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Evaluation of Carbon Emission and Carbon Contribution Capacity Based on the Beijing–Tianjin–Hebei Region of China

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Abstract: In 2020, during the 75th United Nations General Assembly, China proposed the goal of "achieving a carbon peak by 2030 and achieving carbon neutrality by 2060". The Beijing–Tianjin–Hebei region is the largest carbon emission metropolitan area in China. Its energy consumption and carbon emission status means the Beijing–Tianjin–Hebei region shoulders the important task of low-carbon transformation. Only by achieving a "carbon peak" and "carbon neutrality" can the economy of the Beijing–Tianjin–Hebei region be sustainable. Based on this, we analyzed and comprehensively evaluated the complete ability of the Beijing–Tianjin–Hebei region to achieve carbon neutrality in 2008–2020, that is, carbon achievement ability, status, and intensity of energy consumption and carbon emissions based on the CRITIC weighting method. The results show that the energy consumption and carbon emission capacity of the Beijing–Tianjin–Hebei region have basically formed a step difference. On this basis, the evaluation of carbon contribution capacity also shows that Hebei Province, as a weak link in the coordinated development of the Beijing–Tianjin–Hebei region, bears the main responsibility of improving carbon contribution capacity and thus achieving the goal of carbon neutrality. This research study suggests that intra-regional cooperation should be strengthened to achieve coordinated development. At the end of the paper, policy suggestions for regional cooperation are given from four aspects: government, industry, low-carbon technology, and regional carbon sinks.

Keywords: CRITIC weighting method; carbon peak; carbon neutral; carbon achieved

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1. Introduction

In recent years, the world has paid more attention to the environmental problem of global warming. In order to deal with climate change, the Paris Agreement proposed a temperature control target of 1.5 °C, which came into force in 2016 [1,2]. Along with upgraded Chinese industry and the continuous progress of industrialization processes, and also considering the development experience of developed countries, carbon emissions will increase gradually with further industrialization and will decrease somewhat after they reach a certain level (i.e., peak value) [3,4]. In addition, coal is a high-carbon resource, accounting for nearly 60% of the country's energy structure. As the world's largest carbon emitting country and coal power country, China actively implements the Paris Climate Agreement to reach the peak as soon as possible and gradually realize near zero carbon emissions, thus showing its responsibility as a big country in building a community with a shared future, which is also an inevitable requirement for China if it hopes to realize sustainable development during modernization [5]. This plan is also consistent with China's goal of basically realizing modernization by 2035 and building a great modern socialist country and a beautiful China by the middle of this century [6,7].

A country is composed of many provinces and municipalities, and it is difficult for the academic community to make a clear demarcation of greenhouse gas emissions. In fact, it requires the full cooperation of each region, and environmental governance itself cannot be separated from collaborative governance [8]. Among China's four metropolitan areas (Beijing–Tianjin–Hebei Metropolitan Area, Yangtze River Delta Metropolitan Area, Aohai–Hong Kong–Macao Greater Bay Area and Chengdu–Chongqing City Group), the Beijing–Tianjin–Hebei Metropolitan Area is located in the political and economic center of the country with unique advantages, but it is also the largest carbon emitting metropolitan area in China. The huge contrast with other urban agglomerations and the current situation in terms of energy consumption and carbon emissions also shows that the Beijing–Tianjin–Hebei region is shouldering the important task of low-carbon transition [9].

In addition, the energy consumption and carbon emissions of Beijing, Tianjin, and Hebei are very different. Hebei's carbon emissions are nearly five times that of Tianjin and seventeen times that of Beijing. It can be seen that the energy structure of Beijing, Tianjin, and Hebei is extremely unbalanced. Improving the energy utilization rate and carbon emission reductions in Hebei Province is an urgent requirement. The Beijing–Tianjin–Hebei region has a high degree of industrialization and a large amount of carbon emissions. Accordingly, the task of carbon emission reduction is becoming more and more arduous, and it plays a pivotal role in the realization of the carbon neutralization plan. In view of this, this paper focuses on the investigation and analysis of energy consumption and carbon emissions in the Beijing–Tianjin–Hebei region and further evaluates and studies the carbon contribution capacity of the region so as to obtain some comprehensive suggestions and decisions that are needed by the Beijing–Tianjin–Hebei region if it is to achieve the goal of carbon neutrality. This study also explores the path to maximizing the effects and benefits of these suggested changes.

2. Research Methods

2.1. Literature Research

In the field of green low-carbon development, the problem of carbon emissions and emission intensity has attracted the interest of scholars in China, who have conducted a considerable amount of research. In this paper, our review of the literature will be roughly divided into several categories. The first includes studies on carbon emissions and energy consumption problems. For example, one group built a scenario analysis model to explore and predict trends in the relationship between energy consumption and carbon emissions in Shanghai; the authors concluded that the short-term rising trend will not change and forecasted that the maximum would be reached by around 2040 [10]. The second category includes research on carbon emissions and economic growth. For example, Peng et al. and Ga et al. explored the development trend of carbon emissions based on energy consumption and economic growth in the coastal areas of China and Liaoning [11,12]. The third category includes studies on carbon emissions and industrial upgrading research. Considering the high pollution and high energy consumption of industries undergoing low-carbon development, Wang et al. analyzed the driving influence of carbon emissions on industrial transfer and upgrading using Guangdong Province as a research area [13]. Overall, research on the influence of carbon emissions in China covers many aspects, and its scope includes domestic-, provincial-, and prefecture-level studies.

With the current two-phased "carbon peak" and "carbon neutral" goals, scholars in our country have further enriched research on carbon emissions. For example, Deng et al. used software to perform an in-depth analysis of international examples of carbon-neutral and system evolution paths, providing a theoretical basis for China's carbon-neutral system [14]. After analyzing the possibility of China's carbon neutrality and the difficulties it will face, Wang et al. provided specific suggestions and measures for China to continue to implement energy upgrading and transformation and achieve carbon neutrality by 2060 [7]. At the same time, at the Taiyuan Energy Low-Carbon Development Forum in 2022, the "Research Report on the carbon neutral Contribution of Chinese Enterprises and Top 50 List" was published. The list evaluated the carbon neutral contribution and driving force of Chinese enterprises according to the characteristics of enterprises in multiple dimensions and added the carbon emission level as a universal index [15]. Based on this—and according to "carbon peak"- and "carbon neutral"-related research and the relevant definitions—we suggest that carbon contribution ability reflects a region's carbon-neutral contribution ability. Thus, carbon contribution ability analysis can be used by provinces to achieve the goal of reasonable carbon-neutral planning and, depending on related conditions and the potential ability to improve their level, help toward steadily achieving a low-carbon economy, as building a low-carbon society is of great significance.

2.2. Carbon Emission Estimation Methods

As the consumption of fossil energy is the main source of carbon emissions, most Chinese scholars have based their measurements of carbon emissions on the IPCC method, including Xu [16], Wang [17], and Li [18]. In this method, carbon emissions are estimated based on total primary energy consumption and the carbon emission coefficient of primary energy. Based on the above analysis and the availability of data, since this study was based on energy consumption in Beijing, Tianjin, and Hebei, the measured carbon emissions mainly included CO from coal, crude oil, and natural gas as the main primary fossil energies. We used the following formula to calculate carbon emissions:

$$C = \sum_i Ei * Si * Fi \quad (1)$$

where C is total carbon emissions, Ei is the consumption of class I fossil energy, Si is the conversion coefficient of class I fossil energy to standard coal, and Fi is the carbon emission coefficient of class I fossil energy.

The relevant consumption data for fossil energy were all obtained from the China Energy Statistical Yearbook. In this study, we adopted the value for the conversion coefficient of fossil energy to standard coal stipulated in the China Energy Statistical Yearbook (2020). In order to base the carbon emission coefficient on China's national conditions, data from the Energy Research Institute of the National Development and Reform Commission were selected for this study, as shown in Tables 1 and 2.

Table 1. Reference coefficient of various energy sources (kg standard coal/kg).

Order Number	Energy	Equivalent to Standard Coal Coefficient
1	coal	0.7143
2	crude oil	1.4286
3	natural gas	1.33

Data source: China Energy Statistical Yearbook (2014).

Table 2. Carbon emission coefficient of various energy sources.

Metric	Coal	Crude Oil	Natural Gas
Carbon emission coefficient t (C)/t	0.7476	0.5825	0.4435

Data source: Energy Research Institute, National Development and Reform Commission.

2.3. Construction of the Carbon Contribution Capacity Index System

The carbon contribution capacity indicator reflects the ability of a region to contribute toward achieving carbon neutrality. Niu et al. established an evaluation index system with 20 indicators at six levels to evaluate the carbon neutral capacity of Chinese provinces [19]. Based on grounded theory, Li et al. constructed a four-dimension quantitative research model of carbon capacity to assess the carbon capacity of residents in Jiangsu Province, China [20]. Sun et al. put forward 16 indicators based on the energy–economy–environment system to evaluate the carbon neutral capacity of 30 provinces in China [21]. In 2022, the Taiyuan Energy Low-Carbon Development Forum added six universal indicators, including carbon emission levels, green investment, and carbon-inclusive benefits, and modified their weights to evaluate the carbon neutral contribution capacity of enterprises. Therefore, on the basis of the above studies, this paper carries out integrated innovation; we took the main factors of population, energy, environment, opening up to the outside world, science and technology, and urban greening to represent regional carbon contribution ability. Carbon sink capacity generally includes forest, grassland, cultivated land, and marine carbon sinks [22]. However, considering the availability of data and the status quo of land use in the Beijing–Tianjin–Hebei region, this paper finally chooses the urban green coverage rate as the measurement index. Regional carbon contribution ability was then subdivided into three secondary capacity indicators and nine tertiary capacity indicators, as shown in Table 3. The data in this section were either obtained from the Beijing Statistical Yearbook, Tianjin Statistical Yearbook, Hebei Economic Yearbook, and China Energy Statistical Yearbook or calculated from the data obtained from the yearbooks.

Table 3. Evaluation index system for regional carbon contribution capacity.

