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Assessing Impacts of Coal Reform in Shanxi Province on Surrounding Provinces using Multi-Regional CGE Model

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As the largest coal-producing and exporting region in China, the structural reform of the coal industry in Shanxi Province has profound impacts on the regional economy and environment. Aiming to assess the economic, social, and environmental impacts of coal sector reform, especially the thermal power phasing out in Shanxi Province on its surrounding provinces, including Beijing, Tianjin, Hebei, Shandong, and Jiangsu province, this study constructs a static multi-regional computable general equilibrium model, based on the multi-regional input-output table of 31 provinces, aggregated into three regions: Shanxi Province, surrounding provinces, and other provinces. Under scenarios of reference and thermal power phasing-out policies, the interregional socio-economic activities are simulated. The results reveal that thermal power phasing-out in Shanxi province will significantly promote the carbon neutrality of Shanxi province. It will reduce about 43.49 % carbon emissions of Shanxi province compared to reference scenario, although it will have a negative carbon reduction impact on surrounding area and other provinces. For economy, due to the capital input increasing, thermal phasing-out will have a benefit on GDP growth for each region. However, it will affect the labor mobility among local sectors, especially the labor in power sector will reduce 8.3 % in Shanxi province, while surrounding area and other provinces will have 0.636 % and 0.116 % labor loss in local power sector.

1. Introduction

As the goals of carbon peak before 2030 and carbon neutrality in 2060, there is an important proposal for China's ambitious goals: The power sector should be net-zero emissions in 2050. Based on this, China has its own near-term strategy and long-term pathway for power generation structure, especially the thermal power phasing out in 2060.

For China's power generation structure, the core type of power generation energy is still coal. As it is shown in China's National Economic and Social Development Statistical Bulletin in 2023, the thermal power generation still accounts for 66.26 % of all power generation, which will be a significant part for the thermal power phasing-out and renewable energy in power sector of Shanxi province on China's carbon neutrality (Liu and Yao, 2021). This will make some resource-based cities suffer from unemployment risks like Shuozhou (Shanxi Province), Huainan (Anhui Province), and Yulin (Shaanxi Province) (Yuan et al., 2022).

This reform has a profound impact not only on the economy and environment of Shanxi Province itself, but also on surrounding provinces, including Beijing, Tianjin, Hebei, Shandong, and Jiangsu. These regions are closely linked to the coal industry in Shanxi Province in economic development, so changes in the coal industry in Shanxi Province will directly or indirectly affect the social and economic activities of these provinces.

For existing research, a study used the input-output model (Sun et al., 2022) while another study utilized provincial asset-level datasets and assumption (Clark and Zhang, 2022) to estimate the economy and employment effects of China's power transition and thermal power phasing-out on provincial level. Some research concentrated on Shanxi province's carbon neutrality pathway by utilizing TIMES (Liu, 2021), LEAP and CA-Markov model (Li et al., 2022). These studies focus more on the impacts of carbon neutrality measures on the entire provincial level or individual Shanxi province. This research object is to discuss the mutual impact of Shanxi province's thermal power phasing-out on itself and its surrounding areas, which more emphasizes the interaction among regions based on the dependence of surrounding areas on Shanxi's coal industry.

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2. Methodology and data

2.1 Multi-regional CGE model

The multi-regional computable general equilibrium (CGE) model is an economic model used to analyse the mutual influence of economic activities between multiple regions or countries and their response to different policies or external shocks. Based on data such as input-output tables, the CGE model simulates the behaviour of various economic entities, such as households, enterprises, governments and the balance of market supply and demand through mathematical equations. The multi-region CGE model extends this analysis to multiple regions and considers inter-regional trade and policy transmission effects.
Its production function, utility function and trade are connected to the market and interact with each other through the price mechanism (Malahayati and Masui, 2021). The model structure of the multi-regional CGE model in this research can be described as Figure 1.

