sustainability

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Virtual Carbon Flow in China's Capital Economic Circle: A Multi-Regional Input–Output Approach

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Abstract: The Capital Economic Circle (CEC) is the area with the largest economic aggregate in northern China and has a strong status in driving the economic development of China. However, the industrial structure dominated by high energy consuming industries leads to a large number of carbon dioxide emissions, and the imbalance between economic development and carbon emissions in CEC is serious; therefore, it is necessary to explore how to solve the carbon imbalance problem of the CEC by relying on interregional cooperation. Based on China's multi-regional input–output tables of 2012, 2015 and 2017, this paper proposes the CEC carbon-extended, multi-regional input–output model to measure virtual carbon flow and analyze how the industrial structure leads to the imbalance of carbon flow distribution in CEC. Indicators such as direct carbon emission coefficients, complete carbon emission coefficients and carbon emissions pull coefficients of the industrial sectors in CEC are calculated and the physical carbon emission and virtual carbon flows among the industrial sectors and the regions are evaluated. The results show that there are potential constraints from the uncoordinated configuration of industrial innovation chains among the CEC, and the "carbon imbalance" of CEC is mainly reflected in the backward production technology of Hebei and its inefficient connection with the industrial innovation chain of Beijing and Tianjin. It is suggested that policymakers should promote the low-carbon production system and strengthen green energy development and utilization to enhance green development in CEC. In future research, we should pay attention to the updating method of the input–output table and the development of carbon circular networks. This study has implications for some areas of China and developing countries in Asia, which also have an imbalance between industrial economy development and carbon emissions, and a similarity in space structure and industry layout with CEC.

Keywords: virtual carbon flow; capital economic circle (CEC); multi-regional input–output model; industrial structure; industrial innovation chain

Citation: Yin, C.; Liu, Y.; Cui, Y. Virtual Carbon Flow in China's Capital Economic Circle: a Multi-regional Input–OutputApproach. *Sustainability* **2022**, *14*, 11782. https://doi.org/10.3390/su141811782

Academic Editors: Huaping Sun, Keliang Wang and Feng Wang

Received: 23 July 2022
Accepted: 15 September 2022
Published: 19 September 2022

1. Introduction

In recent years, more and more people are paying close attention to the environmental problems in metropolitan areas and their harm to the human body [1]. China is still suffering from air pollutants such as haze that could be predicted more and more accurately and efficiently now [2], as well as the greenhouse effect from fossil energy consumption. At the COP 26 UN Climate Change Conference held in 2021, it was pointed out that global warming caused by greenhouse gas emissions would have an inestimable impact on the earth. Reducing carbon dioxide emissions is the common goal of mankind all over the world. "Peak carbon dioxide emissions in 2030" and "carbon neutrality in 2060" are the strategic goals put forward by China in response to global climate change, which are crucial to the sustainable and high-quality development of China and even the world. From 1997 to 2019, the Capital Economic Circle (CEC), including Beijing (the capital of China), Tianjin (the municipality directly under the Central Government and close to Beijing) and Hebei (a province surrounding Beijing), implemented China's peak carbon dioxide emissions and carbon neutral strategy. Haze and PM2.5 are serious in CEC [3, 4] and CEC's carbon emissions mostly account for more than 11.73% of the country's total in 2019 [5–7]. However, the GDP and population of CEC also account for about 8.62% and 8.08% of the country, respectively, in 2019, which are lower than the carbon emission portion of the CEC [8]. The CEC's economic development and its carbon emission cost are imbalanced. Therefore, as one of the most important economic growth poles in China, the CEC still has serious problems such as "high energy consumption, high pollution and high carbon emissions" [9] and the long-term sustainable development of CEC cannot be achieved at the cost of its high carbon emissions. With the promotion of the integrated and coordinated development of the CEC, Beijing, Tianjin and Hebei have increased the frequent exchanges in the economy. Therefore, it is necessary to explore how to solve the carbon imbalance problem of the CEC by relying on interregional cooperation. It was found that energy consumption in Hebei is dominated by coal and oil, with large industrial production and greater emission reduction potential than Beijing and Tianjin [10]. Scholars thought that it was necessary to continuously optimize the industrial structure and reduce the total consumption of fossil fuels, and carbon emission can be reduced upon CEC industrial structural optimization and rationalization [11]. CEC should base on its own functional positioning, take industrial characteristics as the basis, give full play to their respective advantages and break through regional and industrial barriers so as to promote industrial transfer, coordination and upgrading of urban agglomeration [12]. However, the studies considered only the physical carbon, rather than the carbon transfer among the regions and not take into account the technological and economic industrial relationships in different regions and the industrial trade among the regions. Therefore, the understanding of the overall industrial structure of carbon emission in CEC is limited.

At present, carbon emission accounting has become a research hotspot in the field of energy and the environment. From the perspective of energy, some scholars have constructed different functions to measure the impact factors of carbon emissions and energy efficiency. The research variables include GDP, renewable energy consumption and non-renewable energy consumption [13, 14], knowledge spillover and innovation diffusion [15, 16], economic growth, trade openness, natural resources, economic globalization and urbanization [14, 16, 17]. It indicated that natural resource abundance significantly improves environmental quality, economic globalization and renewable energy consumption mitigate emission levels in the Gulf Cooperation Council (GCC) economies and that urbanization, economic growth and non-renewable energy consumption significantly deteriorate environmental quality [14]. Majeed et al. pointed out that natural resources drastically damage the environment quality, whereas technological innovations are helpful in reducing environmental degradation in Belt and Road Initiative (BRI) economies [17]. Meanwhile, FDI and technology innovation have shaped the energy intensity in the high-tech industry, which causes a fluctuation in carbon emissions over time [18]. Sun et al. constructed an environmental efficiency function on industrial structure, globalization, population density and energy price. His research shows that in Asia, industrial structure has an important impact on environmental efficiency and carbon emissions [19]. Economic differences, industrial structure, population, consumption and energy efficiency of CEC will have great impact on the production and emission of carbon, restricting the implementation of the low-carbon strategy [20]. The heterogeneity of industrial structures is the main aspect of regional economic difference. Industrial sectors produce carbon emissions in the production process [21], and the adjustment of interregional industrial structure is often accompanied by carbon transfer; therefore, accelerating industrial transformation and guiding the reasonable transfer of carbon emissions in various regions are important for achieving the carbon emission reduction goals [22]. Therefore, CEC are responsible for reducing carbon emissions and promoting the rational allocation of carbon flow to realize low-carbon sustainable development through strengthening of the regional integration and coordination in optimizing the industrial structure.

