Inter-sectoral CO_2 flows implied in trade for Zhejiang Province, China

Ying Zhu[1,a*], Tianhao Cui[2,b], Yanzheng Liu[2,c], Shizhong Yang[1,d], Hongxia Du[1,e]

[1]School of Environment and Municipal Engineering, Xi'an University of Architecture and Technology, Xi'an, China
[2]Xi'an University of Architecture and Technology of South Australia An De College, Xi'an University of Architecture and Technology, Xi'an 710055, China

Abstract. The transfer of carbon dioxide (CO_2) implied in inter-sectoral trade is significantly affecting the process of reducing CO_2 emissions in China. This phenomenon also affects Zhejiang Province, which has the top five GDP in China. In this study, a universal modeling system is developed to clarify CO_2 emission reduction responsibilities and visualize relationships of each pair of transfers in Zhejiang Province. The system includes "three modules", namely input-output module, CO_2 emission factor module and ecological network module. The proposed modelling system is employed for sectors of Zhejiang province. Research results demonstrate that industry should assume more responsibility for emission reduction; the existing development models of various industries need to be further adjusted. Achievements of this research will provide a scientific reference and a strong basis for decision-makers to formulate reasonable emission reduction policies in Zhejiang Province.

1 Introduction

As the largest CO_2 emissions country in the world, China emits 30% of global CO_2 emissions [1]. In order to achieve the goal of 'peak carbon dioxide emissions' in China, all industries are faced with greater responsibility for reducing emissions. Among provinces in China, Zhejiang is not only a major economic province, but also a major CO_2 emitter. It is necessary to rationally allocate the emission reduction responsibilities and implement targeted emission reduction measures of various industries in Zhejiang Province.

In recent years, scholars have applied different methods to identify emission reduction responsibilities of various industries. In 2020, Fenner et al. proposed a framework to quantify the carbon footprint of built environment and assess the emission responsibilities of buildings at various stages [2]. Compared with the above methods, the input-output method (IOA) is more accurate and effective in dealing with the transfer of emission reduction responsibilities between regions. IOA was first proposed by Leontief in 1936 and it can distinguish responsibilities of end users by quantifying indirect emissions contained in supply chain across geographic boundaries [3]. In 2014, Liu et al. took China as an example and improved input-output model to study carbon transfers and carbon emission responsibilities of 17 sectors in 8 major regions in 1997 to 2007 [4]. Liu et al. established an input-output simulation model for environmental expansion and analyzed the CO_2 emission reduction responsibilities of various industries in Saskatchewan, Canada [5].

After allocating responsibilities for CO_2 emission reduction, how to determine the existing emission situation and future development direction of various industries is also an urgent problem to be solved. IOA cannot describe the relationship between various components in the system. It is gratifying that the introduction of ecological network analysis (ENA) will make up for this shortcoming and vividly expound internal relationships of system. In 2008, Fath first proposed a concept of describing the pairing relationship between various parts of system on the basis of IOA, and proved that it is feasible to understand and judge the complex internal system by studying relationships between different parts [6]. This method was utilized to research relationships between components in different systems by scholars. For example, Guan et al. established a new type of composite waste input-output model to study the internal metabolic structure of industrial waste in Guangdong Province [7]. In this study, the introduction of ENA clearly described the relationship between the various components within the system, and made up for shortcomings of IOA.

Therefore, the objective of this study is to combine IOA, CO_2 emission factors and ENA into a general modeling system for quantifying transfers of CO_2 and visualizing emission relationships between each pair of components in the system. Specifically, the IOA module uses the input-output table and energy balance table of Zhejiang Province in 2017, quantifies CO_2 emissions and transfers implicit in trade between different industries, and clarifies the emission reduction responsibilities. On the

[a*]email: zhuying@xauat.edu.cn, [b]email: 1650993385@qq.com
[c]email: liuyanzheng1@126.com, [d]email: yangshizhong@163.com, [e]email: 361295721@qq.com

basis of the IOA, emission relationships between various industries are visually expressed through ENA, which provides a direction for the future development of industries. Research results are helpful for allocating emission reduction targets for various industries in Zhejiang Province, and will provide more valuable suggestions for formulating CO_2 reduction policies for various industries in the province.