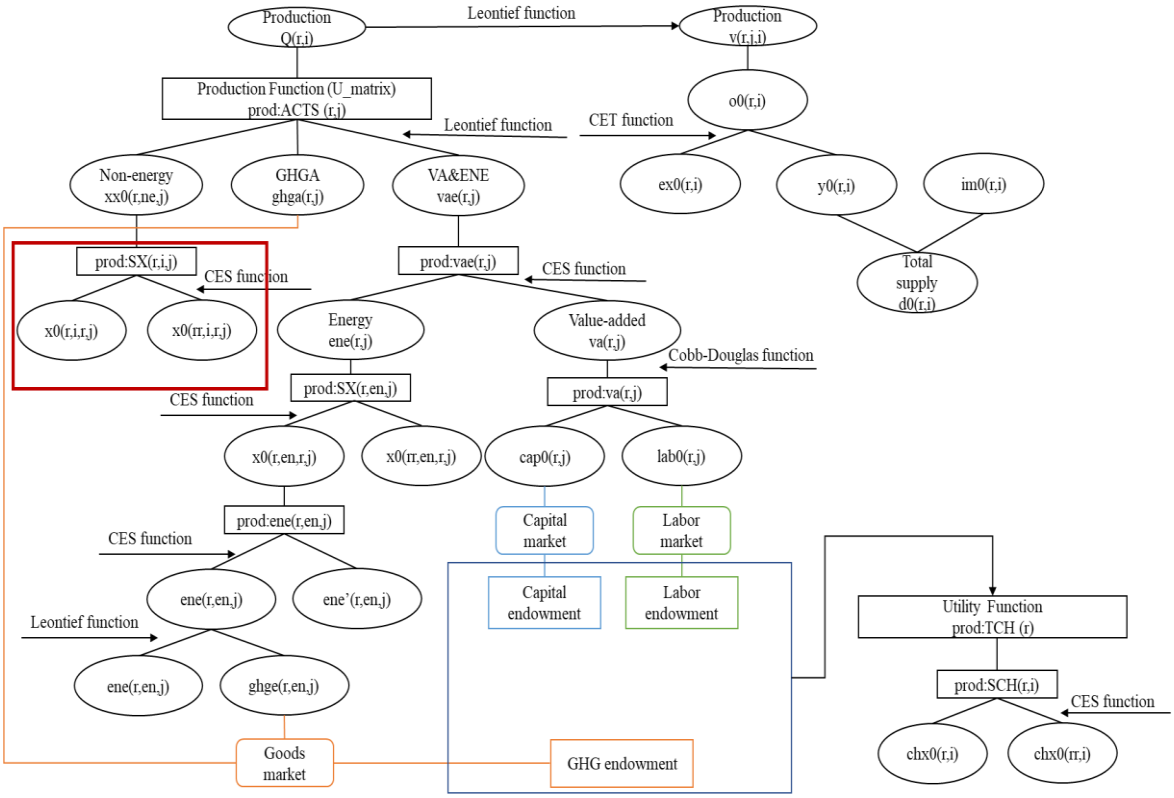

Figure 1: Multi-regional Computable General Equilibrium model structure

In this research, a static multi-regional CGE model is constructed to simulate the future scenario in 2060 to discuss the thermal power phasing out impacts.

2.2 Data source

The basic 2017 multi-provincial input-output table including 31 provinces and 42 sectors is obtained from the CEADs database (Zheng al et., 2020). They are aggregated into three regions and 12 sectors as shown in Table 1 and Table 2. The detailed factors of base year 2017, such as labor, population, GDP, power generation, energy production and consumption are derived from National Economic and Social Development Statistical Bulletin of Shanxi province. For the assumption in the future, the population for the labor input refers to the research of China's energy foundations (Wang 2023).

Table 1: Aggregated regions

Region	Code	Description
Surrounding	R1	Beijing, Tianjin, Hebei, Shandong, and Jiangsu
Shanxi province	R2	Shanxi
Others	R3	Other 25 provinces

Table 2: Aggregated sectors

No.	Sector	Description
01	Agriculture	Agriculture, forestry and fishery products and services
02	Coal mining	Coal mining and products
03	Oil and Gas mining	Oil and gas mining and products
04	Chemical	Chemical products
05	Cement	Non-metallic mineral products
06	Steel	Metal smelting and rolling processed products
07	Fuel processed	Refined petroleum and nuclear fuel processed products
08	Other manufacture	Equipment, instrumentation, and manufactured products
09	Electricity	Electricity and heat production and supply
10	Town Gas	Gas production and supply
11	Transportation	Transportation, storage and postal
12	Services	Other services

2.3 Scenario and assumption

Unlike the dynamic model, which is iterative and endogenous every year, as a static model, the future parameters are supposed to be given exogenously. So, in this research, there will be only base year (2017), target year (2060), and two scenarios, reference and thermal power phasing out (TPO) scenario.

