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Structural Path Analysis of Carbon Emission in Guangdong Province

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Abstract. With the emission of a large number of greenhouse gases, global warming has become the focus of attention. In this paper, structural path analysis (SPA) and environmental extended input-output analysis (EEIOA) are used to study the carbon emission of various sectors in Guangdong Province. The proportion of carbon emission in different sectors is analyzed from different final demand, and the key carbon emission sectors and key carbon emission paths are determined. The results show that HEA sector (heavy industry sector) and ELE sector (electric power sector) are the key carbon emission sectors in Guangdong Province, accounting for 30.7 % and 17.1 % of total carbon emission, respectively. Export is the final demand for carbon emission in Guangdong, accounting for 66.7%. Most of the carbon emission paths of export are relatively short, tending to direct carbon emission, and most of the end points of the paths are HEA sector (heavy industry sector) and LIG sector (light industry sector). Most of the carbon emission paths of consumption mainly flow into consumption with SER sector (service sector) and ELE sector (electric power sector) as the end points. Most of the carbon emission paths of investment are more than two sectors, and most of the carbon emission of the paths flow into investment with CON sector (construction industry) as the end point, while CON sector (construction industry) causes carbon emission inflows from other sectors, so a large number of indirect carbon emission caused by investment.

Keywords. Structural path analysis (SPA), environmental extended input-output analysis (EEIOA), carbon emission

1. Introduction

Global warming caused by a large number of greenhouse gas emission has threatened the survival and development of mankind, and the large use of fossil energy is the main reason for greenhouse gas emission. China is not only a big country of energy is consumption, but also a big country of carbon emission, in 2006 China became the world’s largest greenhouse gas power, in 2017 China’s greenhouse gas emission occupy

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more than a quarter of the global greenhouse gases [1], in 2020 China's carbon emission continue to grow for the fourth consecutive year, an increase of 0.6%, carbon intensity decreased by 1% [2], to achieve China's carbon peak and carbon neutrality requires not only national-level research, but also regional research, and Guangdong is a large province in China's economic development, with industrialization and urbanization, Guangdong's carbon emission is also increasing, and it is more regionally representative to study the carbon emission pathway in Guangdong Province.

Input-output analysis (IOA) was first proposed by Wassily Leontief and was mainly used to analyze interdependencies and production relationships in the economy of various industries. With the application of input-output analysis to the analysis of the environmental domain, the environmentally extended input-output table (EEIO) was born. Environmentally extended input-output table is very important for studying environmental stress indicators such as carbon emission and PM2.5 in industry sectors.

Structural path analysis (SPA), which was initially proposed by Defourny and Thorbecke [3] in 1984, was mainly applied to analyze the relationships among factors in complex economic networks, and many scholars later combined the IOA method with the SPA method and applied it to studies in the energy and environmental fields, such as Zhang [4, 5] and Zhang et al. [6] studied the utilization of natural resources in China's supply chain tracking, Meng et al. [7] analyzed the main emission pathways of PM2.5 in China, and Zhang et al. [8] analyzed the demand of primary energy in structural pathways. Other scholars have combined IOA method and SPA method to study specific economic sectors, such as Castaño et al. [9] who used IOA method and SPA method to analyze the structural pathway of mining industry in Chile, Li et al. [10] who used IOA method and SPA method to study the key transmission sectors in China's supply chain to reduce carbon emission, Hong et al. [11] studied key energy supply chains in China's construction industry using the IOA method with the SPA method, and Jia et al. [12] used the IOA method with the SPA method to identify key CO_2 reduction potential sectors from a supply chain perspective.

Most of the existing literature analyzes carbon emission by country, lacking regional provincial-level carbon emission analysis, such as Zhang et al. [4] study China's GHG emission, while most of the literature now mainly analyzes the supply chain by final demand, without classifying final demand in detail before analyzing the supply chain, such as Meng et al. [7]. Therefore, we combine the EEIOA method and SPA method to analyze the carbon emission pathways in Guangdong Province, and also classify the final demand into consumption (including urban consumption, rural consumption and government consumption), investment and export (including international export and out-of-province transfer) in detail to analyze the key carbon emission sectors and key carbon emission pathways.

