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Modeling China's interprovincial coal transportation under low carbon transition

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HIGHLIGHTS

- A 30-province energy system optimization model (China TIMES-30P) is developed.
- Coal transportation and emissions are explored under the NDC and 2 degrees targets.
- Low carbon transition will reduce coal transportation and freight turnover.
- The overall coal transfer pattern will be simplified and concentrated in the future.
- Corresponding emissions will be further reduced owing to change in power structure.

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ABSTRACT

Coal transportation plays an important role in the coordinated development of China's provinces. To analyze changes in China's interprovincial coal transportation and corresponding emissions under China's Nationally Determined Contribution (NDC) and Well Below 2 degrees target, this study develops a 30-province energy system optimization model (China TIMES-30P) to simulate three low carbon scenarios, including PEAK2030 (Emissions peak at 2030), PEAKA (Emissions peak before 2030) and WBD2 (Well below 2 degrees). The low carbon development will lead to the reduction of coal transportation to 1114,728 and 653 Mtce in 2050 (48%, 66% and 69% lower than the reference scenario) under the PEAK2030, PEAKA and WBD2 scenarios. Meanwhile, the overall coal transportation pattern will be simplified and concentrated. These will cause the decrease of the corresponding freight turnover to 1337, 887,787 billion tkm in 2050 (44%, 63%, 67% lower than the reference) under the PEAK2030, PEAKA and WBD2 scenarios, respectively. Moreover, low carbon transition will also promote the transformation of power generation structure, contributing to the drop of the emission per unit of freight turnover of coal transportation to 3.00, 1.61, 0.52 kt CO_2/btkm in 2050 under the PEAK2030, PEAKA and WBD2 scenarios. Owing to the decrease of coal transportation amount, transportation distance and the emission coefficients of coal transportation, cumulative emissions from coal transportation for the period 2010 to 2050 are estimated to be 28%, 48% and 64% lower than the reference scenario in the PEAK2030, PEAKA and WBD2, respectively.

1. Introduction

1.1. Insufficient coal transportation capacity

Coal, accounting for 64% of total energy consumption in 2015, is China's major energy source and will continue to play an important role in China's energy system for the foreseeable future [1]. The separation between coal production and consumption centers has given rise to the North–South and West–East coal transportation patterns. China's three western provinces (Shanxi, Shaanxi and Inner Mongolia) contain 63% of the national coal reserves while 55% of the country's GDP is produced in the Eastern coastal area, which includes JJJ Region (Beijing, Tianjin and Hebei) and the Coastal region [2]. Thus, coal is currently transported from Shanxi and the Northwest region to JJJ, the Coastal and Middle regions, as shown in Fig. 1.

The Chinese government has established detailed plans to transport energy from the areas with abundant resources endowment to the Eastern coastal area. The 13th 5-year plan highlights the cooperative strategy between the Western, Northeastern, Eastern coastal and Central areas. The Western part of the country is set to promote the use of oil, gas and renewable energy resources, establish energy bases and develop energy-related industries that support future national energy

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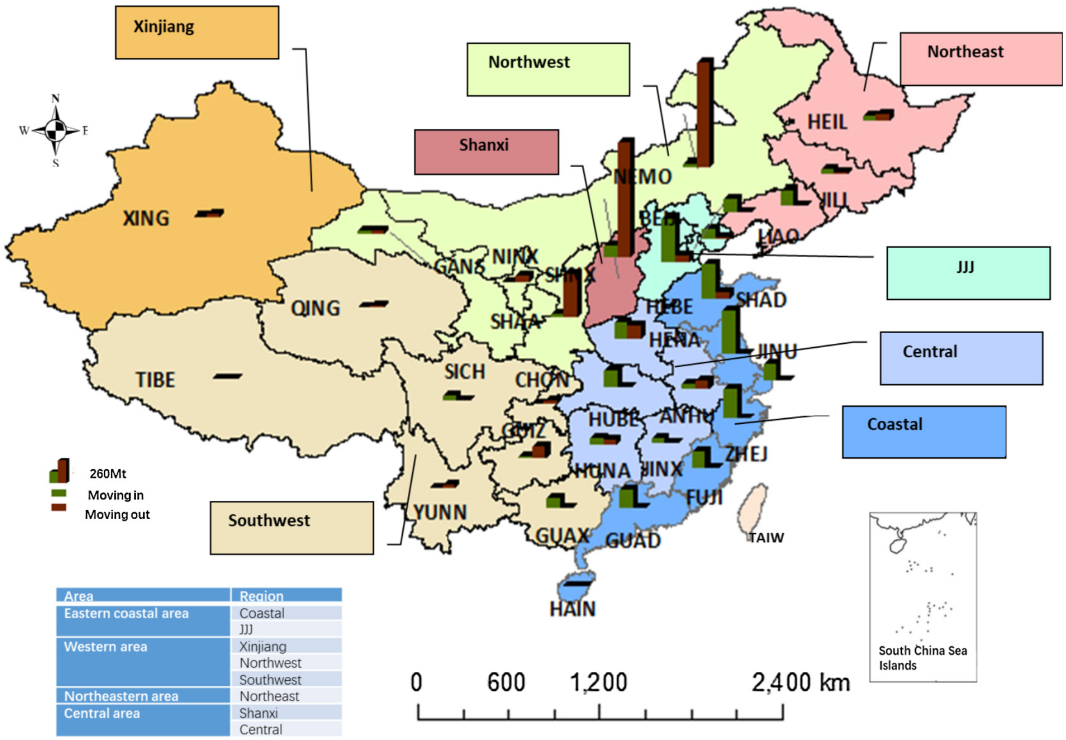

