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Toward carbon neutrality: The transition of the coal industrial chain in China

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In order to achieve China's ambitious carbon neutrality target, coal industry should play a key role in mitigating its carbon emission and ensuring energy supply. Therefore, it is urgent for this coal industry to realize its transition toward low carbon development. This study investigates the status and policy options of China's coal industry by considering the entire coal industrial chain, covering coal production, delivery, and consumption so that key challenges involving clean and efficient utilization and stable coal supply can be identified. Further, policy recommendations for the transition of this coal industrial chain toward low carbon development are proposed, including the implementation of appropriate national policies, research and development (R&D) efforts, the application of economic instruments and capacity building activities.

KEYWORDS

coal industrial chain, energy transition, clean and efficient utilization, energy security, carbon neutrality

Introduction

In 2020, China pledged to peak its carbon emission by 2030 and achieve carbon neutrality by 2060 (The Central People's Government of the People's Republic of China, 2020). It is therefore crucial to achieve energy transition toward renewable and clean energy (Zhang and Chen, 2022). Meanwhile, it is necessary to gradually phase out the use of coal. China has made great efforts to promote clean and renewable energy during the past few decades. However, due to its sizeable domestic coal endowments, coal consumption is still dominated in China, with a 57% share in total primary energy consumption in 2020 (Figure 1). This reflects its vital role in maintaining China's economic development and energy security (Zhang et al., 2017). As shown in Figure 1, domestic coal production and consumption volumes had been high from 2011 to 2020, with figures of 3,902 million tons (Mt) and 4,040 Mt in 2020, respectively. In addition, China also imported a considerable amount of coal to meet its domestic demand. Such a figure reached 303 Mt in 2020.

Such high coal consumption indicates a serious challenge for China to achieve its ambitious climate targets since coal combustion generates significant carbon dioxide

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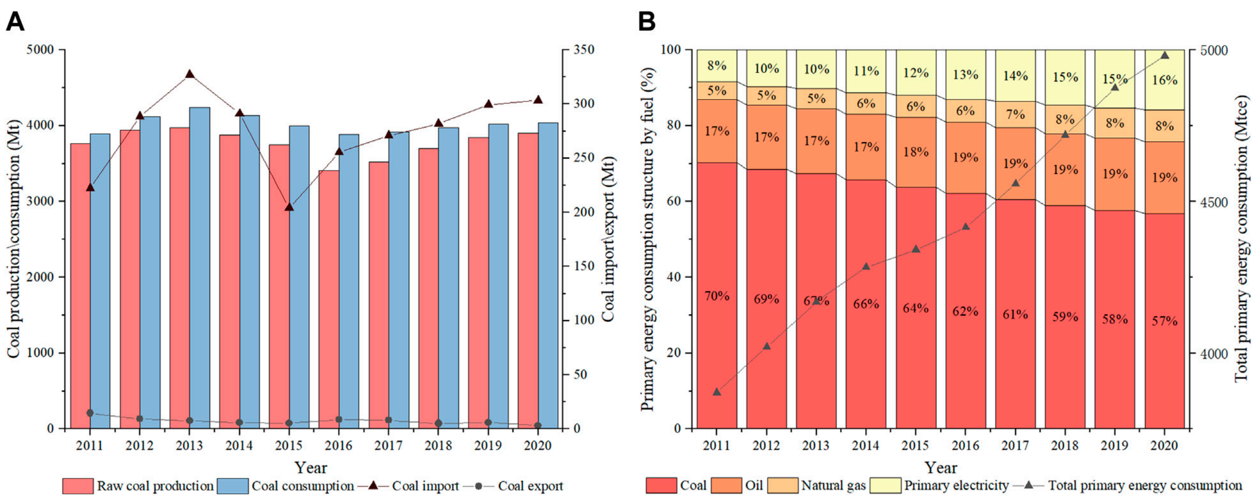

FIGURE 1
Coal production, consumption, and trade in China from 2011 to 2020 **(A)**; Primary energy consumption and its structure in China from 2011 to 2020 **(B)**. Note: 1. Mt refers to megatons, namely million tons, and Mtce refers to millions of tons of coal equivalents. 2. Primary electricity consists of electricity generated from hydropower, nuclear power, wind power, solar power, etc. Source: National Bureau of Statistics of the People's Republic of China, 2015–2022.