Concerning the other aspect, under the promotion of the national strategy, the economic and inter-industry trade links have been strengthened. The strengthening of inter-industry trade driven by demand may cause regions or industries with low direct carbon emission intensity to consume a large number of intermediate products from other regions or industries, and the direct carbon emissions from the production of these intermediate products will become indirect carbon emissions in regions with low emission intensity, making these regions and their industries into the regions or industries with high virtual carbon output. As early as 1974, at a meeting of IFIAS, it was pointed out that in order to measure the total amount of certain resources directly and indirectly consumed in the production process of a certain product or service, the concept of "embodied" can be used. In the 1990s, Tony applied the concept of 'embodied' to the research of water resources and proposed the concept of "virtual water", which means the amount of water resources directly and indirectly consumed in the production of a product or service [23]. As for carbon emissions, the production of any product will directly or indirectly produce carbon emissions. In order to obtain a certain product, the carbon dioxide emitted directly and indirectly in the whole production chain is called "virtual carbon". Therefore, it is extremely necessary to calculate and analyze the amount of carbon flow among the provinces and sectors in CEC from the perspectives of virtual carbon and the industrial structure for establishing its accurate carbon emission account and identify the carbon responsibilities.

The input–output table could reflect the structural linkage of industry, which covers the input–output relationship among various industrial sectors of the regional economy, and reveals the economic and technological relations of interdependence and mutual restriction among the industrial sectors in the production process. Therefore, combining carbon emission accounting and the input–output model to describe the distribution of virtual carbon flow among industrial sectors and the overall impact of industrial structure on carbon emission has been the research hotspot. Two main models are used in the study, including the single regional input–output model (SRIO) [24, 25] and the multi-regional input–output model (MRIO) [26, 27, 22]. SRIO traditionally focuses on the analysis of carbon flow interaction between industrial sectors within the region and is limited in the analysis on the interregional carbon transfer and multi-regional interaction. In contrast, the research on the transfer of carbon emissions driven by interregional trade started relatively late. With the development of the method of compiling multi-regional input-output tables, Isard [28] first proposed the MRIO model, pointing out that compared with the SRIO model, the MRIO model takes into account the technological differences in different regions and the industrial trade between regions, so that different economies and sectors can be linked through intraregional and interregional trade, and the embodied carbon emissions of various sectors between regions through trade can be captured [29]. Relevant achievements mainly include city-centered researches and country-centered researches. In the research of carbon flow among cities, Lin et al. [30] developed a city-centered global multi-regional input–output model (CCG-MRIO) and calculated the carbon emissions in the trade between Beijing and its trading cities. Xing et al. [31] studied the city level carbon footprint and interregional carbon dioxide transfer reflected in the domestic and foreign product trade of the 29 cities in the Central Plains urban agglomeration by compiling the nested multi-regional input–output tables. In the research of carbon flow among countries, Brizga et al. [32] analyzed the household carbon dioxide equivalent (CO2e) emissions related to the product consumption in the Baltic countries (Estonia, Latvia and Lithuania) from 1995 to 2011 based on the MRIO model; Duarte et al. [33] calculated the carbon emissions and carbon exchange among the sectors of 39 countries from 1995 to 2009 based on the MRIO model; and Gilles et al. [34] applied the environmental extended MRIO model to estimate Bogota's carbon dioxide emission responsibility and its relationship with other parts of Colombia and the rest of the world. At present, there is more research on the energy consumption and carbon emissions of industries at the national or urban level, but less research on provincial and inter-provincial levels. Moreover, the existing literature mostly makes static analysis on the embodied carbon emissions of China's interregional trade based on single year data, which is difficult to reflect the trend and structural change of interregional carbon flow during the implementation of regional economic policies. Although the industrial structure has been mentioned as the impact factor of carbon emission in CEC, the literature is insufficient in revealing the technological and economic relationships among different regions and the industrial trade among the regions, and policy implications are relatively limited and need to be enhanced in discussing the real carbon emission accounting. Therefore, this study is designed and policy implications are discussed on the perspectives of industrial chain and the carbon transfer.

For the incoordination of China's regional economy, including CEC, the potential unbalance of carbon transfer between industries and regions is predominant. This MRIO model can describe the economic relationship among regions and industries, and describe the carbon transfer relationship and inter-industrial and inter-regional structure in detail. Therefore, it is reasonable to analyze the virtual carbon flow based on the MRIO in China. MRIO has been widely applied to measure the resources directly and indirectly consumed in the production process of a certain product or service, and verified by much empirical research. Therefore, to solve the imbalance between the CEC's economic development and carbon emissions, based on China's multi-regional input-output tables of 2012, 2015 and 2017 and the carbon emission data of industrial sectors, this paper proposes the CEC carbon-extended, multi-regional input–output model to calculate the virtual carbon flow among the industrial sectors and the provinces (or cities), to explore the carbon flow transfer and distribution of space and industry, identify the main industry structure factors affecting CEC's carbon emissions and provide applicable suggestions for CEC to achieve synergy between industrial development and carbon emission reduction and lay a basis for promoting the coordinated development of low-carbon civilization in CEC. This article contributes to the application of the virtual carbon model based on province-centered MRIO of CEC and giving the policy recommendation for CEC on strengthening cooperation from the perspective of the industrial innovation chain integration.

2. Materials and Methods

2.1. Data Sources

Beijing, Tianjin and Hebei Province are included in CEC and are abbreviated as BJ, TJ and HB, respectively. The multi-regional input–output tables for the CEC are from the "China Multi-Regional Input–Output Table 2012, 2015 and 2017" downloaded in CEADS [35]. Until the completion of this study, the data after 2017 had not been published, so the China Multi-Regional Input–Output Tables of 2012, 2015 and 2017 are selected for this study. As the economic system is assumed to be stable in a certain period, it still has practical value. In order to fit better with the carbon emission tables and to facilitate systematic analysis, the 42 sectors in the input–output tables are combined into 13, including Agriculture (01), Mining and Dressing (02–05), Food and Tobacco (06), Textile and clothing (07–08), Wood processing (09), Papermaking and printing (10), Petrochemical (11–12), Metal and non-metal (13–15), Equipment manufacturing (16–21), Other manufacturing (22–24), Electric and water supply (25–27), Construction (28) and Service (29–42) (the numbers with the sector are the serial numbers in the input–output tables). The carbon emission data are from "Emission Inventories for 30 Provinces 2012, 2015 and 2017" downloaded in CEADS [5–7, 36]. The 45 sectors in the tables are combined into 13, including Agriculture (01), Mining and Dressing (02–07), Food and Tobacco (09–12), Textile and clothing (13–15), Wood processing (08, 16, 17), Papermaking and printing (18–20), Petrochemical (21–26), Metal and non-metal (27–30), Equipment manufacturing

(31–36), Other manufacturing (37–38), Electric and water supply (39–41), Construction (42) and Service (43–45) (the numbers with the sector are the serial numbers in the carbon emission tables). All the abbreviations of this paper are shown in Appendix Table A1.

2.2. CEC Carbon-Extended Multi-Regional Input–Output Model

This section describes the models and methods used in the study. MRIO is a method based on matrix theory and linear algebra. We construct this model strictly under the constraints of relevant conditions, so the model could be solved on the input–output tables reasonably. Moreover, the MRIO model takes into account the technological and economic relationships in different regions and the industrial trade between regions, so that different economies and sectors can be linked through intraregional and interregional trade, and the embodied carbon emissions of various sectors among the regions through trade can be identified. Therefore, we choose the MRIO method as our basis model. First, based on the national multi-regional input–output tables, the CEC input–output model of 3 × 3 regions and 13 × 13 sectors is constructed. Second, as the physical carbon emissions and virtual carbon transfer need to be taken into account, based on the CEC input–output model, the carbon efficiency coefficients of CEC are applied combining the input–output table data and carbon emission data. DCE, CCE and CEP are selected to describe the direct carbon emission efficiency, indirect carbon emission efficiency and complete carbon emission efficiency of different regions and industries, respectively. Third, in order to reflect the actual effect of interregional and industrial structure on virtual carbon flow, the virtual carbon net flow matrix and the multi-regional virtual carbon trade flow matrix are constructed to describe the structure of virtual carbon and the flow among the industrial sectors and regions in CEC.

