economy. There are also some practical problems, such as dependence on traditional industries and insufficient energy structure. All these seriously affect China’s target of peak carbon emissions in 2030. This paper takes the Bohai Rim region as the research object and uses the basic model of carbon emission prediction to analyze the peak carbon situation of the provinces and municipalities in the Bohai Rim region.

With the increasing public attention to global warming issues, scholars have also conducted comprehensive and indepth research and analysis on the peaking of carbon emissions in various countries. The research view of most scholars is that most developed countries have already passed the peak of carbon emissions because of their early industrialization. China is the largest developing country and is still in the stage of industrialization and modernization and has not yet reached the peak of carbon emissions. A large number of domestic scholars use different mathematical and economic methods to predict China’s future carbon emissions. Some scholars directly use the system model to predict the total amount of carbon emissions in the future. The main methods include the grey prediction model and computable general equilibrium (CGE) model. The grey model was originally used to predict energy consumption demand and supply. Later, the grey model was used to predict carbon emissions. Pao et al. [1] used the nonlinear grey Bernoulli model (NGBM) to predict the three indicators of carbon emissions, energy consumption, and actual output. The forecast results show that, between 2011 and 2020, China’s average annual compound emissions, energy consumption, and GDP growth are set to 4.47%, −0.06%, and 6.67%, respectively. Wang and Ye [2] used a nonlinear grey multivariate model to predict the carbon emissions of China’s fossil energy consumption. Huang et al. [3] explored sixteen potential factors affecting carbon emissions and used grey correlation analysis to identify factors closely related to carbon emissions. Ye et al. [4] proposed a novel time-delay multivariate grey model to measure the CO₂ emissions’ accumulating impact of China’s transportation sector. Zhu and Ling [5] used to calculate the general equilibrium theory, construct a dynamic CGE model, and draw the conclusions of carbon emission reduction policies to promote industrial structure optimization. Li et al. [6] used the generalized dividing index method to find that GDP has the highest cumulative contribution rate to carbon emissions in my country’s construction industry.

In addition, Grossman and Krueger [7] discussed the environmental Kuznets curve (abbreviation for the “EKC”) between environmental conditions and economic growth. Debdatta and Subrata [8] studied the cointegration relationship between carbon dioxide emissions and economic activity and tested the environmental Kuznets curve (EKC) hypothesis. Lin and Jiang [9] used a traditional EKC model simulation and carbon dioxide emission prediction and comparative research and prediction of China’s carbon dioxide emissions. Jiang et al. [10] used the environmental Kuznets curve to quantitatively study the relationship between coal consumption, economic development, and carbon emissions, and the results showed that China has not yet reached the “inflection point.”

However, most scholars decompose and analyze the influencing factors of carbon emissions and then use scenario analysis to predict future carbon emissions. The main models used to decompose the influencing factors of carbon emissions include the one proposed by Ehrlich and Holdren [11], the model that environment (I) is equal to the product of population (P), affluence (A), and technology (T) (abbreviation for the “IPAT”). The model of stochastic impacts by regression on population, affluence, and technology is abbreviated to the “STIRPAT”. The logarithmic mean Divisia index (abbreviation for the “LMDI”) decomposition method of carbon dioxide emission driving factors was proposed by Ang et al. [12]. Qu and Guo [13] used the STIRPAT model to predict the peak of China’s carbon emissions in the future and proposed that if the economic and social development keeps a reasonable decline in carbon emission intensity, the peak time for China should be between 2020 and 2045. Wang et al. [14] used the extended STIRPAT model based on the classic IPAT identity to determine the main drivers of energy-related carbon emissions in Xinjiang. Lin et al. [15] focused on the impact of the extended STIRPAT model on carbon dioxide emissions from urbanization and economic development in non-high-income countries. Chang et al. [16] used the STIRPAT model to study the regional differences in the impact of population size, GDP per capita, energy structure, energy intensity, urbanization level, and industrialization level on CO₂ emissions. Quan et al. [17] uses the LMDI decomposition model to decompose the factors affecting carbon emissions of the logistics industry. Chai and Xu [18] conducted an in-depth analysis of the four paths and scenarios for China to achieve total emission control and peak emissions based on the IAMC model, carefully tested the relevant conditions, and put forward reasonable target recommendations at this stage. Li et al. [19] established an assessment framework of provincial carbon emission drivers using system dynamics modelling. Part of the research will also directly use scenario analysis to predict future carbon emissions [20–24].

2. Model Construction, Parameter Determination, and Data Source

2.1. Decomposition of Comprehensive Carbon Emission Coefficient Based on the IPAT Model. The research methods of carbon emission prediction mainly include the IPAT model, Kaya identity, STIRPAT model, and LEAP model. The reasonably optimized IPAT equation has the potential for carbon emission prediction. The IPAT equation was first proposed by Ehrlich et al. in 1971. It systematically reflects the relationship between population, economy, technology, and environment. The model can decompose and analyze the influencing factors according to the actual situation and can clarify which factors have the greatest impact on the
environment. The impact is the greatest, and the general form of the equation is as follows:

\[ I = P \times A \times T. \quad (1) \]

Among them, \( I \) (impact) represents the impact of the population on the environment, \( P \) (population) represents the total population of the study area, \( A \) (affluence) represents per capita output, and \( T \) (technology) represents the impact of unit economic output on the environment, which is determined by the level of technological progress. When studying the effects of the population on the environment, we use emissions, GDP levels, and energy consumption per unit of GDP to replace \( I, A, \) and \( T \). The formula is shown as follows:

\[ C = P \times \frac{G}{E} \times \frac{C}{G} \quad (2) \]