2. Methodology and Data Sources

2.1. Methods of EEIOA and SPA

According to the input-output model theory, the input-output table of Guangdong Province can be represented as:

$$X = A \cdot X + C + V + E - M \tag{1}$$

where X is total output, a column vector; A is the matrix of direct consumption coefficients, a matrix of $n \times n$ (n is the number of industry sectors in the IO table); C is consumption which includes rural household consumption, urban household consumption and government consumption, a column vector; V is the column vector of investment; E is international exports and inter-provincial exports, a column vector; M is international imports and inter-provincial imports, a column vector.

Since this is a structural pathway analysis of carbon emission for sectors within the province of Guangdong, the import and inter-provincial import shares should be removed from final demand to isolate the province's internal supply chain, referring to previous studies [7, 13].

$$A^d = \left(I - K\right) \cdot A \tag{2}$$

$$k_{ii} = \frac{M_i}{X_i - E_i + M_i} \tag{3}$$

where A^d is the matrix of intra-provincial direct consumption coefficients after removing the import and inter-provincial import shares; I is the identity matrix; $K = diag(k_{ii})$; k_{ii} is the proportion of imports and inter-provincial imports used by each sector.

$$Y' = C^d + V^d + E \tag{4}$$

$$X = A^d \cdot X + Y' \tag{5}$$

Here C^d is consumption after removing the import and inter-provincial import shares, $C_i^d = \left(1 - k_i\right) C_i$; V^d is investment after removing the import and inter-provincial import shares, $V_i^d = \left(1 - k_i\right) V_i$.

$$X = \left(I - A^d\right)^{-1} \cdot Y' \tag{6}$$

$$EEF = F \cdot E \cdot \left(I - A^d\right)^{-1} \cdot Y' \tag{7}$$

where E is the energy direct consumption intensity (energy consumption per unit of total output) matrix; F is the energy carbon emission factor matrix; and EEF is the carbon emission based on final demand.

To find the significant supply chain paths, the Leontief inverse matrix in equation (6) is subjected to a Taylor expansion as follows.

$$L = \left(I - A^d\right)^{-1} = I + A^d + \left(A^d\right)^2 + \left(A^d\right)^3 + \cdots \left(A^d\right)^n + \cdots \tag{8}$$

Thus based on equation (8), EEF can be written as

$$EEF = \overbrace{F \cdot E \cdot I \cdot Y'}^{layer\ 0} + \underbrace{F \cdot E \cdot I \cdot A^d \cdot Y'}_{layer\ 1} + \overbrace{F \cdot E \cdot I \cdot \left(A^d\right)^2 \cdot Y'}^{layer\ 2} + \cdots \overbrace{F \cdot E \cdot I \cdot \left(A^d\right)^n \cdot Y'}^{layer\ n} + \cdots \quad (9)$$

According to equation (9), the total carbon emission is the sum of carbon emission of all layers, and the carbon emission of each layer can be calculated. layer 0 denotes the direct carbon emission caused by final demand, where $F_i \cdot E_i \cdot I \cdot Y'_{im}$ denotes the direct carbon emission of sector i caused by final demand m, and the path is sector $i \rightarrow$ final demand m. $F_i \cdot E_i \cdot A_{ij}^{\ d} \cdot A_{ik}^{\ d} \cdot Y'_{km}$ denotes the carbon emission of sector i of production layer 2 caused by final demand m, and the path is sector $i \rightarrow$ sector $j \rightarrow$ sector $k \rightarrow$ final demand m.

2.2. Data Source

The consumption of fossil energy is the main cause of carbon emission. The consumption of fossil energy by industry can be obtained from the Guangdong Statistical Yearbook and the China Energy Statistical Yearbook [14, 15], containing 12 energy types such as raw coal, fine washed coal, briquettes, coking, coke oven gas, crude oil, gasoline, diesel, kerosene, fuel oil, LPG and natural gas. Based on IPCC [16] data and methods, energy low-level heat generation, carbon oxidation factor and carbon content per unit calorific value of various fossil energy sources are obtained, and carbon emission factors of various fossil energy sources are calculated, so that sectoral carbon emission can be calculated based on carbon emission factors and fossil energy consumption data.

In this study we use the latest input-output table of Guangdong Province [17], the original input-output table covers 42 industrial sectors, and in order to study the linkage on the path between industry sectors, we merge the sectors into 11 industrial sectors as shown in Table 1, and refer to Reference [18] for the specific sector merger classification.

Table 1. Sector classification and abbreviations.