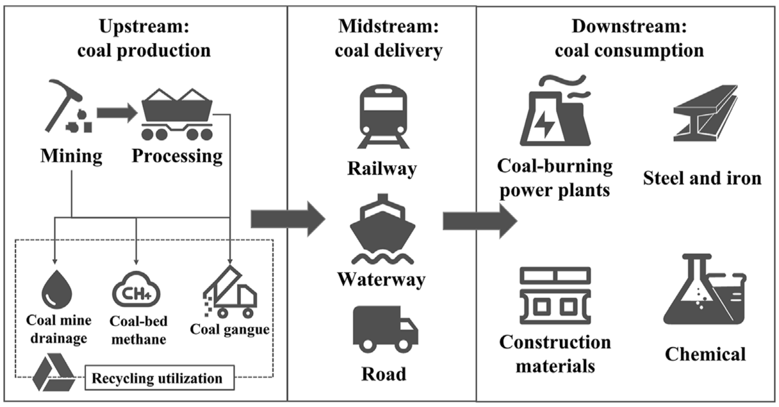

FIGURE 2
Coal industrial chain in China.

(CO_2) emissions. According to the latest CO_2 emissions inventory released by China Emission Accounts and Data sets (CEADs), coal-generated emissions accounted for 75.4% of China's total carbon emissions in 2019 (Guan et al., 2021). Moreover, coal mining, production, processing, delivery, and final consumption generate severe air pollutants and other ecological problems (Jia and Lin, 2021). Under such circumstances, it is critical to transit the entire coal industrial chain so that co-benefits can be obtained, covering economic development, energy security, carbon emission mitigation, and environmental protection.

Regarding the transition of the entire coal industrial chain, studies have been conducted to assess the energy efficiency and carbon emissions efficiency of coal throughout its life cycle, from its upstream suppliers to the final consumers (Wang et al., 2019b; Wang et al., 2021a; Sun et al., 2022). These studies provide policy implications for achieving clean and efficient coal production and utilization. For instance, several studies focused on assessing

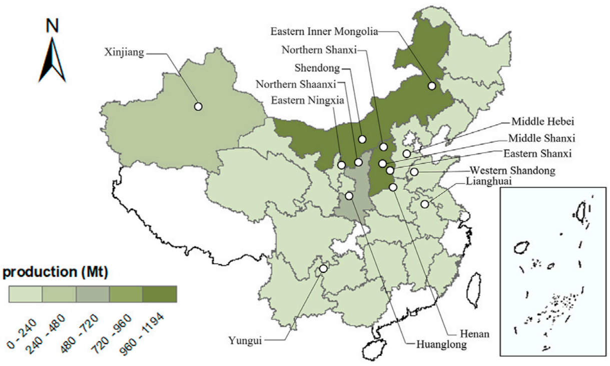

FIGURE 3
China's 14 large coal bases and corresponding production amounts in 2021.

transition policies from a coal industrial chain perspective (Liu et al., 2017; Zhao et al., 2021). More policy studies focused on individual stages of the coal industrial chain, such as from the coal production perspective or from the coal consumption perspective (Spencer et al., 2018; Zhang et al., 2021; Jia et al., 2022). However, although some studies considered carbon neutrality targets, a comprehensive and industrial chain stage-specific analysis is still lacking. Therefore, this study investigates how China's coal industrial chain can achieve such a transition toward low carbon development, covering all the stages along its upstream, midstream, and downstream (Figure 2). We expect that valuable policy insights can be provided to those policymakers and stakeholders so that appropriate transition measures can be implemented.