In addition, considering the impact of the energy structure on emissions, Kaya [25] proposed the Kaya equation, which decomposes the influencing factors by constructing a chain product to further increase the accuracy of the result. The calculation formula is as follows:

\[ C = P \times \frac{G}{E} \times \frac{E}{G} \times \frac{C}{E} \quad (3) \]

Among them, \( E \) represents the total energy consumption, \( E = \sum S_i \times R_i \), \( S_i \) represents the carbon emission coefficient of the \( i \)th energy, \( R_i \) indicates the consumption of type \( i \) energy, and \( C/E \) indicates the energy structure. In addition, when using the IPAT model to make predictions, the population changes in the future period must be predicted first. This is also a factor that causes large differences in the prediction results. Therefore, formula (3) is simplified:

\[ C = G \times \frac{E}{G} \times \frac{C}{E}. \quad (4) \]

From formula (4), we know that the changes in carbon emissions in the short term are only affected by economic aggregates, energy intensity, and energy structure. Suppose that the annual growth rate of GDP is represented by \( r \) and \( g \) is the reduction rate of energy consumption per unit of GDP. Let \( v \) represent the comprehensive carbon emission coefficient of energy structure adjustment, that is, the optimization coefficient of the energy structure. Based on the improvement of the model by Zhu et al. [26] combined with the definition of the reduction rate of energy consumption per unit of GDP, the relationship between the energy consumption per unit of GDP in the current period and the energy consumption per unit of GDP in period \( t \) can be expressed as

\[ \frac{E_t}{G_t} = \frac{E_0}{G_0} (1 - g)^t = \frac{E_t}{G_0} (1 + r)^t. \quad (5) \]

That is, \( E_t = E_0(1 - g)^t (1 + r)^t \).

Therefore, carbon dioxide emissions can be expressed as

\[ C^0 = \frac{44}{12} \times E_0 \times v_0, \quad (6) \]

\[ C^t = \frac{44}{12} \times E_t \times v_t. \quad (7) \]

From (5) to (7), the relationship between the current carbon dioxide emissions and the carbon dioxide emissions during \( t \) can be derived:

\[ C^t = C^0 (1 + r)^t (1 - g)^t (1 - e)^t. \quad (8) \]

In formula (8), we introduce \( e \) as the rate of change in the comprehensive carbon emission coefficient brought about by the optimization of the energy structure. Among them, \( v_i = v_0 (1 - e)^t \), \( v_i \) represents the comprehensive carbon emission coefficient for the \( i \)th period, \( v_0 \) represents the comprehensive carbon emission coefficient for the base period, \( C^0 \) represents the total carbon dioxide emissions during the \( t \)th period, and \( C^0 \) represents the total carbon dioxide emissions during the base period.

Under the current technological level and technological development, considering the driving factors of energy structure optimization, the replacement of renewable energy is the most important factor. Due to the nonrenewability of traditional energy, the development of alternative energy and the development and utilization of new energy have become the focus of research. Bastianoni et al. [27] used renewable energy and nonrenewable energy to build a model and concluded that the only way to achieve sustainable economic and social development is to use traditional nonrenewable energy while increasing investment in alternative renewable energy. Sustainable development is realized by improving the energy structure. Therefore, the optimization of the energy structure is, on the one hand, the optimal allocation of traditional energy sources such as coal and oil and, on the other hand, the increase in the replacement rate of renewable energy sources. We decompose the comprehensive carbon emission coefficient change ratio \( e \) brought about by the optimization of the energy structure into the sum of two effects, namely,

\[ e = \alpha_t + \beta_t, \quad (9) \]

\[ \alpha_t = \frac{\sum (R_i - R_{i(t-1)})}{R_{i(t-1)}}, \]

\[ \beta_t = \frac{(N_t/E_t) - (N_{t-1}/E_{t-1})}{N_{t-1}/E_{t-1}}. \quad (10) \]

Among them, \( N \) represents the total consumption of renewable energy in primary energy consumption, including clean energy such as hydropower, bioenergy, solar energy, and nuclear energy. \( \beta \) represents the change rate of the carbon emission coefficient affected by the change in the replacement rate of renewable energy, and then \( \alpha \) indicates the change ratio of the carbon emission coefficient of the optimal allocation of coal, oil, and other traditional energy.
sources on the energy structure. The carbon dioxide emissions during $t$ are finally expressed as

$$C^t = C^0 (1 + r)^t (1 - g)^t (1 - \alpha - \beta)^t. \quad (11)$$

2.2. Data Sources and Parameter Prediction

2.2.1. Data Sources. The carbon dioxide emissions produced by human activities mainly come from energy consumption. In a large number of previous studies, scholars have used the carbon dioxide emissions of total energy consumption to represent the total carbon emissions of a certain area. In this paper, the carbon emissions of provinces around the Bohai Sea are also calculated in this way, and the actual carbon emissions of each province are calculated by the energy consumption cost of each province and its corresponding carbon emission coefficient. The actual carbon emissions of the provinces and cities in the Bohai Sea Rim from 2000 to 2018 are calculated based on the consumption of various major energy sources and the corresponding carbon emission indexes. The major energy sources include coal, oil, and natural gas, the consumption of which is based on the relevant data in the Statistical Yearbook (2001–2020) of all provinces in the Bohai Rim region. The national carbon dioxide emissions are calculated using the carbon emission coefficient method. The carbon emission coefficient of coal, oil, and natural gas is 0.7476 kg carbon/kg standard coal, 0.5825 kg carbon/kg standard coal, and 0.4435 kg carbon/kg standard coal, respectively, and the relevant data released by the Energy Research Institute of the National Development and Reform Commission are adopted to calculate the national carbon emissions.