Primary Indicators	Secondary Indicators	Tertiary Indicators	Indicator Characterization
Regional carbon contribution capacity	Energy consumption and carbon emission capacity, B1	Energy intensity, C_1 (Tt of standard coal/10,000 CNY)	Energy consumption per unit GDP
		Carbon emission intensity, C_2 (ton/10,000 CNY)	Carbon emissions per unit GDP
		Energy footprint, C_3 (Tt of standard coal/person)	Per capita energy consumption
		Carbon footprint, C_4 (ton/person)	Per capita carbon emissions
	Carbon transfer capacity, B2	Net carbon transfer level, C5 (ton)	Carbon leakage capacity
		Share of import and export volume in GDP, C_6 (%)	Transfer of carbon emission capacity
	Technology and carbon sink capacity, B3	Regional technology market transaction volume, C_7 (CNY 10,000)	Low-carbon technology capabilities
		Regional (R&D) funding input intensity, C_8 (%)	Support for scientific and technological innovation
		Urban green coverage rate, C_9 (%)	Carbon sink capacity

(1) Energy consumption and carbon emission capacity

Energy intensity: energy consumption per unit GDP, used to explore the economic benefits brought by energy utilization.
Carbon emission intensity: carbon dioxide emissions per unit GDP, mainly measures the relationship between the regional economic situation and carbon dioxide emissions.
Energy footprint: reflects per capita energy consumption in the region.
Carbon footprint: reflects per capita carbon emissions in the region.

The above research indicators reflect the situation of energy utilization efficiency and the control of carbon emissions in the research area. They are all negative indicators, that is, the greater the index ratio, the lower the energy consumption and carbon emission capacity.

(2) Carbon transfer capacity

Net carbon transfer level: the difference between carbon transfers in a province can reflect the degree of “carbon leakage” in the province, measured by the difference between carbon emissions measured by the production side and consumption side.
Proportion of import and export trade in GDP: ratio of regional income from goods and labor trade activities to GDP.

The above two indicators mainly reflect the degree of connection between regions and the degree of opening up to the outside world, production, and consumption. This is because China is both a big manufacturer and a country with a large population. On the one hand, it plays the role of "OEM" in foreign exchanges. On the other hand, it has a developed manufacturing industry and many domestic products are sold at home and abroad; thus, China has to undertake carbon transfer from some countries. Therefore, these two indicators can reflect regional openness, and the greater the ratio, the stronger the carbon transfer ability.

(3) Technology and carbon sink capacity

Regional technology market turnover: reflects the regional technology investment situation.
Regional (R&D) funding intensity: reflects the strength of regional support for scientific and technological innovation.
Urban greening coverage rate: the ratio of the total area of all types of urban green space (public green space, street green space, courtyard green space, special green space, etc.) to the total urban area.

The first two indicators reflect the strength of regional investment in technology and R&D. The greater the proportion, the stronger the regional carbon emission reduction capacity. The carbon sinks mentioned in this paper mainly include forest and green space carbon sinks.

2.4. Comprehensive Evaluation Model Based on the CRITIC Weighting Method

In the literature, the methods used to determine index weights can be divided into subjective empowerment methods and objective empowerment methods. Objective empowerment methods include the entropy weighting method, standard separation method, and CRITIC weighting method. In this study, the CRITIC weighting method was used to carry out an objective evaluation of the whole index system for carbon contribution ability in the Beijing–Tianjin–Hebei region.

The CRITIC weighting method was introduced by Diakoulaki, who proposed the method of objective empowerment [23]. In this method, the objective weight of the evaluation index is comprehensively measured based on the contrast intensity of the evaluation index and conflict among the indicators. Contrast strength refers to the size of the value gap between the evaluation schemes of the same index in the form of standard deviation, where the larger the value difference among the schemes, the higher the positive correlation between the two indexes, the smaller the conflict, and the lower the weight [24]. The specific steps for determining index weight using the CRITIC method are as follows:

(1) Standardize the data to make them comparable.

For larger datasets, the positive indicator is the better indicator:

$$x'_{ij} = \frac{x_{ij} - min\{x_{ij}\}}{max\{x_{ij}\} - min\{x_{ij}\}}\ (\mathrm{i} = 1, 2, \ldots, \mathrm{m}; \mathrm{j} = 1, 2, \ldots, \mathrm{n})$$

For smaller datasets, the negative indicator is the better indicator:

$$x'_{ij} = \frac{max\{x_{ij}\} - x_{ij}}{max\{x_{ij}\} - min\{x_{ij}\}}\ (\mathrm{i} = 1, 2, \ldots, \mathrm{m}; \mathrm{j} = 1, 2, \ldots, \mathrm{n})$$

(2) The information quantity of the calculated index hypothesis $\mathrm{C_j}$ represents the amount of information contained in the j-th evaluation index. $\mathrm{C_j}$ can be expressed as:

$$\mathrm{C_j} = \sigma_\mathrm{j} \sum_{\mathrm{i}=1}^{\mathrm{m}} (1 - \mathrm{r_{ij}})\ (\mathrm{i} \neq \mathrm{j}; \mathrm{j} = 1, 2, \ldots, \mathrm{m})$$

where σ is the standard deviation of the j-th index and r_{ij} is the correlation coefficient between the evaluation indices i and j, which is calculated as follows:

$$r_{ij} = \frac{\sum_{h=1}^{n}(x_{hi} - \overline{x_i})(x_{hi} - \overline{x_j})}{\sqrt{\sum_{h=1}^{n}(x_{hi} - \overline{x_i})^2 \sum_{h=1}^{n}(x_{hi} - \overline{x_j})^2}}, \text{ i} \neq \text{j}$$

where x_{hi} and x_{hj} are the values of the i-th and j-th indicators of h evaluation objects, respectively, $\overline{x_i}$ and $\overline{x_j}$ is the mean of the i-th and j-th indicators of n objects.

(3) Calculate the weight of each index:

$$W_J = \frac{C_j}{\sum_{k=1}^{m} C_j} \text{ (j = 1, 2, \ldots, m)} \quad (2)$$

3. Empirical Data and Model Analysis

3.1. Overview of Energy Consumption in Beijing, Tianjin, and Hebei

According to calculation data for carbon monoxide and carbon dioxide divided by key industries, it is concluded that the power and power supply industry in Beijing, the residential combustion industry in Tianjin, and the industrial combustion industry in Hebei are the most important industries [25], which further explains the imbalanced regional development in the Beijing–Tianjin–Hebei region. In terms of energy consumption and energy consumption structure, Hebei Province is far behind Beijing and Tianjin with respect to its development. The coordinated development of the Beijing–Tianjin–Hebei region requires considerable energy consumption and pollution to realize energy transformation as soon as possible. Reducing carbon emissions will allow for the construction of a low-carbon society [26]. The following section mainly analyzes energy consumption in the Beijing–Tianjin–Hebei region.

(1) Total energy consumption

With the development and progress of the regional economy, energy consumption demands in the Beijing–Tianjin–Hebei region have increased each year from 2008 to 2020. Although the total energy demand is increasing, the growth rate of the energy demand is gradually slowing down. As shown in Figure 1 below, in 2020, China's total energy consumption and that of the Beijing–Tianjin–Hebei region were 498,000 million tons of standard coal and 476.49 million tons of standard coal, respectively; in 2008, these values were 3206,110,000 tons of standard coal and 354,720,700 tons of standard coal, respectively. It can be seen that the increase in energy consumption in the Beijing–Tianjin–Hebei region is in line with actual national energy consumption; however, the proportion of energy consumption in the Beijing–Tianjin–Hebei region accounted for 11.06% of total consumption in 2008 and 9.57% in 2020, showing a lower overall decline.

From 2008 to 2020, the energy consumption of the Beijing–Tianjin–Hebei region accounted for more than 9% of the whole country, of which the energy consumption of Hebei Province accounted for about 6%. Except for fluctuations in 2015, an overall downward trend can be observed; however, this change is not obvious. Generally, the proportion of energy consumption in Beijing and Tianjin is relatively small. Energy consumption in Beijing has decreased each year to less than 2%, indicating that its economic structure is developing well and its utilization of energy efficiency is relatively high. Energy consumption in Tianjin showed an overall increasing trend from 2008 to 2015, which echoes its higher economic growth rate. The proportion of energy consumption in Hebei Province has been consistently high over the years, even more than 7% most of the time. It can be seen that its economic growth is heavily dependent on a large amount of energy consumption; however, its consumption has declined slightly in the past five years. The overall energy consumption ratio in the Beijing–Tianjin–Hebei region has decreased, indicating that the utilization rate of energy is constantly improving. Nevertheless, the energy consumption ratio in Hebei is more than twice that of Beijing and Tianjin, which is enough to indicate that the energy consumption ratio in the Beijing–Tianjin–Hebei region is largely determined by Hebei Province (Table 4).

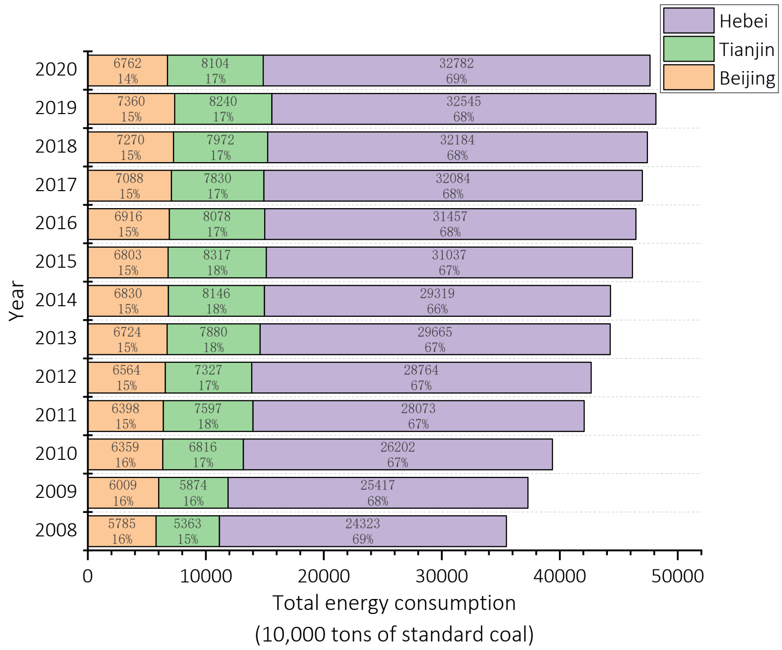

Figure 1. Total energy consumption in Beijing, Tianjin, and Hebei.

Table 4. Proportion of energy consumption in Beijing, Tianjin, and Hebei with respect to total energy consumption in China.