2.2.1. CEC Three-Region Input–Output Model

The input–output model analyzes the dependence among the sectors of the national economy in various production relations. The multi-regional input–output (MRIO) could reflect the differences in production and consumption among regions in terms of technology and structure, making up for the defects of the single-region input–output model. The principal of the interregional input–output table is shown in Appendix Table A2.

Suppose an economy system is divided into m regions, and each region contains n economic sectors, among them, z_{ij}^{hk} represents the intermediate output of the products of the sector i in the region h by the sector j in the region k. f_i^h represents the final use of the products of the sector i in the region h. X_i^h represents the gross output of the sector i in the region h.

According to the balance of rows, the gross output is equal to the intermediate output plus the final use [37] and is expressed as

$$X_i^h = \sum_{k=1}^{m}\sum_{j=1}^{n} z_{ij}^{hk} + \sum_{k=1}^{m} f_i^h \tag{1}$$

For the input–output table, the direct consumption coefficient is defined as

$$A_{ij}^{hk} = \frac{z_{ij}^{hk}}{X_j^h} \tag{2}$$

As CEC includes three regions [38], the CEC three-region input-output model is constructed as

$$\begin{vmatrix}\mathbf{X}^1\\ \mathbf{X}^2\\ \mathbf{X}^3\end{vmatrix} = \begin{vmatrix}\mathbf{A}^{11}\mathbf{A}^{12}\mathbf{A}^{13}\\ \mathbf{A}^{21}\mathbf{A}^{22}\mathbf{A}^{23}\\ \mathbf{A}^{31}\mathbf{A}^{32}\mathbf{A}^{33}\end{vmatrix}\begin{vmatrix}\mathbf{X}^1\\ \mathbf{X}^2\\ \mathbf{X}^3\end{vmatrix} + \begin{vmatrix}\mathbf{F}^1\\ \mathbf{F}^2\\ \mathbf{F}^3\end{vmatrix} \tag{3}$$

In Formula (3), $\mathbf{A}$, $\mathbf{X}$, $\mathbf{F}$ are direct consumption coefficient matrices, gross output matrices and final use matrices. In addition, '1', '2' and '3' represent Beijing, Tianjin and Hebei, respectively. For example, $\mathbf{A}^{11}$ is the regional direct consumption coefficient matrix of Beijing, and $\mathbf{A}^{12}$ is the multi-regional direct consumption coefficient matrix from Tianjin to Beijing. $\mathbf{X}^1$ and $\mathbf{F}^1$ are the gross output matrices and the final use matrices of Beijing, respectively. The gross output of CEC could be derived from the deformation of this formula.

2.2.2. Carbon Emission Coefficients of CEC

(1) Direct carbon emission coefficient

The direct carbon emission coefficient (DCE) is the carbon emission directly generated by the sector j of region r in producing unit product, as shown in formula (4).

$$DCE_j^r = \frac{C_j^r}{X_j^r} \tag{4}$$

where DEC_j^r is the direct carbon emission coefficient of the sector j in the region r, C_j^r refers to the physical carbon emissions of the sector j. X_j^r refers to the gross output of the sector j. DEC can reflect the direct carbon emission intensity of industries in the process of producing their own products, and has the intuitive and clear meaning [39]. When DCE is higher, it indicates that the technical energy use efficiency of the sector is lower.

(2) Complete carbon emission coefficient

The complete carbon emission (CCE) is the sum of direct carbon emissions and indirect carbon emissions, which refers to the increase in the total carbon emissions of the entire economic system caused by the increase of unit products in the industrial sector, and can be used to measure the impact of the sector's production process on the entire economy [39], as shown in Formula (5).

$$CCE = DCE\left(\mathbf{I} - \mathbf{A}\right)^{-1} \tag{5}$$

where DCE is the column vector of DEC_j^r, and $\left(\mathbf{I} - \mathbf{A}\right)^{-1}$ is the Leontief inverse matrix. Compared with the DEC, the CCE can more accurately measure the pressure of various production sectors on carbon emissions. When CCE is higher, it indicates that the sector's integration capacity of technical energy use is weaker.

(3) Carbon emissions pull coefficient

The carbon emissions pull coefficient (CEP) is the total increase of carbon emissions of the entire economic system caused by the increase of unit carbon emissions in the output of the industrial sector [40, 41]. It is used to measure the driving effect of production changes of any industrial sector on the carbon emissions of the entire economic system, as shown in formula (6). When CEP is higher, it indicates that the sector's integrated technological innovation capacity is weaker in the industrial chain.

$$CEP = \frac{CCE^T}{DCE} \tag{6}$$

2.2.3. Virtual carbon net flow of CEC

(1) The virtual carbon net flow matrix

The virtual carbon net flow matrix ($\mathbf{TE_{c\text{-}net}}$) represents the unidirectional net flow of virtual carbon. In order to get $\mathbf{TE_{c\text{-}net}}$, virtual carbon flow matrix $\mathbf{TE_c}$ is constructed [42].

$$\mathbf{TE}_c = \mathbf{V}_c - \mathbf{V}_c^{\,T} \quad (7)$$

$$\mathbf{V_c} = \mathbf{D}(\mathbf{I} - \mathbf{A})^{-1}\mathbf{F} \quad (8)$$

where $\mathbf{V_c}$ is the total carbon emission matrix, $\mathbf{D}$ is the row vector of the direct carbon emission coefficient, $\mathbf{F}$ is the final use matrix and $\mathbf{TE_c}$ is the virtual carbon flow matrix, which is the complete carbon emission matrix minus its own transposition. Formula (8) is derived in appendix expansion 1. The elements in $\mathbf{TE_c}$ represent the difference in the bidirectional flow of virtual carbon between regions. The main diagonal element in the matrix is 0, which means that there is no transfer of virtual carbon consumption within the sectors themselves. Elements that are symmetrical on both sides of the diagonal are opposite. The plus and minus sign represent direction of the flow, and the absolute value represents the net flow intensity. Set the negative elements in the transition matrix to 0, representing the unidirectional net flow of virtual carbon, and obtain the virtual carbon net flow matrix $\mathbf{TE_{c\text{-}net}}$.

(2) Multi-regional virtual carbon trade flow matrix

Virtual carbon emission flow between regions is

$$\mathbf{C_{h\text{-}k}} = \sum_{j=1}^{n} CCE_{jk} t_{jk} - \sum_{j=1}^{n} CCE_{jh} t_{jh} \quad (9)$$

where $\mathbf{C_{h\text{-}k}}$ is the virtual carbon net flow obtained by region h from region k. CCE_{jk} and CCE_{jh} are the complete carbon emission coefficients of industry j in region k and region h, respectively and t_{jk} represents the sum of the product value of industrial sector j obtained by region h from region k. t_{jh} represents the sum of the product value of industry j transferred from region h to region k.