Refer to the database of China's provincial population projection from 2025-2060, the population structures in 2060 for three regions is utilized, especially the labor population aged 15-64, which is shown in Table 3 (Wang 2023).

Table 3: population assumption (Age 15-64, Million person)

	R1	R2	R3
2017	210.54	26.47	766.95
2060	180.45	14.62	545.87

In order to assume the future economy situation, the labor input is calculated by the aggression as Eq(1).

$$\ln(\text{Labor input}) = c + a * \ln(\text{GDP}) + b * \ln(\text{POP\_15\_64}) \quad (1)$$

Similarly, the capital input in the future is calculated by the aggression as Eq(2).

$$\ln(\text{GDP}) = \ln(\text{TFP}) + \text{a} * \ln(Labor\ input) + b * \ln(\text{Capital input}) \quad (2)$$

By using historical data, these two regressions can be settled and utilized to simulate the future scenario.

As a result, the assumed capital input and labor input are introduced to the benchmark model to simulate 2060's economy situation. Then, to simulate the thermal power phasing-out, this study assumes that the thermal power will be totally replaced by renewable energy, especially wind and solar power in 2060. So, the thermal power capital will be replaced by renewable energy, which will be calculated by the real investment on Shanxi province's power sector.

According to the calculation, if the situation shifts from the reference scenario to the TPO scenario, the real annual capital cost in Shanxi province's power sector will become 2.88 times than the reference scenario due to the high cost of renewable energy.

3. Results and discussion

3.1 Carbon emission effects

As shown in Figure 2, the simulation results show that with the thermal power phasing out in Shanxi province's power sector, its carbon emissions will certainly reduce due to cleaner power structure. In 2060, as the thermal power is replaced by renewable energy, the total carbon emissions of Shanxi province will reduce by 43.39 % than reference scenario, while the carbon emissions of Shanxi province's power sector will reduce by 99.68 %. Meanwhile, due to the coal demand decreasing in the power sector, the carbon emissions in coal mining sector will also have a reducing of 3.42 %.

However, as shown in Figure 3, for the surrounding area and other provinces, the total carbon emissions will increase 1.77 % and 1.90 %, when Shanxi province's thermal power shifts to zero. Specially, the most influenced sector is coal mining sector, which will increase 5.35 % and 5.18 % carbon emissions in surrounding area and other provinces. This mainly results from the higher cost of Shanxi's electricity and energy. As the energy

exporting province, the higher cost of Shanxi province' energy will lead to more local production of surrounding area and other provinces.