Figure 1 shows the calculated changes in actual carbon emissions of the provinces in the Bohai Sea Rim from 2000 to 2018. The calculation results show that Shandong and Shanxi provinces are large in population and energy, and the total carbon emissions of Shandong and Shanxi provinces are more than other provinces in the region, and the overall trend is increasing year by year. The total carbon emissions in Shandong province dropped significantly in 2013. In this year, the Shandong Provincial Party Committee and the Provincial Government attached great importance to the prevention and control of air pollution and successively implemented the Shandong Province 2013–2020 Air Pollution Prevention and Control Plan, and the Air Pollution Prevention and Control Plan Phase I (2013–2015) Action Plan has achieved certain results. Due to geographical factors, its own climate, and industrial development, the total carbon emissions in Hebei province are relatively high, while those in Inner Mongolia and Liaoning are slightly lower. Beijing and Tianjin, as the two major municipalities in the Beijing-Tianjin-Hebei region, have lower total carbon emissions than other provinces in the region, but the overall trend is slowly increasing.

Figure 2 shows the actual carbon emission change rate of the provinces in the Bohai Rim region from 2000 to 2019. It can be seen that the overall carbon emission growth rate in the Bohai Rim region is declining year by year. Shanxi province and Shandong province experienced negative growth in total carbon emissions in 2014 and 2015, respectively. Liaoning province and Inner Mongolia also experienced negative growth in total carbon emissions in 2013. The growth rate of carbon emissions in Beijing has been at a relatively low level. In 2020, Beijing’s carbon intensity was expected to drop by more than 23% in 2015, exceeding the goal of the 13th Five-Year Plan. Carbon emissions are the lowest in the provinces of the country. Beijing is one of the first provinces and cities in the country to carry out carbon emission trading pilot projects. In 2013, the carbon market was officially launched. As of the end of 2020, there were 843 key carbon emission units incorporated into the Beijing pilot carbon market management, covering 8 industries including electricity, heating, and aviation. The overall growth rate of carbon emissions in Tianjin has shown a downward trend year by year and achieved negative growth in 2017.

2.2.2. Parameter Prediction

(1) Gross Domestic Product. This paper uses the quadratic parabolic model $y_t = a + bt + ct^2$ to predict GDP. From the new normal stage to the high-quality development stage, the GDP growth rate in the Bohai Rim region has hovered around 6%. In recent years, the average GDP growth rates of Shandong province, Liaoning province, Hebei province, Shanxi province, Inner Mongolia, Beijing, and Tianjin are around 7.3%, 4.5%, 7.1%, 6.5%, 5.6%, 7.2%, and 6.1%, respectively. Using the quadratic parabola method of GDP and time to forecast, with three scenarios from 2000 to 2020, 2005 to 2020, and 2010 to 2020, the GDP from 2021 to 2050 (constant prices in 2005) is predicted. The annual growth rate of GDP in the three base periods is calculated from the predicted GDP of each province, as shown in Tables 1 and 2.

(2) Energy Intensity. This paper uses an improved GM (1, 1) model to predict the energy intensity of each province. The GM (1, 1) with fractional Hausdorff accumulation model is a univariate first-order differential equation. A nonnegative sequence is $X^{(0)} = \{x^{(0)} (1), x^{(0)} (2), \ldots, x^{(0)} (n)\}$. This article refers to the grey model method with the fractional Hausdorff derivative proposed by Yan et al. [28], which improves the prediction accuracy of the traditional grey model. There are large differences in energy intensity and its changes in various provinces due to the influence of factors such as population, geographical environment, and economic and social development level. Three scenarios with 2000–2020, 2005–2020, and 2010–2020 as the base years are used to predict the energy intensity of each province from 2021 to 2050. Other provinces are also treated in the same way, and the annual average decline rate of energy intensity in each province under the three scenarios is calculated as shown in Table 3.

According to the energy intensity forecasts of various provinces, it can be seen that Shanxi province is rich in mineral resources, with reserves of 276,785 billion tons of coal. The total energy consumption is relatively large. From 2000 to 2010, the average annual energy intensity reached...
Figure 1: Total carbon emissions of provinces in the Bohai Rim region (unit: 10,000 tons).

Figure 2: The rate of change of carbon emissions by provinces in the Bohai Rim region (unit: %).
96,000 tons of standard coal per 100 million yuan, making it the province with the highest energy intensity in the Bohai Rim. The main reason is that Shanxi province is in a period of vigorously developing heavy industry, and the heavy-duty economy has brought high energy consumption, which has led to a rapid increase in energy consumption. However, energy intensity basically shows a downward trend year by year. After 2010, Shanxi province’s National Resource-Based Economy Transformation Comprehensive Supporting Reform Pilot Zone was officially approved. During the “Thirteenth Five-Year Plan” period, with the improvement of energy utilization efficiency and the continuous adjustment of the industrial structure in Shanxi province, the trend of energy intensity decline is obvious.

