The driving force effect of trade embodied carbon emissions and embodied SO2 emissions transferred in resources-rich areas: A case study of Shanxi province

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Research Article

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Abstract

SDA (Structural Decomposition Analysis) model was applied to analyze the driving factors of embodied carbon and SO$_2$ emissions transferred in Shanxi during 2007–2012 based on the input-output model from the perspectives of region and industry. The results showed that the change of embodied carbon emissions and embodied SO$_2$ emissions of Shanxi and other regions were hindered by the carbon (sulfur) emissions strength effect, but promoted by the intermediate (final) demand scale effect, the intermediate (final) structure effect and the input-output structure effect. The carbon emissions strength effect had a significant contribution to reducing the embodied carbon emissions transferred from industries in Shanxi to other regions. The intermediate (final) demand scale effect was the driving factor to increase the embodied carbon emissions transferred from industries in Shanxi to other regions. The sulfur emissions strength effect was the only factor that reduced the embodied SO$_2$ emissions transferred from Shanxi to other industries. The change of embodied carbon emissions from industries in other regions to Shanxi was hindered by the carbon emissions strength effect, but the input-output structure effect and final demand scale effect both increased the embodied carbon emissions from industries in other regions to Shanxi. The change of the embodied SO$_2$ emissions transferred from industries in other regions to Shanxi was inhibited by the sulfur emissions strength effect, but the input-output structure effect, the intermediate demand structure effect and the final demand scale effect were both the driving force effect of increasing the embodied SO$_2$ emissions transferred from industries in other regions to Shanxi. The corresponding suggestions and measures were put forward.

1 Introduction

Climate change and atmospheric control have become the widespread concern focus (Su et al., 2013; Zheng et al., 2020). The IPCC's Fifth Global Climate Assessment report showed that the sharp increase of greenhouse gas mainly including carbon dioxide emissions is an important trigger leading to the rise of global average temperature in recent decades (IPCC 2013). China has become a major energy consumer in the world (Dong et al., 2020; Liu et al., 2019; Wang et al., 2016), and coal resources still play the main role in the energy structure. With the continuous modern industrialization and urbanization development, the consumption of coal resources in China has increased sharply (Wang et al., 2015; Zheng et al., 2020), which has resulted in a large amount of carbon and SO$_2$ emissions. China's carbon emissions from energy consumption was as high as 9.83 billion t, accounting for 28.8% of the world's total carbon emissions from energy consumption in 2019 (BP 2019). Meanwhile, a large amount of SO$_2$ produced by energy combustion will also cause severe haze in many regions of China, extremely pollute the air, seriously harm human health, and deeply affect the sustainable economic development and social harmony (Yang et al., 2013). 53.4% of the 337 prefecture-level and above cities in China had substandard ambient air quality in 2019 (National ecological and environmental quality 2019). Additionally, China's carbon emissions and SO$_2$ emissions are among the top in the world (Cao et al., 2018; He et al., 2015; Sun et al., 2020; Zhang et al., 2017). China has been under the dual pressure of public opinion in international climate negotiations and domestic energy conservation, emissions reduction and
governance in terms of joint governance and emissions reduction (Zhang et al., 2016). The task of emissions reduction and haze control should be implemented in all regions to alleviate the huge pressure of carbon emissions reduction and haze control faced by China (Weber et al., 2016). However, trade will promote resource redistribution in the process of regional economic integration (Peters et al., 2008). Meanwhile, producers and users of commodities will transfer embodied carbon emissions and embodied SO\textsubscript{2} emissions due to trade activities (Liu et al., 2016; Meng et al., 2013). Therefore, it is urgent to jointly study the important scientific problems with the embodied carbon and SO\textsubscript{2} emissions transferred affecting factors, which can provide a certain reality reference for local governments making emissions reduction policies, implementing scenario simulation, forecasting, and conducive to the development of local governments to develop more suitable for the region and haze management comprehensive measures to reduce emissions. Therefore, the ideal synergistic effect of carbon emissions reduction and effective haze control can be achieved (Chen et al., 2020; Deng et al., 2017; Hubacek et al., 2014).

Index decomposition analysis (IDA) and Structural decomposition analysis (SDA) are the main methods for assessing and analyzing the driving forces of carbon and sulfur emissions transferred. Feng et al. (2015) decomposed the influencing factors of carbon emissions into six categories: total population, total consumption, production structure, consumption pattern, energy strength and energy structure, and explored the effect of these factors on carbon emissions in USA during 1997–2013 using the SDA model. Cansino et al. (2016) studied the main driving factors of Carbon emissions in Spain, and concluded that the scale effect was the dominant factor leading to the increase of carbon emissions in Spain during 2009–2015 according to the model. Li et al. (2018) conducted the study on the driving force effect of carbon emissions in Nanjing using STIRPAT model, and concluded that economic development was the driving factor to increase carbon emissions in Nanjing during 2000–2016. Zhong et al. (2016) calculated the carbon emissions of 39 major countries in the world from a global perspective based on the perspective of consumer responsibility system, and used the extended STIRPAT model to discuss the influencing factors of global environmental pressure. Deng et al. (2014) used the LMDI decomposition method to analyze the impact degree of each driving force effect on the carbon emissions change of each study area in China. Sun et al. (2017) used the SDA model to explore the driving factors of carbon emissions change in the whole industry in China during 1977–2012, and divided the driving factors into five categories: technological progress, industrial connection, economic structure, population scale and economic scale. Wang et al. (2016) conducted structural decomposition and studied the influencing factors of carbon emissions generated by energy consumption in Xinjiang Uygur Autonomous Region during 1997–2012 using the expanded IO-SDA model.

Currently, domestic and foreign scholars mainly focus on the analysis of the influencing factors of embodied carbon emissions, and there are few collaborative studies on the driving force effect of embodied SO\textsubscript{2} emissions. Besides, most studies only decompose the driving factors of final demand embodied carbon emissions, and tend to ignore the research on influencing factors of intermediate demand embodied carbon emissions. Additionally, the research area is mainly at the international and national macro level, and there are few related studies on the driving force analysis of embodied carbon
in trade and SO₂ embodied emissions transferred in specific regions. As an important functional type area in China, energy-rich areas are the energy supply base to ensure the rapid development of China's modern industrialization and urbanization process (Wen et al., 2014). While the energy-rich region transfers resources to other regions through trade, the resource input region will increase the corresponding embodied carbon and SO₂ emissions in the consuming process. Investigating the driving force factors of embodied carbon and SO₂ emissions of energy enrichment region transferred to other regions, which can help local district government to clarify the structure and weights of factors of region embodied carbon and SO₂ emissions sources, and it can provide a certain reference for fairly and effectively control the carbon emissions and SO₂ emissions of each region. As a typical energy rich region in China, Shanxi Province is extremely rich in coal resources, which can supply coal resources to many regions in China. Additionally, while Shanxi continues to provide coal resources to other regions, it will also transfer the embodied carbon and SO₂ emissions to the resource receivers through trade. Therefore, the driving force effect of trade embodied carbon and embodied SO₂ emissions transfer in energy-rich area of Shanxi was studied combined with the multi-regional input-output model and structural decomposition model. The influence factors of intermediate demand and final demand of trade embodied carbon and embodied SO₂ emissions transferred in Shanxi were analyzed in detail from the perspective of region and industry, which provided certain practical reference value for Shanxi and other energy-rich areas to formulate carbon emissions reduction and haze control.

