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Mining Industry's Energy and Carbon Performance Improvement in China: Evidence during 11th and 12th five-year plan

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ABSTRACT

Energy consumption of China's mining industry is larger than the total energy consumption of some European countries, such as the Netherlands and Spain. It is therefore significant to study the driving forces of the mining industry's energy and carbon performance. This paper adopts the non-radial directional distance function to calculate the energy and carbon performance of China's mining industry and uses metafrontier Malmquist index to disassemble the results into three components to analyze the driving forces of the mining industry's energy and carbon performance improvement during the 11th and 12th five-year plan. We found that the main forces that drive the energy and carbon performance improvement are catch-up effects and technical gap ratio change, but the innovation effect does not have obvious contribution to the improvement. As for policymakers, the government should support improving the technology progress of the mining sector, reduce surplus capacity, and open up the mineral market.

Keywords: China's mining industry; energy and carbon performance; efficiency change; best practice gap change; technological leadership

NONMENCLATURE

Abbreviations	
FYP	five-year plan
NDDF	non-radial directional distance function
ECPI	energy and carbon performance index
MNMECPI	metafrontier non-radial Malmquist energy and carbon performance index

1. INTRODUCTION

According to Karl, Arguez [1], the global surface temperature increases by 0.116 degrees centigrade every decade from 2000. Global warming will lead to climate change, the rise of sea level, and other serious consequences, which threaten the existence of the human race. In recent years, research and discourse on global climate change have become mainstream worldwide, and all the countries should take responsibility for the CO2 emission restriction, which undoubtedly brings enormous pressure on industry development in developing and developed countries. At the early stage of the 11th five-year plan (11th FYP) (2006-2010), China has been implementing many policies to save energy and cut down the carbon emission. During the 12th five-year plan (12th FYP) (2011-2015), the central government demanded that the energy intensity and CO2 emission must be greatly decreased, which meant to increase energy efficiency. Therefore, a lot of attention was paid to the high energy consumption industries' carbon emission [2-5]. Improving these industries' energy and carbon performance and achieving the CO2 emission reduction goal is always the primary consideration for the Chinese government. The mining industry is one of the basic industries in China which ensures energy security. Based on the 13th energy development FYP, in 2015, the 84.19% of primary energy consumption in China was produced locally. Therefore, the mining sector plays a significant role in China's whole industry.

However, as a traditional heavy industry, the amount of mining industry's energy consumption is huge. Based on CEIC global database, the energy consumption of mining sector in China is even bigger than the energy consumption of some European economies such as the Netherlands and Spain. Therefore, improving the energy and carbon performance of the mining industry has a significant effect on China's economy and environment.

Since the energy conservation and emission reduction policies were implemented since 2006, it has had a huge impact on the whole industry until now. As for the significant amount of energy consumption and carbon emission of the mining industry, questions need to be answered. First of all, did the energy and the carbon performance improve during the 11th and 12th FYP? Secondly, what are the main forces that improve the energy and carbon industry for different regions in China? Based on these questions, this paper uses the metafrontier non-radial Malmquist energy and carbon performance index (MNMECPI) to calculate the dynamic change of the mining industry's energy and carbon performance during the 11th and 12th FYP (2005-2015) and analyze the driving forces of improvement.

2. MATERIAL AND METHODS

Based on Zhang and Choi [6], we adopt the NDDF to benchmark the mining industry's energy and carbon performance in China and use the metafrontier Malmquist index to calculate the dynamic change, and the combined index, called metafrontier non-radial Malmquist energy and carbon performance index (MNMECPI). As for the contributions of our research, we analyze the dynamic change of the regional mining sector's energy and carbon performance in China with the provincial level panel data, which fills the gap in the existing literature. Furthermore, we decompose the MNMECPI into three components to analyze the driving forces for performance improvement.