Since 2000, the energy intensity of Shandong province, Beijing city, and Tianjin city has not exceeded 20,000 tons of standard coal per 100 million yuan. They have maintained a relatively stable downward trend. In particular, Beijing reached 21,000 tons of standard coal per 100 million yuan in 2019. In recent years, Beijing has continued to promote industrial structure optimization and clean energy transformation. Vigorous efforts have been made to relieve non-capital functions, and coal consumption has dropped drastically. As one of the first pilot provinces and cities to carry out carbon emission trading in the country, Beijing has officially launched the carbon market since 2013. A total of 843 key carbon emission units have been incorporated into Beijing’s pilot carbon market management. By the end of 2020, Beijing’s carbon intensity was expected to drop by more than 23% in 2015, exceeding the goal of the “Thirteenth Five-Year Plan.” The successful pilot in Beijing has provided certain experience for the Bohai Rim provinces. The development of carbon emission trading has effectively promoted the reduction of energy intensity, thereby further conducting research on special plans for carbon emission reduction based on the vision of carbon neutrality.

The energy intensities of the Inner Mongolia Autonomous Region, Liaoning province, and Hebei province are all falling steadily in the range of 8,000 to 25,000 tons of standard coal per 100 million yuan. They are relatively lagging behind Hebei province in terms of geographical factors and technological development. However, in recent years, the energy structure of the Inner Mongolia Autonomous Region has been further optimized, and green coal mines account for 1/3 of production coal mines. Liaoning province has joined universities and other research institutions to continuously explore scientific and technological innovation in the energy field to improve energy utilization.

### Table 1: Prediction of annual growth rate of GDP of Shandong, Liaoning, Hebei, and Shanxi from 2021 to 2050 (unit: %).

| PR       | Shandong | Liaoning | Hebei | Shanxi |
|----------|----------|----------|-------|--------|
| 2021     | 6.69     | 6.08     | 5.81  | 5.60   |
| 2022     | 6.47     | 5.85     | 5.56  | 5.30   |
| 2023     | 6.27     | 5.64     | 5.33  | 5.25   |
| 2024     | 6.08     | 5.44     | 5.12  | 5.21   |
| 2025     | 5.89     | 5.26     | 4.92  | 5.17   |
| 2026     | 5.72     | 5.09     | 4.75  | 5.12   |
| 2027     | 5.56     | 4.93     | 4.58  | 5.09   |
| 2028     | 5.41     | 4.78     | 4.43  | 5.05   |
| 2029     | 5.27     | 4.65     | 4.29  | 4.98   |
| 2030     | 5.13     | 4.52     | 4.16  | 4.83   |
| 2031     | 5.00     | 4.40     | 4.04  | 4.75   |
| 2032     | 4.88     | 4.28     | 3.92  | 4.61   |
| 2033     | 4.76     | 4.17     | 3.81  | 4.58   |
| 2034     | 4.65     | 4.07     | 3.71  | 4.45   |
| 2035     | 4.54     | 3.98     | 3.62  | 4.32   |
| 2036     | 4.44     | 3.88     | 3.53  | 4.28   |
| 2037     | 4.34     | 3.80     | 3.44  | 4.17   |
| 2038     | 4.25     | 3.71     | 3.36  | 4.04   |
| 2039     | 4.16     | 3.63     | 3.28  | 3.89   |
| 2040     | 4.08     | 3.56     | 3.21  | 3.74   |
| 2041     | 3.99     | 3.49     | 3.14  | 3.62   |
| 2042     | 3.92     | 3.42     | 3.07  | 3.51   |
| 2043     | 3.84     | 3.35     | 3.01  | 3.47   |
| 2044     | 3.77     | 3.29     | 2.95  | 3.34   |
| 2045     | 3.70     | 3.23     | 2.89  | 3.21   |
| 2046     | 3.63     | 3.17     | 2.84  | 3.16   |
| 2047     | 3.56     | 3.11     | 2.79  | 3.03   |
| 2048     | 3.50     | 3.06     | 2.73  | 2.97   |
| 2049     | 3.44     | 3.01     | 2.69  | 2.82   |
| 2050     | 3.38     | 2.96     | 2.64  | 2.76   |

Table 1: Prediction of annual growth rate of GDP of Shandong, Liaoning, Hebei, and Shanxi from 2021 to 2050 (unit: %).
efficiency. In recent years, the energy intensity of Liaoning province has declined slightly. Energy intensity in 2019 has increased compared with 2018.

Comparing the annual reduction rate of energy intensity of each province in the comparison table, it can be found that Shandong province has a relatively high reduction rate in recent years, and the reduction rate of other provinces in recent years is lower than in previous years. Beijing had a high rate of energy intensity reduction before 2010, and it has maintained a steady downward trend in recent years. Liaoning province has the lowest energy intensity reduction rate in the Bohai Rim region after 2010. The other provinces and cities in the descending order are Inner Mongolia, Tianjin, Beijing, Shanxi, Hebei, and Shandong. Liaoning province and the Inner Mongolia Autonomous Region have low rates of energy intensity reduction due to geographical factors and relatively backward technological development. As municipalities directly under the Central Government, Tianjin and Beijing have relatively low energy intensity, and the degree of decline has been slowed. Shanxi province and Hebei province rely on the adjustment of the energy structure and the upgrading of industries, and their energy intensity has fallen to a relatively high level. Shandong province is rich in energy resources, emphasizes the industrial structure, and has prominent problems such as a high proportion of coal consumption. However, during the ”13th Five-Year Plan” period, Shandong province seized the opportunity to rapidly promote the construction of new energy and renewable energy projects. Significant