The remainder of this study is organized as below. *The Status Quo of China's Coal Industrial Chain* overview China's coal industry; *Transition Policies in China's Coal Industrial Chain Under Carbon Neutrality* analyzes China's policy efforts related to the coal industry under the national energy transition contexts and discusses the challenges faced by this coal industrial chain; *Policy Recommendations* proposes policy recommendations to facilitate the transition of China's coal industrial chain toward low carbon development; *Conclusion* draws research conclusion.

The status quo of China's coal industrial chain

In terms of the upstream of this coal industrial chain, China has built 14 large coal bases, which locate in Shandong, Shanxi, Inner Mongolia, Yunnan, Guizhou, Henan, Middle Hebei, Ningxia, Shaanxi, and Xinjiang (The State Council of the People's Republic of China, 2014). These provinces are mainly from northern China and southwest China and have rich coal reserves, reflecting the uneven distribution of coal resources (Figure 3). During the 13th Five-Year Plan (2016–2020), the Chinese government had optimized coal production structure, aiming to promote intensive, efficient, and clean coal development. By the end of 2021, about 5,500 small and medium sized coal mines were shut down, most of which do not have advanced coal production technologies and equipment (China National Coal Association, 2022). To date, large coal production bases dominate China's coal production. They can gain their competitive advantages due to their large scale, safer operation, more advanced technologies, and more efficient equipment. As shown in Figure 3, according to the National Bureau of Statistics (2022), China produced 4,071 Mt of raw coal in 2021. The total coal production reached 3,496 Mt in the top six coal production provinces (Shanxi, Inner Mongolia, Shaanxi, Xinjiang, Guizhou, and Anhui), accounting for 85.9% of the national total.

Unfortunately, the final users of such coal are mainly those coastal regions, leading to a huge need for long-distance coal delivery. Railway and road transport are two major coal delivery modes, although railway is more suitable for longer distance delivery while the road is more suitable for shorter distance delivery. In 2021, more than 2,580 Mt of coal were delivered by railways. In addition, shipping is also functioning, especially in the north Bohai sea region, to meet the coal demand of several coastal provinces (Mou and Li, 2012). More than 800 Mt of coal were delivered in this region in 2021 (China National Coal Association, 2022). In summary, these coal delivery businesses are major middle stream enterprises in the coal industrial chain.

In terms of final coal users, namely those downstream industries along this coal industrial chain, coal-burning power plants, steel and iron firms, construction materials firms, and chemical firms are four primary coal-consuming industries, together accounting for over 80% of the national coal consumption. As the largest coal-consuming industry, coal-burning power plants accounted for 53% of the national coal consumption, while sectors of steel and iron, construction materials, and chemical industry accounted for 18%, 14%, and 3% of the national total, respectively (Wu et al., 2017). In order to respond to both climate change challenges and severe air pollution, the Chinese government has made great efforts to promote technological upgrades and energy structure adjustments in these sectors, leading to that more than 85% of the national coal consumption has been utilized more efficiently. By the end of 2020, the total installed capacity of coal-burning power plants with ultra-low emission standards reached 9.5×10^8 kW, accounting for about 88% of the national total (China Electricity Council, 2021). China has now established the world's most extensive ultra-low-emission coal power supply system.

TABLE 1 Key policies and guidelines on the transition of the coal industrial chain.

Issued time	Code	Name	Key areas related to the coal industrial chain
2016–12	P01	The 13th five-year plan for the development of the coal industry	Supply-side reforms; intensive, safe, efficient, and green development
2021–11	P02	The 14th five-year plan for energy technology innovation	Green and intelligent mining; clean and efficient conversion; advanced coal-fired power generation technology
2022–1	P03	The 14th five-year plan for the modern energy system	Energy supply security
2021–6	G01	Guiding opinions on high-quality development of coal industry during the 14th five-year plan period	High-quality development; safe and green development; clean and low-carbon utilization; modern industry chain

Transition policies in China's coal industrial chain under carbon neutrality

In 2021, the Chinese government issued a national policy on achieving carbon peak and carbon neutrality targets. This policy aims to optimize energy structure by setting up a 25% share of non-fossil energy consumption in the total energy consumption in 2030 and an 80% share in 2060, respectively (The Central People's Government of the People's Republic of China, 2021). Since coal will still dominate national energy consumption in the near and medium term, it is urgent for the Chinese government to promote the clean and efficient use of coal while ensuring energy security. Table 1 lists all the relevant national policies and guidelines for facilitating the transition of this coal industrial chain.