3. Results and Disscusion

3.1. Industrial Sector Carbon Emission Coefficients

We calculated the direct carbon emission coefficient (DCE), the complete carbon emission coefficient (CCE) and the carbon emission multiplier (CEP) of different industrial sectors in CEC, and the results are shown in Table 1.

Table 1. Industrial sector carbon emission coefficient of CEC.

		2012			2015			2017		
Sectors	**Regions**	**DCE**	**CCE**	**CEP**	**DCE**	**CCE**	**CEP**	**DCE**	**CCE**	**CEP**
Agriculture	BJ	0.42	0.70	1.66	0.38	0.66	1.75	0.18	0.36	1.93
	TJ	0.63	2.04	3.24	0.55	1.75	3.17	1.97	2.25	1.14
	HB	0.40	1.47	3.64	0.29	1.33	4.63	0.22	0.78	3.51
	CEC	1.45	4.21	8.54	1.22	3.74	9.55	2.37	3.39	6.58
Food and tobacco	BJ	1.20	2.55	2.12	0.45	1.65	3.64	0.11	0.26	2.36
	TJ	1.48	2.33	1.57	0.07	0.37	5.43	0.07	0.27	3.73
	HB	2.90	7.15	2.47	3.68	6.85	1.86	0.62	2.72	4.40
	CEC	0.36	3.08	24.32	0.26	2.90	31.54	0.16	1.7	37.11
Mining and Dressing	BJ	0.07	0.41	5.99	0.05	0.37	8.14	0.02	0.21	10.57

	TJ	0.11	0.88	8.35	0.07	0.74	10.43	0.09	0.54	5.98
	HB	0.18	1.79	9.98	0.14	1.79	12.97	0.05	0.95	20.56
	CEC	5.58	12.03	6.16	4.20	8.87	10.93	0.8	3.25	10.49
Textile and Clothing	BJ	0.08	0.32	4.20	0.09	0.26	2.85	5.19	5.43	1.05
	TJ	0.21	0.88	4.26	0.05	0.58	12.85	0.22	0.41	1.85
	HB	0.21	2.73	13.2	0.15	2.22	14.88	0.02	1.54	75.63
	CEC	0.50	3.93	21.66	0.29	3.06	30.58	5.43	7.38	78.53
Wood processing	BJ	0.06	0.54	8.73	0.07	0.43	6.02	0.11	0.59	5.44
	TJ	0.28	1.11	3.90	0.11	0.77	6.86	0.39	0.79	2.01
	HB	0.14	4.67	32.45	0.09	3.93	41.96	0.10	2.21	22.77
	CEC	0.48	6.32	45.08	0.27	5.13	54.84	0.60	3.59	30.22
Papermaking and printing	BJ	0.09	0.81	8.84	0.08	0.56	7.39	0.08	0.32	3.72
	TJ	0.21	1.98	9.59	0.1	1.63	15.97	0.09	0.42	4.39
	HB	0.25	5.68	23.14	0.18	4.77	26.91	0.04	1.97	51.03
	CEC	0.55	8.47	41.57	0.36	6.96	50.27	0.21	2.71	59.14
Petrochemical	BJ	0.45	0.77	1.70	0.53	0.82	1.55	0.53	0.72	1.35
	TJ	0.61	3.69	6.07	0.58	3.18	5.53	0.29	0.59	2.02
	HB	0.81	5.58	6.9	0.77	4.63	6.04	0.39	2.47	6.29
	CEC	1.87	10.04	14.67	1.88	8.63	13.12	1.21	3.78	9.66
Metal and non-metal	BJ	0.71	2.26	3.20	0.61	1.70	2.78	0.19	0.94	5.06
	TJ	2.07	5.18	2.50	1.95	4.99	2.56	0.66	1.26	1.91
	HB	6.55	14.48	2.21	7.02	14.02	2.00	4.63	8.06	1.74
	CEC	9.33	21.92	7.91	9.58	20.71	7.34	5.48	10.26	8.71
Equipment manufacturing	BJ	0.03	0.57	18.63	0.04	0.38	8.71	0.05	0.27	5.15
	TJ	0.06	1.37	21.23	0.08	1.16	13.75	0.02	0.27	15.66
	HB	0.17	7.52	45.00	0.12	6.30	50.67	0.12	3.47	29.02
	CEC	0.26	9.46	84.86	0.24	7.84	73.13	0.19	4.01	49.83
Other manufacturing	BJ	0.20	0.81	4.13	0.08	0.55	7.28	0.11	0.29	2.68
	TJ	0.07	0.94	12.87	0.07	1.00	13.73	0.01	0.21	84.38
	HB	0.12	6.43	51.44	0.11	4.88	44.78	0.01	2.28	171.62
	CEC	0.39	8.18	68.44	0.26	6.43	65.79	0.12	2.78	258.68
Electric and water supply	BJ	4.81	8.68	1.80	4.70	8.53	1.82	4.01	7.36	1.83
	TJ	19.95	27.39	1.37	16.10	22.47	1.40	1.11	1.68	1.52
	HB	29.30	43.18	1.47	21.08	33.52	1.59	21.83	25.06	1.15
	CEC	54.06	79.25	4.64	41.88	64.52	4.81	26.95	34.10	4.50
Construction	BJ	0.04	1.24	28.99	0.03	0.84	32.37	0.04	0.75	20.95
	TJ	0.12	2.31	19.23	0.09	1.93	21.08	0.53	1.00	1.87
	HB	0.03	6.89	220.34	0.04	6.11	145.28	1.54	5.13	3.32
	CEC	0.19	10.44	268.56	0.16	8.88	198.73	2.11	6.88	26.14
Service	BJ	0.19	0.49	2.63	0.16	0.43	2.59	0.14	0.34	2.48
	TJ	0.24	1.16	4.74	0.17	0.90	5.17	0.18	0.38	2.10
	HB	0.33	2.14	6.55	0.25	1.71	6.82	0.40	1.83	4.53
	CEC	0.76	3.79	13.92	0.58	3.04	14.58	0.72	2.55	9.11

The maximums of the common coefficient, sector and year for the three regions in each year are shown in gray.

According to the difference of indicators, the industrial sectors can be divided into the following categories.