### Table 2: Prediction of annual growth rate of GDP of Inner Mongolia, Beijing, Tianjin from 2021 to 2050 (unit: %).

| PR     | Inner Mongolia | Beijing | Tianjin |
|--------|----------------|---------|---------|
| Base period | 2000 | 2005 | 2010 | 2000 | 2005 | 2010 | 2000 | 2005 | 2010 |
| 2021   | 5.72 | 7.04 | 6.09 | 5.25 | 5.29 | 5.62 | 6.46 | 5.51 | 7.56 |
| 2022   | 5.55 | 6.77 | 5.75 | 5.09 | 5.13 | 5.48 | 6.24 | 5.27 | 7.24 |
| 2023   | 5.38 | 6.33 | 5.45 | 4.95 | 4.98 | 5.34 | 6.03 | 5.04 | 6.94 |
| 2024   | 5.23 | 6.3 | 5.18 | 4.81 | 4.84 | 5.21 | 5.84 | 4.83 | 6.67 |
| 2025   | 5.09 | 6.09 | 4.93 | 4.68 | 4.71 | 5.09 | 5.66 | 4.65 | 6.43 |
| 2026   | 4.96 | 5.9 | 4.7 | 4.55 | 4.59 | 4.97 | 5.5 | 4.47 | 6.2 |
| 2027   | 4.83 | 5.72 | 4.5 | 4.44 | 4.47 | 4.85 | 5.34 | 4.31 | 5.98 |
| 2028   | 4.71 | 5.55 | 4.31 | 4.33 | 4.36 | 4.74 | 5.19 | 4.16 | 5.75 |
| 2029   | 4.60 | 5.38 | 4.13 | 4.22 | 4.25 | 4.64 | 5.05 | 4.03 | 5.37 |
| 2030   | 4.49 | 5.23 | 3.97 | 4.12 | 4.15 | 4.54 | 4.92 | 3.90 | 5.16 |
| 2031   | 4.38 | 5.09 | 3.82 | 4.03 | 4.06 | 4.44 | 4.79 | 3.78 | 4.73 |
| 2032   | 4.29 | 4.96 | 3.68 | 3.94 | 3.97 | 4.35 | 4.68 | 3.66 | 4.65 |
| 2033   | 4.19 | 4.83 | 3.54 | 3.85 | 3.88 | 4.26 | 4.56 | 3.56 | 4.37 |
| 2034   | 4.10 | 4.71 | 3.42 | 3.77 | 3.8 | 4.17 | 4.46 | 3.46 | 4.25 |
| 2035   | 4.02 | 4.6 | 3.3 | 3.7 | 3.72 | 4.09 | 4.36 | 3.36 | 4.1 |
| 2036   | 3.93 | 4.49 | 3.19 | 3.62 | 3.65 | 4.01 | 4.26 | 3.28 | 3.97 |
| 2037   | 3.85 | 4.38 | 3.09 | 3.55 | 3.58 | 3.94 | 4.17 | 3.19 | 3.82 |
| 2038   | 3.78 | 4.29 | 2.99 | 3.48 | 3.51 | 3.86 | 4.08 | 3.11 | 3.68 |
| 2039   | 3.71 | 4.19 | 2.9 | 3.42 | 3.44 | 3.79 | 3.99 | 3.04 | 3.54 |
| 2040   | 3.64 | 4.1 | 2.81 | 3.35 | 3.38 | 3.72 | 3.91 | 2.96 | 3.42 |
| 2041   | 3.57 | 4.02 | 2.73 | 3.29 | 3.32 | 3.66 | 3.83 | 2.90 | 3.3 |
| 2042   | 3.5 | 3.93 | 2.64 | 3.23 | 3.26 | 3.59 | 3.76 | 2.83 | 3.19 |
| 2043   | 3.44 | 3.85 | 2.57 | 3.18 | 3.2 | 3.53 | 3.69 | 2.77 | 3.09 |
| 2044   | 3.38 | 3.78 | 2.49 | 3.12 | 3.15 | 3.47 | 3.62 | 2.71 | 2.99 |
| 2045   | 3.32 | 3.71 | 2.42 | 3.07 | 3.09 | 3.41 | 3.55 | 2.65 | 2.9 |
| 2046   | 3.27 | 3.64 | 2.35 | 3.02 | 3.04 | 3.36 | 3.49 | 2.6 | 2.81 |
| 2047   | 3.21 | 3.57 | 2.29 | 2.97 | 2.99 | 3.3 | 3.43 | 2.54 | 2.73 |
| 2048   | 3.16 | 3.5 | 2.22 | 2.93 | 2.95 | 3.25 | 3.37 | 2.49 | 2.64 |
| 2049   | 3.11 | 3.44 | 2.16 | 2.88 | 2.9 | 3.2 | 3.31 | 2.44 | 2.57 |
| 2050   | 3.06 | 3.38 | 2.1 | 2.84 | 2.86 | 3.15 | 3.25 | 2.4 | 2.49 |

### Table 3: Forecast value of annual energy intensity reduction in each province.

| Province         | 2000–2020 (%) | 2005–2020 (%) | 2010–2020 (%) | Annual average (%) |
|------------------|---------------|---------------|---------------|--------------------|
| Shandong         | 4.25          | 5.80          | 7.12          | 5.72               |
| Liaoning         | 5.24          | 4.14          | 1.02          | 3.47               |
| Hebei            | 6.12          | 6.42          | 3.99          | 5.51               |
| Shanxi           | 5.39          | 4.10          | 2.93          | 4.14               |
| Inner Mongolia   | 6.91          | 4.70          | 1.74          | 4.45               |
| Beijing          | 9.56          | 6.44          | 2.72          | 6.24               |
| Tianjin          | 7.10          | 4.20          | 1.83          | 4.38               |
achievements have been made in the transition to a green and low-carbon energy structure. Since 2020, the province’s installed capacities of photovoltaic power generation and biological power generation have both ranked first in the country, and the energy intensity has fallen sharply.