3. THEORY/CALCULATION

. Chung, Fare [7] first adopted the DDF to measure environmental efficiency. The DDF can be defined as followed:

$$\vec{D}(K,L,E,Y,C;\mathrm{g}) = \sup\{\beta: ((K,L,E,Y,C) + g\cdot\beta)\epsilon R\} \qquad (1)$$

Where $\boldsymbol{g} = (\boldsymbol{g_K}, \boldsymbol{g_E}, \boldsymbol{g_L}, \boldsymbol{g_Y}, \boldsymbol{g_C})^{\boldsymbol{T}}$ means the direction of variables. $\boldsymbol{\beta} \geq \boldsymbol{0}$ is the slack vector of the variables. However, the DDF can only change the inputs and outputs in the same proportion. To benchmark the environmental performance, the non-radial directional distance function (NDDF) was created [8-10]. The formal definition of the NDDF was put forward by Zhou, Ang [11], which can be described as followed:

$$\overrightarrow{ND}(K,L,E,Y,C;\mathrm{g}) = \sup\{w^T\beta: ((K,L,E,Y,C) + diag(\beta)\cdot g)\epsilon T\} \qquad (2)$$

Where $\boldsymbol{w} = (\boldsymbol{w_K}, \boldsymbol{w_L}, \boldsymbol{w_E}, \boldsymbol{w_Y}, \boldsymbol{w_C})^{\boldsymbol{T}}$ means the weight given to the variables, and $\boldsymbol{g} = (\boldsymbol{g_K}, \boldsymbol{g_E}, \boldsymbol{g_L}, \boldsymbol{g_Y}, \boldsymbol{g_C})^{\boldsymbol{T}}$ shows the direction of variables. $\boldsymbol{\beta} = (\boldsymbol{\beta_K}, \boldsymbol{\beta_E}, \boldsymbol{\beta_L}, \boldsymbol{\beta_Y}, \boldsymbol{\beta_C})^{\boldsymbol{T}} \geq \boldsymbol{0}$ is the slack vector which is the ratio of the increase or reduction in the variables. Moreover, the diag(·) means the diagonalization of β. To benchmark pure energy and carbon performance, we define $\boldsymbol{w} = (\boldsymbol{0}, \boldsymbol{0}, \frac{\boldsymbol{1}}{\boldsymbol{3}}, \frac{\boldsymbol{1}}{\boldsymbol{3}}, \frac{\boldsymbol{1}}{\boldsymbol{3}})^{\boldsymbol{T}}$. We eliminate the weights for capital (K) and labor (L). Therefore, the weight of energy (E), yield (Y), and CO2 emission (C) are each 1/3. The directional vector can be defined as $\boldsymbol{g} = (\boldsymbol{0}, \boldsymbol{0}, -\boldsymbol{E}, \boldsymbol{Y}, -\boldsymbol{C})$. Therefore, the slack vector can be defined as $\boldsymbol{\beta} = (\boldsymbol{0}, \boldsymbol{0}, \boldsymbol{\beta_E}, \boldsymbol{\beta_Y}, \boldsymbol{\beta_C})^{\boldsymbol{T}} \geq \boldsymbol{0}$. The linear optimization of the NDDF can be described as followed:

$$\overrightarrow{ND}(K,E,L,Y,C;g) = \max w\beta_E + w\beta_Y + w\beta_C$$

$$\sum_{t=1}^{T}\sum_{n=1}^{N}\lambda_{nt}\,K_{nt} \leq K_{nt}$$

$$\sum_{t=1}^{T}\sum_{n=1}^{N}\lambda_{nt}\,L_{nt} \leq L_{nt}$$

$$\sum_{t=1}^{T}\sum_{n=1}^{N}\lambda_{nt}\,E_{nt} \leq E_{nt} - \beta_E g_E,$$

$$\sum_{t=1}^{T}\sum_{n=1}^{N}\lambda_{nt}\,Y_{nt} \leq Y_{nt} - \beta_Y g_Y,$$

$$\sum_{t=1}^{T}\sum_{n=1}^{N}\lambda_{nt}\,C_{nt} = C_{nt} - \beta_C g_C,$$

$$\beta_E, \beta_Y, \beta_C \geq 0, \qquad \lambda_{nt} \geq 0$$

$$n = 1,2,3,\ldots,N \quad t = 1,2,\ldots,T \qquad (3)$$

Under the condition that the capital (K) and the labor (L) are fixed, the optimization above can maximize yield (Y) and minimize CO2 emission (C) and energy (E). The weight vector $\boldsymbol{w}$ can describe the significance of minimum and maximum targets. The optimal solution of Eq. (3) is $\boldsymbol{\beta}^* = (\boldsymbol{0}, \boldsymbol{0}, \boldsymbol{\beta_E^*}, \boldsymbol{\beta_Y^*}, \boldsymbol{\beta_C^*})^{\boldsymbol{T}}$. Therefore, the energy and carbon performance index (ECPI) can be established as followed based on Zhou, Ang [11]:

$$\mathrm{ECPI} = \frac{\frac{1}{2}[(1-\beta_E^*)+(1-\beta_C^*)]}{1+\beta_Y^*} \qquad (4)$$

Furthermore, the MNMECPI can be established according to the global production technology set:

$$MNMECPI(K^S, L^S, E^S, Y^S, C^S) = \frac{ECPI^G(K^{t+1}, L^{t+1}, E^{t+1}, Y^{t+1}, C^{t+1})}{ECPI^G(K^t, L^t, E^t, Y^t, C^t)} \qquad (5)$$

In terms of the Eq. (5), MNMECPI indicates a dynamic change from period t to period t+1 of ECPI. Furthermore, according to Oh and Lee [12], MNMECPI can be disassembled into three parts:

$$MNMECPI(K^S, L^S, E^S, Y^S, C^S) = \frac{ECPI^G(.^{t+1})}{ECPI^G(.^t)}$$
$$= \left[\frac{ECPI^C(.^{t+1})}{ECPI^C(.^t)}\right] * \left[\frac{ECPI^I(.^{t+1})/ECPI^C(.^{t+1})}{ECPI^I(.^t)/ECPI^C(.^t)}\right] * \left[\frac{ECPI^G(.^{t+1})/ECPI^I(.^{t+1})}{ECPI^G(.^t)/ECPI^I(.^t)}\right]$$
$$= \left[\frac{TE^{t+1}}{TE^t}\right]\left[\frac{BPR^{t+1}}{BPR^t}\right]\left[\frac{TGR^{t+1}}{TGR^t}\right] = EC \cdot BPC \cdot TGC$$

(6)

4. RESULTS

4.1 Energy and carbon performance index (ECPI)

According to Table 1, the results show that the mining industry's ECPI is relatively low, and there is significant energy conservation potentiality for the mining industry. On the other hand, the regional distinction still exists. The ECPI in eastern China is the largest among all regions, and the ECPI in central China and western China are much lower than that in eastern China. The mining industry's energy and carbon performance in the eastern, central, and western China increased at an average rate of 2.4%, 1.0% and 1.6% per year respectively during the 11th FYP and increased by 1.1%, 2.7% and 1.7% per year respectively during the 12th FYP, which means the energy and carbon performance improved in the three regions during these two periods.

Table 1. ECPI estimation results of China's mining industry from 2005 to 2016

Regions	Maximum	Minimum	Average
Eastern China	0.456	0.346	0.400
Central China	0.166	0.128	0.148
Western China	0.204	0.130	0.165
China	0.456	0.128	0.238