No.	Sectors	Abbreviations
1	Agricultural sector	AGR
2	Refined oil and coal sector	RPN
3	Oil and gas sector	OAG
4	Light industry sector	LIG
5	Chemical industry sector	CHE
6	Electric power sector	ELE
7	Residential gas sector	GDT
8	Heavy industry sector	HEA
9	Construction sector	CON
10	Transportation sector	TRA
11	Service sector	SER

3. Results

There is a total 547.759 million tons of carbon dioxide emission in Guangdong Province. Figure 1 shows the total composition of total EEF under final demand. In the inner circle, export-driven carbon emission accounts for 66.7% of carbon emission in Guangdong Province, followed by consumption-driven carbon emission accounting for 20.6% of carbon emission in Guangdong Province, and finally, investment accounts for 12.7%. The total carbon emission caused by exports in Guangdong Province are more than three times that of the consumption and more than five times that of investment. Guangdong Province's exports have been the leading first in China for many years [19], and exports are also the main contributor to Guangdong Province's GDP, and Guangdong Province's exports are also one of the important factors causing carbon emission. Consumption is the second largest contributor to carbon emission in Guangdong Province, as shown in the outer circle of Figure 1. Consumption mainly consists of urban consumption, rural consumption and government consumption, in which urban consumption causes 13.4% of carbon emission, rural consumption 2.9% and government consumption 4.3%, in which carbon emission caused by urban consumption are more than four times of rural consumption and more than three times of government consumption. With the progress of urbanization, the urbanization rate of Guangdong Province has reached 74% in 2021 [20], urban consumption has become an important factor causing carbon emission, and it is also found that there is a great difference between urban and rural areas in Guangdong Province causing carbon emission. Investment is causing carbon emission and urban consumption close to it. As the urbanization rate in Guangdong Province increases, investment in infrastructure in the province is also growing [20], and investment drives a lot of construction, tertiary and heavy industrial activities, which also brings carbon emission.

Figure 2 shows the share of carbon emission by sector, in which the HEA sector generates the most carbon emission with 30.7%, followed by the ELE sector with 17.1%, and the TRA sector and SER sector with 13.5% and 12.1%, respectively. Heavy industry is the most important carbon emitting sector in Guangdong Province, which is due to the large scale of heavy industry in Guangdong Province, and partly due to the fact that the heavy industry sector consumes a large amount of fossil energy in the process of production activities, thus generating a large amount of carbon emission. The large amount of carbon emission generated by the electric power sector is mainly attributed to the presence of a large share of thermal power generation in the development of Guangdong Province [21] which has high emission because the main fossil energy consumed by thermal power generation is coal. The reasons for the higher carbon emission from the TRA sector are, on the one hand, the high dependence of transport on fossil resources and, on the other hand, the fact that the efficiency of the transport system is not yet very high.

Different final demand categories drive carbon emission of industries differently. Figure 3 shows the carbon emission of each production layer of each sector driven by urban consumption, and since the carbon emission generated by each sector after the fourth production layer are much smaller than those of the previous four layers, we denote the 4th→∞ layer as the sum of carbon emission generated by all layers after the fourth production layer, and obviously the SER sector generates the largest carbon emission is the largest, reaching 30.91 million tons of carbon emission, and its carbon emission is mainly distributed in production layer 0 and production layer 1, accounting for 41% and 32%, respectively. The ELE sector is the second largest emitter, generating

17.72 million tons of carbon emission, mainly in production layer 0, accounting for 57% of the emission. The LIG sector is the third largest carbon emitting sector, generating 7.52 million tons of carbon emission, and its main carbon emission is also in production layer 0, with a share of 50%. All sectors in the figure have their main carbon emission in production layer 0, which also shows that urban consumption has a clear direct consumption demand on each sector, and all sectors have a decreasing carbon emission as the generation layer increases.

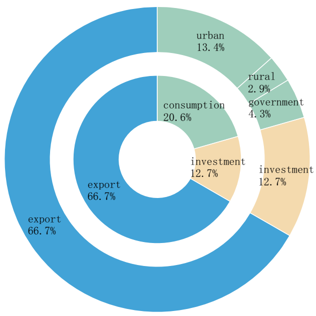

Figure 1. Carbon emission composition of final demand.