Year	Beijing's Energy Consumption with Respect to National Total Energy Consumption (%)	Tianjin's Energy Consumption with Respect to National Total Energy Consumption (%)	Hebei's Energy Consumption with Respect to National Total Energy Consumption (%)	Total Energy Consumption in the Beijing–Tianjin–Hebei Region with Respect to National Total Energy Consumption (%)
2008	1.80	1.67	7.59	11.06
2009	1.79	1.75	7.56	11.10
2010	1.76	1.89	7.27	10.92
2011	1.65	1.96	7.25	10.87
2012	1.63	1.82	7.15	10.61
2013	1.61	1.89	7.12	10.62
2014	1.59	1.90	6.85	10.34
2015	1.57	1.92	7.15	10.63
2016	1.57	1.83	7.13	10.52
2017	1.55	1.72	7.04	10.31
2018	1.54	1.69	6.82	10.05
2019	1.51	1.69	6.68	9.88
2020	1.36	1.63	6.58	9.57

As shown in Table 5, among the three provinces, energy consumption in Hebei Province was more than four times that of Beijing and Tianjin. In 2008, the total energy consumption in Hebei Province was 321.85 million tons of standard coal, while Beijing and Tianjin had a total energy consumption of 72.7 and 79.73 million tons of standard coal, respectively. The energy consumption in Hebei, Tianjin, and Beijing accounted for 67.86%, 15.33%, and 16.81% of total energy consumption in the Beijing–Tianjin–Hebei region, respectively; these proportions have been stable in recent years. However, compared with energy consumption in Beijing and Tianjin, low energy utilization in Hebei has not resulted in considerable change.

Table 5. Proportion of energy consumption in Beijing, Tianjin, and Hebei with respect to total energy consumption in the region.

Year	Total Energy Consumption in the Beijing–Tianjin–Hebei Region (10,000 Tons of Standard Coal)	Total Energy Consumption in Beijing with Respect to Energy Consumption in the Beijing–Tianjin–Hebei Region (%)	Total Energy Consumption in Tianjin with Respect to Energy Consumption in the Beijing–Tianjin–Hebei Region (%)	Total Energy Consumption in Hebei with Respect to Energy Consumption in the Beijing–Tianjin–Hebei Region (%)
2008	35,472.07	16.31	15.12	68.57
2009	37,301.39	16.11	15.75	68.14
2010	39,378.91	16.15	17.31	66.54
2011	42,070.33	15.21	18.06	66.73
2012	42,652.13	15.39	17.18	67.44
2013	44,270.11	15.19	17.80	67.01
2014	44,296.47	15.42	18.39	66.19
2015	46,159.00	14.74	18.02	67.24
2016	46,453.00	14.89	17.39	67.72
2017	47,003.00	15.08	16.66	68.26
2018	47,428.00	15.33	16.81	67.86
2019	48,146.45	15.29	17.12	67.59
2020	47,649.46	14.19	17.01	68.80

(2) Types of energy consumption

We queried China's statistical yearbooks to investigate the various types of energy consumption in the Beijing–Tianjin–Hebei region. In order to facilitate comparison, we used the standard coal reference coefficient—a unified unit for ten thousand tons of standard coal—found in the statistical yearbook appendix to calculate coal, coke, and crude oil consumption, as shown in Table 6 and energy consumption in the Beijing–Tianjin–Hebei region.

Table 6. Types of energy consumption in the Beijing–Tianjin–Hebei region (2008–2020) (unit: 10,000 tons of standard coal).

Year	Coal	Coke	Crude Oil	Gasoline	Kerosene	Diesel Oil	Fuel Oil	Natural Gas	Power
2008	22,243.30	6760.74	4663.98	1031.15	506.00	1528.07	262.76	1148.92	4139.86
2009	23,786.91	7080.98	4838.22	1113.42	542.82	1552.43	281.16	1342.75	4563.11
2010	24,934.07	7968.75	5828.30	1199.78	620.45	1840.17	355.59	1549.13	5206.60
2011	27,443.41	8881.26	6319.81	1350.90	667.05	2036.89	388.42	1634.64	5662.51
2012	27,805.55	9050.46	5954.41	1453.72	707.05	2063.09	321.46	2060.81	5900.04
2013	27,829.96	9030.25	5737.20	1446.98	810.40	1922.09	186.31	2263.29	6144.53
2014	26,000.07	8822.47	5706.40	1445.03	860.79	1922.92	165.43	2613.01	6290.50
2015	26,718.05	8558.75	6107.38	1670.47	909.91	1540.30	215.40	3445.22	6177.60
2016	25,672.85	8919.78	5738.01	1736.28	1011.95	1527.10	148.11	3857.47	6340.11
2017	24,672.34	9237.17	5799.48	1684.02	1137.48	1531.45	123.75	4163.44	6823.85
2018	24,073.93	9916.90	6149.33	1849.67	1217.72	1379.58	242.70	5158.85	7516.70
2019	23,348.57	9981.93	6868.53	1778.25	1236.78	1374.45	220.37	5539.18	7614.40
2020	22,898.41	10237.86	6095.80	1659.62	819.33	1296.98	209.12	5658.80	7621.40

As can be seen in Table 6 below, from 2008 to 2020, the consumption of coal and coke in the Beijing–Tianjin–Hebei region fluctuated, increasing slightly in 2008. The consumption of crude oil, oil, gasoline, and kerosene increased each year, with gasoline consumption increasing significantly and kerosene consumption doubling, thus showing a steady growth trend. Both diesel and fuel oil rose first and then fell; however, consumption fell only slightly in 2008 compared with 2020. The consumption of natural gas and electricity increased each year, with consumption in the Beijing–Tianjin–Hebei region quadrupling from 2008 to 2020.

It can be seen from Tables 7–9 that coal and coke account for the largest share of energy consumption in the Beijing–Tianjin–Hebei region, where the proportion is far greater than that of several other energy sources. It can also be seen that energy consumption in the

Beijing–Tianjin–Hebei region is still dominated by high-carbon coal and coke, while energy consumption trends in Beijing, Tianjin, and Hebei differ.

Table 7. Different types of energy consumption in Beijing (2008–2020) (unit: 10,000 tons of standard coal).

Year	Coal	Coke	Crude Oil	Gasoline	Kerosene	Diesel Oil	Fuel Oil	Natural Gas	Power
2008	1962.90	226.21	1595.40	501.63	468.48	331.08	36.60	735.93	870.13
2009	1903.61	205.91	1661.36	535.02	503.12	349.97	60.57	842.10	932.81
2010	1882.18	214.15	1594.73	546.67	578.16	345.94	95.27	907.50	1021.30
2011	1690.03	32.43	1578.72	573.54	617.81	351.34	106.63	892.58	1049.57
2012	1621.46	31.35	1536.85	611.96	652.32	314.47	111.66	1117.18	1120.85
2013	1442.34	0.77	1244.20	623.30	701.95	282.53	11.86	1198.96	1116.79
2014	1240.41	0.62	1478.06	648.33	746.85	286.26	8.04	1379.64	1147.16
2015	832.29	0.43	1416.51	680.89	801.00	265.70	7.01	1782.24	1169.09
2016	605.45	0.20	1172.88	692.10	874.41	251.63	6.63	1969.47	1253.89
2017	350.34	0.17	1275.08	720.91	947.58	255.15	4.01	1996.77	1311.20
2018	197.28	0.01	1302.57	726.28	1016.78	260.50	2.20	2279.74	1403.99
2019	130.57	0.01	1338.58	737.02	1026.74	235.86	0.69	2292.35	1433.51
2020	96.42	0.01	1116.84	622.49	673.72	164.00	0.39	2326.18	1407.33

Table 8. Energy consumption in Tianjin Municipality (2008 to 2020) (unit: 10,000 tons of standard coal).

Year	Coal	Coke	Crude Oil	Gasoline	Kerosene	Diesel Oil	Fuel Oil	Natural Gas	Power
2008	2837.91	698.66	1129.07	218.89	26.68	422.21	132.13	204.49	694.97
2009	2942.92	843.81	1206.65	266.37	30.50	442.33	135.22	220.03	749.52
2010	3433.64	644.92	2238.32	301.81	31.49	486.00	205.28	280.50	876.83
2011	3758.65	689.19	2505.79	327.49	36.09	525.52	214.23	315.96	944.37
2012	3784.36	857.47	2206.64	373.37	43.27	551.82	174.76	395.62	996.33
2013	3770.55	928.15	2513.12	312.29	82.57	473.05	124.19	458.88	1032.03
2014	3590.99	927.09	2290.29	333.74	88.06	487.30	111.72	552.39	1070.30
2015	3242.09	878.82	2309.65	393.19	96.79	569.10	134.49	776.91	1105.62
2016	3021.60	861.91	2048.04	404.33	120.68	541.69	64.76	905.02	1119.22
2017	2768.35	785.57	2321.26	403.40	149.35	508.69	58.12	1011.63	1113.24
2018	2737.83	842.43	2411.81	402.65	160.26	475.10	67.13	1263.24	1220.06
2019	2690.13	878.14	2419.12	418.55	162.71	461.78	71.43	1334.43	1185.12
2020	2675.25	902.79	1991.70	418.95	125.54	473.63	75.16	1439.47	1195.52

Table 9. Energy consumption in Hebei Province (2008–2020) (unit: 10,000 tons of standard coal).

Year	Coal	Coke	Crude Oil	Gasoline	Kerosene	Diesel Oil	Fuel Oil	Natural Gas	Power
2008	17,442.49	5835.87	1939.51	310.63	10.84	774.78	94.03	208.50	2574.76
2009	18,940.38	6031.26	1970.21	312.03	9.20	760.13	85.37	280.62	2880.78
2010	19,618.25	7109.68	1995.25	351.30	10.80	1008.23	55.04	361.13	3308.47
2011	21,994.73	8159.64	2235.30	449.87	13.15	1160.03	67.56	426.10	3668.57
2012	22,399.73	8161.97	2210.92	468.39	11.46	1196.80	35.04	548.01	3782.86
2013	22,617.07	8101.33	1979.88	511.39	25.88	1166.51	50.26	605.45	3995.71
2014	21,168.67	7894.76	1938.05	462.96	25.88	1149.36	45.67	680.98	4073.04
2015	22,643.67	7679.50	2381.22	596.39	12.12	705.50	73.90	886.07	3902.89
2016	22,045.80	8057.67	2517.09	639.85	16.86	733.78	76.72	982.98	3967.00
2017	21,553.65	8451.43	2203.14	559.71	40.55	767.61	61.62	1155.04	4399.41
2018	21,138.82	9074.46	2434.95	720.74	40.68	643.98	173.37	1615.87	4892.65
2019	20,527.87	9103.78	3110.83	622.68	47.33	676.81	148.25	1912.40	4995.77
2020	20,126.74	9335.06	2987.26	618.18	20.07	659.35	133.57	1897.15	5018.55

Separately, from 2008 to 2020, the consumption of coal and coke in Beijing decreased significantly each year. In 2020, coal consumption decreased to 0.9642 million tons of standard coal, and the consumption of coke decreased to 0.01 million tons of standard coal.