4.2 Dynamic change of ECPI

Fig. 2 shows the MNMECPI values of three regions during two periods. To ensure Eq. (6) valid, we use geometric means to represent the average value of regional MNMECPI and its components. Generally, the MNMECPI values of all regions were bigger than 1 during two periods, which indicates that the ECPI of the mining sector in three regions all increased during the two FYPs. As for Eastern China, the average MEMECPI values were 1.024 and 1.011 respectively in two periods, which indicates the average growth rate of ECPI was 2.4% annually during the 11th FYP and 1.1% annually during the 12th FYP. The MNMECPI values in central China were 1.010 and 1.027 for the two periods, which means the ECPI in central China increased by 1.0% annually during the 11th FYP and increased by 2.7% annually during the 12th FYP. The MNMECPI values in western China during these two periods were relatively similar, and the growth rates of the ECPI were 1.6% and 1.7% respectively. Among the three regions, the growth rate of the mining sector's ECPI in eastern China is the highest during the 11th FYP. During the 12th FYP, central China had the highest growth rate, while eastern China is the lowest. Though the mining sector's ECPI is the highest in eastern China depending on the advantages of technology and location, central and western China will have higher growth rates for the mining sector's energy and carbon performance with the development center of the mining industry transferred to the central and western China.

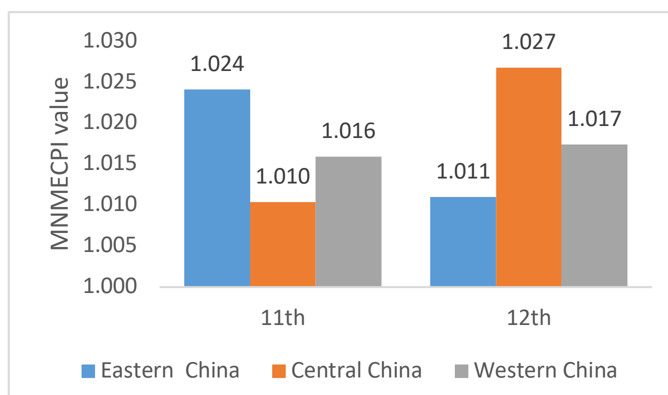

Fig.2 MNMECPI values of the mining industry in three regions

4.3 Decompositions of metafrontier non-radial Malmquist energy and carbon performance index (MNMECPI)

Based on Fig.3, in eastern China, the EC index was 1.056 during the 11th FYP, which means the energy and carbon efficiency of the mining sector in eastern China increased 5.6% annually. The EC index in eastern China was 1.015 during the 12th FYP, which means the energy and carbon efficiency in eastern China increased by 1.5% annually. In central China, the mining industry's energy and carbon efficiency decreased by 5.0% per year during the 11th FYP and increased by 10.1% per year during the 12th FYP. In western China, the mining sector's energy and carbon efficiency increased by 1.2% per year during the 11th FYP and increased by 17.6% per year during the 12th FYP.

Eastern China and western China's mining industry both showed a catch-up effect during the 11th FYP except for the mining sector in central China. During the 12th FYP, all regions showed catch-up effects, which is one of the factors that drive energy and carbon performance improves.

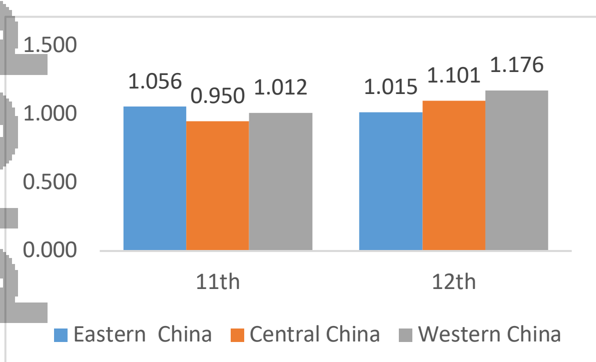

Fig. 3. EC values of the mining industry in three regions

Based on Fig.4, the BPC index values in eastern China were 0.956 and 0.999 on average during these two periods, which means the technical change of the mining sector decreased by 4.4% per year during the 11th FYP and decreased by 0.1% per year during the 12th FYP. The technical change of the mining sector in central China decreased by 0.2% annually during the 11th FYP and decreased by 8.9% annually during the 12th FYP. The technical change of the mining sector in western China decreased by 9.0% annually during the 11th FYP and decreased by 1.1% annually during the 12th FYP. The mining industry in the three regions didn't show any innovation effect in these two periods, which means their technology regressed.