2 Methodology And Data Sources

2.1 Methods

The research method of combining the multi-region input-output model with the structure decomposition model was adopted. And the driving force effect of carbon and SO₂ emissions transferred in energy rich area of Shanxi Province was analyzed and explored. The calculation of the multi-region input-output model involves direct and indirect energy consumption, so that all the emissions of resource consumption in the economic system can be calculated objectively (Huang et al., 2016; Zhang et al., 2014). The structural decomposition model deeply dissects the industry information in the input-output table and the relationship between them based on the input-output analysis theory, (Wang et al., 2016) to identify the factors affecting pollutant emissions in the economy (Liu et al., 2019). The basic principle of the model is to decompose an identity according to its constituent elements, and decompose the changing value of the research object into the sum of the changes of several constituent factors. And the driving force effect of direct and indirect factors on the transfer of carbon (sulfur) emissions is calculated under the condition that other conditions remain unchanged (Butnar et al., 2011).

The intra-regional embodied carbon (sulfur) emissions were calculated based on the input-output model (refer to the specific calculation formula of reference (Wu et al., 2020)), and driving factors of intra-regional embodied carbon (sulfur) emissions transferred were decomposed by structural decomposition model.
Intermediate demand corresponds to the first quadrant of the input-output table, which mainly reflects the production technology connections among various industries in the national economy. Final demand is the second quadrant of the input-output table, which mainly shows the size and structure of the final product. Among them, the intermediate demand can be further decomposed into the intermediate demand structure effect and the intermediate demand scale effect; Final demand can be decomposed into final demand structure effect and final demand scale effect. The corresponding structure decomposition formula is as follows:

See formula 1 in the supplementary files section.

The carbon (sulfur) emissions generated by intermediate demand and final demand are respectively as follows:

See formula 2 in the supplementary files section.

Where $T$ is the domestic interregional embodied carbon (sulfur) emissions; $\Delta T_X$ represents the variation of embodied carbon (sulfur) emissions by intermediate demand between domestic regions; $\Delta T_F$ represents the variation of embodied carbon (sulfur) emissions by final demand in domestic regions; $F$ is the strength effect of carbon (sulfur) emissions; $L$ is the input-output structure effect; $A$ is the intermediate demand structural effect; $S$ is the intermediate demand scale effect; $M$ is the final demand structural effect; $V$ is the final demand scale effect.

2.2 Data sources and processing

Table 1 Industry division
| Codes | Industries                                      | Codes | Industries                                      |
|-------|------------------------------------------------|-------|------------------------------------------------|
| N1    | Agriculture                                    | N10   | Mechanical industry                            |
| N2    | Mining industry                                | N11   | Transportation equipment manufacturing         |
| N3    | Food manufacturing and tobacco processing      | N12   | Electrical machinery and electronic Communication equipment manufacturing |
| N4    | Textile services                               |       |                                                |
| N5    | Wood processing and furniture manufacturing    | N13   | Other manufacturing                            |
| N6    | Paper printing and cultural and educational Supplies manufacturing industry | N14   | Production and supply of electricity, gas and water |
| N7    | Chemical industry                              | N15   | Construction                                   |
| N8    | Non-metallic mineral products industry         | N16   | Commerce and transportation                    |
| N9    | Metal smelting and products industry           | N17   | Other services                                 |

The data from “China 2007 Interregional Input-output Table of 30 Provinces, Autonomous regions and municipalities” (compiled by key Laboratory of Analysis and Simulation of Regional Sustainable Development, Chinese Academy of Sciences) and “China 2012 Interregional Input-output Table of 31 provinces, autonomous regions and municipalities” were applied (Liu et al., 2018). The data in the input-output tables of China in 2007 and 2012 are processed in a unified manner to facilitate calculation. And the data of Tibet Autonomous Region in 2012 are excluded. According to the industry classification standard, the industries in China’s interregional input-output table in 2007 and 2012 are merged into 17 industries, and the classification results are shown in Table 1. The data of energy consumption are derived from China Energy Statistical Yearbook 2008 (China Energy Statistical Yearbook 2008) and China Energy Statistical Yearbook 2013 (China Energy Statistical Yearbook 2013). \( \text{SO}_2 \) data required for calculation are derived from China Environmental Statistical Yearbook 2008 (China's Environmental Yearbook 2008) and China Environmental Statistical Yearbook 2013 (China's Environmental Yearbook 2013).

### 3 Driving Force Effect Of Embodied Carbon Emissions And Embodied \( \text{SO}_2 \) Emissions Transferred In Shanxi Province And Other Regions

#### 3.1 Driving force effect of embodied carbon emissions transferred from Shanxi to other regions

SDA model was adopted to carry out structural decomposition of driving force effect of the embodied carbon emissions transferred in the intermediate demand and final demand from Shanxi Province to other regions during 2007-2012 combined with the multi-regional input-output model (see Fig.1). The
driving force effect of intermediate (final) demand embodied carbon emissions transferred in Shanxi to other regions was decomposed into carbon emissions strength effect, input-output structure effect, intermediate (final) demand structure effect and intermediate (final) demand scale effect.

The strength effect of carbon emissions had a significant inhibitory effect on the transfer of intermediate demand embodied carbon emissions from Shanxi to other regions. And it reduced the embodied carbon emissions transferred amount by 141.49%, and then reduced the embodied carbon emissions transferred amount from Shanxi to other regions (see Fig. 1(a)). The input-output structure effect, intermediate demand structure effect and intermediate demand scale effect increased the intermediate demand carbon emissions transferred from Shanxi to other regions. The input-output structure effect and the intermediate demand structure effect increased the embodied carbon emissions by 5.36% and 7.24%, respectively, while the intermediate demand scale effect accounted for 228.89% of the embodied carbon emissions value-added when the intermediate demand was transferred to other regions. Because the increase of the intermediate demand scale effect on the embodied carbon emissions offset the reduction of carbon emissions strength, the intermediate demand embodied carbon emissions transferred to other regions in Shanxi showed an increasing trend during 2007-2012.

Additionally, the carbon emissions strength effect had a significant negative effect on the change of final demand embodied carbon emissions transferred from Shanxi to other regions during 2007-2012, and the proportion of carbon emissions reduced was as high as 464.60 (see Fig. 1(b)). And the effect of carbon emissions strength had a significant promoting effect on reducing the final demand embodied carbon emissions transferred from Shanxi to other regions. The input-output structure effect, final demand structure effect and final demand scale effect had a significant positive effect on the change of final demand embodied carbon emissions transferred from Shanxi to other regions. The input-output structure effect and the final demand structure effect increased the embodied carbon emissions by 17.60% and 30.62%, respectively. And the proportion of the embodied carbon emissions transferred to other regions by the final demand scale effect in Shanxi was as high as 516.37%, and the final consumption demand was the main factor to increase the emissions. The increase of embodied carbon emissions from input-output structure effect, final demand structure effect and final demand scale effect was higher than the reduction of embodied carbon emissions from carbon emissions strength effect, so that the increment of embodied carbon emissions from final demand transferred from Shanxi to other regions reached 30,512,500 t during 2007-2012.

In conclusion, the carbon emissions strength effect was obviously conducive to reducing the embodied carbon emissions from Shanxi to other regions during 2007-2012, while the input-output structure effect, the intermediate (final) demand structure effect and the intermediate (final) demand scale effect should be the main factors leading to the increase of the embodied carbon emissions from Shanxi Province. In particular, the scale effect of intermediate (final) demand contributes the most to the increase of embodied carbon emissions. China elaborated concrete measures to combat climate change at the 2007 United Nations Climate Change Conference held in Bali. Local governments in China vigorously advocate the development concept of energy conservation, emissions reduction, green and low carbon throughout
the social and economic development, and the CO₂ emissions per unit of GDP was effectively controlled. Therefore, when Shanxi transferred resources to other regions, the carbon emissions from other regions was effectively hindered by the effect of carbon emissions strength. China actively implemented low-carbon emissions reduction policies and measures and has made certain progress in terms of reducing carbon emissions strength, which also showed the effectiveness of policy guidance. Additionally, other regions should pay attention to the increase of input structure, production structure and consumption structure. Therefore, other regions should optimize the production and consumption scale, and adjust the input, production and consumption structure, to reduce the carbon emissions embodied by the input of trade activities.