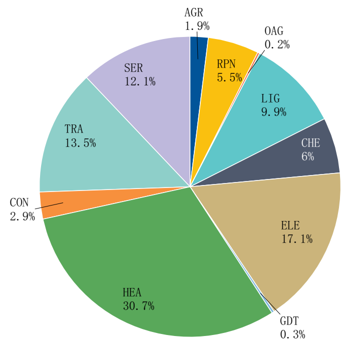

Figure 2. Carbon emission composition by industry.

Figure 4 shows the carbon emission from rural consumption for each sector of the economy at each layer of production, with the ELE sector generating the largest amount of carbon emission at 6.41 million tons of carbon emission, while urban consumption causes 2.7 times more carbon emission in the ELE sector than rural consumption. The LIG sector generates 1.22 million tons of carbon emission, which is only one-sixth of the carbon emission of the LIG sector caused by urban consumption. On the whole, the carbon emission caused by urban consumption and rural consumption are mainly gathered in the SER sector, ELE sector and LIG sector, and the carbon emission caused by both urban consumption and rural consumption are mainly distributed in production layer 0. However, in terms of the total carbon emission caused by consumption in each sector, the carbon emission caused by rural consumption in each sector are smaller than the carbon emission caused by urban consumption in each sector, and the carbon emission caused by rural consumption in the TRA sector and RPN sector account for 4.5% of the total carbon emission caused by rural consumption. The carbon emission from the TRA and RPN sectors caused by rural consumption account for 4.5% of the total carbon emission from rural consumption, while the carbon emission from the TRA and RPN sectors caused by urban consumption account for 13.1% of the total carbon emission from rural consumption. The carbon emission from rural consumption in the transportation sector and the refined oil and coal sector are not significant and are only one-third of the carbon emission from urban consumption in the transportation sector and the refined oil and coal sector.

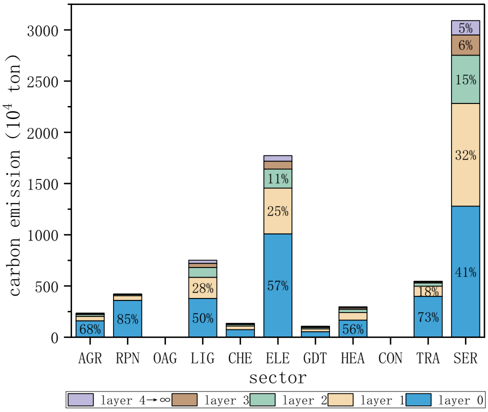

Figure 3. Sectoral carbon emission driven by urban consumption.

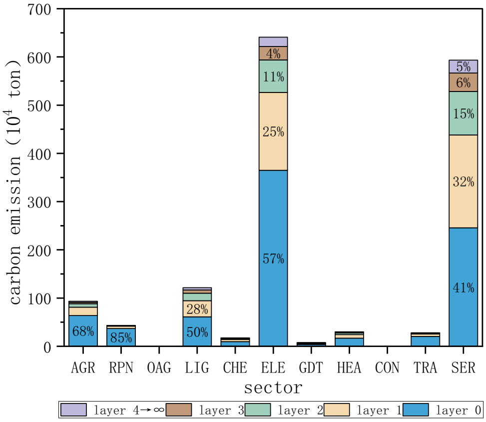

Figure 4. Sectoral carbon emission driven by rural consumption.

The carbon emission caused by government consumption in each sector show a homogeneity, as shown in Figure 5, the carbon emission caused by government consumption are mainly clustered in the SER sector and TRA sector, which generate 19.78 million tons of carbon emission and 3.26 million tons of carbon emission, respectively, and 0.26 million tons of carbon emission in the AGR sector, and government consumption causes no carbon emission to the rest of the sectors, which is due to the fact that government consumption on the rest of the sector is 0, and government consumption is mainly in the service sector and transportation sector. The production layer 0 of the TRA sector generates 73% of the carbon emission of the TRA sector, which indicates that the carbon emission of the TRA sector are mainly caused by the direct consumption of the government. the SER sector generates carbon emission mainly in production layer 0 and production layer 1, and only 41% of the carbon emission is caused by the direct consumption of the government. Indirect carbon emission reach 59%. Although the distribution of carbon emission caused by government consumption in the sector is single, the total carbon emission caused by government consumption is larger than the total carbon emission caused by rural consumption, as shown in Figure 1.