Althought the environmental regulation can improve the energy intensity in most case [13]. Based on Zhang and Choi [6], the strong regulation for carbon reduction can harm the innovation because the costs of regulation are high which squeezes the funding of innovation. Since 2006, China's government has been implementing a series of policies to restrict energy consumption and CO2 emission. Ju, Zhou [14] measured kinds of environmental regulation intensity and green total factor productivity (GTFP) of 37 China's industries based on the panel data from 2003 to 2015. They found that under the intensity of existing mandatory control environmental regulation (MCR), the GTFPs of heavy polluting industries which include most of mining industry are the highest. If the intensity of MCR rises, the GTFPs of heavy polluting industries will decrease. Besides, according to Ouyang, Li [15], the environmental regulation is not conductive to the innovation of state-owned companies because of the high costs. The mining industry is the main supervision sector of environmental protection department because of the high pollution. The high intensity of MCR will add the cost of pollution control and crowd out the cost of technological innovation, which may cause the technical regress.

Furthermore, since the financial crisis in 2012, China's economy has stepped into the "new normal" phase which caused the mining industry market to being sluggish. Consumption of bulk mineral resources fell and the investment of the mining industry was relatively low. The research and development of the mining industry could not be promoted without market and investment. Most mining corporations could not afford new technologies but only used existing equipment to maintain daily operation, thus causing the lag of the mining sector's technological level.

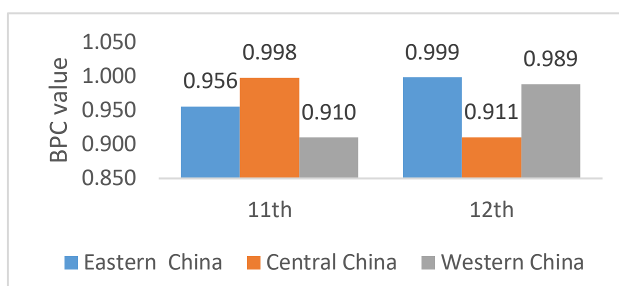

Fig. 4. BPC values of the mining industry in three regions

Based on Fig.5, the values of the TGC index in eastern China were 1.015 and 0.997 on average during the two periods, which means the technical gap ratio change of the mining sector in eastern China increased by 1.5% per year during the 11th FYP and decreased by 0.3% per year during the 12th FYP. The technical gap ratio change in central China increased by 6.5% per year during the 11th FYP and increased by 2.5% during the 12th FYP. In western China, the technical gap ratio change increased by 10.3% during the 11th FYP but decreased by 12.5% during the 12th FYP.

The technical gap becomes narrow and DMU catch up with the contemporaneous production technology frontier which does not only occur under the situation that the technological progress, but can also happen when technology regresses. This can be explained as when the contemporaneous production technology frontier degenerates, the degeneration speed of the DMU is slower than that of the contemporaneous frontier. The mining sector in all regions had a technological leadership effect during the 11th FYP because the values of the TGC index in all regions are bigger than 1. However, during the 12th FYP, only the mining industry in central China showed the technological leadership effect. Based on the results of the BPC index, it is obvious that the technology regressed during the two periods. We can conclude that even though the technology deteriorated during the sample period, the degeneration speed of technological levels of the mining sector in all the region was slower than that of the contemporaneous frontier technology degeneration during the 11th FYP. The impact of technical regress appeared during the 12th FYP which is that the technical gap increased in the eastern and western regions.