Upstream industry: Coal production

For all the upstream enterprises, carbon emissions are generated from three sources: embodied emissions from energy consumption of related operations (such as electricity usage, fuels for equipment, etc.), gas escaping, and spontaneous combustion of raw coal and coal gangue (Wang et al., 2018b). Thus, necessary actions should be taken to mitigate such emissions.

Currently, the Chinese government is actively promoting green coal mining and washing, ecological compensation, and coal production structure adjustment. These measures are reflected in the 13th Five-Year Plan (2016–2020) for the development of the coal industry (P01). Also, circular economy has become a national development strategy, in which the comprehensive utilization of coal gangue and the collection and reuse of coalbed methane are included. This policy also encourages the application of ecological compensation so that necessary funds can be obtained for recovering local ecosystem functions. Similarly, the 14th Five-Year Plan (2021–2025) for energy technology innovation (P02) proposes key technological innovations for green and efficient coal development and utilization. In addition, both P01 and P02 support optimizing the coal production structure toward low carbon development.

However, several challenges exist and should be addressed. First, with large-scaled coal mining for decades, most available coal reserves are now low graded, indicating great technological difficulties, higher costs, and more serious environmental impacts (Li, 2021). Also, although most small and medium sized coal mines are gradually being phased out, some of them are still operating with their inefficient equipment and backward technologies, leading to higher energy consumption and serious impacts to local environment. Third, China has relied on importing coal from other countries during the recent years. However, coal price in the international markets varies significantly. In addition, international coal delivery is facing uncertainties due to COVID-19 and other geopolitical issues, leading to an unstable coal supply. Besides, the coal-washing process is both energy and emission intensive. Many coal washing firms do not have advanced coal washing technologies and equipment, leading to serious emissions and higher energy consumption.

Midstream industry: Coal delivery

The demand for coal is increasing, which results in more delivery needs. Among the three major coal delivery modes, both railway and waterway are more environmentally friendly due to their lower energy consumption and corresponding emissions intensities (Kaack et al., 2018). Therefore, a seamless connection of railway-waterway was proposed as one preferable mode for coal delivery in the 13th Five-Year Plan (2016–2020) for the development of the coal industry (P01). Necessary infrastructure (such as coal piling stations, distribution service centers, information centers, etc.) should be constructed to facilitate such connections, as well as those connections of road-railway and road-waterway so that final coal users can easily get such coal (He et al., 2017). Moreover, advanced information and communications technologies (ICT) are useful to promote such connections, such as the

Internet of Things and Cloud Computing, which were supported in both the 13th Five-Year Plan (2016–2020) for the development of the coal industry (P01) and the 14th Five-Year Plan for the modern energy system (P03). Unfortunately, none of these national policies encourage the promotion of low carbon vehicles such as electric or hydrogen vehicles. The main reason is that technologies for such new energy vehicles are still in their early stages, and corresponding purchasing and operation costs are also high.

From a spacial perspective, since China's major coal production bases are concentrated in northwest China (Shanxi, Shaanxi, Inner Mongolia, and Xinjiang) and major coal users are those eastern provinces, demand for long distance coal delivery is huge. Fortunately, with the increasing investment on transportation infrastructure, China's national railway network has been extensively expanded, which can facilitate coal delivery through railways. However, most railway stations locate in the urban centers and are away from those final coal users, such as coal-burning power plants and iron/steel plants. These final users have to transfer such coal to their destinations by heavy trucks, leading to that many coal users still prefer to choose road delivery due to its convenience. Furthermore, the overall delivery capacities of both railway and waterway systems are limited and cannot meet with the increasing coal demands, especially during peak periods.