In terms of consumption, Beijing uses less than Tianjin and far less than Hebei Province. The consumption of natural gas in Beijing is twice that of Tianjin and Hebei and has increased each year. By 2020, the consumption of natural gas in Beijing was 23.2618 million tons of standard coal. Thus, work on overall energy conservation and emission reduction has performed well in the three regions. In Tianjin, the consumption of coal and coke increased from 2008 to 2012. Consumption also declined somewhat in 2013, but the decline was not obvious. Tianjin's natural gas consumption showed steady growth from 2008 to 2020, increasing by 10 million tons of standard coal. However, the consumption of coal and coke in Hebei Province remains at a high level. Although declining momentum has been observed in the past two years, this decline is only slight and consumption is still too high due to the large energy consumption base in Hebei Province and the difficulty of energy transformation and carbon emission reduction. Hebei's natural gas and electricity consumption grows every year, but far less than that of coal and coke. Therefore, Hebei Province represents the most important area for carbon emission reduction work in the Beijing–Tianjin–Hebei region, which needs to be further strengthened from merely reducing the use of fossil energy to focusing on the development of renewable resources and new energy, thus striving to build a clean and low-carbon energy structure that reduces carbon dioxide emissions and environmental pollution.

(3) Energy consumption per capita

As can be seen from Figure 2, per capita energy consumption in the three regions of Beijing, Tianjin, and Hebei showed a slow growth rate. Per capita energy consumption in Beijing showed a small increase from 2016 to 2019 and declined in 2020. In 2008, per capita energy consumption was 3267.19 kg of standard coal/person, while in 2020 it was 3089.13 kg of standard coal/person. From 2008 to 2020, per capita energy consumption was relatively stable with little fluctuation and was the lowest among the three regions. Per capita energy consumption in Tianjin fluctuated more, showing a roughly M-shaped trend. Although Tianjin's per capita energy consumption has decreased in recent years, it is still the largest among the three regions. In Hebei Province, per capita energy consumption increased each year. In 2008, per capita energy consumption was 3480.02 kg standard coal/person, while in 2020 it was 4392.21 kg standard coal/person. Hebei's per capita energy consumption was found to be at an intermediate level between the other two regions.

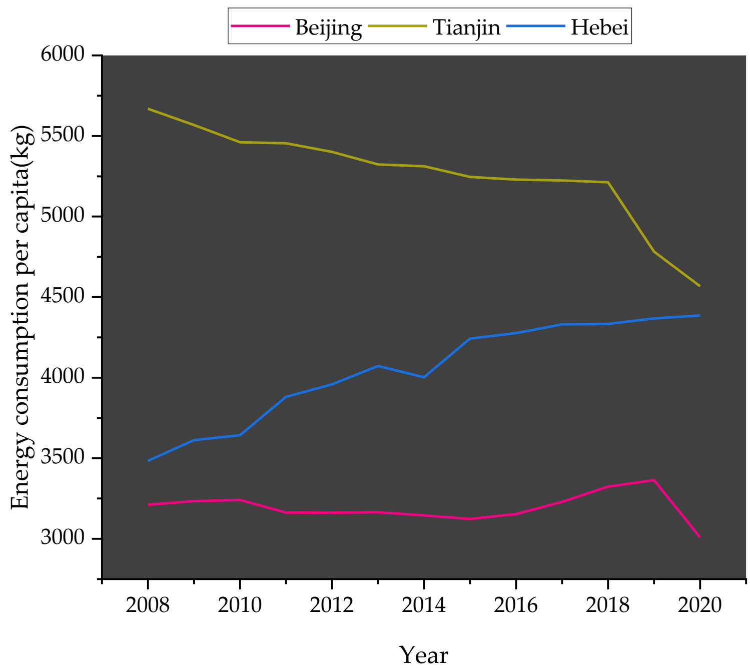

Figure 2. Per capita energy consumption in Beijing, Tianjin, and Hebei.

(4) Energy intensity analysis

Energy intensity can be calculated as total energy consumption divided by a country or region's energy consumption per unit GDP; its unit is tons of standard coal/10,000 CNY. This measure reflects the degree to which a country or region utilizes energy efficiency in its economic activities and provides further information on its economic structure, which is useful in saving energy and reducing consumption levels. The formula is expressed follows:

Energy consumption per unit GDP = total energy consumption/domestic (regional) GDP.

As can be seen from Table 10 above, GDP energy consumption has shown a significant downward trend in Beijing, Tianjin, and Hebei. Among the three regions, the energy intensity value of Hebei is consistently the largest (more than three times that of Beijing and more than twice that of Tianjin). From 2008 to 2020, energy consumption per unit GDP in Beijing decreased from 0.49 tons of standard coal/10,000 CNY to 0.19 tons of standard coal/10,000 CNY, while energy consumption per unit GDP in Tianjin decreased from 0.79 tons of standard coal/10,000 CNY to 0.57 tons of standard coal/10,000 CNY. Energy consumption per unit GDP in Hebei decreased from 1.51 tons of standard coal/10,000 CNY to 0.90 tons of standard coal/10,000 CNY. From 2008 to 2020, energy consumption per unit GDP in Beijing, Tianjin, and Hebei decreased by 61.22%, 27.85%, and 40.40%, respectively. It can be seen that energy intensity in Beijing is consistently the lowest and has decreased the most in recent years. In Beijing, energy utilization efficiency is high, the economic structure is constantly improving, and energy-saving and consumption reduction practices are common. Meanwhile, Tianjin and Hebei lag behind.

Table 10. Energy consumption per unit GDP in Beijing, Tianjin, and Hebei.

Year	Energy Consumption per Unit GDP in Beijing	Energy Consumption per Unit GDP in Tianjin	Energy Consumption per Unit GDP in Hebei Province
2008	0.49	0.79	1.51
2009	0.47	0.77	1.47
2010	0.42	0.74	1.28
2011	0.39	0.67	1.15
2012	0.37	0.57	1.08
2013	0.34	0.55	1.04
2014	0.32	0.52	1.00
2015	0.30	0.50	1.04
2016	0.28	0.45	0.99
2017	0.25	0.42	0.89
2018	0.24	0.42	0.89
2019	0.21	0.58	0.93
2020	0.19	0.57	0.90

(5) Analysis of energy consumption structure

Tables 11–13 below show coal, oil, and gas consumption from 2008 to 2020 in the Beijing–Tianjin–Hebei region. From the proportions in the tables, it can be seen that the demand for coal resources was particularly large, especially in Hebei and Tianjin; coal was the most common type of energy used in the Beijing–Tianjin–Hebei region, oil consumption accounted for about 20% of total consumption, and gas was the least utilized form of energy. Overall, the Beijing–Tianjin–Hebei region relies heavily on coal resources and is characterized by a consumption structure imbalance. In recent years, with increasing calls for energy conservation and emission reduction, the consumption of coal in the Beijing–Tianjin–Hebei region has decreased, the consumption of natural gas has increased, and the proportion of oil consumption has changed very little. Although coal consumption is showing a downward trend, it still accounts for a very large proportion of energy consumption; thus, considerable changes will not be observed for a while. The growth of natural gas consumption is also very slow. Therefore, the energy consumption structure in the Beijing–Tianjin–Hebei region must be transformed over time.

Table 11. Proportion of coal, oil, and natural gas in total energy consumption for Beijing.

Year	Proportion of Coal in Total Energy Consumption (%)	Proportion of Oil in Total Energy Consumption (%)	Proportion of Natural Gas in Total Energy Consumption (%)
2008	46.13	27.57	12.72
2009	43.08	27.65	14.01
2010	29.59	30.94	14.58
2011	26.66	32.92	14.02
2012	25.22	31.61	17.11
2013	23.31	32.19	18.20
2014	20.37	32.56	21.09
2015	13.05	33.79	29.18
2016	9.22	33.14	31.88
2017	5.06	34.00	32.00
2018	2.77	34.14	34.17
2019	1.81	34.55	34.01
2020	1.50	29.27	37.16

Table 12. Proportion of coal, oil, and natural gas in total energy consumption for Tianjin.

Year	Proportion of Coal in Total Energy Consumption (%)	Proportion of Oil in Total Energy Consumption (%)	Proportion of Natural Gas in Total Energy Consumption (%)
2008	64.00	23.10	4.20
2009	68.13	20.54	3.75
2010	68.49	32.83	4.11
2011	67.27	32.98	4.16
2012	70.25	30.12	5.40
2013	65.06	31.88	5.82
2014	59.96	28.12	6.78
2015	53.00	27.76	9.34
2016	50.87	25.35	11.20
2017	48.07	29.64	12.92
2018	46.70	30.25	15.84
2019	43.30	29.36	16.19
2020	44.14	24.57	17.71

Table 13. Proportion of coal, oil, and natural gas in total energy consumption for Hebei.

Year	Proportion of Coal in Total Energy Consumption (%)	Proportion of Oil in Total Energy Consumption (%)	Proportion of Natural Gas in Total Energy Consumption (%)
2008	92.31	6.67	0.94
2009	92.51	6.21	1.21
2010	89.71	7.75	1.51
2011	89.09	8.12	1.66
2012	88.86	7.48	2.04
2013	88.69	7.22	2.23
2014	88.46	6.98	2.54
2015	88.83	5.99	3.13
2016	87.33	6.23	3.42
2017	86.05	6.14	3.94
2018	83.61	4.47	5.49
2019	81.96	5.86	6.61
2020	80.51	5.67	7.00

By separating the three cities, it can be seen that the proportion of coal energy consumption declined the most significantly in Beijing, decreasing by more than 40%. The proportion of oil was relatively stable at about 30%, and the proportion of natural gas energy consumption increased by about 20% to 37.16% in 2020. In 2008, coal, oil, and natural gas accounted for 71.50%, 16.70%, and 3.40% of total energy consumption, respectively. In Tianjin, coal, oil, and gas accounted for 64.00%, 23.10%, and 4.20% of total energy consumption, respectively. The energy consumption structure of Tianjin is better than the consumption structure at the national level; from 2008 to 2020, the proportion of coal consumption declined, while the consumption of oil and gas increased each year. Natural gas consumption also increased significantly. In Hebei, the utilization of coal has shown a downward trend, while that of natural gas has shown a slow growth trend; however, these trends are not as obvious as those in Beijing. Moreover, although the use of coal has decreased, it still accounts for more than 80% of total energy consumption, which indicates high dependency. Among the three regions, Beijing has the best energy consumption structure, while Hebei is the most in need of transformation and improvement.