(3) Setting the Replacement Rate of Renewable Energy and Other Parameters. On the basis of calculating the number of renewable energy replacement rates of 2000–2020, 2005–2020, and 2010–2020, according to the prediction of energy intensity under three scenarios, the change ratio \( \beta \) of the carbon emission coefficient affected by the replacement rate of renewable energy and the change ratio \( \alpha \) of the carbon emission coefficient affected by the optimal allocation of traditional energy such as coal and oil on the energy structure were set under the three scenarios, as shown in Table 4 (\( \alpha \)) and Table 5 (\( \beta \)).

### 3. The Prediction of Carbon Emissions of Various Provinces in the Bohai Rim Region

The aforementioned domestic product, energy intensity, renewable energy replacement rate change ratio, and coal, oil, and other traditional energy optimization configurations affect the rate of the energy structure of the carbon emission coefficient of the carbon emission factor belt in formula (11). The total amount of carbon emissions in the provinces under three scenarios and the peak of carbon emissions in various provinces are shown in Figures 3–5.

Based on the above prediction results, the following results can be drawn:

1. After 2020, the total carbon emission forecasts of the provinces and cities in the Bohai Rim are from high to bottom: Shanxi province, Shandong province, Hebei province, Liaoning province, Inner Mongolia, Tianjin, and Beijing. Although there are differences in the growth of total carbon emissions among provinces and cities, the proportion of overall emissions in the Bohai Rim region has not changed much. Shandong province and Shanxi province, as the most populous provinces and energy provinces, have higher overall carbon emissions than other provinces in the region. The pressure to reduce emissions will be relatively greater in the future. Beijing and Tianjin are municipalities directly under the Central Government, and their total carbon emissions are lower than other provinces in the region. In the next few years, priority should be given to achieving “carbon neutrality” as a strategic goal. Beijing has also established the country’s first “carbon neutral” park to form a benchmark experience of “carbon neutral” as soon as possible, providing a reference for further emission reductions in other regions around the Bohai Sea.

2. On the premise that all provinces and cities in the Bohai Rim region continue to promote and maintain high-quality development, all provinces and cities can reach their peak carbon emissions around 2030 under the three prediction scenarios. However, there are obvious differences in the peak situation of each province.

(3) Beijing predicts that it will reach its carbon peak in 2025. If under the background of the base period in 2000, Beijing could reach its carbon peak in 2021. In recent years, Beijing has continued to promote the optimization of the industrial structure and the transition to clean energy, and the amount of coal burned has dropped significantly. In this case, the replacement of renewable energy sources and the development of renewable energy sources are critical to achieving peak carbon. Tianjin and Beijing are very similar in terms of peaking carbon emissions,

### Table 4: Prediction of a parameter under three scenarios.

| Province   | Years     | 2000–2020 | 2005–2020 | 2010–2020 |
|------------|-----------|-----------|-----------|-----------|
| Shandong   | 2021–2025 | -0.009    | -0.040    | -0.090    |
|            | 2026–2030 | -0.006    | -0.037    | -0.087    |
|            | 2031–2035 | -0.003    | -0.034    | -0.084    |
|            | 2036–2040 | 0         | -0.031    | -0.081    |
|            | 2041–2045 | 0.003     | -0.029    | -0.079    |
|            | 2046–2050 | 0.006     | -0.026    | -0.076    |
| Liaoning   | 2021–2025 | -0.008    | -0.004    | 0.008     |
|            | 2026–2030 | -0.004    | 0         | 0.012     |
|            | 2031–2035 | 0         | 0.004     | 0.016     |
|            | 2036–2040 | 0.004     | 0.008     | 0.02      |
|            | 2041–2045 | 0.008     | 0.012     | 0.022     |
|            | 2046–2050 | 0.012     | 0.016     | 0.024     |
| Hebei      | 2021–2025 | -0.004    | 0.001     | 0.001     |
|            | 2026–2030 | -0.002    | 0.003     | 0.003     |
|            | 2031–2035 | 0         | 0.005     | 0.005     |
|            | 2036–2040 | 0.002     | 0.007     | 0.007     |
|            | 2041–2045 | 0.004     | 0.009     | 0.009     |
|            | 2046–2050 | 0.006     | 0.011     | 0.011     |
| Shanxi     | 2021–2025 | -0.003    | -0.002    | -0.008    |
|            | 2026–2030 | -0.005    | 0         | -0.006    |
|            | 2031–2035 | -0.002    | 0.005     | -0.004    |
|            | 2036–2040 | 0.001     | 0.008     | -0.002    |
|            | 2041–2045 | 0.004     | 0.011     | 0.005     |
|            | 2046–2050 | 0.007     | 0.014     | 0.006     |
| Inner Mongolia | 2021–2025 | -0.003    | -0.002    | -0.002    |
|            | 2026–2030 | -0.001    | 0         | -0.002    |
|            | 2031–2035 | 0.001     | 0.007     | 0.011     |
|            | 2036–2040 | 0.003     | 0.004     | 0.014     |
|            | 2041–2045 | 0.005     | 0.006     | 0.015     |
|            | 2046–2050 | 0.007     | 0.008     | 0.002     |
| Beijing   | 2021–2025 | 0.006     | 0.006     | 0.01      |
|            | 2026–2030 | 0.007     | 0.007     | 0.011     |
|            | 2031–2035 | 0.008     | 0.008     | 0.012     |
|            | 2036–2040 | 0.009     | 0.009     | 0.013     |
|            | 2041–2045 | 0.010     | 0.010     | 0.014     |
|            | 2046–2050 | 0.011     | 0.011     | 0.015     |
| Tianjin   | 2021–2025 | -0.001    | -0.002    | -0.002    |
|            | 2026–2030 | 0         | -0.001    | 0         |
|            | 2031–2035 | 0.001     | 0         | 0.002     |
|            | 2036–2040 | 0.002     | 0.001     | 0.004     |
|            | 2041–2045 | 0.003     | 0.002     | 0.006     |
|            | 2046–2050 | 0.004     | 0.003     | 0.008     |
and they are expected to peak in 2024. If 2010 is the base period, it will reach its peak in 2030. Faced with the goal of carbon peaking, Tianjin city still has considerable pressure and challenges.