Downstream industry: Coal consumption

The final coal consumption occurs in those final coal users. They are the most significant contributors to carbon emissions along China's coal industrial chain (Wang et al., 2021a). The total carbon emission from coal-burning power plants is the largest among all the industrial sectors, accounting for almost 50% of the national total (Wang et al., 2021b).

National policies on these downstream enterprises mainly focus on technology upgrades. For instance, the 13th Five-Year Plan (2016–2020) for the development of the coal industry (P01) required all the coal-burning power plants to retrofit their production facilities to achieve ultra-low emissions. Similarly, the 14th Five-Year Plan for the modern energy system (P03) required rational construction and flexible retrofit of coal-burning power plants. In terms of other coal-consuming industries, such as steel/iron, construction materials, and chemical industry, the 13th Five-Year Plan (2016–2020) for the development of the coal industry (P01) required that these enterprises should strictly follow national energy conservation standards and environmental emissions standards, promote the cascade utilization of coal, and improve energy efficiency and resource utilization efficiency by fully engaging in circular economy. Also, both the 13th Five-Year Plan (2016–2020) for the development of the coal industry (P01) and the 14th Five-Year Plan for the modern energy system (P03) highlighted the importance of research and development (R&D) so that key energy efficient technological barriers can be removed (Wang et al., 2018a).

Unfortunately, China lacks innovative technologies and equipment, leading to that the overall energy efficiency of these final coal users are still low (Li, 2021). Also, legal enforcement is inefficient and ineffective. Many grassroots officials do not have adequate abilities to fully enforce all the related laws and regulations, further resulting in that many coal users do not abide by those laws and regulations (Karplus et al., 2018; Shi et al., 2021). In addition, many industrial sectors do not have their national emission standards and cannot guide practitioners toward low carbon development.

In summary, various efforts have been made by the Chinese government to accelerate the coal industrial chain transition toward low carbon development. Among them, technology innovation is critical to improve efficiency and mitigate emissions along this coal industrial chain. Also, it is necessary to establish national emissions standards for specific industrial sectors and improve environmental awareness of governmental officials and corporate employees through various capacity-building activities.

Policy recommendations

In order to respond to global climate change and national carbon peak and carbon neutrality targets, all coal-related enterprises should move toward low carbon development. We hereby propose several policy recommendations by considering the Chinese realities.

Firstly, the Chinese government should prepare more appropriate policies to support such low carbon development transition along the entire coal industrial chain. The targeted guidelines and standards for different sectors of the coal industrial chain, which are currently missing or outdated, should be formulated and updated regularly depending on the technology progress and the requirement of carbon neutrality. More specifically, it is urgent to set up national standards on green mining and corresponding ecological recovery. These standards can guide those coal mining enterprises to change their operations by considering how to minimize the overall impacts. Also, with clear stipulations on the coal mining scale, those inefficient small and medium sized mining firms should be further phased out. As such, strict ecological recovery standards can induce these mining firms to pay more attention to their daily operations to reduce their overall wastes. Such standards may include ecological compensation items so that necessary funds can be collected from those firms with serious environmental impacts. These funds can be allocated to support tailings treatment and ecological recovery activities. In addition, a strategic plan on future coal industry development should be prepared, covering all the stages of this industrial chain. Such a plan provides fundamental principles on exploring and mining domestic coal reserves, facilitating green coal delivery, and mitigating the overall carbon emission from all the final coal users, coal prices, and coal trade quotas. It is necessary to ensure the coordination of this coal industry development plan and other critical national plans, such as energy transition action plans, so that appropriate coal supply plans can be created. For instance, with the increasing electrification rates, the demand for coal is reducing. More coal will be delivered by electricity railways, and more direct coal combustion will be replaced by clean coal-fired power generation (Jie et al., 2021). In order to make sure that all the initiatives can be implemented seriously, all the governments at different levels should improve their enforcement abilities so that illegal actions can be identified and terminated quickly.