2 Materials and Methods

The purpose of the IOA module is to build an IOA model for quantifying transfers of CO_2 in system.

$$c_i^v = \sum_{w=1}^{p}\sum_{j=1}^{q} z_{ij}^{vw} + \sum_{w=1}^{p} f_i^{vw} = \left(g_{i1}^{v1} + \ldots + g_{iq}^{v1}\right) + \ldots + \left(g_{i1}^{vp} + \ldots + g_{iq}^{vp}\right) + f_i^{v1} + \ldots + f_i^{vp} \tag{1}$$

Where c_{ij}^{vw} means total output of sector *i* in province *v*; f_i^{vw} is the final demand of province *w* from sector *i* in province *v*; g_{ij}^{vw} indicates intermediate input from sector *i* in province *v* to sector *j* in province *w*.

$$E^v = \left[e_j^v\right],\ e_j^v = h_j^v / c_j^v \tag{2}$$

Where E^v is direct energy consumption coefficient matrix of province *v*; h_j^v is direct energy consumption of sector *j* in province *r*.

CO_2 emission factors are established to analyze the condition of CO_2 emissions [8].

$$SS = O^{vv} = \left[ss_{vw}\right], ss_v = o_{vv}, \tag{3}$$

$$DO = \left[do_{vw}\right], do_w = \sum_{v=1}^{p} c_{vw},\quad DS = \left[ds_{vw}\right], ds_w = \sum_{v=1}^{p} o_{vw} - o_{vv} \tag{4}$$

$$CS = \left[cs_{vw}\right], cs_v = \sum_{w=1}^{p} o_{vw},\quad COA = \left[coa_{rs}\right], coa_r = \sum_{s=1}^{m} c_{rs} - c_{rr} \tag{5}$$

Where *SS* is the degree of self-supply, which represents the ability of an sector to supply its own development; *DO* is the degree of dependence on other sectors, which means the ability of an sector to transfer its own CO_2 emissions to other sectors (including this sector); *DS* is the degree of dependence on system, which expresses the ability of an sector to transfer its own CO_2 emissions to other sectors (except this sector); *CO* is the degree of contribution to others, which is the CO_2 emissions that one sector undertakes for the development of other sectors (including this sector); *CS* is the degree of contribution to system, which indicates the CO_2 emissions that one sector undertakes for the development of other sectors (except this sector).

The interrelationship between components is evaluated through ENA.

$$D = \left(d_{ij}\right) = \left(f_{ij} - f_{ji}\right)\left(f_{ij} - f_{ji}\right) \Big/ T_i \tag{6}$$

$$U = \left(u_{ij}\right) = D^0 + D^1 + D^2 + \cdots + D^m + \cdots = \left(I - D\right)^{-1} \tag{7}$$

The positive and negative signs in *D* and *U* represent mutual relationships of each pair of sectors in the system [9]. There are four mutual relationships: (+, -) stands for exploitation relationships; (-, +) for utilization relationships; (+, +) for reciprocal relationships and (-, -) for competition relationships.

3 Results & Discussion

Based on IOA, CO_2 transfers among sectors in Zhejiang Province are obtained. As shown in Table 2, in general, most sectors are closely connected with industry (Department classification and corresponding codes are shown in Table 1). Specifically, construction accounts for a considerable proportion; The transfer between industry and transportation is the largest other than the transportation industry's own supply and this happens in all six industries. It seems that industry occupies a dominant position in the six major sectors in Zhejiang Province, and is also the most important contributor to CO_2 emissions. In addition, during the ten years from 2007 to 2017, the amount of CO_2 transferred in various industries has generally increased, with construction being the most significant. As shown in table 3, in construction, CO_2 transferred from products of other sectors consumed by it has increased from 14.41 million tons in 2007 to 39.65 million tons in 2017. With the rapid development of the construction industry in recent years, the emission reduction responsibilities it should bear have also increased.