(4) Shandong province is expected to reach its carbon peak before 2028. If in the context of the 2010 base period, the peak goal will be achieved in 2031. Shandong province itself is a big energy-consuming province, and it is also a big coal-consuming province. The energy structure is biased towards coal, the energy intensity is too high, and the replacement rate of renewable energy is relatively low. The peaking process still needs to actively reduce energy intensity and, at the same time, develop renewable energy. Shanxi province and Shandong province have similar problems. Shanxi province is predicted to reach its peak in 2027 or even 2030. As a large industrial province, Liaoning province also has problems with its industrial structure and high energy intensity. It is predicted that the carbon peak will be reached in 2027.

(5) As an important province to relieve Beijing’s non-capital pressure, Hebei province is under pressure to reduce emissions. However, relying on Beijing itself, renewable energy utilization technology is relatively advanced. In recent years, the industrial structure has been continuously optimized, and energy intensity has declined rapidly. It is predicted that the

| Province | Years    | 2000–2020 | 2005–2020 | 2010–2020 |
|----------|----------|-----------|-----------|-----------|
| Shandong | 2021–2025| 0.020     | 0.030     | 0.040     |
|          | 2026–2030| 0.022     | 0.032     | 0.045     |
|          | 2031–2035| 0.024     | 0.034     | 0.050     |
|          | 2036–2040| 0.026     | 0.036     | 0.055     |
|          | 2041–2045| 0.028     | 0.038     | 0.060     |
|          | 2046–2050| 0.030     | 0.040     | 0.065     |
|         | 2021–2025| −0.001    | 0.001     | 0.001     |
|          | 2026–2030| 0         | 0.003     | 0.003     |
|          | 2031–2035| 0.001     | 0.005     | 0.005     |
|          | 2036–2040| 0.002     | 0.007     | 0.007     |
|          | 2041–2045| 0.003     | 0.009     | 0.009     |
|          | 2046–2050| 0.004     | 0.011     | 0.011     |
| Liaoning | 2021–2025| 0.002     | 0.007     | 0.010     |
|          | 2026–2030| 0.004     | 0.008     | 0.012     |
|          | 2031–2035| 0.006     | 0.009     | 0.014     |
|          | 2036–2040| 0.008     | 0.010     | 0.016     |
|          | 2041–2045| 0.010     | 0.011     | 0.018     |
|          | 2046–2050| 0.012     | 0.012     | 0.020     |
| Hebei    | 2021–2025| −0.008    | 0.010     | 0.010     |
|          | 2026–2030| −0.006    | 0.012     | 0.020     |
|          | 2031–2035| −0.004    | 0.014     | 0.030     |
|          | 2036–2040| −0.002    | 0.016     | 0.040     |
|          | 2041–2045| 0         | 0.018     | 0.050     |
|          | 2046–2050| 0.002     | 0.02      | 0.060     |
| Shanxi   | 2021–2025| 0.010     | 0.015     | 0.020     |
|          | 2026–2030| 0.015     | 0.020     | 0.025     |
|          | 2031–2035| 0.020     | 0.025     | 0.030     |
|          | 2036–2040| 0.025     | 0.030     | 0.035     |
|          | 2041–2045| 0.030     | 0.035     | 0.040     |
|          | 2046–2050| 0.035     | 0.040     | 0.045     |
| Inner Mongolia | 2021–2025| 0.003     | 0.004     | 0.002     |
|           | 2026–2030| 0.005     | 0.006     | 0.005     |
|           | 2031–2035| 0.007     | 0.008     | 0.008     |
|           | 2036–2040| 0.009     | 0.010     | 0.011     |
|           | 2041–2045| 0.011     | 0.012     | 0.014     |
|           | 2046–2050| 0.013     | 0.014     | 0.017     |
| Beijing  | 2021–2025| 0         | 0.010     | 0.014     |
|           | 2026–2030| 0.005     | 0.012     | 0.016     |
|           | 2031–2035| 0.010     | 0.014     | 0.018     |
|           | 2036–2040| 0.015     | 0.016     | 0.020     |
|           | 2041–2045| 0.020     | 0.018     | 0.022     |
|           | 2046–2050| 0.025     | 0.020     | 0.024     |
Figure 3: Carbon emissions of each province and city under the 2000–2020 scenario (unit: 10,000 tons).