Secondly, it is critical to promote advanced technologies along this coal industrial chain. For those mining firms, it is necessary to update their equipment so that those energy-inefficient equipment can be phased out. Also, it is suggested to promote cooperation between coal mining and coal washing and processing industries to work together to reduce wastes and corresponding emissions, such as recovering and recycling coalbed methane, coal mine drainage, and coal gangue. Led by the government, the cooperation between upstream and downstream firms should also be promoted by establishing a long-term cooperation mechanism. For instance, some mining solid wastes can be used for road paving and construction materials (Li et al., 2022). For those coal delivery firms, it would be preferable to promote new energy trucks, such as hydrogen trucks, so that the overall emissions from such trucks can be mitigated. In addition, railways and waterways are recommended for long distance coal delivery, although necessary connection infrastructure should be established. Especially a coal logistic information platform should be created so that all the coal delivery businesses can share related information and data to avoid unnecessary delays. Finally, those coal users should actively engage in circular economy so that their total carbon emissions can be mitigated. Useful measures include eco-design, cleaner production, energy and material cascading, process integration, responsible waste management, and industrial/urban symbiosis. In particular, carbon capture utilization and storage (CCUS) is useful to reduce the overall carbon emission. Unfortunately, the current CCUS deployment is restricted by many technological barriers, which should be solved through continuous research efforts (Wei et al., 2021; Lyu et al., 2022). The implementation of these measures relies on feasible and advanced technologies. Therefore, these enterprises should work with local research institutes together to solve potential technological problems. Governments at different levels may consider providing research funds to support these innovation activities.

Thirdly, economic instruments should be applied to mitigate the overall carbon emission along this coal industrial chain. For instance, appropriate pricing on coal can reflect the true costs of coal extraction and processing so that environmental externalities can be internalized. Similarly, carbon tax is effective to induce all the related firms to positively involve in carbon emission mitigation actions. Moreover, carbon trade can significantly encourage all the enterprises to take necessary efforts to reduce their emissions. To date, China has established a national carbon trade market, although only coal-burning power plants are allowed to make transactions. It is expected that more carbon emission-intensive sectors will be encouraged to join this national carbon trade market, such as steel/iron, cement, metallurgical, chemicals, and pulp and paper. However, the absence of efficient and equitable carbon emission quota discourages firms from participating in the carbon trading market (Wang et al., 2019a). Transparent and accurate accounting methods for these sectors should be solved so that all the stakeholders can be confident to accept such accounting results.

Lastly, various capacity building activities should be supported. It is essential for all the stakeholders along this coal industrial chain to change their behaviors to learn how to reduce corresponding carbon emissions. TV and radio promotions, regular seminars, pamphlets, and online training programs are mature capacity building efforts. Both related enterprises and governments at different levels should allocate necessary funds to facilitate such training activities. In addition, both regional and international cooperation should be initiated so that more advanced mitigation technologies can be transferred. Especially, those more developed coastal provinces should support their inland and western counterparts through technological transfer, technical secondments, and financial subsidies.

Conclusion

The transition of the coal industrial chain toward low carbon development is crucial to achieve China's carbon peak and carbon neutrality targets. The Chinese government has issued a series of national policies to guide such transition along the entire coal industrial chain, including coal production, delivery, and consumption. Although significant progress has been made in industrial structure adjustment and technology upgrades, various challenges exist and should be removed.

Firstly, the backward mining technologies lead to potential coal supply risks. Meanwhile, ecological degradation occurred due to the lack of motivation and ineffective enforcement. Secondly, great efforts should be made to reconfigure the entire coal transportation network to achieve green coal delivery. Thirdly, more advanced mitigation technologies should be incubated to improve clean and efficient coal production, delivery, and consumption. Under such circumstances, several policy recommendations are proposed to promote this coal industrial chain to move toward low carbon development, including appropriate national policies, research and development (R&D) efforts, the application of various economic instruments and necessary capacity building activities.

Author contributions

CZ designed the idea, while all other authors jointly wrote this paper.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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References

China Electricity Council (2021). China power industry annual development report 2021. (in Chinese) Available at: https://news.bjx.com.cn/html/20210708/1162855.shtml (Accessed May 25, 2022).