Table 1 Sectors name and corresponding code

Code	A	B	C	D	E	F
Sectors	Agriculture, Forestry, Animal Husbandry and Fishery	Industry	Construction	Wholesale and Retail Trades, Hotels and Catering Services	Transport, Storage and Post	Other Sectors

CO_2 emission factors will facilitate further analysis of CO_2 transfers between sectors in Zhejiang province. Among all sectors, agriculture, forestry, animal husbandry, fishery, and transportation bear more of the CO_2 transferred to itself from other industries; on the contrary, the construction industry obviously transfers a large amount of CO_2 to other industries to supply the development of the industry; Industrial consumption and output are in a state of equilibrium; it is worth mentioning that the transfer situation of wholesale and retail industry, which is dominated by the tertiary industry, has undergone major changes and its transfer status has changed from a CO_2 input department to a CO_2 output department, and then gradually tends to a balanced state, indicating that the development status of this department has gradually improved after going through ups and downs.

Letters in the outermost circle of figure 1 figure 2 and are the codes of each industry. In these two figures, yellow areas occupy the largest proportion, which expresses that CO_2 transfer caused by intra-B trade and trade between B and other sectors has a great impact in Zhejiang Province. In the past ten years, the amount of CO_2 transferred from D to B has been rising, which indicates that industry is one of the important supporters of the development of Wholesale and Retail Trades, Hotels and Catering Services. The transfer volume of E to B has always maintained a certain percentage of value, which shows that industry and Transport, Storage and Post are inseparable.