3.2 Driving force effect of embodied SO₂ emissions transferred from Shanxi to other regions

The driving force effect of intermediate (final) demand embodied SO₂ emissions exported from Shanxi to other regions during 2007-2012 was decomposed into sulfur emissions strength effect, input-output structure effect, intermediate (final) demand structure effect, and intermediate (final) demand scale effect (see Fig. 2).

The sulfur emissions strength effect was the main driving factor to reduce the intermediate demand embodied SO₂ emissions transferred from Shanxi to other regions, and the proportion of embodied SO₂ emissions reduced was as high as 333.67% (seen Fig. 2 (a)), which showed that sulfur emissions per unit of GNP were decreasing as GNP increased. The input-output structure effect, intermediate demand structure effect and intermediate demand scale effect were the leading factors that increasing the intermediate demand embodied SO₂ emissions transferred from Shanxi to other regions. The input-output structure effect and intermediate demand structure effect increased the embodied SO₂ emissions by 68.91% and 18.75%, respectively. The proportion of embodied SO₂ emissions by the increase of the intermediate demand scale effect could reach 346.01%, which indicated that the intermediate consumption demand played an important leading role in the increase of carbon emissions, and that reducing the intermediate consumption demand was an effective way to reduce carbon emissions. Due to the intermediate demand SO₂ emissions by the input and output structure effect, intermediate demand structure effect and the intermediate demand scale effect increased transferred from Shanxi to other regions implicit more than the embodied SO₂ discharge of sulfur emissions strength effect, thus which made the intermediate demand SO₂ emissions transferred from Shanxi to other regions increased during 2007-2012.

Additionally, the sulfur emissions strength effect was the only driving factor to reduce the final demand embodied SO₂ emissions transferred from Shanxi to other regions, and the reduced embodied SO₂ emissions reach 851.01%, which made a significant contribution to the reduction of the final demand embodied SO₂ emissions transferred from Shanxi to other regions (see Fig. 2 (b)). The input-output structure effect, final demand structure effect and final demand scale effect were the main driving factors to increase the final demand embodied SO₂ emissions transferred from Shanxi to other regions, and the
corresponding increased embodied SO\textsubscript{2} emissions of each effect reached 175.74\%, 41.55\% and 733.71\%, respectively. Therefore, the sulfur emissions strength effect transferred from Shanxi to other regions was the coupled effects with the negative effect of the final demand embodied SO\textsubscript{2} emissions and the positive effects of the input-output structure effect, the final demand structure effect, the final demand scale effect, which caused the final demand embodied SO\textsubscript{2} emissions effect from Shanxi to other regions overall presented a significant increasing Trend during 2007-2012.

In conclusion, the sulfur emissions strength effect was the only driving force effect to reduce the SO\textsubscript{2} emissions transferred from Shanxi to other regions. China released the 11\textsuperscript{th} Five-Year Plan for the prevention and control of sulfur dioxide pollution in 2007. And the overall goal was to reduce the total emissions of sulfur dioxide and reduce the concentration of sulfur dioxide in urban air. It was shown that the control of sulfur dioxide emissions and the strengthening of environmental supervision in China have been effectively implemented, thus reducing the sulfur emissions strength in China through calculation. The input-output structure effect, intermediate (final) demand structure effect and intermediate (final) demand scale effect were all the driving factors that lead to the increase of embodied SO\textsubscript{2} emissions from Shanxi to other regions. Among them, the intermediate (final) demand scale effect was the main factor that increased the embodied SO\textsubscript{2} emissions from Shanxi Province to other regions, and the input-output structure effect increased the embodied SO\textsubscript{2} emissions from Shanxi Province to other regions. Therefore, while other regions obtained resources from Shanxi Province for processing and use, the production scale and final demand scale significantly increased the embodied SO\textsubscript{2} emissions, and the embodied SO\textsubscript{2} emissions caused by inefficient and unreasonable input-output structure could not be ignored. Therefore, other regions should strengthen the detection and control of input-output structure, production, processing and final use of SO\textsubscript{2} emissions, to reduce the emergence and input of embodied SO\textsubscript{2} emissions.

3.3 Driving force effect of embodied carbon emissions transferred from other regions to Shanxi

The carbon emissions strength effect had a significant inhibitory effect on the increasing of embodied carbon emissions by intermediate demand transferred from other regions to Shanxi, and the reduced carbon emissions could reach 148.50\%, which played an important role in reducing the embodied carbon emissions by intermediate demand transferred from other regions to Shanxi (see Fig. 3 (a)). The input-output structure effect, the intermediate demand structure effect and the intermediate demand scale effect were the driving factors to increase the embodied carbon emissions by the intermediate demand transfer from other regions to Shanxi. Among them, the input-output structure effect, the intermediate demand structure effect and the intermediate demand scale effect increased the embodied carbon emissions by 63.87\%, 51.87\% and 132.76\%, respectively. The intermediate demand scale effect was the most important driving factor leading to the increasing of the embodied carbon emissions from other regions to Shanxi. Therefore, the industrial structure of Shanxi needed to be further optimized and adjusted, and its final consumption demand was the leading factor leading to the increasing of emissions from other regions to Shanxi. Because the increased embodied carbon emissions from input-
output structure effect, intermediate demand structure effect and intermediate demand scale effect were greater than the decreased embodied carbon emissions from carbon emissions strength effect, the overall trend of the embodied carbon emissions transferred from other regions to Shanxi was increased during 2007-2012.

Meanwhile, the variation of the final demand embodied carbon emissions transferred from Shanxi to other regions was hampered by the carbon emissions strength effect, which had significant contributions to reduce the final demand embodied carbon emissions transferred from other regions to Shanxi, and the reduced embodied carbon emissions value of 148.15% (see Fig. 3 (b)). The input-output structure effect, final demand structure effect and final demand scale effect had a significant promoting effect on the increasing of final demand embodied carbon emissions transferred from other regions to Shanxi, and the increased embodied carbon emissions were 61.14%, 29.04% and 151.98%, respectively. The final demand scale effect was the main driving factor to increase the embodied carbon emissions transferred from other regions to Shanxi. The input-output structure and the emissions generated by the final consumption demand should be paid to attention to reduce the emissions transferred from other regions to Shanxi through trade. It was not difficult to find that the final demand embodied from other region to Shanxi during 2007-2012 was still increased compared with the negative effect of the embodied carbon emissions strength and the positive effects of the input and output structure effect, the final demand structure effect and final demand scale effect.

In conclusion, the carbon emissions strength effect was the main driving factors to reduce the embodied carbon emissions transferred from other regions to Shanxi. And the input-output structure effect, intermediate (final) demand structure effect and intermediate (final) demand scale effect was the main driving force effect to increase the embodied carbon emissions shifted elsewhere to Shanxi. Among them, the intermediate (final) demand scale effect had a significant contribution to increase the embodied carbon emissions of imported Shanxi. The carbon emissions embodied in trade in Shanxi was mainly derived from the production and processing scale and consumption demand in the region. Additionally, the intermediate input technology, production structure and consumption structure also increased the embodied carbon emissions of Shanxi in trade. As an important energy-rich region in China, Shanxi should reasonably adjust the production, processing scale and consumption demand, optimize the economic production structure, efficiently improve the technical efficiency in the future trade with other regions, which could effectively reduce the embodied carbon emissions transferred from other regions to Shanxi.