The CON sector is the largest carbon emission sector caused by investment, reaching 42.35 million tons of carbon emission, as shown in Figure 6, accounting for 60% of the entire investment-induced carbon emission, and the carbon emission of the CON sector is mainly distributed in production layer 0 and production layer 1, whose carbon emission generated by production layer 1 are larger than those of production layer 0. The indirect carbon emission of the CON sector caused by investment is 64% and the direct carbon emission is 36%. The SER sector is the second largest carbon emission sector caused by investment, with 14.03 million tons of carbon emission, and the proportion of indirect carbon emission in the SER sector is 59%. The investment-induced HEA sector generates 10.49 million tons of carbon emission, which are mainly distributed in production layer 1, with a share of 56%.

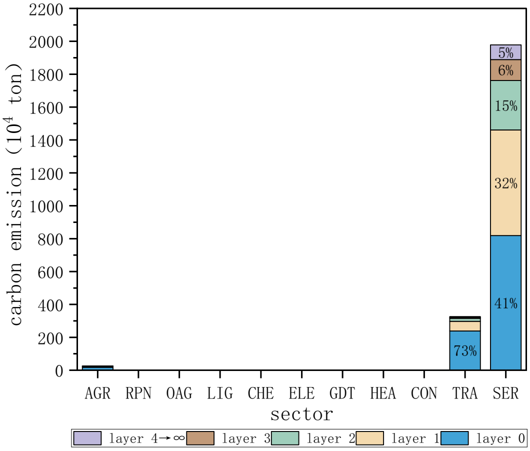

Figure 5. Sectoral carbon emission driven by government consumption.

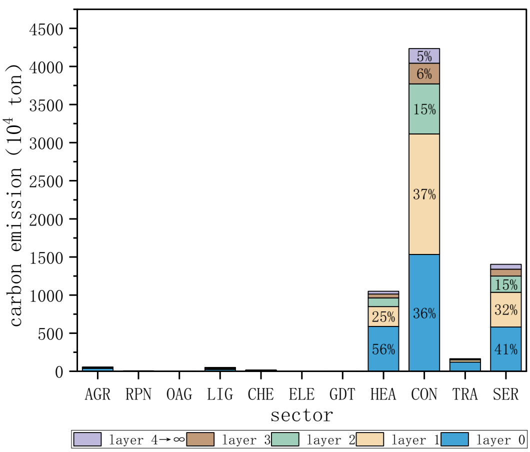

Figure 6. Sectoral carbon emission driven by investment.

As shown in Figure 7, the export-induced carbon emission is mainly distributed in the HEA sector, LIG sector, CHE sector, TRA sector and SER sector, and the largest sector of export-induced carbon emission is the HEA sector, reaching 19.492 million tons of carbon emission, accounting for 53% of the whole export-induced carbon emission, while 56% of them are direct carbon emission and 44% is indirect carbon emission. However, the small proportion of carbon emission after layer 3 indicates that the supply chain is very short. The LIG sector is the second largest carbon emitting sector due to exports, reaching 70.77 million tons of carbon emission, accounting for 19% of the overall export-induced carbon emission, while 50% of them is direct carbon emission. The LIG sector is the third largest carbon emitting sector due to exports, with 30.95 million tons of carbon emission and 55% of its direct carbon emission. Export-induced direct carbon emission of each economic sector are high, all above 50%, while export-induced carbon emission is high, accounting for 66.7% of total carbon emission, as shown in Figure 1.

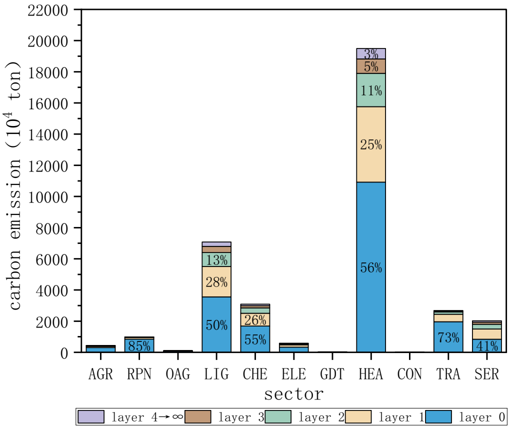

Figure 7. Sectoral carbon emission driven by export.