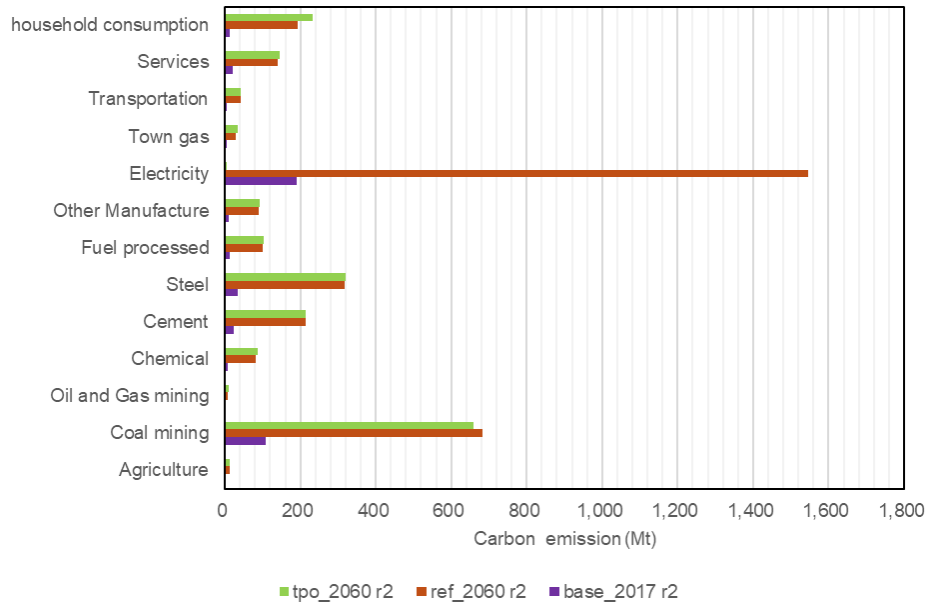

Figure 2: Carbon emissions of Shanxi province in each scenario

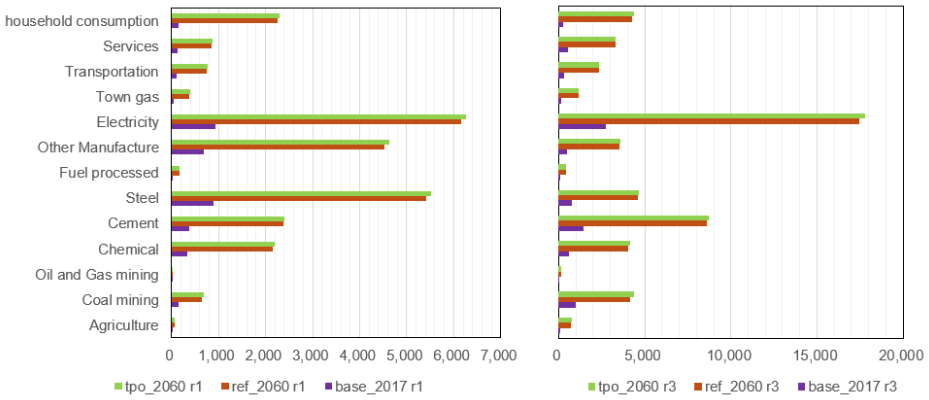

Figure 3: Carbon emissions of surrounding area and other provinces in each scenario

3.2 Economic effects

For the economic effects, the results indicates that the thermal power phasing out in Shanxi province will lead to an economic benefit as shown in Table 4.

The reason why the economy is increasing may be the capital input increasing of renewable energy. The introduction of renewable energy in Shanxi province's power sector requires more capital input, and the input from other sectors.

Table 4: GDP (Constant price with 2017, Billion RMB)

		R1	R2	R3
2017	Base	2,115,109	115,618	6,024,394
2060	Reference	16,248,041	1,124380	46,300,822
2060	TPO	16,256,503	1,131,845	46,322,543
Changing rate		0.052 %	0.664 %	0.047 %

3.3 Labor mobility

For the Labor input, because there is no changing on model input of labor input. The total labor input for each region is consistent between two scenarios and the labor will transfer among local sectors.
The Figure 4 shows that when the thermal power is phasing-out, the labor in Shanxi province will shift to other sectors from coal-related industries, such as coal mining, cement, steel, power sector and transportation. The labor loss in Shanxi province's power sector will be 8.30 % while the labor loss in coal mining sector will be 6.29 %. And the labor input will increase 3.75 % in agriculture, 1.69 % in oil and gas mining sector, 0.79 % in fuel processed sector, 12.69 % in town gas and 1.96 % in services sector.

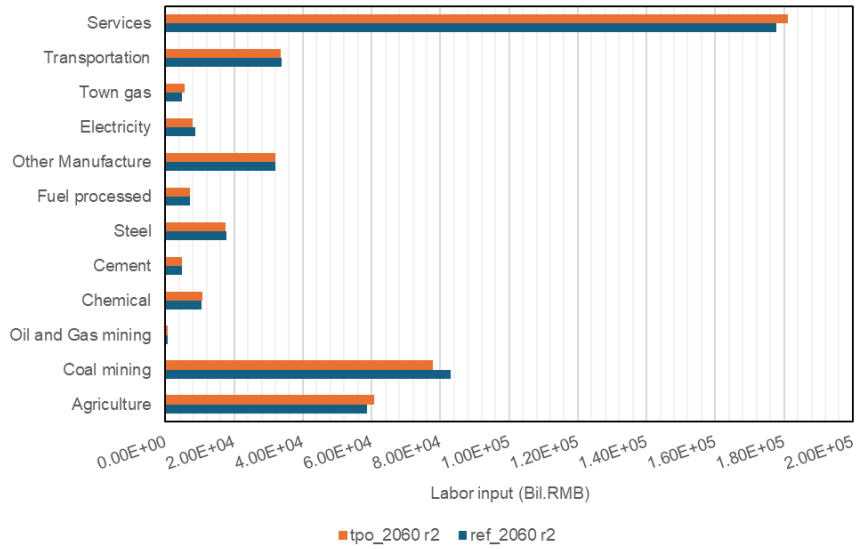

Figure 4: Labour mobility of Shanxi province in each scenario

However, as it shown in Figure 5, for the surrounding area and other provinces, the labor mobility direction is a little bit different. The labor in both regions prefer to transfer to energy sectors from cement, steel, and power sector. The lack of power and coal supplying from Shanxi province may lead them to search for their own basic energy industry.