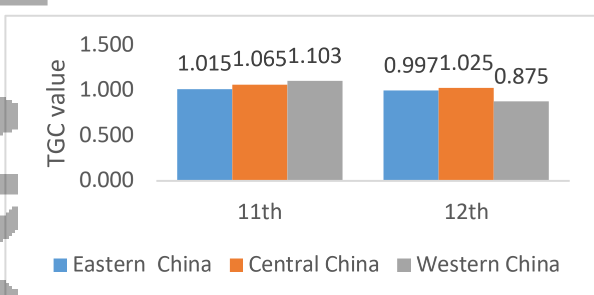

Fig. 5. TGC values of the mining industry in three regions

5. DISCUSSION

Given China's resource endowment, the output of the coal industry always accounts for a large proportion of China's mining industry. From 2009 to 2012, the output of the coal industry accounted for 50% of the mining sector’s total output, and the proportion decreased after 2012. In 2016, the output of the coal industry accounted for 44.18% of the mining sector’s output, while the proportion of other subsectors accounted for 12% to 15%. China’s mining industry is dominated by the coal industry.

The geographical distribution of China’s coal resources is unbalanced. The coal resources of Shanxi, Inner Mongolia, Shaanxi, Xinjiang, Guizhou, and Ningxia account for most of China's coal reserves, which mainly concentrate in the central and western regions.

Since 2014, the government has implemented many measures to resolve the overcapacity of coal and steel. In 2016, the central government promoted the structural reform of the supply side to control the exploitation of coal and demand the key large coal bases take the dominant position of the total coal production capacity. In addition to removing excess capacity, the coal industry gradually concentrated in Shanxi, Shaanxi, and Inner Mongolia with excellent resource endowment, which has a positive impact on energy and carbon performance in central and western China. Based on Fig.2, during the 12th FYP, the values of the MNMECPI index in central and western China were both higher than that of eastern China, which means the energy and carbon performance of the mining sector in the central and western region grew faster than that of the eastern region. Therefore, removing excess capacity and giving priority to large coal bases are conductive to improve the energy efficiency of the mining sector.

6. CONCLUSIONS

Perfecting the energy and carbon performance of China’s mining industry has a significant influence on carbon emission reduction and energy conservation. In this paper, we use the NDDF to calculate the ECPI of China's mining industry and use the MNMECPI to calculate the dynamic change of the energy and carbon performance during the 11th and the 12th FYP. Furthermore, we decompose the MNMECPI into three components to analyze the main driving forces for the improvement of energy and carbon performance.

The results show that the mining industry’s ECPI is relatively low, and there is significant energy conservation potentiality for the mining industry. On the other hand, the regional distinction still exists. The ECPI in eastern China is the largest among all regions, and the ECPI in central China and western China are much lower than that in eastern China. The mining industry's energy and carbon performance in the eastern, central, and western China increased at an average rate of 2.4%, 1.0% and 1.6% per year respectively during the 11th FYP and increased by 1.1%, 2.7% and 1.7% per year respectively during the 12th FYP, which means the energy and carbon performance improved in the three regions during these two periods.

The decomposition components of the MNMECPI of the mining industry are EC index, BPC index, and TGC index. The EC index and TGC index are greater than 1 in eastern China during the 11th FYP, which means the driving forces of energy and carbon performance improvement showed a catch-up effect and technological leadership. Only the EC index in eastern China was greater than 1 during the 12th FYP, meaning that only the catch-up effect drove the energy and carbon performance improvement. Technological leadership is a driving force in central China during the 11th FYP. The catch-up effect and technological leadership both drove the energy and carbon performance improvement in central China during the 12th FYP. In western China, the catch-up effect and technological leadership were the driving forces for energy and carbon performance of the mining sector during the 11th FYP, and only the catch-up effect is the driving force during the 12th FYP.

The mining sector's energy and carbon performance benchmarked by the NDDF only represents the relative distance between observation and technology frontier. If technology regresses, it is still possible that the energy and carbon performance increase. According to the results, although the energy and carbon performance of the mining sector in the three regions improved during the two periods, the driving forces were either catch-up effect or technological leadership in most cases, the innovation effect did not contribute to the improvement, which means the technology frontier deteriorated. Without the innovation effect, the improvement of energy and carbon performance cannot be sustainable.

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