Figure 8 shows the distribution of total carbon emission and carbon intensity (carbon emission divided by total output) by sector, with zone I indicating high carbon emission and high carbon intensity regions, zone II indicating low carbon emission and high carbon intensity regions, zone III indicating low carbon emission and low carbon intensity regions, and zone IV indicating high carbon emission and put low carbon intensity regions. Only ELE sector is in the zone I, according to Figures 3 and 4, the carbon emission of ELE sector is mainly caused by urban consumption and rural consumption, the total carbon emission of ELE sector is very large, on the one hand, Guangdong Province has a great demand for ELE, on the other hand, the current source of electricity in Guangdong Province is thermal power through thermal power generation, the reliance on fossil energy such as coal is very high, the carbon intensity of ELE sector is the highest sector, the carbon emission produced per unit of product is very high, which on the one hand comes to the ELE sector's consumption of energy structure is still dominated by fossil energy, on the other hand, the efficiency of energy use is still very low. There is only HEA sector in zone IV, and the total carbon emission of HEA sector is very large, as shown in Figure 2, accounting for 30.7% of the total emission. According to Figure 7, the carbon emission of HEA sector in Guangdong Province is mainly driven by export, but the carbon emission generated by the energy consumption per unit product of HEA sector is actually very small, which indicates that the HEA sector is driven by export, the production scale is very large, and the energy consumption per unit generates low carbon emission.

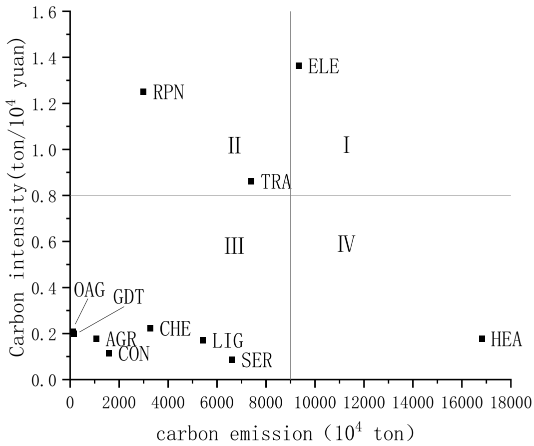

Figure 8. Sectoral carbon emission and carbon intensity distribution map.

The TRA sector and RPN sector are in Zone II, and consumption, investment and export all have significant driving effects on the carbon emission of the TRA sector, and the TRA sector accounts for 13.5% of the total carbon emission, as shown in Figure 2. On the one hand, the TRA sector is inefficient in transportation, and on the other hand, it is highly dependent on fossil resources, and the total transportation in Guangdong Province is huge [22]. The carbon emission of the RPN sector is driven by urban consumption, rural consumption and exports, as shown in Figures 3, 4 and 7. The RPN sector mainly processes refined products of petroleum and coal, so the energy consumption per unit product generates higher carbon emission, but generates low total carbon emission. Zone III is a dense sectoral distribution area, SER sector, LIG sector, CHE sector, AGR sector, CON sector, OAG sector and GDT sector are all located in this zone, and the carbon intensity of sectors in this zone are all relatively low, compared with sectors in zone I and zone IV, the sectors in this zone consume less total fossil energy, and at the same time the total sectoral output value in this zone is higher, so the carbon intensity is lower.

According to different final demands, the carbon emission paths corresponding to consumption (including urban consumption, rural consumption and government consumption), investment and export are calculated, and the top twenty carbon emission paths of different final demands are selected, and the carbon emission and carbon emission contribution rate on each path are calculated as shown in Tables 2-4.

Table 2 shows the top twenty carbon emission paths caused by consumption, most of the carbon emission of the top twenty paths are finally flowing into consumption through SER sector, ELE sector and TRA sector, which indicates that SER sector, ELE sector and TRA sector occupy a very important position in consumption. Meanwhile, the downstream of some carbon emission pathways is the SER sector, while the upstream is the ELE sector and TRA sector, which indicates that the SER sector is closely related to the ELE sector and TRA sector, and the carbon emission from the SER sector causes indirect carbon emission from the ELE sector and TRA sector. There are more paths with only one sector in the top twenty carbon emission paths, which indicates that consumption-induced carbon emission tend to be more direct than sector-induced carbon emission.

Table 2. Carbon emission pathways driven by consumption.