Area	Region
Eastern coastal area	Coastal
	JJJ
Western area	Xinjiang
	Northwest
	Southwest
Northeastern area	Northeast
Central area	Shanxi
	Central

Fig. 1. Coal transportation in 2015 and regional definition [1–5].

supply while the energy and material industries will be developed in the Central area and the petrochemical industry will be revitalized in the Northeastern area [3–6].

Improving the national coal transportation capacity is key to ensuring the provincial coordinated development. China has 68,000 km of railway, accounting for 8% of the world's total, and achieves 24% of the total amount of freight transportation volume, meaning China's average loading is three times the global average [7]. Railway capacity for coal transportation will increasingly be squeezed by passenger transportation during the passenger transportation peak period. As the demand of railway freight turnover has increased, the satisfaction rate has gradually decreased. The satisfaction rate was 60%–70% during the 12th 5-year period, showing that the lack of railway transportation capacity was restricting increases in coal transportation [8–10]. The 13th 5-year development plan for the railway notes that during the 13th period the freight turnover capacity must satisfy the basic interregional transportation of energy and resources. To realize this target requires rational planning of railway construction to meet future development trends [11].

1.2. Literature review

Related research interests included the mode selection and route optimization of coal transportation system in the other countries. Satar applied a generalized shipper transportation cost function to show the optimal choice of all major transportation modes to achieve allocative efficiency with respect to market prices in the US [12]. Lawrie examined the cost curves of different transport options to identify the transport distance when economic advantage switched from one transport mode to the other, in which rail will be an optimal option for distances larger than 30 km in eastern Australia [13]. Evija adopted Multi Criteria Decision Analysis to access the potential of multimodal coal transportation in Indonesia based on a financial and qualitative comparison of different transportation modes [14]. Although these researches provided an insight about coal transportation option selection, few of them considered the impact of change in the supply and demand center. Except that the United States' vast territory and separation of coal production and consumption center offer similarities to China [15,16], the geographical conditions and coal transportation demand in other countries is quite different from China. Moreover, China's large population and passenger turnover lead to much more pressure on the freight turnover and interprovincial coal transportation. A number of studies focusing on improving coal transportation pattern in China have yielded good results. Liu used Gini Coefficient to study changes in the concentration of inter-provincial coal flow in China from 1985 to 2010 and the Zipf law to further explore the rank-size distribution of coal flow [17]. They pointed out that the output is shifting to Western China while the input is shifting to Southeastern China. Wang adopted the gravity model and space tracking maps to describe the evolution of spatial pattern of source-sink regions of China's Coal Resources Flow in 1991–2010 [18]. Field theory had also been applied to study the regularity and pattern of China's coal flow field [19–22]. Lv and Liu used the complex network method and empirical analysis to evaluate the network of interregional coal transportation [23,24]. Gao analyzed the situation of China's coal resource distribution, production and consumption by applying the Lorenz curve and pointed out the change of coal transportation path in the future by tracking the historical pattern [25]. In the context of climate change, researchers also paid attention to the emissions in the transportation sector [26,27], but few of them explored emissions caused in the coal transportation system in the long run. Lv measured the provincial CO_2 emissions by calculating the fixed emission coefficients and analyzed the improvement potential in 2014 by using a least emission function [28].

However, these researches separated the coal transportation system from the whole energy system, which failed to reflect the interaction in the different provinces and different sectors to a certain extent. This paper develops a 30-province China TIMES (The Integrated MARKAL-EFOM System model) model, China TIMES-30P, to investigate changes