3.4 Driving force effect of embodied SO\textsubscript{2} emissions transferred from other regions to Shanxi

The sulfur emissions strength effect was the driving force to reduce the intermediate demand embodied SO\textsubscript{2} emissions transferred from other regions to Shanxi (see Fig. 4 (a)). The reduced SO\textsubscript{2} emissions was as high as 238.49%, and it was the leading force to reduce the intermediate demand embodied SO\textsubscript{2} emissions imported from Shanxi due to trade activities. The input-output structure effect, the intermediate demand structure effect and the intermediate demand scale effect were the main driving forces to
increase the intermediate demand embodied \(\text{SO}_2\) emissions transfer from other regions to Shanxi. And the input-output structural effect, intermediate demand structural effect and intermediate demand scale effect increased the embodied \(\text{SO}_2\) emissions by 93.61%, 75.12% and 169.75%, respectively. The intermediate demand scale effect was the driving force that increased the intermediate demand embodied \(\text{SO}_2\) emissions from other regions to Shanxi. It could be found that the intermediate demand embodied \(\text{SO}_2\) emissions from other regions to Shanxi showed an obvious increasing trend during 2007-2012 through the analysis of the influence of the above four factors on the change of intermediate demand embodied \(\text{SO}_2\) emissions transferred from other regions to Shanxi.

The change of final demand embodied \(\text{SO}_2\) emissions transferred from other regions to Shanxi during 2007-2012 was hindered by the sulfur emissions strength effect, and the reduction of embodied \(\text{SO}_2\) emissions reached 213.19% (see Fig. 4(b)). The effect of sulfur emissions strength has a significant positive effect on reducing the \(\text{SO}_2\) emissions embodied by the final demand transfer from other regions to Shanxi Province. The input-output structure effect, final demand structure effect and final demand scale effect were the main driving factors to increase the final demand embodied \(\text{SO}_2\) emissions transferred from other regions to Shanxi, and the increased embodied \(\text{SO}_2\) emissions could reach to 83.68%, 32.91% and 196.60%, respectively. Therefore, the input-output structure effect and the final demand scale effect were the driving factors that leading to the \(\text{SO}_2\) emissions transferred from other regions to Shanxi. Obviously, the final demand embodied \(\text{SO}_2\) emissions transferred from other regions to Shanxi increased year by year during 2007-2012.

In conclusion, the existence of sulfur emissions strength effect could reduce the embodied \(\text{SO}_2\) emissions transferred from other regions to Shanxi, while the input-output structure effect, intermediate (final) demand structure effect and intermediate (final) demand scale effect could increase the embodied \(\text{SO}_2\) emissions transferred from other regions to Shanxi. Among them, the input-output structure effect and intermediate (final) demand scale effect contributed the most to the increasing of embodied \(\text{SO}_2\) emissions. Shanxi Province was the typical heavy industrial base in China. Shanxi Province was one of the provinces with heavy \(\text{SO}_2\) pollution in 2007 due to the production scale and final demand (State of China's Environment Bulletin 2008). Shanxi Province had a large demand for energy due to the regional industrial structure characteristics. Therefore, it was urgent to increase the capital investment in clean energy technology and increase the use of clean energy in Shanxi Province, to reduce the sulfur emissions caused by primary energy consumption.

4 Driving Force Effect Of Embodied Carbon Emissions And Embodied \(\text{SO}_2\) Emissions Transferred In Industries Of Shanxi Province And Other Regions

4.1 Driving force effect of embodied carbon emissions transferred from industries in Shanxi to other regions
The driving force effect of intermediate (final) demand embodied carbon emissions transferred from Shanxi to other industries during 2007-2012 was decomposed, and the driving force effect of the industries with the largest increase in intermediate (final) demand embodied carbon emissions transferred from Shanxi to other regions was analyzed (see Fig. 5).

The intermediate demand embodied carbon emissions transferred from Shanxi to other regions were mainly concentrated in the production and supply of electricity, gas and water, chemical industry, construction industry, electrical machinery and electronic communication equipment manufacturing industry, metal smelting and product industry, et al. (see Fig. 5 (a)). In general, the carbon emissions strength effect and the intermediate demand scale effect had the biggest impact on the change of intermediate demand embodied carbon emissions exported from Shanxi to other regions. For the change of carbon emissions, the carbon emissions strength effect had a significant inhibition effect, the intermediate demand scale had a significant promotion effect, and the input-output structure effect and the intermediate demand structure effect had different effects in different industries. The increasing of intermediate demand embodied carbon emissions of the production and supply of electricity, gas and water transferred from other regions to Shanxi Province during 2007-2012 was as high as 20.2039 million t. Among them, the carbon emissions reduced by the carbon emissions strength effect was 20.6069 million t, and the input-output structure effect played a restraining role. Additionally, the embodied carbon emissions increased by the intermediate demand structural effect and the intermediate demand scale effect were 17.7653 million t and 23.8733 million t, respectively. The intermediate demand carbon emissions embodied reduced by the carbon emissions strength effect transferred from Shanxi to the chemical industry in other regions was as high as 18.06009 million t. The input-output structure effect, intermediate demand structure effect and intermediate demand scale effect were the driving factors that leading to the increase of intermediate demand embodied carbon emissions transferred from Shanxi Province to chemical industry in other regions, and the intermediate demand scale increased the embodied carbon emissions by 28.702 million t. Therefore, the intermediate demand carbon emissions embodied transferred from Shanxi to the chemical industry in other regions increased by 12.897 million t during 2007-2012. The increasing of intermediate demand embodied carbon emissions transferred from Shanxi to other regions was promoted by the input-output structure effect and hindered by the intermediate demand structure effect. The embodied carbon emissions reduced by the carbon emissions strength effect was 13.7905 million t, and the embodied carbon emissions increased by the intermediate demand scale was 28.1492 million tons. The input-output structure effect and the intermediate demand structure effect were the influencing factors to increase the intermediate demand embodied carbon emissions transferred from Shanxi to other regions. The input-output structure effect and the intermediate demand structure effect had a significant negative effect on the change of intermediate demand embodied carbon emissions transferred from Shanxi to the metal smelting and product industry in other regions. and the intermediate demand scale effect had an obvious positive effect on the increase of the intermediate demand embodied carbon emissions transferred from Shanxi to the metal smelting and product industry in other regions, and the increased carbon emissions reached to 39.7033 million t.
The intermediate demand embodied carbon emissions transferred from Shanxi to the metal smelting and product industry in other regions increased by 7.942 million t during the study period.

The carbon emissions strength effect and the final demand scale effect had the most significant effect on the final demand embodied carbon emissions transferred from Shanxi to industries in other regions (see Fig. 5(b)). The effect of carbon emissions strength effectively reduces the carbon emissions and the final demand scale effect played a leading role in the increase of carbon emissions. The final demand embodied carbon emissions transferred from Shanxi to the construction industry in other regions increased by 11.012 million t during 2007-2012, and the input-output structure effect and the final demand structure effect had positive effects on it. The final demand embodied carbon emissions reduced by the carbon emissions strength effect transferred from Shanxi to the transportation equipment manufacturing in other regions was 5.5372 million t, and the input-output structure effect and the final demand structure effect are the driving factors to increase the carbon emissions embodied in the final demand of the transportation equipment manufacturing industry in other regions, and the embodied carbon emissions increased by the final demand scale effect was as high as 896.98 million t. The input-output structure effect and the final demand structure effect were the influencing factors to increase the final demand embodied carbon emissions transferred from the electrical machinery and electronic communication equipment manufacturing industry in other regions to Shanxi. The carbon emissions strength effect reduced the embodied carbon emissions in the electrical machinery and electronic communication equipment manufacturing industry by 8.3687 million t. The final demand carbon emissions embodied transferred from Shanxi Province to other regions in the manufacturing of electrical machinery and electronic communication equipment increased by 2.5173 million t during 2007-2012. The final demand embodied carbon emissions transferred from Shanxi to other services in other regions increased by 2.2996 million t during the study period. The final demand structural effect had a negative effect on the change of final demand embodied carbon emissions transferred from Shanxi to other services in other regions. And the input-output structure effect was the driving force effect of increasing the final demand embodied carbon emissions transferred from Shanxi to other services in other regions.