3.2. Carbon Emission Estimates in the Beijing–Tianjin–Hebei Region

(1) Estimation of carbon emissions

In this study, we selected 14 samples from 2008 to 2020 as research data to calculate carbon emissions in the Beijing–Tianjin–Hebei region. Fossil energy data based on the measurement of carbon emissions were derived from the regional energy balance sheet in the China Energy Statistical Yearbook (2009–2021). Carbon emissions in the Beijing–Tianjin–Hebei region from 2008 to 2020 were calculated using Formula (1) (see Table 14). A comparison of carbon emissions between the three regions is shown in Figure 3.

Table 14. Carbon emissions in the Beijing–Tianjin–Hebei region from 2008 to 2020 (ten tons).

Year	Beijing	Tianjin	Hebei
2008	2432.56	2789.24	14,179.90
2009	2431.82	2913.69	15,321.11
2010	2380.16	3884.43	15,846.38
2011	2226.46	4284.94	17,766.02
2012	2161.72	4098.95	18,060.52
2013	1861.32	4304.74	18,091.22
2014	1855.37	4045.31	16,987.69
2015	1533.98	3806.89	18,358.51
2016	1231.58	3495.90	17,995.39
2017	1101.71	3470.89	17,452.94
2018	1017.06	3513.04	17,300.23
2019	987.27	3484.27	17,250.41
2020	834.19	3229.21	16,877.81

As can be seen from Figure 3, carbon emissions in Hebei Province were on the rise before 2013. After 2013, carbon emissions in Hebei Province decreased until 2015, when they rose again. Overall, carbon emissions in Hebei Province were much higher than those in Beijing and Tianjin. This is mainly due to the industrial structure in Hebei Province that still gives priority to the primary industry, while the development of the secondary and tertiary industries is weak. The two cities of Beijing and Tianjin have high pollution but lack the high emissions from industry seen in Hebei, which has resulted in decreased carbon emissions in these regions. As can be seen from the figure, carbon emissions in Beijing have been at their lowest and most stable in recent years; this is due to the fact that Beijing does not rely on the development of primary industry and has completed the industry upgrading transformation. Based on this fact and coupled with the "carbon peak carbon neutral" concept and the policies that have been put forward, we can expect that carbon emissions will continue to decrease in Beijing. Tianjin's carbon emissions show a similar trend to those of Beijing, although slightly increased. It can be seen that Tianjin has considerable carbon neutrality potential.

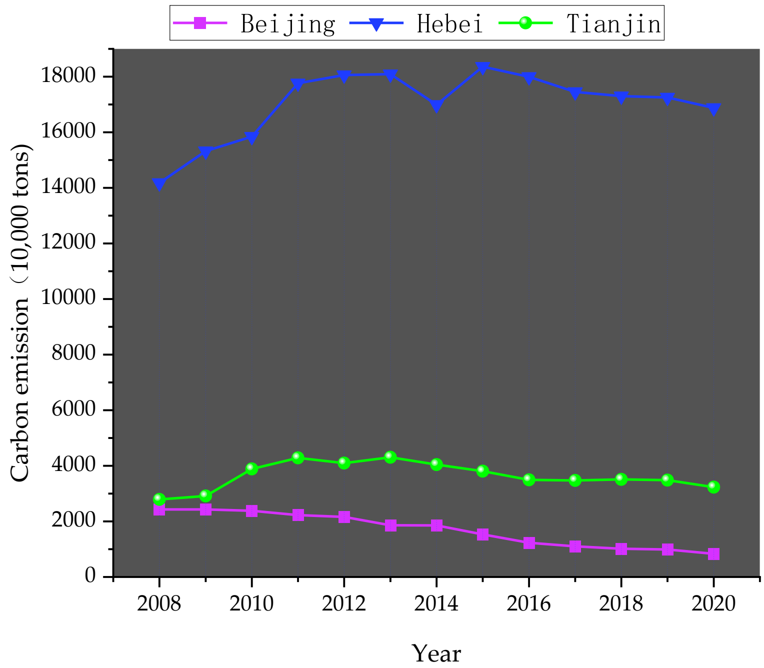

Figure 3. Comparison of carbon emissions in Beijing, Tianjin, and Hebei (2008–2020).

(2) Estimation of carbon emission intensity

Carbon intensity is equal to carbon dioxide emissions per unit of GDP and can be affected by many factors, such as energy consumption, the pollutant carbon emission coefficient, etc. In addition to the development of energy-saving technologies, upgrading industrial structures and opening the regional economy will also restrict the size of carbon intensity. As can be seen from Table 15, with the development of the economy and the progress and application of energy-saving technologies, carbon emission intensity has decreased each year, with some fluctuations. The carbon emission intensity of the Beijing–Tianjin–Hebei region from 2008 to 2020 was obtained using the following formula: carbon emission intensity = carbon emissions/GDP.

Table 15. Carbon emission intensity of Beijing, Tianjin, and Hebei (ton of carbon/10,000 CNY).

Year	Beijing	Tianjin	Hebei
2008	0.21	0.41	0.88
2009	0.19	0.38	0.88
2010	0.16	0.42	0.77
2011	0.14	0.38	0.72
2012	0.12	0.32	0.68
2013	0.09	0.30	0.64
2014	0.09	0.26	0.58
2015	0.07	0.23	0.62
2016	0.05	0.20	0.57
2017	0.04	0.19	0.49
2018	0.03	0.19	0.48
2019	0.03	0.25	0.49
2020	0.02	0.23	0.47

As can be seen from Figure 4, the carbon emission intensities of Beijing, Tianjin, and Hebei all showed a downward trend. In the past 13 years, Beijing saw the smallest decline, followed by Tianjin City; Hebei Province saw the largest decline. Beijing's decline was small mainly because its carbon emission intensity was already relatively low. In 2008, Beijing's carbon emissions were 0.21 tons of carbon per 10,000 CNY, only 51% of that of Tianjin and 24% of that of Hebei Province. These results show that Beijing has a good low-carbon economy and green GDP development, as does Tianjin. Due to its high energy consumption, high emissions, and high-pollution enterprises, Hebei's low-carbon economy still needs to be greatly improved.

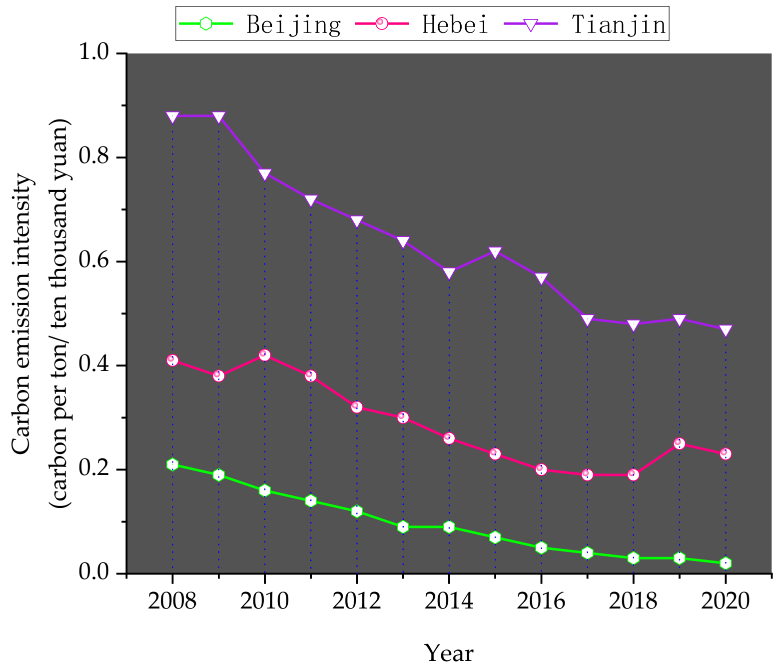

Figure 4. Comparison of carbon emission intensity between Beijing, Tianjin, and Hebei (carbon ton/10,000 CNY).

(3) Estimate of per-capita carbon emissions

Per capita carbon emissions eliminate the differences in regional total amounts, which is more conducive to a comparative analysis of carbon emissions between regions. It can be seen from Figure 5 that the per capita carbon emissions in Beijing consistently showed a decreasing trend each year, while the per capita carbon emissions in Hebei and Tianjin were much higher than those in Beijing. Among the three regions, the per capita carbon emissions in Tianjin increased each year until 2011, at which point they reached their highest value (3.16) and then began to decrease slowly; this was followed by a small increase in the past year. Per capita carbon emissions in Hebei Province are on the rise as a whole. By 2020, Beijing's carbon emissions per capita were 0.45 tons carbon/person; for Tianjin and Hebei, carbon emissions per capita were 2.28 and 2.31 tons carbon/person, respectively. On the whole, the three places all show a downward trend, which is closely related to China's economic development and policy protection in recent years. For example, research on China's Air Pollution Prevention and Control Action Plan proposed in 2013 shows that the APCAP can effectively reduce China's per capita carbon emissions at the national level without considering the spatial spillover effect. This is consistent with the development trend of the Beijing–Tianjin–Hebei region [27].

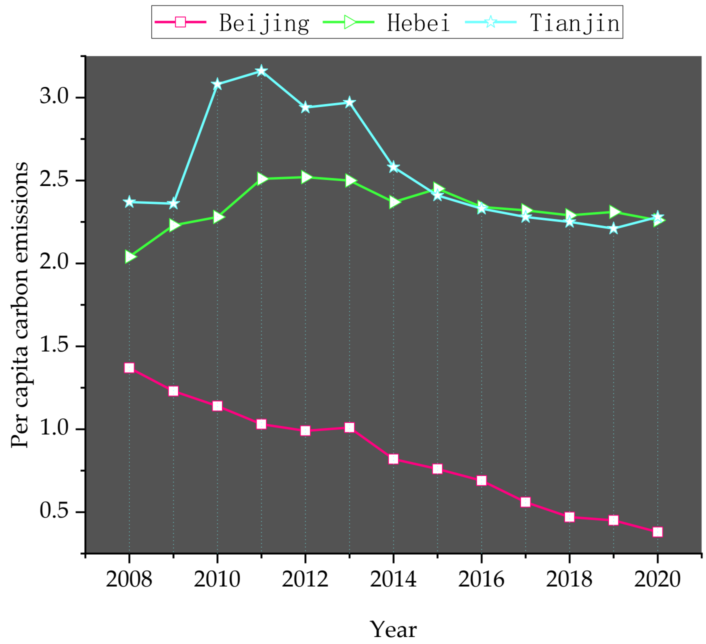

Figure 5. Comparison of per capita carbon emissions in the Beijing–Tianjin–Hebei region (2008–2020) (ton of carbon/person).