(1) Industrial sectors with much higher CEP in Beijing and lower CEP in Tianjin and Hebei. These sectors are the high resource-consuming and energy-consuming ones and include the electric and water supply sector, construction sector and metal and non-metal sector. They had the highest coefficients in almost all the industrial sectors in CEC. DCE

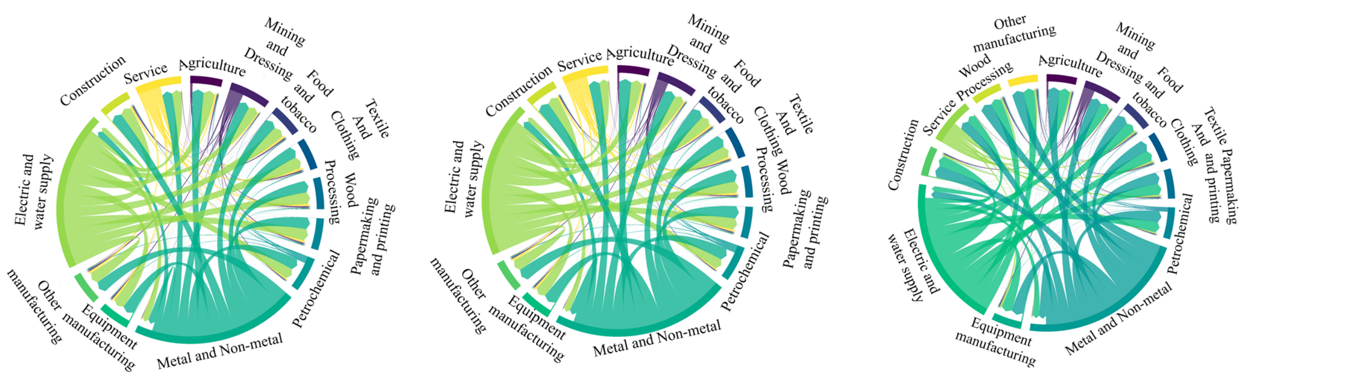
and CCE were lower and CEP was higher for the electric and water supply sector in Beijing, whereas in Hebei it was just the opposite. The construction sector in Hebei had the highest DCE and CCE, but CEPs in the construction sector in Tianjin and Hebei were in a decreasing trend, whereas CEP in the construction sector in Beijing was high all the time. The metal and non-metal sector in Hebei had the highest DCE and CCE, whereas the CEP decreased during the period. Since CEPs of such sectors in Tianjin and Hebei were in a downward trend, it is suitable to transfer those sectors from Beijing to Tianjin and Hebei. Efforts were made to separate the above sectors from the industrial functions of the capital lasted for the period from 2012 to 2017. However, some high energy-consuming sectors in Hebei with higher DCE and CCE demanded to import advanced production technology to improve resource and energy efficiency.

(2) Industrial sectors with much higher CEP or CCE in Hebei and higher DEC in Beijing or Tianjin. DCE of such sectors as the mining and dressing, textile and clothing, wood processing and papermaking and printing in Beijing were higher, whereas the CEP of these sectors was lower in Tianjin and Hebei. DCE of these sectors rapidly declined in Hebei, but CCE remained at a high level all the time. Moreover, DCE and CCE of Tianjin's agriculture were higher and CEP was lower, whereas those of Hebei were just the opposite. It can be seen that the development of the above-mentioned sectors in the three regions is uncoordinated, and there is the problem of industrial chain mismatch. For the mining and dressing sector and the light industries, CEC should focus on rearranging the production chain, with Beijing focusing on brand building and high-end product innovation, Tianjin on product design and development and Hebei on product processing and manufacturing to reduce costs and improve energy use efficiency.

(3) Industrial sectors with higher DEC, CCE and CEP in Hebei and much lower DEC, CCE and CEP in Beijing and Tianjin. DEC, CCE and CEP of such sectors as petrochemical, equipment manufacturing and service sectors were the highest in Hebei than in the other regions and continued to be at a high level. The services belong to the intellectual and talent-intensive sector, and petrochemical and equipment manufacturing are the capital-intensive and high-tech sectors. It seems that the lack of technological innovation capacity of related sectors in Hebei and stagnation of technological progress had resulted in an inefficient use of energy. Hebei's overall industrial innovation chain was incomplete, and it is difficult to be connected to the Beijing-Tianjin science and technology resource and the upstream innovation chain, which made production technology and equipment at the rather low-end, exacerbating the excessive energy consumption. CEC should promote the integration of relevant industrial innovation chains. The three regions in CEC should carry on reasonable industry division, with Beijing focusing on the supplying of high-quality science and technology innovation resources and the key technology in the upstream of the industrial innovation chain, Tianjin focusing on industrial application technology development and core parts processing and manufacturing, with Hebei strengthening its technology integration capability and terminal green and efficient industry manufacturing capability.

3.2. Industrial Virtual Carbon Flow and Space Movement in CEC

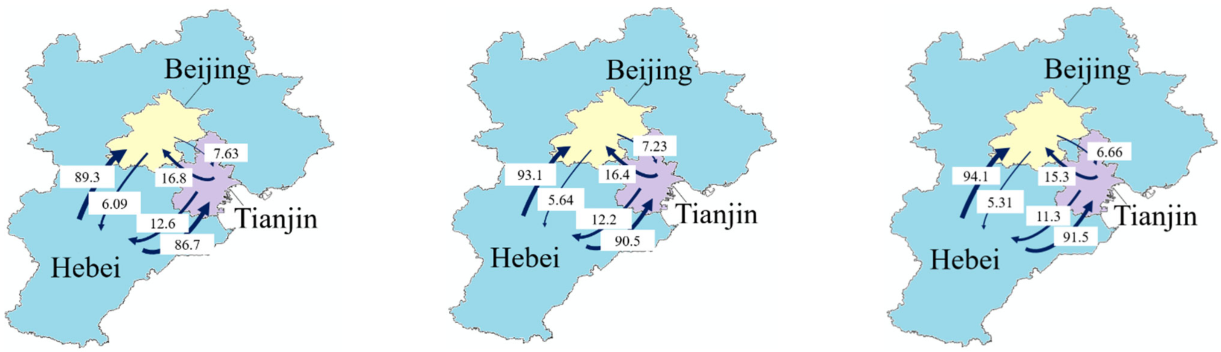
Figure 1 shows the interaction of carbon flows among CEC's sectors in detail. Clearly, the metal and non-metal sector had the largest scale of carbon flow and the most sectors interaced, followed by the electric and water supply sector. These two sectors were mainly the hubs of carbon outflows, but the scale of carbon inflows was small. In contrast, the hubs of carbon inflows are distributed, and mainly manufacturing, including equipment manufacturing, the food and tobacco sector and the textile and clothing sector were the important hubs of carbon inflows, whereas the scale of carbon outflows is not large and involves a smaller range of sectors. The outflow of the papermaking and printing sector, petrochemical sector and wood processing sector was also low. The level of carbon inflows and outflows for the service sector was generally more balanced. This characteristic did not change much in 2012, 2015 and 2017. In general, sectors in the downstream of the industrial chain in CEC are the ones with carbon inflows, whereas industries in the upstream of the chain are the sectors with immense carbon outflows. The carbon flows in a unidirectional movement mainly from the upstream of resouce-consuming and energy-consuming sectors in industrial chains and downstream in manufacturing sectors, ands result in the difficulty of forming an effective closed industrial carbon cycle in CEC. The virtual carbon flow burden of the downstream sectors in the chain is reletively heavy, which easily make its potential impact on carbon emissions underestimated. Yan has pointed that the key sectors of CEC's virtual carbon are mainly concentrated in the four major industries, including " production and distribution of electric power and heat power", " mining and processing of nonmetal and other ores", "smelting and processing of metal" and " transport, storage, and postal services "[43]. However, a considerable part of physical carbon emissions in these sectors is caused by the downsteam sectors in the industrial chain. Zhang pointed that compared with the rationalization of industrial structures, the upgrading of industrial structures in Beijing and Hebei has a more obvious effect on carbon emission reduction, whereas the rationalization of industrial structures in Tianjin has a more significant effect on carbon emissions [11]. Obviously, the carbon responsibility of these upstream industries of energy and resources tend to be overestimated and the carbon obligation is underestimated in traditional carbon accounting. Therefore, regional emission reduction should not be only focused on these upsteam industries in CEC, but the construction of the low-carbon production system and the development of new green energy technologies to promote the upgrading of industrial structures in Beijing and Hebei is very necessary.