In conclusions, the embodied carbon emissions transferred from Shanxi to other regions were mainly concentrated in high-energy-consuming industries, and the carbon emissions strength effect and the intermediate (final) demand scale effect had the biggest impact on them. Among them, the carbon emissions strength effect significantly reduced the embodied carbon emissions imported from Shanxi to industries in other regions, and the intermediate (final) demand scale effect was conducive to the increase of carbon emissions. And the input-output structural effect and intermediate (final) demand structural effect had different effects in different industries. The most effective way to reduce carbon emissions input was to adjust and optimize the consumption demand of industries in other regions according to the above analysis results. Additionally, the role of input-output technology and production (consumption) structure in different industries was targeted to develop mitigation plans.

4.2 Driving force effect of embodied SO$_2$ emissions transferred from industries in Shanxi to other regions
The intermediate demand scale effect and the input-output structure effect were the driving factors that increasing the intermediate demand embodied SO\(_2\) emissions transferred from Shanxi to industries in other regions, and the effect of the intermediate demand scale effect was more significant. Additionally, the carbon emissions strength effect of was the leading force to reduce the intermediate demand embodied SO\(_2\) emissions (see Fig. 6(a)). The construction industry was the industry with the largest increase of 77,700 t in the intermediate demand embodied SO\(_2\) emissions transferred from Shanxi to other regions during 2007-2012. The intermediate demand structural effect was a factor to reduce the embodied SO\(_2\) emissions transferred, and the SO\(_2\) emissions increased by the intermediate demand scale effect as much as 163,900 t. The intermediate demand structural effect increased the intermediate demand embodied SO\(_2\) emissions transferred from Shanxi to the production and supply of electricity, gas and water in other regions. The intermediate demand embodied SO\(_2\) emissions transferred from Shanxi to the production and supply of electricity, gas and water in other regions increased by 64,500 t during the study period. The change of intermediate demand embodied SO\(_2\) emissions from Shanxi to other regions of metal smelting and product industry was hindered by the intermediate demand structural effect, and the embodied SO\(_2\) emissions increased by the scale effect of intermediate demand was 234,600 t. Additionally, the intermediate demand embodied SO\(_2\) emissions transferred from Shanxi to the metal smelting and product industry in other regions increased the by 50,500 t during 2007-2012. With the increase of input-output structure effect, intermediate demand structure effect and intermediate demand scale effect, the intermediate demand embodied SO\(_2\) emissions transferred from Shanxi to the electrical machinery and electronic communication equipment manufacturing industry in other regions offset that of sulfur emissions strength effect. Therefore, the intermediate demand transferred from Shanxi to the electrical machinery and electronic communication equipment manufacturing industry in other regions increased the SO\(_2\) emissions during 2007-2012.

The final demand scale effect and the input-output structure effect were the driving factors that increasing the final demand embodied SO\(_2\) emissions transferred from Shanxi to other industries during 2007-2012, and the sulfur emissions strength effect was the leading factor to reduce the final demand embodied SO\(_2\) emissions (see Fig. 6(b)). The construction industry was the industry with the largest increase of 74,300 t in final demand embodied SO\(_2\) emissions transferred from Shanxi to other regions during the study period. And the final demand structural effect of increased the final demand embodied SO\(_2\) emissions. The input-output structure effect, the final demand structure effect and the final demand scale effect increased the final demand embodied SO\(_2\) emissions of the transportation equipment manufacturing industry transferred from Shanxi to other regions by 33,700 t. The influencing factors of the final demand embodied SO\(_2\) emissions of electrical machinery and electronic communication equipment manufacturing industry transferred from Shanxi to other regions were decomposed. It could be seen that the increased embodied SO\(_2\) emissions from input-output structure effect, final demand structure effect and final demand scale effect offset the decreased embodied SO\(_2\) emissions from the effect of sulfur emissions strength. Therefore, the final demand embodied SO\(_2\) emissions transferred from Shanxi to the electrical machinery and electronic communication equipment manufacturing
industry in other regions increased by 13,300 t during 2007-2012. The change of the embodied SO$_2$ emissions transferred from Shanxi to the machinery industry in other regions was promoted by the final demand structural effect during 2007-2012.

Combined with the above analysis, it could be seen that the hidden SO$_2$ emissions transferred from Shanxi to other regions were mainly distributed in industries with large energy demand. The intermediate (final) demand scale effect and input-output structure effect both increased the embodied SO$_2$ emissions in other regions, while the sulfur emissions strength effect had a negative effect, and the intermediate (final) demand structure effect increased the embodied SO$_2$ emissions in most industries in other regions. Therefore, controlling the input of SO$_2$ emissions in other industries required controlling the consumption demand, adjusting the production structure and improving the technology input.

4.3 Driving force effect of embodied carbon emissions transferred from industries in other regions to Shanxi

The driving force effect of intermediate (final) demand embodied carbon emissions transferred from industries in other regions to Shanxi was decomposed into carbon emissions strength effect, input-output structure effect, intermediate (final) demand structure effect and intermediate (final) demand scale effect. The paper focused on the industries with large increase in intermediate (final) demand embodied carbon emissions transferred from industries in other regions to Shanxi during 2007-2012 (see Fig. 7).

The carbon emissions strength effect effectively hindering the increasing of intermediate demand embodied carbon emissions from industries in other regions to Shanxi, and the intermediate demand scale effect and input-output structure effect had significant contribution to its increasing (see Fig. 7(a)). The intermediate demand carbon emissions transferred from the main industries including the mining industry, construction industry, metal smelting and product industry, commercial industry and transportation industry to Shanxi had a large increasing, during 2007-2012. The intermediate demand structural effect played a positive effect on the increasing in carbon emissions of these industries. The mining industry was the industry with the largest increasing in the intermediate demand embodied carbon emissions transferred from other regions to Shanxi, and only the intermediate demand scale effect increased the carbon emissions as high as 9.2516 million t. Additionally, the intermediate demand embodied carbon emissions transferred from other regions to Shanxi increased by 6.0034 million t during 2007-2012. The intermediate demand embodied carbon emissions transferred from the construction industry in other regions to Shanxi increased by 5.2880 million t, and the carbon emissions strength effect reduced the intermediate demand embodied carbon emissions by 6.3206 million t, which had a significant negative effect on the change of the intermediate demand embodied carbon emissions in Shanxi Province during 2007-2012. By decomposing the factors affected the intermediate demand embodied carbon emissions transferred from the metal smelting and product industry in other regions to Shanxi, it could be seen that the carbon emissions decreased by the carbon emissions strength effect reached to 5.6057 million t, and the carbon emissions increased by the input-output structure effect, the intermediate demand structure effect and the intermediate demand scale effect reached to 8.714 million
Therefore, the intermediate demand embodied carbon emissions transferred from the metal smelting and product industry in other regions to Shanxi increased by 3.1087 million t during 2007-2012. Among the factors affected the intermediate demand embodied carbon emissions transferred from the commercial and transportation industries in other regions to Shanxi, the positive effects of the input-output structure effect, the intermediate demand structure effect and the intermediate demand scale effect were greater than the negative effects of the carbon emissions strength effect. Therefore, the intermediate demand embodied carbon emissions transferred from the commercial and transportation industries in other regions to Shanxi increased during 2007-2012.