3.3. Analysis of Carbon Contribution Capacity in the Beijing–Tianjin–Hebei Region

(1) The connotation of the carbon contribution capacity of Beijing, Tianjin, and Hebei

With the development of the global economy, the emissions of carbon dioxide and other greenhouse gases in various countries have increased sharply, and climate change has gradually become a major global challenge facing humankind. It is not only related to energy, but also affects the restructuring and reorganization of industrial chains and new international standards. At the same time, it has also deeply affected various aspects of our social economy. Achieving "carbon neutrality" and a "carbon peak" is the only way to promote high-quality development of the Chinese economy, and the "double carbon" goal, especially the "carbon neutrality" goal, is referred to as "carbon reach". In order to better support Chinese cities in achieving high-quality carbon emission reduction targets, a research group of the Chongyang Institute for Financial Studies at Renmin University of China and the Ecological Finance Research Center under operational management collected public data, designed a "six dimensional integrated" comprehensive evaluation system of carbon emission reduction effects based on the international comprehensive development evaluation mechanism, and analyzed the gap between the carbon emission reduction effect achieved by various cities and the benchmark. "Carbon achievement rate" is put forward to explore a better path toward emission reductions and the adjustment of emission reduction strategies according to the actual situation. In addition, during the Taiyuan Low-Carbon Development Forum in 2022, the "2022 Carbon Neutral Contribution Research Report and Top 50 List of Chinese Enterprises" released the 2022 Energy Business Owners list. The list was jointly researched and compiled by China Energy News, the Digital Double Carbon Research Institute, Tsinghua University, and the China Academy of Energy Economics and proposed the concept of carbon neutral contribution from Chinese enterprises (CCC) for the first time. It strives to reflect the carbon neutral contribution and impact of Chinese enterprises in a scientific, accurate, and multidimensional way. Based on this, as well as on relevant definitions of "carbon peaking" and "carbon neutrality" and relevant studies, this paper holds that carbon contribution capacity reflects the contribution capacity of a region toward achieving "carbon neutrality", and the analysis of carbon contribution capacity is the only way for provinces and municipalities to achieve the national carbon neutrality goals.

(2) Data collection and processing

This section focuses on the carbon contribution capacity of Beijing, Tianjin, and Hebei. The data were obtained from the China Energy Statistical Yearbook (2009–2021), China Statistical Yearbook (2009–2021), China Science and Technology Statistical Yearbook (2009–2021), and China Urban Statistical Yearbook (2009–2021). Due to the availability of the selected carbon contribution capacity indicators, data from 2008 to 2020 were selected for the study. The data obtained from the statistical yearbooks have the advantages of accuracy and authority, ensuring that the methods and results of this study are rigorous and scientific. In this study, each index was first standardized. The CRITIC weighting method using Formula (2) in SPSS software was then used to determine the weight of each index for Beijing, Tianjin, and Hebei. The specific results are shown in Tables 16–18.

Table 16. Indicators and weights for carbon contribution capacity in Beijing.

Secondary Indicators	Tertiary Indicators	Indicator Variability	Indicator Conflict	Amount of Information	Weight
B_1 (0.3600)	C_1	0.338	3.867	1.307	0.0744
	C_2	0.347	3.828	1.327	0.0755
	C_3	0.282	8.094	2.281	0.1299
	C_4	0.357	4.05	1.447	0.0823
B_2 (0.4000)	C_5	0.363	12.793	4.647	0.2645
	C_6	0.444	5.352	2.378	0.1354
B_3 (0.2400)	C_7	0.335	4.21	1.411	0.0803
	C_8	0.288	4.443	1.278	0.0728
	C_9	0.29	5.131	1.49	0.0848

Table 17. Indicators and weights for carbon contribution capacity in Tianjin.

Secondary Indicators	Tertiary Indicators	Indicator Variability	Indicator Conflict	Amount of Information	Weight
B_1 (0.4100)	C_1	0.376	5.737	2.159	0.1022
	C_2	0.389	5.336	2.075	0.0982
	C_3	0.28	8.087	2.268	0.1074
	C_4	0.37	5.625	2.08	0.0985
B_2 (0.2600)	C_5	0.351	7.162	2.511	0.1189
	C_6	0.279	11.365	3.168	0.1500
B_3 (0.3300)	C_7	0.354	5.343	1.894	0.0896
	C_8	0.361	7.944	2.871	0.1359
	C_9	0.293	7.164	2.098	0.0993

Table 18. Indicators and weights for carbon contribution capacity in Hebei Province.

Secondary Indicators	Tertiary Indicators	Indicator Variability	Indicator Conflict	Amount of Information	Weight
B_1 (0.4800)	C_1	0.342	7.696	2.631	0.1114
	C_2	0.348	7.348	2.557	0.1083
	C_3	0.35	10.18	3.563	0.1509
	C_4	0.326	8.274	2.696	0.1141
B_2 (0.2300)	C_5	0.34	6.851	2.331	0.0987
	C_6	0.299	9.968	2.984	0.1263
B_3 (0.2900)	C_7	0.29	6.612	1.918	0.0812
	C_8	0.325	7.26	2.36	0.0999
	C_9	0.304	8.489	2.581	0.1093

3.4. Analysis of Results

(1) Comprehensive analysis of carbon contribution capacity in the Beijing–Tianjin–Hebei region.

Based on the CRITIC weighting method, comprehensive scores for the carbon contribution ability of Beijing, Tianjin, and Hebei from 2008 to 2020 were obtained, as shown in Tables 19–21.

Table 19. Comprehensive scores of carbon contribution ability in Beijing (2008–2020).

Year	Energy Consumption and Carbon Emission Capacity	Carbon Transfer Capacity	Technology and Carbon Sink Capacity	Carbon Achievement Contributing to Comprehensive Capacity
2008	0.0580	0.1541	0.0011	0.0828
2009	0.0986	0.0808	0.0606	0.0824
2010	0.1255	0.0991	0.1187	0.1133
2011	0.1946	0.1253	0.1081	0.1461
2012	0.2127	0.1145	0.1359	0.1550
2013	0.2442	0.1037	0.1435	0.1638
2014	0.2572	0.0964	0.1792	0.1742
2015	0.3096	0.2191	0.1894	0.2446
2016	0.3085	0.2428	0.2005	0.2563
2017	0.2818	0.2614	0.1407	0.2398
2018	0.2322	0.2888	0.1923	0.2453
2019	0.2201	0.2931	0.2213	0.2532
2020	0.2046	0.3021	0.2521	0.2550

Table 20. Comprehensive scores of carbon contribution ability in Tianjin (2008–2020).

Year	Energy Consumption and Carbon Emission Capacity	Carbon Transfer Capacity	Technology and Carbon Sink Capacity	Carbon Achievement Contributing to Comprehensive Capacity
2008	0.1287	0.2490	0.0153	0.1226
2009	0.1358	0.1502	0.0070	0.0970
2010	0.0961	0.1350	0.0464	0.0898
2011	0.1277	0.0941	0.1011	0.1102
2012	0.2379	0.0750	0.1453	0.1650
2013	0.2434	0.0574	0.1884	0.1769
2014	0.2617	0.0566	0.2565	0.2067
2015	0.2520	0.0536	0.2218	0.1905
2016	0.2727	0.0709	0.2152	0.2013
2017	0.2794	0.1064	0.1452	0.1901
2018	0.2506	0.1367	0.2054	0.2061
2019	0.2462	0.1388	0.2212	0.2101
2020	0.2105	0.1467	0.2344	0.2018

As can be seen from Figure 6, the carbon contribution capacities of Beijing, Tianjin, and Hebei fluctuated between 2008 and 2020. However, in the past two years, with the carbon peak in 2030 and the establishment of the carbon neutrality target for 2060, the carbon contribution capacity of Beijing, Tianjin, and Hebei has gradually increased. Compared with 2008, the carbon contribution capacity of Hebei Province has not increased significantly, lagging behind Beijing and Tianjin. Hebei Province is still in the industrialization stage; the primary and secondary industries are still the main driving force for GDP growth, while the importance of the tertiary industry has increased slowly. Tianjin and Beijing also showed changing trends, and the growth rate of Beijing is now significantly higher than that of Tianjin. The carbon contribution capacity of Beijing lagged behind Tianjin and Hebei Province before 2009, at which point it gradually caught up with the largest overall increase. As a whole, over the past four years, overall carbon emission reduction capacity in the Beijing–Tianjin–Hebei region has formed a gradient difference, where Tianjin is in the middle position. Hebei Province has considerable carbon emission reduction potential and surpassed Tianjin over the 17 years considered here; however, the coordinated forces of the Beijing–Tianjin–Hebei region must be used to reduce carbon emissions and energy consumption in Hebei Province.

Table 21. Comprehensive scores of carbon contribution ability in Hebei Province (2008–2020).

Year	Energy Consumption and Carbon Emission Capacity	Carbon Transfer Capacity	Technology and Carbon Sink Capacity	Carbon Achievement Contributing to Comprehensive Capacity
2008	0.2657	0.1592	0.0001	0.1642
2009	0.2095	0.0771	0.0546	0.1341
2010	0.2600	0.0935	0.1226	0.1819
2011	0.1897	0.0816	0.1101	0.1418
2012	0.1935	0.0467	0.0536	0.1192
2013	0.1961	0.0444	0.0674	0.1239
2014	0.2768	0.0728	0.0987	0.1782
2015	0.1746	0.0696	0.1105	0.1319
2016	0.2078	0.0769	0.0931	0.1444
2017	0.2583	0.0753	0.1402	0.1820
2018	0.2686	0.1073	0.2113	0.2149
2019	0.2791	0.1204	0.2311	0.2287
2020	0.2803	0.1211	0.2521	0.2355

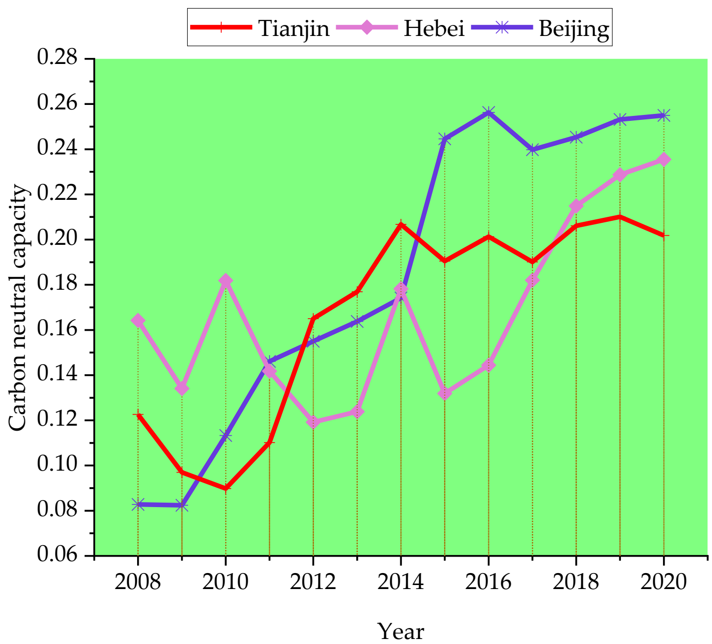

Figure 6. Comparison of the comprehensive carbon contribution capacity of Beijing, Tianjin, and Hebei (2008–2020).