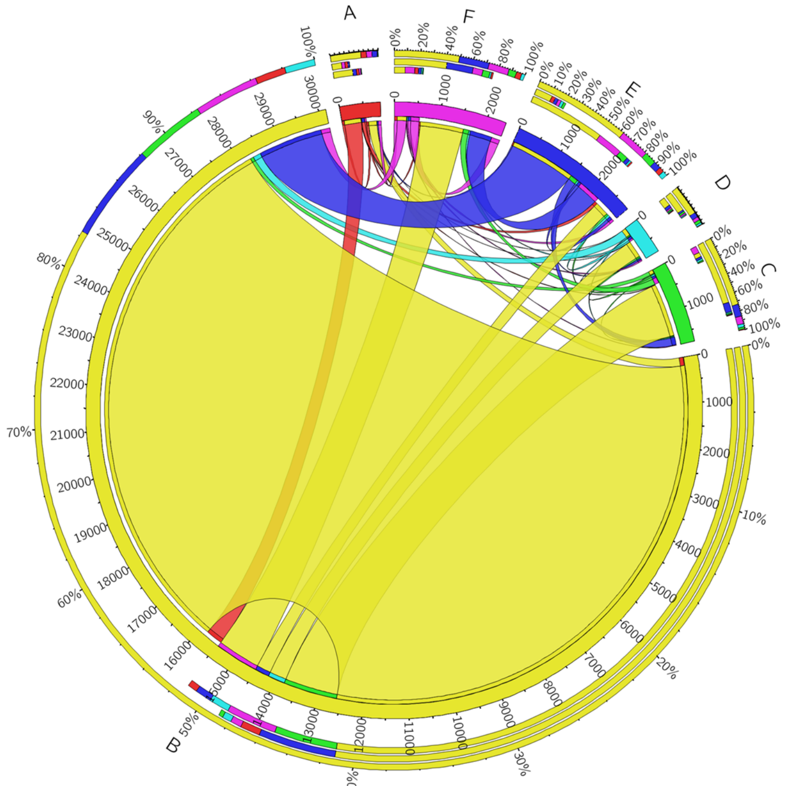

Figure 1 Inter-sector CO_2 transfer path in Zhejiang in 2007

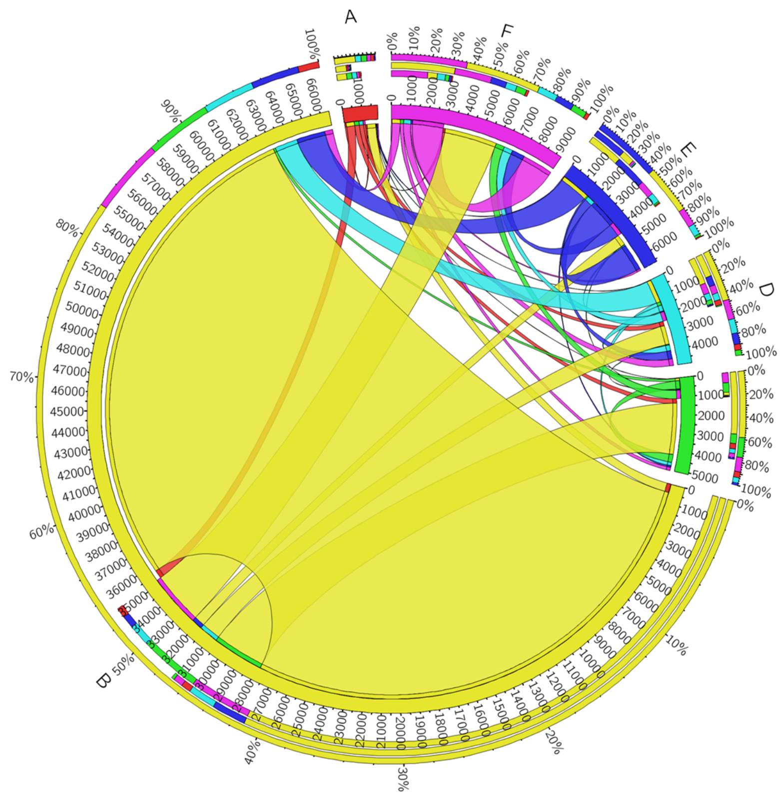

Figure 2 Inter-sector CO_2 transfer path in Zhejiang in 2017

Table 2 CO_2 transfers of sectors in Zhejiang (million tons)

2017 y	Code of sectors					
Code of sectors	A	B	C	D	E	F
A	0.78	4.50	2.47	2.37	0.00	1.13
B	4.78	273.56	28.23	10.51	5.94	29.17
C	0.13	1.38	4.37	0.42	0.22	4.72
D	0.26	12.66	1.94	3.23	0.52	4.96
E	0.51	15.84	0.76	4.43	15.05	7.11
F	0.55	4.43	1.89	3.87	1.05	17.04
2007 y						
A	0.50	3.73	0.11	0.03	0.67	0.33
B	1.81	124.10	11.99	3.83	3.14	9.74
C	0.00	0.81	0.20	0.35	0.46	1.30
D	0.04	1.69	0.21	0.18	0.51	0.34
E	0.28	14.51	1.76	0.36	0.67	4.92
F	0.66	2.06	0.12	0.27	0.56	1.87

As shown in Figure 3(a)-(c), there are 21 pairs of inter-industry CO_2 emissions correlations, which can be divided into four categories: exploitation relations, utilization relations, competition relations and reciprocal relations. Among four mutual relationships, efforts should be made to establish more reciprocal relationships, which can enable the corresponding two parties to achieve common development; the two parties in a competition relationship can interact to offset their negative effects, which is also a direction worthy of development; how to change exploitation relationships and utilization relationships should become the focus of future development planning. During the ten-year development process of Zhejiang Province from 2007 to 2017, exploitation and utilization relationships were in a dominant position among sectors in Zhejiang Province. With the economic development, competition relationships gradually disappeared and reciprocal relationships were reduced to only one group. Therefore, how to establish a model that is conducive to the positive development of most industries in the future development process is a worth considering problem.