China National Coal Association (2022). Annual report on coal industry development in 2021. (in Chinese) Available at: http://www.coalchina.org.cn/index.php?m=content&c=index&a=show&catid=60&id=137613 (Accessed May 25, 2022).

Guan, Y., Shan, Y., Huang, Q., Chen, H., Wang, D., and Hubacek, K. (2021). Assessment to China's recent emission pattern shifts. *Earth's. Future* 9 (11), e2021EF002241. doi:10.1029/2021EF002241

He, Z., Chen, P., Liu, H., and Guo, Z. (2017). Performance measurement system and strategies for developing low-carbon logistics: A case study in China. *J. Clean. Prod.* 156, 395–405. doi:10.1016/j.jclepro.2017.04.071

Jia, Z., and Lin, B. (2021). How to achieve the first step of the carbon-neutrality 2060 target in China: The coal substitution perspective. *Energy* 233, 121179. doi:10.1016/j.energy.2021.121179

Jia, Z., Wen, S., and Sun, Z. (2022). Current relationship between coal consumption and the economic development and China's future carbon mitigation policies. *Energy Policy* 162, 112812. doi:10.1016/j.enpol.2022.112812

Jie, D., Xu, X., and Guo, F. (2021). The future of coal supply in China based on non-fossil energy development and carbon price strategies. *Energy* 220, 119644. doi:10.1016/j.energy.2020.119644

Kaack, L. H., Vaishnav, P., Morgan, M. G., Azevedo, I. L., and Rai, S. (2018). Decarbonizing intraregional freight systems with a focus on modal shift. *Environ. Res. Lett.* 13 (8), 083001. doi:10.1088/1748-9326/aad56c

Karplus, V. J., Zhang, S., and Almond, D. (2018). Quantifying coal power plant responses to tighter SO_2 emissions standards in China. *Proc. Natl. Acad. Sci. U. S. A.* 115 (27), 7004–7009. doi:10.1073/pnas.1800605115

Li, K., Ma, M., Xiang, X., Feng, W., Ma, Z., Cai, W., et al. (2022). Carbon reduction in commercial building operations: A provincial retrospection in China. *Appl. Energy* 306, 118098. doi:10.1016/j.apenergy.2021.118098

Li, Q. (2021). The view of technological innovation in coal industry under the vision of carbon neutralization. *Int. J. Coal Sci. Technol.* 8 (6), 1197–1207. doi:10.1007/s40789-021-00458-w

Liu, H., Chen, Z., Wang, J., and Fan, J. (2017). The impact of resource tax reform on China's coal industry. *Energy Econ.* 61, 52–61. doi:10.1016/j.eneco.2016.11.002

Lyu, X., Yang, K., and Fang, J. (2022). Utilization of resources in abandoned coal mines for carbon neutrality. *Sci. Total Environ.* 822, 153646. doi:10.1016/j.scitotenv.2022.153646

Mou, D., and Li, Z. (2012). A spatial analysis of China's coal flow. *Energy Policy* 48, 358–368. doi:10.1016/j.enpol.2012.05.034

National Bureau of Statistics of the People's Republic of China (2015–2022). *China statistical yearbooks 2014–2021*. Beijing, China: China Statistics.

Shi, J., Huang, W., Han, H., and Xu, C. (2021). Pollution control of wastewater from the coal chemical industry in China: Environmental management policy and technical standards. *Renew. Sustain. Energy Rev.* 143, 110883. doi:10.1016/j.rser.2021.110883

Spencer, T., Colombier, M., Sartor, O., Garg, A., Tiwari, V., Burton, J., et al. (2018). The 1.5°C target and coal sector transition: at the limits of societal feasibility. *Clim. Policy* 18 (3), 335–351. doi:10.1080/14693062.2017.1386540

Sun, Z., Ma, Z., Ma, M., Cai, W., Xiang, X., Zhang, S., et al. (2022). Carbon peak and carbon neutrality in the building sector: A bibliometric review. *Buildings* 12 (2), 128. doi:10.3390/buildings12020128

The Central People's Government of the People's Republic of China (2021). The Communist Party of China Central Committee and the State Council's guiding document on the country's work to achieve carbon peaking and carbon neutrality goals under the new development philosophy. (in Chinese) Available at: http://www.gov.cn/zhengce/2021-10/24/content_5644613.htm (Accessed May 25, 2022).