The final demand scale effect and the input-output structure effect increased the final demand embodied carbon emissions imported from other regions to Shanxi Province (see Fig. 7(b)). The carbon emissions strength effect had a great hindering effect on the final demand embodied carbon emissions imported from industries other regions into Shanxi, and the final demand structural effect increased the embodied carbon emissions of most industries in Shanxi. The industry with the largest increase in final demand embodied carbon emissions transferred from other regions to Shanxi was the construction industry during 2007-2012. The embodied carbon emissions strength effect reduced by 6.3106 million t, and the input-output structure effect, final demand structure effect and final demand scale effect increased the embodied carbon emissions by 11.775 million t. Therefore, the final demand embodied carbon emissions transferred from the construction industry in other regions to Shanxi increased by 5.4669 million t. The final demand embodied carbon emissions transferred from the machinery industry in other regions to Shanxi with the increasing of the final demand scale effect was as high as 168.8 million t, and the final demand carbon emissions embodied transferred from the machinery industry in other regions to Shanxi increased by 1.3587 million t during 2007-2012. The carbon emissions strength effect effectively reduced the final demand embodied carbon emissions transferred from the commercial and transportation industry in other regions to Shanxi by 2.1329 million t during the study period. The increased embodied carbon emissions from input-output structure effect, final demand structure effect and final demand scale effect offset the reduced embodied carbon emissions from carbon emissions strength effect, so that the final demand embodied carbon emissions transferred from the commercial and transportation industry in other regions to Shanxi increased by 985,900 t during 2007-2012. The final demand embodied carbon emissions increased by final demand scale effect transferred from the electrical machinery and electronic communication equipment manufacturing industry in other regions to Shanxi was as high as 897,400 t, and the final demand embodied carbon emissions transferred from the electrical machinery and electronic communication equipment manufacturing industry in other regions to Shanxi increased during 2007-2012.

Additionally, the embodied carbon emissions transferred from other regions to Shanxi were mainly concentrated in the industries developing coal resources, which was closely related to the development of leading industries in this region. The embodied carbon emissions transferred from industries in other regions to Shanxi were promoted by the intermediate (final) demand scale effect and input-output structure effect, and hindered by the carbon emissions strength effect. The intermediate (final) demand structure effect played different roles in different industries. Therefore, it was necessary to focus on the
development of leading industries of coal resources, and made reasonable adjustment and optimization of their economic production structure, final consumption and production technology to control the input of trade embodied carbon in Shanxi, and to reduce the embodied carbon emissions transferred from other regions during the Shanxi’s economic development.

4.4 Driving force effect of embodied SO$_2$ emissions transferred from industries in other regions to Shanxi

The structural decomposition model was used to decompose the intermediate (final) demand embodied SO$_2$ emissions transferred from other regions to Shanxi by the sulfur emissions strength effect, input-output structure effect, intermediate (final) demand structure effect and intermediate (final) demand scale effect. The driving factors transferred to the industries with more intermediate (final) demand SO$_2$ emissions were analyzed (see Fig. 8).

The intermediate demand embodied SO$_2$ emissions transferred from the construction industry, mining and selection industry, metal smelting and product industry, commerce and transportation industry in other regions to Shanxi were mainly concentrated (see Fig. 8(a)). The input-output structure effect, intermediate demand structure effect and intermediate demand scale effect increased the embodied SO$_2$ emissions of the above industries. Only the sulfur emissions strength effect could hinder the increasing of embodied SO$_2$ emissions. With the increasing of input-output structure effect, intermediate demand structure effect and intermediate demand scale effect, the intermediate demand embodied SO$_2$ emissions transferred from the construction industry in other regions to Shanxi increased by 57,900 t, and then the intermediate demand embodied SO$_2$ emissions transferred from the construction industry in other regions to Shanxi increased by 22,400 t during 2007-2012. The embodied SO$_2$ emissions increased by the intermediate demand scale effect was the largest, which was as high as 38,300 t decomposing the influencing factors of the intermediate demand embodied SO$_2$ emissions transferred from the mining industry in other regions to Shanxi. Therefore, the intermediate demand embodied SO$_2$ emissions transferred to the construction industry in Shanxi increased the by 20,800 t during 2007-2012. The sulfur emissions strength effect effectively reduced the intermediate demand embodied SO$_2$ emissions transferred from the metal smelting and product industry in other regions to Shanxi, and reduced the embodied SO$_2$ emissions transferred by 35,600 t. Therefore, the intermediate demand embodied SO$_2$ emissions transferred from the metal smelting and product industry in other regions to Shanxi increased by 8,700 t during 2007-2012. It was known that the embodied SO$_2$ emissions increased by the intermediate demand scale effect was 10,200 t analyzing the intermediate demand embodied SO$_2$ emissions transferred from the commercial and transportation industries in other regions to Shanxi. Therefore, the intermediate demand embodied SO$_2$ emissions transferred from the commercial and transportation industries in other regions to Shanxi increased during 2007-2012.

The sulfur emissions strength effect played an important role in reducing the final demand embodied SO$_2$ emissions from industries in other regions to Shanxi, the input-output structure effect and the final demand scale effect increased the final demand embodied SO$_2$ emissions of various industries in Shanxi,
and the final demand structure effect had a promoting effect on the increasing of embodied SO$_2$ emissions in most industries in Shanxi (see Fig. 8(b)). The industry with the final demand embodied SO$_2$ emissions transferred from in other regions to Shanxi was the construction industry. Because the increased embodied SO$_2$ emissions from input-output structure effect, final demand structure effect and final demand scale effect offset the decreased embodied SO$_2$ emissions from the sulfur emissions strength effect, the embodied SO$_2$ emissions from the final demand transferred to the construction industry in Shanxi increased by 23,400 t during 2007-2012. The final demand structural effect was an influential factor that increased the final demand embodied SO$_2$ emissions transferred from the machinery industry in other regions to Shanxi. The final demand embodied SO$_2$ emissions transferred from the machinery industry in other regions to Shanxi was increased during the study period. The final demand structural effect could promote the reduction of the final demand embodied SO$_2$ emissions transferred from the commercial and transportation industries in other regions to Shanxi. Therefore, the final demand embodied SO$_2$ emissions transferred from the commercial and transportation industries in other regions to Shanxi only increased by 3,600 t during 2007-2012. The final demand structural effect had a significant contribution to the increasing of the final demand embodied SO$_2$ emissions transferred from the electrical machinery and electronic communication equipment manufacturing industry in other regions to Shanxi during the study period, and the final demand embodied SO$_2$ emissions transferred from the electrical machinery and electronic communication equipment manufacturing industry in other regions to Shanxi increased.

In conclusion, the major industries with embodied SO$_2$ emissions transferred from other regions to Shanxi were extremely related to the mining and use of coal resources. The intermediate (final) demand scale effect and carbon emissions strength effect were the influencing factors to increasing the embodied SO$_2$ emissions in trade in Shanxi. Additionally, the carbon emissions strength effect had negative effect, while the intermediate (final) structure effect had positive effect for most industries in Shanxi. Therefore, the proportion of clean energy used, the industrial structure adjusted, production technology improved were needed to increase. Additionally, the consumption scale, production structure and input technology needed to be reduced. Therefore, it was meaningful to effectively control the embodied SO$_2$ emissions transferred from other regions to Shanxi through trade activities.