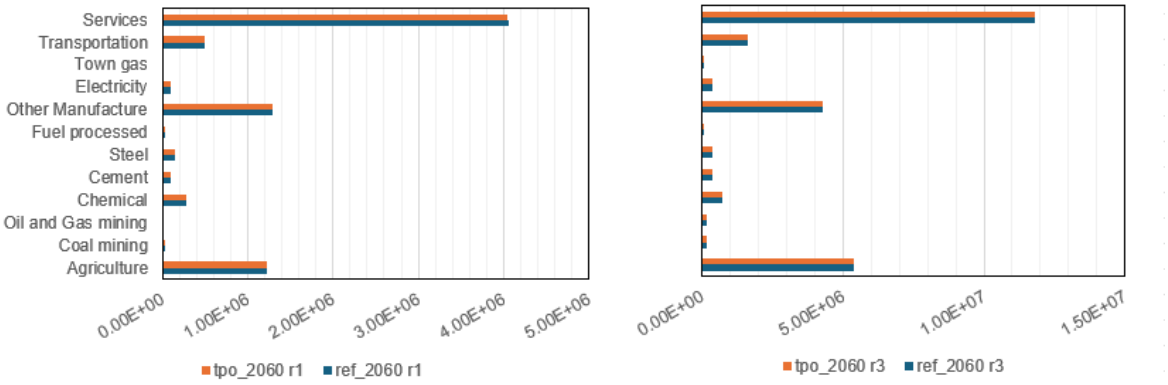

Figure 5: Labour mobility of surrounding area and other provinces in each scenario

4. Conclusions

As a coal-dependence province, the thermal power phasing-out in Shanxi province can significantly reduce the carbon emissions and affect the labour mobility between coal-related industries and other sectors.
However, from this research, it can be conceded that there are not only interdependencies between industries, but since Shanxi is a major coal producing and exporting province, surrounding provinces are also dependent on Shanxi's coal and power industries. After Shanxi Province's energy production and supply were affected, surrounding provinces would try to seek their own energy industry development.

So, when formulating policies, the interdependence among industries should be taken into account, and comprehensive policies should be formulated to promote the coordinated development of the overall economy. In this research, there are still some problems have not been considered. A dynamic model is required to construct more scenarios and set more reasonable parameters for the future assumption. And in this model, the labor and capital cannot flow among regions, which will be a limitation to deeper understand the impact of policies on labor mobility between provinces. If there will be some mobility between different regions, how to face this challenge for local government will also be a problem. A study tried to analyse the impact of carbon tax revenue recycling schemes on employment in Shanxi province by utilizing the CGE model to give suggestions on how to alleviate the employment with carbon. This will be a suggestion or direction for further study.

Nomenclature

xx0(r,i,j) – initial intermediate input of goods i in sector j of region r
ghga0(r,j) – activity related GHG emission from sector j of region r
x0(rr,i,r,j) – initial intermediate input of goods i of region rr in sector j of region r
va0(r,j) – initial total value added in sector j of region r
o0(r,j) – initial total produced goods in sector j of region r -
d0(r,i) – initial total supply in sector i of region r
ex0(r,i) – initial export in sector i of region rr_{in} – outer radius of a plain tube, m
chx0(r,i) – initial final consumption in sector i by household of region r
vae0(r,j) – initial total value added and energy in sector j of region r
ene0(r,j) – initial total energy composite in sector j of region r
ghge0(r,en,j) – GHG emission from sector j of region r
y0(r,i) – initial total domestic output in sector i of region r
im0(r,i) - initial import in sector i of region r
cap0(r,j) – initial capital input in sector j of region r
lab0(r,j) – initial labor input in sector j of region r

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