(2) Secondary index analysis of carbon contribution capacity in Beijing, Tianjin, and Hebei

As can be seen from Figure 7, which shows the energy consumption and carbon emission capacity of the three provinces and cities from 2008 to 2020, Beijing had the lowest energy consumption and carbon emission capacity before 2010, at which point it rose annually until peaking at 0.3096 in 2015. This was followed by another decrease until 2020, where it had the lowest level of the three provinces and cities at 0.2046.

The minimum energy consumption and carbon emission capacity in 2010 was 0.0961. After that, it increased each year and did not decline until 2017. Energy consumption and carbon emission capacity were at a midpoint in 2020. Before 2010, Hebei Province had the highest values, despite fluctuations in energy consumption and carbon emission capacity; since then, although a decline was observed, energy consumption and carbon emissions in Hebei have increased each year since 2015, and they surpassed Beijing and Tianjin as of 2018. According to our analysis of Beijing, Tianjin, and Hebei, as high energy consumption and high-emissions industries gradually transferred to Hebei province, the energy consumption and carbon emission capacity of the other two cities gradually declined. However, the transformation and upgrading of high energy consumption and high-emissions industries is imminent and will drive the coordinated development of the Beijing–Tianjin–Hebei region to reduce energy consumption and carbon emissions.

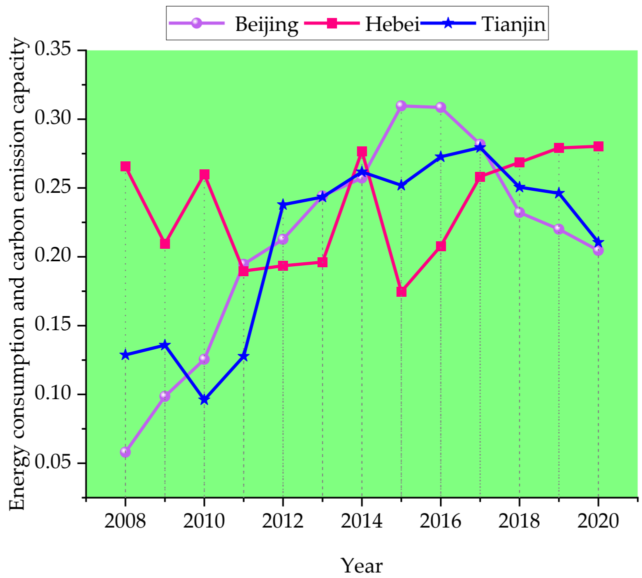

Figure 7. Comparison of energy consumption and carbon emission capacity in the Beijing–Tianjin–Hebei region (2008–2020).

As can be seen from Figure 8, Beijing's carbon transfer capacity trend during 2008–2009 was similar to that of Hebei Province and decreased to a minimum of 0.0808 in 2009, before rising in 2010 and 2011. Although there was a small decline in carbon transfer capacity after 2011, it was still the highest of the three provinces and cities and saw a significant increase after 2014, far more than the other two provinces and cities. Tianjin's carbon transfer capacity has generally declined, despite a small increase after 2015; even after this rise, it was still significantly less than carbon transfer capacity in 2008. The carbon transfer capacity trend in Hebei Province was similar to that of Tianjin; however, overall, as the weakest of the three provinces, Hebei's carbon transfer capacity needs to be strengthened. In terms of the degree of increase, only Beijing's transfer capacity has risen (from 0.1541 in 2008 to 0.3021 in 2020). For Tianjin and Hebei Province, carbon transfer capacity has decreased to varying degrees since 2008; however, it has started to show an upward trend in the past three years and is expected to show a more significant increase in the future. From another point of view, with regard to carbon transfer ability in Tianjin and Hebei, a lack of attention was paid to the regional economy and trade, which led to a decrease in carbon transfer capacity after 2008. Beijing, however, hosted the 2008 Olympic Games, which led to an increase in regional openness and the degree of foreign trade, gradually improving carbon transfer ability in the region.

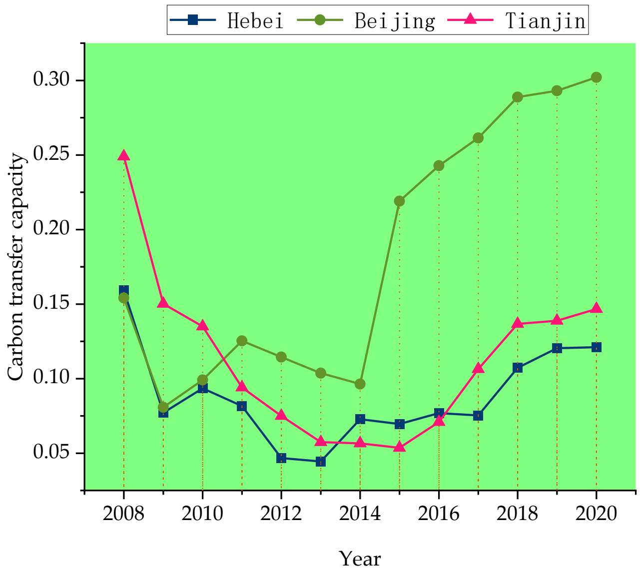

Figure 8. Comparison of carbon transfer capacity in Beijing, Tianjin, and Hebei (2008–2020).

It can be seen from Figure 9 that the technology and carbon sink capacity of the Beijing–Tianjin–Hebei region gradually increased, with some fluctuations, from 2008 to 2020. Since 2017, this growth trend has continued gradually as it is closely related to national policies, where the carbon peak and carbon neutral target, technological innovation, and the low-carbon economy have gradually become a new path for regional economic growth. The technology and carbon sequestration capacity of Beijing increased from 0.0011 in 2008 to 0.2521 in 2020, that of Tianjin increased from 0.0153 in 2008 to 0.2344 in 2020, and that of Hebei Province increased from 0.0001 in 2008 to 0.2521 in 2020. In terms of improvement, the technology and carbon sink capacity of Hebei was the highest at 0.2520, followed by Beijing and Tianjin. From 2008 to 2011, the technology and carbon sink capacity trend in Beijing and Tianjin was basically the same. After 2011, Tianjin's technology and carbon sink capacity gradually increased to a greater degree than that of Beijing, reaching a peak of 0.2565 in 2014, at which point it decreased with each year. It can be seen from the figure that the overall technology and carbon sink capacity of Hebei Province was not high from 2011 to 2016, especially with respect to the other regions; however, a significant increase was observed. After 2016, the gradual growth was finally higher than that of the other two cities in 2018.

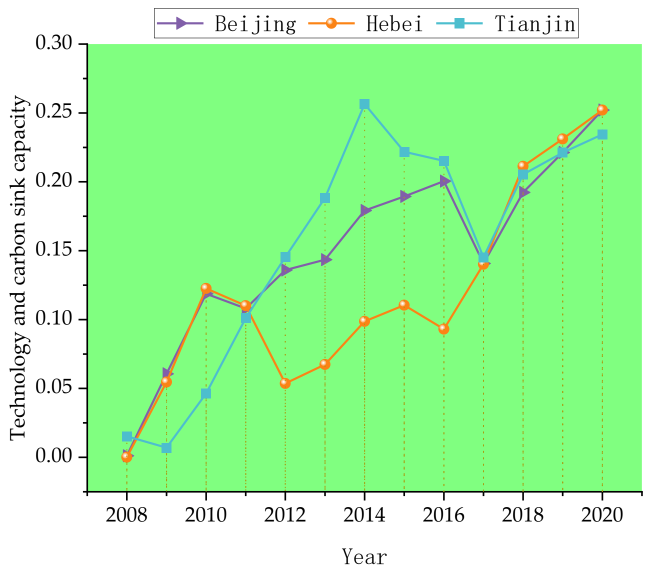

Figure 9. Comparison of technology and carbon sink capacity in Beijing, Tianjin, and Hebei (2008–2020).

4. Conclusions and Policy Recommendations

4.1. Conclusions

Cooperation between Beijing, Tianjin, and Hebei is a very effective means to reducing carbon emissions, and the calculation of carbon contribution capacity between regions forms the basis for a smooth completion of carbon neutrality goals. Therefore, we clarified the relevant connotation of carbon contribution ability and analyzed the current situation and characteristics of economic development, energy consumption, and carbon emission in Beijing, Tianjin, and Hebei before applying the CRITIC weighting method to comprehensively evaluate the carbon contribution ability of the Beijing–Tianjin–Hebei region from 2008 to 2020. Our main conclusions are as follows:

This paper first discussed the development of the Beijing–Tianjin–Hebei region from 2008 to 2020, including GDP; per capita GDP; the GDP of the primary, secondary, and tertiary industries; the proportion of total energy; and the different categories of energy consumption. By calculating carbon emissions and carbon intensity in the Beijing–Tianjin–Hebei region from 2008 to 2020, we further analyzed the development of the industry, the economy, energy consumption, population, and carbon emissions. The following can be concluded:

(1) Beijing's economic development from 2008 to 2020 has been dominated by the tertiary industry, showing an increasing trend each year; in 2020, tertiary industries accounted for more than 80% of industry in Beijing. In addition, the proportion of secondary industries has declined each year, which shows that Beijing has entered the late stage of industrialization. The developed proportion of secondary and tertiary industries in Tianjin is almost the same; however, in recent years, the development trend of the tertiary industry in Tianjin has been relatively fierce. Despite this, its economy still depends on secondary industries. This shows that Tianjin is in the middle stage of the industrialization process. In Hebei Province, although the ratio of primary industry to GDP has gradually declined in recent years, the tertiary industry has also grown to a certain extent, playing a leading role in the development of GDP. From our analysis of energy consumption in Beijing, Tianjin, and Hebei, Beijing and Tianjin have lower energy consumption that is still dominated by high-carbon coal and coke. From our regional analysis, energy consumption in Beijing, Tianjin, and Hebei depends on coal resources, and the region has an unbalanced consumption structure. Although the consumption of coal has decreased in recent years, it is still large, and the increasing trend of natural gas consumption is not obvious, which indicates that the transformation of energy consumption in Beijing, Tianjin, and Hebei is urgent. In Hebei Province, as the main body of regional energy consumption, carbon emissions are the highest of the three provinces and cities; this shows that energy consumption and carbon emissions in the Beijing–Tianjin–Hebei region are mainly determined by Hebei Province. Therefore, adjustment of the industrial structure and transformation of the energy consumption structure in Hebei Province are the key to reducing overall carbon emissions in the region.