The Central People's Government of the People's Republic of China (2020). Xi jinping proposed an important speech at general debate of the 75th united nations general assembly. (in Chinese) Available at: http://www.gov.cn/xinwen/2020-09/22/content_5546168.htm (Accessed May 25, 2022).(

The State Council of the People's Republic of China (2014). Strategic action plan for energy development (2014-2020). (in Chinese) Available at: http://www.nea.gov.cn/2014-12/03/c_133830458.htm (Accessed May 25, 2022).

Wang, B., He, L., Yuan, X.-C., Sun, Z.-M., and Liu, P. (2021a). Carbon emissions of coal supply chain: an innovative perspective from physical to economic. *J. Clean. Prod.* 295, 126377. doi:10.1016/j.jclepro.2021.126377

Wang, B. J., Zhao, J. L., and Wei, Y. X. (2019a). Carbon emission quota allocating on coal and electric power enterprises under carbon trading pilot in China: Mathematical formulation and solution technique. *J. Clean. Prod.* 239, 118104. doi:10.1016/j.jclepro.2019.118104

Wang, C., Engels, A., and Wang, Z. (2018a). Overview of research on China's transition to low-carbon development: the role of cities, technologies, industries and the energy system. *Renew. Sustain. Energy Rev.* 81, 1350–1364. doi:10.1016/j.rser.2017.05.099

Wang, N., Ren, Y., Zhu, T., Meng, F., Wen, Z., and Liu, G. (2018b). Life cycle carbon emission modelling of coal-fired power: Chinese case. *Energy* 162, 841–852. doi:10.1016/j.energy.2018.08.054

Wang, N., Shen, R., Wen, Z., and De Clercq, D. (2019b). Life cycle energy efficiency evaluation for coal development and utilization. *Energy* 179, 1–11. doi:10.1016/j.energy.2019.04.111

Wang, P., Lin, C.-K., Wang, Y., Liu, D., Song, D., and Wu, T. (2021b). Location-specific co-benefits of carbon emissions reduction from coal-fired power plants in China. *Nat. Commun.* 12 (1), 6948. doi:10.1038/s41467-021-27252-1

Wei, N., Jiao, Z., Ellett, K., Ku, A. Y., Liu, S., Middleton, R., et al. (2021). Decarbonizing the coal-fired power sector in China via carbon capture, geological utilization, and storage technology. *Environ. Sci. Technol.* 55 (19), 13164–13173. doi:10.1021/acs.est.1c01144

Wu, Y., Xiao, X., and Song, Z. (2017). Competitiveness analysis of coal industry in China: a diamond model study. *Resour. Policy* 52, 39–53. doi:10.1016/j.resourpol.2017.01.015

Zhang, D., Wang, J., Lin, Y., Si, Y., Huang, C., Yang, J., et al. (2017). Present situation and future prospect of renewable energy in China. *Renew. Sustain. Energy Rev.* 76, 865–871. doi:10.1016/j.rser.2017.03.023

Zhang, S., and Chen, W. (2022). Assessing the energy transition in China towards carbon neutrality with a probabilistic framework. *Nat. Commun.* 13 (1), 87. doi:10.1038/s41467-021-27671-0

Zhang, Y., Shi, X., Qian, X., Chen, S., and Nie, R. (2021). Macroeconomic effect of energy transition to carbon neutrality: Evidence from China's coal capacity cut policy. *Energy Policy* 155, 112374. doi:10.1016/j.enpol.2021.112374

Zhao, L.-T., Liu, Z.-T., and Cheng, L. (2021). How will China's coal industry develop in the future? A quantitative analysis with policy implications. *Energy* 235, 121406. doi:10.1016/j.energy.2021.121406