No.	Carbon emission pathways driven by consumption	Carbon emission (10^4 tons)	Carbon emission (%)
1	SER→consumption	2344.17	4.280
2	ELE→consumption	1374.36	2.509
3	TRA→SER→consumption	664.73	1.214
4	TRA→consumption	658.19	1.202
5	SER→SER→consumption	549.97	1.004
6	ELE→ELE→consumption	549.95	1.004
7	LIG→consumption	439.31	0.802
8	RPN→consumption	396.42	0.724
9	ELE→SER→consumption	350.78	0.640
10	AGR→consumption	242.57	0.443
11	ELE→ELE→ELE→consumption	220.06	0.402
12	HEA→consumption	183.47	0.335
13	TRA→SER→SER→consumption	155.96	0.285
14	ELE→ELE→SER→consumption	140.36	0.256
15	SER→SER→SER→consumption	129.03	0.236
16	ELE→ELE→ELE→ELE→consumption	88.06	0.161
17	TRA→TRA→SER→consumption	85.91	0.157
18	TRA→TRA→consumption	85.07	0.155
19	CHE→consumption	83.25	0.152
20	ELE→SER→SER→consumption	82.30	0.150

Table 3. Carbon emission pathways driven by investment.

No.	Carbon emission pathways driven by investment	Carbon emission (10^4 tons)	Carbon emission (%)
1	CON→investment	1532.56	2.798
2	HEA→investment	587.67	1.073
3	SER→investment	581.00	1.061
4	TRA→CON→investment	477.49	0.872
5	HEA→CON→investment	450.29	0.822
6	ELE→CON→investment	343.09	0.626
7	SER→CON→investment	165.88	0.303
8	TRA→SER→investment	164.75	0.301
9	HEA→HEA→investment	145.85	0.266
10	ELE→ELE→CON→investment	137.29	0.251
11	SER→SER→investment	136.31	0.249
12	TRA→investment	119.92	0.219
13	HEA→HEA→CON→investment	111.75	0.204
14	ELE→SER→investment	86.94	0.159
15	RPN→CON→investment	66.04	0.121
16	TRA→TRA→CON→investment	61.71	0.113
17	ELE→ELE→ELE→CON→investment	54.94	0.100
18	TRA→SER→CON→investment	47.04	0.086
19	ELE→HEA→investment	43.34	0.079
20	SER→SER→CON→investment	38.92	0.071

Table 3 shows the top twenty carbon emission paths caused by investment, most of the paths of carbon emission are through the CON sector finally flowing into investment, which shows that the CON sector has a very important position in investment, and most of the carbon emission paths have two sectors and more than two, which shows that the carbon emission paths caused by investment are long, and also shows that investment causes a lot of indirect carbon emission. The TRA sector, HEA sector, ELE sector and SER sector appear frequently in the upstream of the carbon emission pathway, which indicates that the CON sector is closely related to these sectors and the CON sector carbon emission cause indirect carbon emission from these sectors.

Table 4. Carbon emission pathways driven by export.

No.	Carbon emission pathways driven by export	Carbon emission (10^5 tons)	Carbon emission (%)
1	HEA→export	10916.66	19.930%
2	LIG→export	3558.90	6.497%
3	HEA→HEA→export	2709.34	4.946%
4	TRA→export	1959.71	3.578%
5	CHE→export	1687.78	3.081%
6	SER→export	837.26	1.529%
7	RPN→export	843.68	1.540%
8	ELE→HEA→export	805.02	1.470%
9	HEA→HEA→HEA→export	672.41	1.228%
10	LIG→LIG→export	610.46	1.114%
11	TRA→HEA→export	480.98	0.878%
12	ELE→LIG→export	435.09	0.794%
13	SER→HEA→export	348.22	0.636%
14	CHE→CHE→export	337.97	0.617%
15	ELE→export	332.58	0.607%
16	ELE→ELE→HEA→export	322.13	0.588%
17	AGR→export	300.22	0.548%
18	TRA→TRA→export	253.28	0.462%
19	CHE→HEA→export	244.41	0.446%
20	TRA→SER→export	237.42	0.433%

Table 4 shows the top twenty carbon emission pathways caused by exports, whose carbon emission pathways are short and export-induced carbon emission tend to be direct carbon emission. The HEA and LIG sectors are in the downstream of the carbon emission pathway, while the ELE, SER and TRA sectors are in the upstream of the carbon emission pathway, indicating that the HEA and LIG sectors cause indirect carbon emission from these sectors. There is also an emission path like HEA→HEA→HEA→export, which indicates that the HEA sector has a high degree of self-reliance and carbon emission flow within the sector.