## 5 Conclusions And Suggestions

### 5.1 Conclusions

(1) The intermediate (final) demand scale effect and carbon emissions strength effect have the largest effect, followed by the intermediate (final) demand structure effect, and the input-output structure has the smallest effect. The intermediate (final) demand scale effect and carbon emissions strength effect have the largest effect, followed by the input-output structure effect, and the intermediate (final) demand structure has the smallest effect. Among them, only carbon (sulfur) emissions strength effect is negative, the rest of the effects are positive.
The carbon emissions strength effect and the intermediate (final) demand scale effect have the largest impact, followed by the input-output structure effect and the intermediate (final) demand structure effect. Among them, the carbon emissions strength effect is the driving factor to reduce the embodied carbon emissions, and the other effects are the driving factors to increase the embodied carbon emissions. The sulfur emissions strength effect reduces the embodied SO$_2$ emissions from other regions to Shanxi, while the input-output structure effect, intermediate (final) demand structure effect and intermediate (final) demand scale effect increase the embodied SO$_2$ emissions from other regions to Shanxi.

Based on the calculation of the influencing factors of the embodied carbon emissions of industries transferred from Shanxi to other regions, the intermediate (final) demand scale effect and carbon emissions strength effect play the biggest role, followed by the input-output structure effect and the intermediate (final) demand structure effect. Among them, the carbon emissions strength effect reduces the embodied carbon emissions transferred, the intermediate (final) demand scale effect increases the embodied carbon emissions, the input-output structure effect and the intermediate (final) demand structure effect have different effects in different industries. By analyzing the influencing factors of SO$_2$ emissions embodied in the transfer of Shanxi Province to other industries, it is found that the intermediate (final) demand scale effect and sulfur emissions strength effect have the largest influence strength, followed by the input-output structure effect and the intermediate (final) demand structure effect. Among them, the sulfur emissions strength effect effectively reduces the embodied SO$_2$ emissions transferred, while the intermediate (final) demand scale effect and input-output structure effect significantly increase the embodied SO$_2$ emissions, and the intermediate (final) demand structure effect has different effects in different industries.

The intermediate (final) demand scale effect and carbon emissions strength effect play the biggest role, followed by the input-output structure effect and the intermediate (final) demand structure effect. The intermediate (final) demand scale effect and the sulfur emissions strength effect have the largest influence strength, followed by the input-output structure effect and the intermediate (final) demand structure effect analyzing the influencing factors of embodied SO$_2$ emissions transferred from other regions to the industries in Shanxi. Among them, the carbon (sulfur) emissions strength effect plays a huge role in reducing the embodied carbon (sulfur) emissions transferred, while the intermediate (final) demand scale effect and input-output structure effect significantly increase the embodied SO$_2$ emissions, and the intermediate (final) demand structure effect has different effects in different industries.

5.2 Suggestions

Shanxi Province, as an important energy-rich region in China, plays an important role in maintaining regional sustainable development. Low carbon emissions reduction and haze management, Shanxi Province, an energy-rich region, seeks a way of energy conservation, emissions reduction and sustainable development, which is of great strategic significance for realizing the green transformation of the region and helps to form a long-term and stable strategic pattern of development under the background of the
country's strong advocacy of sustainable development strategy. Meanwhile, Shanxi should actively conduct trade activities with other regions to promote regional coordinated development and achieve the dual effects of environmental governance and economic development.

To reduce the carbon and SO\textsubscript{2} emissions of Shanxi and other regions, we should seek diversified schemes to strengthen the governance effect of emissions reduction. Adjusting the final demand model is an important way to effectively alleviate the transfer of hidden (sulfur) carbon emissions, such as promoting rational and green consumption, actively encouraging the green consumption, and developing green environmental protection industries to control the further expansion of industries with high strength of emissions, transforming key industries into green ones, and strengthening legal and policy guarantees for green development. Besides, adjusting the consumption structure, increasing the trade proportion of products from low-carbon and environmental protection industries, improving the trade structure, special paying attention to the energy-intensive consumption structure, and a special regulatory system will be formulated for highly pollution-intensive industries to optimize the final demand pattern. Additionally, improving the structure of economic production, attaching importance to cleaner production and technological progress, and increasing the capital and technology input of cleaner production. Besides, formulating policies for production structure and technical efficiency, such as reducing the use of fossil fuels through a carbon tax, tax breaking to encourage manufacturers to produce environmentally friendly products, providing financial subsidies to develop clean energy, and supporting innovation in green technologies. Though the carbon (sulfur) emissions strength effect plays a significant role in reducing the embodied carbon (sulfur) emissions, its effect strength needs to be further developed. Increasing the use of clean energy, reducing the proportion of primary energy used, in particular, desulphurization of energy, strengthening of pipeline terminal treatment, and construction of dust removal facilities can effectively reduce carbon emissions strength and sulfur emissions strength, and then increasing the contribution rate of reducing embodied carbon and embodied SO\textsubscript{2} emissions.

**Declarations**

**Author contributions**

**Jinghui Wu**: Design the research idea of this paper, collect data, write this article and English polished.

**Data availability**

The datasets generated and/or analyzed during the current study are not publicly available but are available from the corresponding author on reasonable request.

**Compliance with ethical standards**

**Ethics approval** The authors commit to uphold integrity of the scientific record by complying with ethical standards.
Contest to participate Not applicable.

Consent for publication Not applicable.

Conflict of interest

The author declares that she has no conflict of interest.

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References

1. BP (2019) Statistical review of world energy. BP, Paris, Beijing
2. Butnar I, Llop M (2011) Structural decomposition analysis and input-output subsystems: Changes in CO$_2$ emissions of Spanish service sectors (2000–2005). Ecol Econ 70:2012–2019.
   https://doi.org/10.1016/j.ecolecon.2011.05.017
3. Cao Y, Zhao YH, Wang HX, Li H, Wang S, Liu Y, Shi QL, Zhang YF (2018) Driving forces of national and regional carbon strength changes in China: Temporal and spatial multiplicative structural decomposition analysis. J Clean Prod 213:1380–1410.
   https://doi.org/10.1016/j.jclepro.2018.12.155
4. Cansino JM, Roman R, Ordóñez M (2016) Main drivers of changes in CO$_2$ emissions in the Spanish economy: A structural decomposition analysis. Energy Policy 89:150–159.
   https://doi.org/10.1016/j.enpol.2015.11.020
5. Chen H, Chen WY, He JK (2020) Pathway to meet carbon emissions peak target and air quality standard for China. China Popul Resour Environ 30:12–18. https://doi.org/10.12062/cpre2020080
6. Department of Energy Statistics (2008) National Bureau of Statistics of the People's Republic of China. China Energy Statistical Yearbook of 2008. China Statistics Press, Beijing
7. Department of Energy Statistics (2013) National Bureau of Statistics of the People's Republic of China. China Energy Statistical Yearbook of 2013. China Statistics Press, Beijing
8. Department Ministry of Environmental Protection (2008) China's Environmental Yearbook. China Environment Press, Beijing
9. Department Ministry of Environmental Protection (2013) China's Environmental Yearbook. China Environment Press, Beijing
10. Dong M, Li CF (2020) Study on low-carbon technology efficiency, technology gap and low-carbon progress in China: based on the method of MinDS-Luenberger. East China Economic Management 34:81–89
11. Deng HM, Liang QM, Liu LJ, Guan DB (2017) Co-benefits of greenhouse gas mitigation: A review and classification by type, mitigation sector, and geography. Environmental Research Letters 12:1–26.
12. Deng JX, Liu X, Wang Z (2014) Characteristics analysis and factor decomposition based on the regional difference changes in China’s CO₂ emissions. Journal of Natural Resources 29:189–200. https://doi.org/10.11849/zrzyxb.2014.02.001