Figure 4: Carbon emissions of each province and city under the 2005–2020 scenario (unit: 10,000 tons).
The carbon peak will be reached before 2026. The Inner Mongolia Autonomous Region predicts that the carbon peak will be reached in 2025. However, under the scenario of 2010 as the base period, the carbon peak is expected to be reached in 2029. Energy intensity has decreased rapidly, but the utilization rate of renewable energy has increased slowly.

4. Conclusions and Recommendations

Based on the analysis of the above prediction results and comparing the carbon emissions of the provinces and cities around the Bohai Sea, this article puts forward the following suggestions:

(1) In recent years, Beijing has continued to promote the optimization of the industrial structure and the transition to clean energy. The amount of coal burned has dropped significantly, and the energy intensity is relatively low. The carbon intensity of Beijing has dropped significantly since the pilot work of carbon emission trading was launched. In 2020, Beijing’s carbon intensity was expected to drop by more than 23% in 2015. The successful pilot in Beijing has provided certain experience for the Bohai Rim provinces. The development of carbon emission trading has effectively promoted the reduction of carbon intensity. Beijing has also established the country’s first “carbon neutral” park to form a benchmark experience of “carbon neutral” as soon as possible, providing a reference for further emission reductions in other regions around the Bohai Sea. Therefore, we will further carry out research on the special plan of carbon emission reduction based on the vision of carbon neutrality and prioritize the realization of “carbon neutrality” as a strategic goal.

(2) Based on the measures taken by Beijing, Tianjin should combine the peaking target with the “14th Five-Year Plan” outline, the energy consumption “dual control” target, and major engineering projects. Tianjin should perfect the scientific research index system and form a complete action plan. We must do a good job not only in the addition of renewable energy but also do a good job in the “subtraction” of reducing coal consumption. Pay close attention to key areas of high energy consumption and provide a good development environment for environmental protection industries such as photovoltaics, hydrogen energy, and green energy conservation. Hebei province should firmly grasp high-tech and use artificial intelligence and big data platforms to actively promote the construction of carbon-inclusive pilots and enrich the low-carbon reward mechanism.

(3) Shandong province, as a major energy-consuming province, faces certain challenges in reaching the peak goal. However, in recent years, it has established the energy structure adjustment target of coal power, new energy and renewable energy, and electricity from outside the province. This provides the basis for further adjustment of the energy structure of Shandong province. Haiyang of Shandong province has become the country’s first “zero-carbon” heating city using nuclear energy technology. Therefore,
Shandong should accelerate the comprehensive utilization of nuclear energy as soon as possible and regard the development of nuclear energy as an important starting point for promoting energy structure optimization and ensuring energy security. Shanxi province and Shandong province have similar problems. Shanxi province should also vigorously develop clean energy, promote the transformation of “three counties and one city” clean heating according to local conditions, and accelerate the access of key coal mining enterprises to special railway lines. Shanxi should pay more attention to emission reduction in key areas of high energy consumption, find out the source of emissions, and provide special emission reduction guidance to key enterprises in key industries.

(4) Liaoning province is a major industrial province in the northeast. Energy consumption focuses on coal, and the industrial structure is uneven. The task of peaking carbon is very difficult. It is necessary to further understand the current status of carbon emissions and formulate specific action plans. Low-carbon transformation and upgrading in energy, industry, construction, agriculture, and forestry should be coordinated and promoted. Resolutely curb the blind development of energy-intensive and high-emission projects. Actively carry out the creation of low-carbon pilot demonstration projects. Promote the construction of zero-emission demonstration projects and carbon neutral demonstration zones. Provide a model for Liaoning province to reach the peak as soon as possible.

(5) The Inner Mongolia Autonomous Region should actively learn from Beijing’s relevant measures. Encourage enterprises to accelerate the implementation of carbon emission management and actively participate in the upcoming carbon emission market transactions. Strengthen the professional training of relevant carbon emission management personnel at different levels and stages, and reduce the total amount of carbon emissions starting from the enterprise industry. There are certain challenges in achieving the goal of achieving carbon peaks in the Bohai Rim as a whole. It should be advanced to drive the backward, focusing on the three provinces of Shandong, Shanxi, and Liaoning that are difficult to reach the peak. Actively try to implement measures to form an effective emission reduction model that can be replicated so as to fully realize the regional emission reduction target in the Bohai Rim.

Data Availability

Previously reported data were used to support this study and are available at http://tjj.shandong.gov.cn/col/col6279/index.html, http://tjj.hebei.gov.cn/hetj/tjsj/jnj/, http://tjj.beijing.gov.cn/tjsj_31433/, http://stats.tj.gov.cn/tjsj_52032/tnj/, http://tjj.ln.gov.cn/tjsj/sjcx/ndsj/, http://tjj.shanxi.gov.cn/tjsj/tnj/, and http://tjj.nmg.gov.cn/datashow/index.htm.

Ethical Approval

Not Applicable.

Consent

Not Applicable.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors’ Contributions

Chuanhui Wang conceptualized the study, developed the methodology, wrote the original draft, and contributed to funding acquisition. Mengzhen Zhao investigated the study, administered the project, and performed formal analysis. Weifeng Gong performed formal analysis and reviewed and edited the article. Zhenyue Fan and Wenwen Li jointly collected and collated data.

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