4. Conclusion and Discussion

4.1. Conclusion

This paper combines SPA method and EEIOA method to analyze the current situation of carbon emission in Guangdong Province from different final demands, and determines the key carbon emission paths and key sectors under each demand, and analyzes the carbon flow between sectors according to the paths of carbon emission. Based on the calculated results, the main conclusions can be summarized into the following:

The carbon emission of the RPN sector is driven by urban consumption, rural consumption and exports. (1) In terms of key carbon emission sectors, the HEA sector and the ELE sector are the two largest emitters in Guangdong Province, accounting for 30.7% and 17.1% of total carbon emission respectively, and they are the sectors that need to be focused on for emission reduction. Carbon emission from the HEA sector is mainly caused by exports, while carbon emission from the ELE sector is mainly caused by consumption. Although the HEA sector has the largest carbon emission, its carbon intensity is low, mainly due to the large scale of export-driven heavy industry in Guangdong Province, which generates low carbon emission per unit of product. The ELE sector not only has large total emission but also high carbon intensity, on the one hand, because most of the electricity in Guangdong Province comes from thermal power generation, which relies on fossil resources and therefore generates a large amount of carbon emission, and on the other hand, because the scale of electricity consumption in Guangdong Province is very large.

(2) In terms of the distribution of carbon emission from different final demands, exports in Guangdong province contribute the most to carbon emission, reaching 66.7%, followed by consumption, accounting for 20.6%, with urban consumption accounting for 13.4%, rural consumption accounting for 2.9%, and government consumption accounting for 4.3%, urban consumption being four times that of rural consumption and three times that of government consumption, and finally carbon emission caused by investment, accounting for 12.7%. Although Guangdong Province generates a large amount of carbon emission, most of them are caused by exports, so it is necessary to control exports appropriately and shift some of the industries with high energy consumption and high emission caused by exports.

(3) In terms of carbon emission from different sectors driven by different final demands, carbon emission from different sectors caused by different final demands are mainly distributed in the top 3 production layers. The carbon emission caused by urban consumption is mainly distributed in the SER, ELE and LIG sectors; the carbon emission caused by rural consumption is mainly distributed in the ELE, SER and LIG sectors; the carbon emission caused by government consumption is mainly distributed in the SER and TRA sectors; the carbon emission caused by investment is mainly distributed in the CON, SER and HEA sectors, carbon emission caused by exports is mainly distributed in the HEA sector, the LIG sector and the CHE sector.

(4) In terms of carbon emission pathways for different final demands, the most of the screened carbon emission paths of exports are relatively short paths, tend to direct carbon emission, and most of the paths end in the HEA sector and LIG sector, and most of the carbon emission caused by exports eventually flow out through the HEA sector and LIG sector; most of the screened carbon emission paths of consumption mainly flow into consumption through the SER sector and ELE sector eventually, and the SER sector and ELE sector appear together many times in the same path, indicating a close

relationship between the sectors, the SER sector causes indirect carbon emission from the ELE sector most of the carbon emission paths of investment are more than two sectors, and most of the paths of carbon emission through the CON sector eventually flow into investment, and the CON sector causes carbon emission from other sectors to his own inflow, so a large number of indirect carbon emission caused by investment.

4.2. Discussion

Through the study of this paper, we found some existing problems. First, Guangdong Province is extremely unbalanced in terms of the proportion of carbon emission from different final demands, and most of the carbon emission are mainly caused by exports, while the proportion of investment and consumption is low; currently, Guangdong leads the country in GDP, but the problem of poverty still exists in Guangdong Province, and investment should be further expanded. Secondly, the carbon emission caused by urban consumption in Guangdong Province is much larger than those caused by rural consumption and government consumption, and the carbon emission generated by consumption is mainly caused by urban consumption, which should further strengthen the publicity of energy saving and emission reduction in cities, and at the same time actively promote the application of emission reduction technologies in relevant industries. Furthermore, investment still causes a lot of carbon emission in the construction industry and should be further promoted to shift investment to science and technology and new service industries. Lastly, carbon emission in Guangdong province is mainly concentrated in the first 3 production layers, with relatively short supply chains, and carbon emission is mainly distributed in the heavy industry sector, so the adjustment of industrial structure needs to be accelerated

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