(**a**) 2012 (**b**) 2015 (**c**) 2017

Figure 1. Industrial virtual carbon flows among sectors of CEC. The outflows of the sectors are represented in different colors. The width of the flow represents the virtual carbon flow intensity. The direction of the flow represents where the virtual carbon flow goes. The flow connected to the outer ring represents outflow and the flow connected to the inner ring represents inflow.

Figure 2 shows the carbon flow interactions among the regions as a whole. In the three periods, the level of carbon flow between Beijing and Tianjin tended to be balanced continuously, and the collaboration ability of the industrial chain between the two regions was reasonable. The carbon flow interactions between Beijing and Hebei, and between Tianjin and Hebei were not equivalent, and Hebei was the region with net carbon outflow, whereas Beijing and Tianjin were the regions with the net inflow. This non-equivalence between Beijing and Hebei had been expanded to some extent, whereas the non-equivalence between Tianjin and Beijing had been contracted. Hebei had an unfavorable position in CEC's carbon cycles, and it was mainly related to the current industrial structure of the three regions and the insufficient talent and technical support from Beijing and Tianjin to Hebei. From the perspective of virtual carbon flow intensity and direction, a considerable part of physical carbon emissions in Hebei are caused by the industrial development of Beijing and Tianjin. Therefore, the carbon responsibility of Hebei is overestimated, and the carbon obligation of Beijing and Tianjin is underestimated. It is consistent with the existing research [44]. Therefore, it is necessary to accelerate the establishment of a virtual carbon accounting system of CEC comprehensively based on the consumption side and the production side to evaluate the carbon emission responsibilities of various regions more accurately.



(**a**) 2012 (**b**) 2015 (**c**) 2017

Figure 2. Regional spatial carbon flow of CEC (100 million tons).

3.3. Virtual Carbon Trade in CEC

This section provides a more in-depth analysis of the inter-industrial and inter-regional carbon flow movements of Section 3.2.

3.3.1. Regional Physical Carbon Emission

The total physical carbon emission and unit carbon emission of CEC are shown in Table 2. Unit carbon emission refers to the tons of carbon emission by an industry for CNY 10 thousand of product added value. The total carbon emissions from CEC had been reduced during these years, but the carbon emissions of most sectors, especially metal and non-metal, electric and water supply and mining and dressing sectors in Hebei were still the largest in the regions. Hebei traditionally focused on heavy industry, and its energy depends on coal and thermal power converted from coal. Tianjin's metal and non-metal, electric and water supply were the sectors with high total carbon emissions. Beijing's total carbon emissions of the service sector were increasing year by year. From the perspective of the unit carbon emissions, the value had decreased in all the years, indicating that the integration and optimization of the industrial chain have achieved the initial effect. However, the unit carbon emissions of metal and non-metal, electric and water supply sectors were still very high. In combination with the virtual carbon emissions among sectors in Section 3.2, sectors with larger physical carbon emissions have smaller virtual carbon emissions, such as mining and dressing and petrochemical sectors. As the industrial energy efficiency is not high, most of the products of these upstream sectors are used as industrial raw materials, energy or intermediate inputs, and the unit emissions are high. However, the energy efficiency of the equipment manufacturing and service sector are high and the proportion of final consumption goods or services is relatively high, for they have higher technological efficiency [45].

Table 2. Total physical carbon emission (Mt) and Unit carbon emission (ton/CNY 10 thousand).

Sectors	Total/Unit Emission	2012			2015			2017		
		BJ	TJ	HB	BJ	TJ	HB	BJ	TJ	HB
Agriculture	Total emission	1.00	1.32	8.36	0.73	1.24	7.04	0.37	1.28	6.94
	Unit emission	0.34	0.54	0.24	0.28	0.42	0.18	0.14	0.79	0.21

Mining and Dressing	Total emission	1.82	5.90	41.62	0.07	1.91	38.61	0.03	1.20	37.98
	Unit emission	0.30	0.40	1.43	0.02	0.18	2.11	0.01	0.08	2.26
Food and tobacco	Total emission	0.35	0.73	2.55	0.20	0.53	2.34	0.12	0.29	2.36
	Unit emission	0.06	0.07	0.25	0.04	0.04	0.25	0.02	0.04	0.15
Textile and Clothing	Total emission	0.11	0.26	0.99	0.06	0.10	1.04	0.04	0.08	0.89
	Unit emission	0.06	0.09	0.10	0.05	0.02	0.08	0.03	0.03	0.09
Wood processing	Total emission	0.04	0.10	0.33	0.04	0.06	0.30	0.06	0.06	0.25
	Unit emission	0.05	0.16	0.22	0.05	0.07	0.13	0.06	0.12	0.11
Papermaking and printing	Total emission	0.13	0.36	1.16	0.09	0.32	1.07	0.07	0.16	1.14
	Unit emission	0.06	0.18	0.32	0.05	0.08	0.23	0.04	0.07	0.25
Petrochemical	Total emission	3.43	7.58	17.64	3.28	7.51	19.32	2.44	5.47	11.52
	Unit emission	0.20	0.66	0.79	0.24	0.58	0.74	0.15	0.40	0.38
Metal and non-metal	Total emission	4.28	48.47	336.21	2.55	51.48	363.23	0.56	43.77	365.20
	Unit emission	0.53	2.46	7.03	0.44	2.49	6.98	0.08	2.88	5.39
Equipment manufacturing	Total emission	0.63	1.35	4.75	0.44	1.31	4.54	0.39	1.84	4.39
	Unit emission	0.01	0.04	0.26	0.01	0.03	0.17	0.01	0.06	0.17
Other manufacturing	Total emission	0.06	0.09	0.11	0.03	0.08	0.09	0.03	0.07	0.09
	Unit emission	0.09	0.03	0.07	0.02	0.03	0.09	0.03	0.09	0.06
Electric and water supply	Total emission	37.35	68.26	278.05	33.07	63.68	279.93	28.50	62.42	290.01
	Unit emission	2.61	21.52	38.92	1.72	15.55	31.16	1.22	12.08	18.30
Construction	Total emission	1.43	3.43	1.68	1.16	3.88	2.33	1.18	4.03	2.14
	Unit emission	0.05	0.25	0.09	0.03	0.20	0.11	0.03	0.32	0.08
Service	Total emission	32.67	15.77	29.79	34.32	14.33	28.99	35.15	14.82	28.92
	Unit emission	0.16	0.20	0.28	0.13	0.13	0.21	0.09	0.16	0.19

The maximums of the common coefficient, sector and year for the three regions in each year are shown in gray.