(2) In this research, we established three aspects (energy consumption and carbon emission capacity, carbon transfer capacity, and science and technology and carbon sink capacity) and carried out a comprehensive evaluation of carbon contribution capacity using nine three-level indicators. Using the CRITIC weighting method, we calculated the carbon contribution capacity of the Beijing–Tianjin–Hebei region from 2008 to 2020 and came to the following conclusions: First, Beijing has the highest overall contribution capacity, followed by Tianjin and Hebei. Beijing's carbon transfer and technology and carbon sink capacities are higher than those of Tianjin and Hebei because Beijing pays more attention to regional openness and the role of science and technology in driving GDP. Finally, energy consumption and carbon emission capacity have basically formed a gradient difference in the Beijing–Tianjin–Hebei region. The key to regional cooperation that enhances carbon neutrality contributions is Hebei Province. Hebei should take advantage of the openness to foreign trade and science and technology found in Beijing and Tianjin. In addition, the location of Hebei

Province should be taken advantage of as a traffic artery between Beijing and Tianjin for foreign trade. By addressing these issues, as well as industrial development, technology, the economy, policy, and other aspects restricting low-carbon development, the advancement of a low-carbon economy and the construction of a low-carbon city can be promoted in Hebei Province.

4.2. Policy Suggestion

From the above conclusions, we can see that in order to achieve the carbon-neutral goal of Beijing, Tianjin, and Hebei and improve the ability to achieve carbon contribution, it is necessary to strengthen cooperation between Beijing, Tianjin, and Hebei (by using Beijing and Tianjin to drive the energy conservation, emission reduction, and industrial upgrading of Hebei Province) so that the three provinces can cooperate with each other to achieve the carbon-neutral goal. This study demonstrates that mutual cooperation between Beijing, Tianjin, and Hebei can be improved from the following aspects:

(1) Strengthening inter-regional intergovernmental cooperation

In order to improve the carbon contribution capacity of Beijing–Tianjin–Hebei and encourage the cooperation needed to achieve the goal of carbon neutrality, we must break through the limitation of currently held ideas and achieve joint participation from governments in the Beijing–Tianjin–Hebei region, as well as cooperation from regional industries, enterprises, and all levels of society. Among these forms of cooperation, the most important is government-led inter-regional cooperation. We should abandon the previous situation in which regional governments act independently while not considering the situation of coordinated development between regions, establish a working group for energy conservation and emission reduction with coordinated participation between regions, and establish and improve a collaborative network system with government guidance, market participation, and the participation of the whole industrial society. The collaborative working group is mainly responsible for the unified planning of inter-regional carbon emission reduction goals, as well as the coordination of efforts toward inter-regional carbon emission reduction. This group is also responsible for coordinating the interests of all parties in order to reduce the cost of work through effective rules and regulations and improve contribution ability to help achieve carbon neutrality goals.

(2) Strengthen cooperation in low-carbon industries

The consumption of fossil energy, especially in industrial industries, is one of the main sources of carbon emissions. The development of an inter-regional low-carbon economy is mainly proposed to reduce the carbon emissions of industries and achieve low-carbon development in various industries, especially the primary industry. Low-carbon industrial cooperation is an important path for the Beijing–Tianjin–Hebei region as it seeks to achieve carbon contributions. Therefore, it is necessary to reasonably guide industrial transfer within the region and industrial convergence between regions while reducing homogenization and disordered competition. Therefore, in the choice of industrial development, Beijing–Tianjin–Hebei should not only consider its own regional advantages, but also consider the industrial development capacity and current situation of the cooperating region. The realization of a regional cooperative alliance between the three provinces and cities would allow their industries to meet their own development needs and complement each other's advantages. Beijing, as the capital of the country, has naturally concentrated the country's excellent human, talent, material, and other resources; thus, it has strong advantages in science and technology. For Tianjin and Hebei, we can learn and introduce the advanced science and technology of the Arctic and learn valuable experience from the development of its emerging industries. Tianjin has strong advantages in logistics, transportation, finance, and advanced manufacturing industries; thus, it should employ these advantages fully in foreign port transportation and strengthen the low-carbon development of Beijing and Hebei. Although there is a clear gap between Hebei Province and Beijing and Tianjin in the development of tertiary industry, its basic resources have strong advantages. Therefore, Beijing, Tianjin, and Hebei can form a low-carbon industrial chain between the respective regions in various aspects, such as technology, education, talent, logistics, finance, manufacturing, and basic resources.

(3) Strengthen inter-regional cooperation in low-carbon technology

Beijing–Tianjin–Hebei regional cooperation should vigorously develop low-carbon technologies. In cooperation, regions with technological advantages and educational resource advantages should provide technical support and talent output to relatively insufficient regions and embrace exchange and cooperation between regions for emerging technologies, especially the cooperation between colleges and universities, in order to promote the transfer and innovation of low-carbon technologies. Although regional cooperation concerning science and education between Beijing, Tianjin, and Hebei has been established, the results are not obvious. There is still a strong gap in science and technology innovation between Beijing, Tianjin, and Hebei, especially in Hebei Province, which is lower than Beijing and Tianjin in terms of education and technology. Therefore, it is necessary to strengthen mutual assistance between Beijing, Tianjin, and Hebei (in terms of technical cooperation and educational resources) and strengthen cooperation in the following aspects in the process of industrial upgrading:

Technology cost sharing: for high-value and advanced low-carbon technologies, Beijing, Tianjin, and Hebei can cooperate with each other to introduce them and share the cost of introduction. Regions with scientific and technological advantages will first learn and conquer the advanced low-carbon technologies and then share the experience with other regions in order to achieve technical contributions.

Strengthen technical cooperation between Beijing, Tianjin, and Hebei: The regions should establish cooperation between industries or enterprises of the same type in the Beijing–Tianjin–Hebei region, actively learn and learn from each other's advantages, carry out the sharing of advantageous resources, help each other with common weaknesses in similar industries or enterprises, and actively seek solutions to common problems through technical cooperation. In addition, the Beijing–Tianjin–Hebei region can strengthen the tightness of the industrial chain by actively establishing technical cooperation between upstream and downstream elements of production, make the cooperation of enterprises in the entire industrial chain closer, promote the low-carbon development of the entire industrial chain through vertical cooperation, reduce the cost of the same type of research and development technology, and improve the competitiveness of regional low-carbon technology as a whole.

Strengthen the combination of production, study, and research: This can be achieved by making use of Beijing's advantages in talent, science, and technology; Tianjin's advantages in logistics and manufacturing; and Hebei's advantages in basic resources, thus helping to establish industries, schools, and research and development platforms between the three provinces and urban areas so that industries or enterprises can better combine with universities, research institutes, and other scientific research institutions. Enterprises can provide financial support for colleges and universities and scientific research institutions, with colleges, universities, and other institutions subsequently providing excellent talent for technology research and development. The emerging technological achievements developed can then be shared by colleges, universities, other institutions, and enterprises. The governments of Beijing, Tianjin, and Hebei should actively play a leading role by promoting the construction of a platform for industry–university–research integration, which would actively promote inter-regional industry–university –research cooperation.

Improve carbon sink capacity among regions: At present, understanding of the connotations of carbon sequestration is still in the initial stage, and the improvement of enterprises' carbon sequestration capacity is also in the exploration stage. Beijing, Tianjin, and Hebei have increased the amount of publicity surrounding carbon sequestration and improved the carbon sequestration capacity of Beijing, Tianjin, and Hebei according to local conditions. Hebei Province is suitable for forest and green space carbon sequestration projects that can improve its carbon sequestration capacity because of the region's good basic resource advantages and vast area of forest and grassland. However, because Hebei's economic conditions are at a disadvantage, and because more financial support is needed to improve its carbon sink capacity, Beijing and Tianjin, as economically developed cities, can make contributions toward improvements in the carbon sink capacity of the Beijing–Tianjin–Hebei region. This can be achieved by establishing carbon sink funds in Beijing, Tianjin, and Hebei provinces and cities, mainly through funds raised from enterprises in Beijing and Tianjin. The establishment of compensation mechanisms and the provision of certain tax compensation for enterprises that provide assistance to the carbon sink capacity fund would also be beneficial.

In addition, in order to improve the capacity for carbon sequestration, it is also necessary to increase the area of carbon sequestration. First of all, it is necessary to clarify the overall carbon sequestration resources available between Beijing, Tianjin, and Hebei, especially the forest and grassland carbon sequestration resources in Hebei Province. This would allow for stakeholders to reasonably plan protection mechanisms for forest and green space and prohibit the unauthorized occupation of forest funds, thus preventing deforestation and protecting grassland and other natural carbon sequestration sites. For the central part of the city, we should reasonably plan the urban development process and the use of land resources, increase the construction of urban parks and green space, and improve the carbon sink capacity of the Beijing–Tianjin–Hebei region as a whole.

5. Research Deficiencies and Future Prospects

(1) The index system of carbon contribution capacity constructed in this paper lacks comprehensiveness. This paper constructs an evaluation system from three aspects: energy consumption and carbon emission, carbon transfer capacity, and science and technology and carbon sink capacity. However, there are many factors affecting carbon emissions that are not included in the evaluation index system of this paper, such as financial and regional policies. At the same time, this paper mainly introduces the evaluation indexes of energy consumption and carbon emissions that have a direct impact on reducing carbon emissions, namely, four indexes of energy intensity, carbon emission intensity, energy footprint. and carbon footprint; however, there is a lack of detailed indicators for carbon transfer capacity and science and technology and carbon sink capacity. Future studies can be supplemented and expanded to accelerate the realization of carbon neutrality goals more accurately and comprehensively.

(2) This paper takes the Beijing–Tianjin–Hebei region as the research object and makes a comparison within the region in order to illustrate the necessity of coordinated development within the region; however, it lacks investigation of the external environment and has certain regional limitations. In the future, studies on the external environment can be added (such as the impact of new national energy policies and the overall carbon emission trend of the country) to show how the development of the Beijing–Tianjin–Hebei region matches the overall development of the country and realizes the coordinated development of both internal and external aspects of the Beijing–Tianjin–Hebei region.

(3) The research conducted in this paper used 12 years of sample data from 2008 to 2020. Limited by the availability of data, the sample size is too small and lacks immediacy, which should be avoided in future research.

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