Table 3 CO_2 emission factors of sectors in Zhejiang (million tons)

2017y	CO_2 emission factors				
Code of sectors	SSA	DOA	DSA	COA	CSA
A	0.78	7.01	6.23	11.25	10.48
B	273.56	312.37	38.81	352.20	78.64
C	4.37	39.65	35.28	11.25	6.88
D	3.23	24.84	21.61	23.57	20.34
E	15.05	22.78	7.73	43.69	28.64
F	17.04	64.14	47.10	28.83	11.79
2007y					
A	0.50	3.29	2.79	5.38	4.88
B	124.10	146.91	22.81	154.60	30.50
C	0.20	14.40	14.20	3.13	2.92
D	0.18	5.03	4.85	2.98	2.80
E	0.67	6.01	5.34	22.50	21.84
F	1.87	18.51	16.65	5.56	3.69

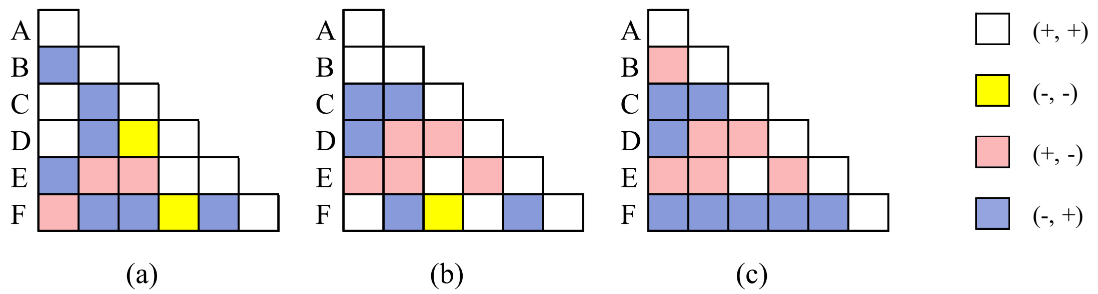

Figure 3 The mutual relationships between each pair of sectors in Zhejiang.

4 Conclusion

A general modeling framework which is combined with IOA, CO_2 emission factors and ENA was constructed to address unclear CO_2 reduction responsibilities and formulate future development direction. Explicitly, this study applied IOA to quantify CO_2 transfers among sectors in Zhejiang Province; visualized transfer relationships between each pair of various sectors through ENA; and put forward CO_2 reduction recommendations for sectors with the help of CO_2 emission factors. Results found that from 2007 to 2017, the amount of CO_2 transfer among sectors in Zhejiang Province continued to increase, and CO_2 transfer of industry accounted for the largest amount and should cause more attention. In addition, compared with 2007, there are more disadvantages relationships between sectors in 2017, and a model that is conducive to an active development of more industries should be sought in the subsequent development process.

Acknowledgments

This research was supported by the National Key Research Projects (2016YFC0207800) and National Natural Science Foundation of China (51608422).

References

1. Climate watch. (2021) Historical GHG emissions. https://www.climatewatchdata.org/ghg-emissions?breakBy=sector&end_year=2018&regions=CHN&source=PIK&start_year=1990.
2. Fenner, A.E., Kibert, C.J., Li, J.X., et al. (2020) Embodied, operation, and commuting emissions: A case study comparing the carbon hotspots of an educational building - ScienceDirect. J. Clean. Prod., 268.
3. Leontief, W.W. (1936) Of economic statistics the review. Rev Econ Stat., 18: 105–25.
4. Liu, H.G., Fan, X.M. (2014) CO_2 emissions transfer embedded in inter-regional trade in China. Acta. Ecologica. Sinica., 34: 3016-24.
5. Liu, L.R., Huang, G.H., Baetz, B., et al. (2018) Environmentally-extended input-output simulation for analyzing production-based and consumption-based industrial greenhouse gas mitigation policies. Appl. Energy, 232: 69-78.
6. Fath, B.D. (2008) Ecological Network Analysis, Environ Analysis. Ecol. Model., 2008: 1083-1088.
7. Guan, Y.R., Huang, G.H, Liu, L.R. et al. (2019) Ecological network analysis for an industrial solid waste metabolism system - ScienceDirect. Environ. Pollut., 244: 279-287.
8. Zhai, M.Y., Huang, G.H., Liu, L.R., et al. (2020) Inter-regional carbon flows embodied in electricity transmission: network simulation for energy-carbon nexus. Renew. Sust. Energy Rev., 118: 109511-.
9. Fath, B.D. (2017) Network mutualism: Positive community-level relations in ecosystems. Ecol. Model., 208(1): 56-67.