3.3.2. Regional Virtual Carbon Trade

As shown in Table 3, although Hebei was the region with net carbon outflow, and Beijing and Tianjin were the regions with net carbon inflow, the absolute amounts of net carbon input and output in the three periods are fluctuating, which is related to the decrease of physical carbon emissions and the evolution of industrial structures within CEC. The CEC's outflow of virtual carbon to external regions (ER) gradually decreased, but the amount of virtual carbon absorbed from ER gradually increased. The virtual carbon emission responsibility has been transferred from ER to CEC. It means that the impact of carbon emissions of CEC has spread to other areas of China to some extent, and it has brought great carbon deficit. The CEC's energy efficiency improvement and energy structure upgrading are urgent. Beijing is the subject of carbon compensation, and Tianjin and Hebei are the recipients of carbon compensation. It is generally accepted that the region with higher levels of economic development should compensate the region with lower levels of economic development [46], which is consistent with the result of CEC.

A more detailed calculation and analysis of the carbon input and output proportion of each sector in CEC is conducted (Figure 3). First, the outflow proportion of electric and water supply sector was high, and its carbon flow activities weremore active. Second, the inflow proportion of wood processing, the papermaking and printing sector, other manufacturing sectors and the petrochemical sector were high, and they were in the downstream of the industrial chain. Meanwhile, agriculture, food and tobacco and textile and clothing were the sectors with high carbon inflow. Third, service sectors in Beijing were the ones with higher carbon outflow proportion. Furthermore, metal and non-metal in Tianjin and Hebei were the sectors with high carbon outflow. Metal and non-metal, electric and water supply and construction are the sectors with virtual carbon net outflow in all three years. This is consistent with the results of the analysis in 3.2 and this further confirms the imbalance of carbon flow distribution in the industrial chain. Sun also pointed out that industrial structures are the main driving factors for the virtual carbon in CEC, and in particular, the impact of industrial efficiency of high energy consuming industries is predominant [47]. In the study, such high energy consuming industries obviously have higher outflows, and the physical and virtual carbon emissions of these industries are both high. This result is basically consistent with the sectors that are substantially and apparently high in carbon emissions, and the equilibrium between dematerialization and energy saving was emphasized [48]. Further, it is found that in the study, the carbon pressure of downstream industries was transferred to the upstream industries to some degree. Therefore, the improvement of energy efficiency should be considered from the whole industrial chains, and all links should be included in the energy-consuming system.

Table 3. Virtual carbon flow trade volume in CEC (100 million tons).

	2012				2015				2017			
	BJ	**TJ**	**HB**	**ER**	**BJ**	**TJ**	**HB**	**ER**	**BJ**	**TJ**	**HB**	**ER**
Inflow	25.25	69.27	0.88	47.14	30.19	60.12	31.11	44.41	25.95	91.73	15.79	35.45
Outflow	0.85	0.23	94.33	2863.37	2.64	6.02	133.93	3184.69	2.42	8.24	160.67	3280.30
Net Inflow	24.40	69.05	–93.45	–2816.24	27.55	54.1	- 102.82	- 3140.28	23.53	83.49	- 144.88	–3244.95

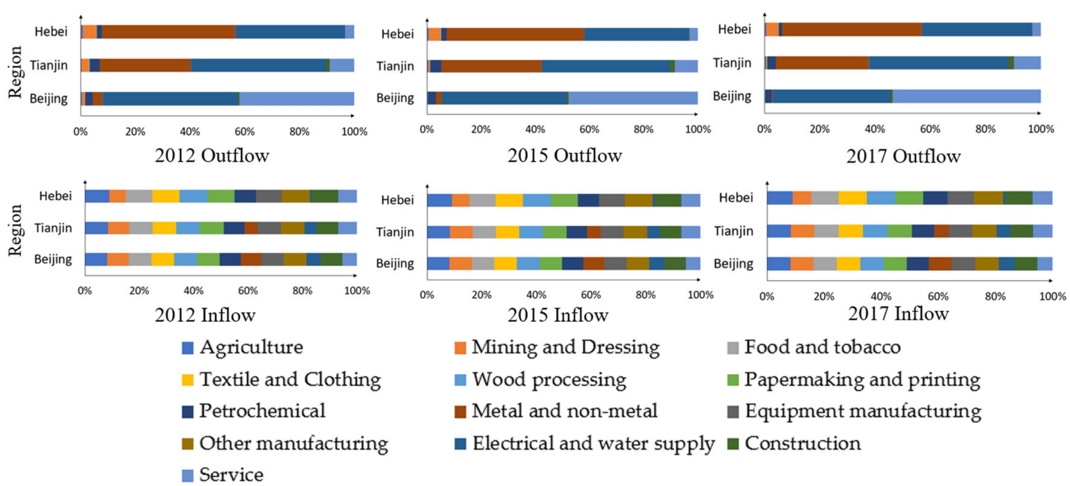


Figure 3. The proportion of virtual carbon trade volume in CEC.

4. Conclusions and Policy Recommendation

4.1. Conclusions

This paper presents an empirical analysis of the virtual carbon flows of the based on the CEC carbon-extended multi-regional input–output model and finds why the imbalance between CEC carbon emissions and its economic development mentioned in the previous introduction happens. The most important influencing factor is the industrial structure, which is consistent with the existing literature that industrial structure and technological factors have the reasonable effect on carbon emissions. However, this paper further finds that there are potential constraints from the uncoordinated configuration of industrial innovation chains among CEC. Hebei has transferred the high-pollution and high-emission sectors of CEC and made important contributions to the green development of the two international cities, Beijing and Tianjin. On the other hand, the high virtual carbon outflow of Hebei restricts the improvement of the CEC's overall green production efficiency. However, this cannot be attributed to Hebei itself, and the responsibilities and obligations of Beijing and Tianjin should not be ignored from the industrial innovation chain or network of CEC. The "carbon imbalance" of CEC is mainly reflected in the backward green production technology and the separation from the industrial innovation chain of Beijing and Tianjin. The basic sectors of energy and raw materials at the upstream end of the industrial chain and the processing and manufacturing sectors at the downstream end of the industrial chain have been gradually transferred to Hebei, but the innovation chain of Beijing and Tianjin has not been effectively extended to Hebei. Due to the lack of support for Beijing and Tianjin's green production technology and digital manufacturing capacity, Hebei's agricultural production efficiency and industrial energy efficiency are not high. The defective industrial innovation chain further aggravates the generation and spillover of virtual carbon in Hebei. Therefore, the distribution of the CEC's carbon flow is seriously imbalanced, and the inter-regional and inter-sector carbon cycle could not operate effectively. In this regard, CEC should improve collaborative innovation systems around efficient green production, and pay attention to policy support.

4.2. Policy Recommendation

For the embodied carbon emissions, CEC should accelerate the establishment of a virtual carbon accounting system based on combined consumption and production, so as to comprehensively and objectively evaluate the carbon emission responsibilities of regions. Furthermore, the following policy recommendations are put forward to promote the sustainable low-carbon development in CEC.