13. Feng KS, Davis SJ, Sun LX, Hubacek K (2015) Drivers of the US CO₂ emissions 1997–2013. Nat Commun 6:7714. https://doi.org/10.1038/ncomms8714

14. He XL, Zhang ZY (2015) Exploration on the distribution of economic activity: technology spillover environmental pollution and trade liberalization. Scientia Geographica Sinica 35:161–167. https://doi.org/10.13249/j.cnki.sgs.2015.02.005

15. Huang K, Xu YJ, Yu YJ, Hu TT, Wang XM (2016) An input-output structural decomposition analysis of changes in sectoral water footprint in China. Ecol Ind 69:26–34

16. Hubacek K, Feng KS (2014) Efficiency targets fall short of achieving a low-carbon future in China. Carbon Manag 5:247–249. https://doi.org/10.1080/17583004.2014.923230

17. IPCC. Climate change 2013: The physical science basis. Contribution of working group I to the IPCC fifth assessment report of the intergovernmental panel on climate change[EB/OL].(2013) [2021-03-06].https://www.ipcc.ch/report/ar5/wg1/

18. Li KQ, Lu R, Chu RW, Ma DD, Zhu LQ (2018) Trends and driving forces of carbon emissions from energy consumption: A case study of Nanjing. China Sustainability 10:4348. https://doi.org/10.3390/su10124348

19. Liu WD, Tang ZP, Han MY (2018) The 2012 China multi-regional input-output table of 31 provincial units. China Statistics Press, Beijing

20. Liu HC, Fan J, Zeng YX, Guo R (2019) Spatio-temporal differences in carbon strength in high-energy-intensive industry and its influence factors in China. Acta Ecol Sin 39, 8357–8369. https://doi.org/10.5846 /stxb201809121957

21. Liu F, Zhang Q, Van DARJ, Zhang B, Tong D, Yan L, Zheng YX, He KB (2016) Recent reduction in NOₓ emissions over China: Synthesis of satellite observations and emissions inventories. Environmental Research Letters 11:1–9. https://doi.org/10.1088/1748-9326/11/11/114002

22. Liu QL, Long Y, Wang CR, Wang Z, Wang Q, Guan DB (2019) Drivers of provincial SO₂ emissions in China-based on multi-regional input-output analysis. J Clean Prod 238, 117893.1-117893.14. https://doi.org/10.1016/j.jclepro.2019.117893

23. Meng B, Xue JJ, Feng KS, Guan DB (2013) China’s inter-regional spillover of carbon emissions and domestic supply chains. Energy Policy 61:1305–1321. https://doi.org/10.1016/j.enpol.2013.05.108

24. Ministry of Ecology (2019) and Environment of the People's Republic of China. National ecological and environmental quality

25. Ministry of Ecology and Environment of the People's Republic of China. State of China's Environment Bulletin 2007[EB/OL] [2020-11-4]
26. Peters GP, Hertwich EG (2008) Post-Kyoto greenhouse gas inventories: Production versus consumption. Clim Change 86:51–66. https://doi.org/10.1007/s10584-007-9280-1
27. Su YX, Chen XZ, Ye YY, Wu QT, Zhang HO, Huang NS, Kuang YQ (2013) The characteristics and mechanisms of carbon emissions from energy consumption in China using DMSP/OLS night light imageries. Acta Geogr Sin 68:1513–1526. https://doi.org/10.11821/dlxb201311007
28. Sun ZQ, Li HH, Liu BL (2020) Industrial green development efficiency and influencing factors under carbon trading in China. East China Economic Management 34:57–64
29. Sun YZ, Shen L, Zhong S, Liu LT, Wu N, Li LP, Kong HX (2017) Driving force analysis of carbon emissions changes in China. Resources Science 39:2265–2274. https://doi.org/10.18402/resci.2017.12.06
30. Wang ZH, Liu W, Yin JH (2015) Driving forces of indirect carbon emissions from household consumption in China: An input-output decomposition analysis. Nat Hazards 75:257–272. https://doi.org/10.1007/s11069-014-1114-7
31. Wang CJ, Zhang XL, Zhang HO, Wang F (2016) Influencing mechanism of energy-related carbon emissions in Xinjiang based on IO-SDA model. Acta Geogr Sin 71:1105–1118. https://doi.org/10.11821/dlxb201607002
32. Weber CL, Matthews HS (2007) Embodied environmental emissions in US international trade, 1997–2004. Environ Sci Technol 41:4875–4881. https://doi.org/10.1021/es0629110
33. Wen Q, Jiao XJ, Li J (2014) Internal temporal-spatial structure characteristics and regional economic development in a resource-rich area. Resources Science 36:1392–1401
34. Wu JH, Zhang G, Wang G (2020) Study on trade embodied carbon and embodied SO₂ emissions transfer in energy enrichment areas: A case study of Shanxi province. Journal of Natural Resources 35:1445–1459. https://doi.org/10.31497/zrzyxb.20200616
35. Zheng DF, Liu XX, Wang YY, Lv LT (2020) Assessment of carbon footprint size, depth and its spatial-temporal pattern at the provincial level in China. Acta Ecol Sin 40:447–458. https://doi.org/10.5846/stxb201901010003
36. Yang K, Dickerson R, Carn S, Ge C, Wang J (2013) First observations of SO₂ from the satellite Suomi NPP OMPS: Widespread air pollution events over China. Geophys Res Lett 40:4957–4962. https://doi.org/10.1002/grl.50952
37. Zhang C, Anadon LD, Mo HP, Zhao ZN (2014) Water-carbon trade-off in China’s coal power industry. Environmental Science Technology 48:11082–11089. https://doi.org/10.1021/es5026454
38. Zheng Y, Lu F, Liu JR, Wang XK (2020) Comparative study on CO₂ emissions from fossil energy consumption and its influencing factors in typical cities of China. Acta Ecol Sin 40, 3315–3327. https://doi.org/10.5846/stxb201901290215
39. Zhong ZQ, Wu LY, Chen ZJ, He LY (2017) Evolution characteristics and structural decomposition of regional carbon emissions transfer and implications for carbon-reduction policy: taking Henan
province as an example. Scientia Geographica Sinica 37:773–782. https://doi.org/10.13249/j.cnki.sgs.2017.05.015

40. Zhong ZQ, Jiang L, He LY, Wang Z, Bai L (2018) Global carbon emissions and its environmental impact analysis based on a consumption accounting principle. Acta Geogr Sin 73:442–459. https://doi.org/10.11821/dlxb201803005

Figures

Figure 1

Decomposition structure of embodied carbon emissions driving force transferred from Shanxi to other regions during 2007-2012: (a) intermediate demand; (b) final demand
Figure 2

Decomposition structure of embodied SO2 emissions driving force transferred from Shanxi to other regions during 2007-2012: (a) intermediate demand; (b) final demand
Figure 3

Decomposition structure of embodied carbon emissions driving force transferred from other regions to Shanxi during 2007-2012: (a) intermediate demand; (b) final demand

Figure 4

Decomposition structure of embodied SO2 emissions driving force from other regions to Shanxi during 2007-2012: (a) intermediate demand; (b) final demand
Figure 5

Driving force effect of embodied carbon emissions transferred of industries from other regions to Shanxi during 2007-2012: (a) intermediate demand; (b) final demand

Figure 6

Driving force effect of carbon emissions of industries transferred from other regions to Shanxi during 2007-2012: (a) intermediate demand; (b) final demand

Figure 7
Driving force effect of carbon emissions of industries transferred from other regions to Shanxi during 2007-2012: (a) intermediate demand; (b) final demand

Figure 8

Driving force effect of embodied SO2 emissions of various industries transferred from other regions to Shanxi during 2007-2012: (a) intermediate demand; (b) final demand

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