(1) The policymakers should promote the cooperation in industrial chains in CEC to create the low-carbon production systems. Although carbon is generated in all links of the production chain, from the perspective of virtual carbon, the downstream industry has a strong driving force for carbon emissions, and the upstream industry is more vulnerable to the impact. Therefore, the improvement of energy efficiency should not be limited to upstream industries. First, industrial structure and production chain adjustment need to be continuously promoted and ecological compensation for the industries based on virtual carbon accounting is encouraged. Beijing is the payer of ecological compensation, and Tianjin and Hebei are the receiver of ecological compensation. Beijing and Tianjin may set up a green low-carbon industry fund to accurately compensate the capital needed for the development of low-carbon production technology according to inter-regional and inter-industrial carbon responsibilities. Second, the government needs to actively guide the advantageous scientific research forces in Beijing and Tianjin to promote joint innovation around carbon-reducing technologies and resource-saving technologies in the industry chains and to support industry leaders, universities, research institutes and enterprises in the upstream and downstream of the industrial chain in CEC to construct green industrial innovation centers to cooperate in project organization, talent gathering, etc. Beijing and Tianjin should take the lead in supporting the establishment of public service platforms with functions of open source and open R&D for key technologies in Hebei's leading sectors, such as equipment manufacturing, petrochemical, mining and dressing and metal and non-metal. Third, the "CEC industry ecological partner" program needs to be implemented. In the program, Hebei's enterprises are encouraged to join the technological applications in the segment sector, and collaborate with upstream and downstream partners in the industry chain in Beijing and Tianjin to share knowledge, data, platforms and technologies.

(2) The policymakers should construct a collaborative system for the development and utilization of new green energy in CEC. Energy structure upgrading is also an important path to promote industrial structure upgrading and reduce carbon emissions, with the substitution of new energy for fossil energy. The three regions need to make full use of their respective advantages in resources, technology and equipment, and develop and utilize local green energy sources such as wind, light, and hydrogen energy. First, clean energy bases in Hebei need to be constructed in megawatt wind power bases in Zhangjiakou and Chengde, and a renewable energy demonstration zone in Zhangjiakou needs to be promoted. Second, we could increase inter-provincial green power trading

and the proportion of green power in external power. Combining various energy modes of solar energy, tidal energy and geothermal energy, the micro-grid network could be formed to realize the mode of power generation, storage and circulating consumption for the maxim use of clean power. Third, the renewable energy green certificate trading system could be implemented in CEC. Through the construction of a new energy spot trading market across regions, pilot research will be conducted to organize the daily and inter-regional transactions in a market-oriented manner [49]. In addition, local and social capital is encouraged to enter the field of green energy equipment manufacturing to mobilize the enthusiasm for independent research and development, maximize cost control and reduce the overall cost of green energy systems. The policymakers may also make good use of relevant laws, policies and green financial services to reduce unreasonable development costs and the cost of loans.

This study has some limitations, highlighting future research opportunities. In future research, we should pay attention to the updating method of the input–output table to make the data better describe the current situation and the purchasing power parities (PPP) method could be used to improve the measurement of carbon flow. Further, network technology can be applied to study the industrial chain and innovation chain in detail and future research could be focused on the development of carbon circular networks based on multi-regional input–output models, so as to explore the optimization mechanism of the structure of carbon flow. As for the similarity to CEC in terms of space structure, industry layout and the unbalance of carbon emissions, the research method and some policies discussed in the paper have implications for other areas of China and some developing countries in Asia.

Author Contributions: Conceptualization, C.Y. and Y.L.; methodology, C.Y. and Y.L.; software, Y.L. and Y.C.; validation, C.Y., Y.L. and Y.C.; formal analysis, C.Y. and Y.L.; investigation, C.Y. and Y.L.; resources, C.Y., Y.L. and Y.C.; data curation, Y.L. and Y.C.; writing—original draft preparation, C.Y. and Y.L.; writing—review and editing, C.Y., Y.L. and Y.C.; visualization, Y.L.; supervision, C.Y.; project administration, C.Y. and Y.L.; funding acquisition, C.Y. All authors have read and agreed to the published version of the manuscript.

Funding: This research was supported by Shandong Humanities and Social Sciences Project (grant number 2021-JCGL-06).

Data Availability Statement: The data used to support the findings of this study are available from the corresponding author upon request. The multi-regional input-output data used in this paper is the open-resource data provided by Carbon Emission Accounts & Datasets for emerging economies at https://www.ceads.net.cn/data/input_output_tables/. The carbon emission data used in this paper is the open-resource data provided by Carbon Emission Accounts & Datasets for emerging economies at https://www.ceads.net.cn/data/province/.

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

Appendix A

Expansion 1

$$\mathbf{V_c} = \hat{\mathbf{D}}(\mathbf{I}-\mathbf{A})^{-1}\hat{\mathbf{F}} = \begin{bmatrix} d^1 & 0 & 0 & 0 \\ 0 & d^2 & 0 & 0 \\ \cdots & \cdots & \cdots & \cdots \\ 0 & 0 & 0 & d^m \end{bmatrix} \times \left(\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ \cdots & \cdots & \cdots & \cdots \\ 0 & 0 & 0 & 1 \end{bmatrix}_{m\times m} - \begin{bmatrix} a^{11} & a^{12} & \cdots & a^{1m} \\ a^{21} & a^{22} & \cdots & a^{2m} \\ \cdots & \cdots & \cdots & \cdots \\ a^{m1} & a^{m2} & \cdots & a^{mm} \end{bmatrix} \right)^{-1} \times \begin{bmatrix} f^1 & 0 & 0 & 0 \\ 0 & f^2 & 0 & 0 \\ \cdots & \cdots & \cdots & \cdots \\ 0 & 0 & 0 & f^m \end{bmatrix} \quad (10)$$

Table A1. Name and Acronym.

Name	Acronym	Name	Acronym
Single regional input-output model	SRIO	Multi-regional input-output model	MRIO

China's Capital Economic Circle	CEC	Direct carbon emission coefficient	DCE
Beijing	BJ	Complete carbon emission coefficient	CCE
Tianjin	TJ	Carbon emissions pull coefficient	CEP
Hebei	HB	External regions	ER

Table A2. Multi-regional input–output table. Assume that the number of regions is m. The number of sectors is n, and in each region is the same, and the classification method and caliber of sectors are consistent.

			Intermediate use							**Final Use**			**Total Final Use**
			Region 1			···	Region m						
			Sector 1	···	Sector n	···	Sector 1	···	Sector n	Region 1	···	Region m	
Intermediate input	Region 1	Sector 1											
		...		z_{ij}^{11}		···		z_{ij}^{1m}		F^{11}	···	F^{1m}	X^{1}
		Sector n											
	...	...		...				...		...	...	...	...
	Region m	Sector 1											
		...		z_{ij}^{m1}		···		z_{ij}^{mm}		F^{m1}	···	F^{mm}	X^{m}
		Sector n											
Total Value Added				$V^{1'}$		···		$V^{m'}$					
Total Input				$X^{1'}$		···		$X^{m'}$					

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