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Original Paper

Study on the driving factors and regulation mode for coal production capacity

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ABSTRACT

Coal production capacity regulation is a complex system involving economic growth, structural optimization, high-efficiency mining, and environmental protection. Based on its driving factors, this paper forms four regulation modes representing different control orientations, establishes a system dynamics model, and predicts the regulation effects of single-factor and combined control mode. The result shows: (1) Except for the mechanization degree and recovery rate, the other nine individual production capacity control policies are all conducive to reducing coal production capacity and restraining the excessive growth of coal production capacity. (2) The effect of combined regulation mode on slowing down the growth of coal demand, regulating the excessive growth of coal production capacity and new capacity investment are obviously better than that of single policy. (3) The combined control modes have obvious differences in the suppression effect on coal production capacity: transformational development mode > technology-driven mode > structural optimization mode > efficiency improvement mode. Therefore, in the process of achieving optimal regulation of coal production capacity, attention should be paid to the preferential use of transformational development and technology-driven mode. At the same time, the comprehensive use of regulation and control methods should also be considered to improve the regulation effect and the regulation efficiency of coal production capacity.

1. Introduction

Since 2012, affected by various factors such as economic slowdown, overheated investment in the coal industry, and energy structure adjustments, coal demand has fallen sharply, supply capacity has been severely overcapacity, supply-demand relations have been severely imbalanced, inventories have remained high, and coal prices have continued to decline. Enterprise losses continues to increase, and overcapacity has become an urgent problem for the coal industry and the country. According to the estimates, the total energy consumption will reach a peak of 5.81 billion tons of standard coal by 2030 (Yang et al., 2016), 4470 Mtoe by 2040 under the current policy scenario (Dong et al., 2017). As the end of 2015, China's coal production capacity exceeded 5.7 billion tons, and coal overcapacity is widespread (Ma et al., 2020). By 2020, China's coal overcapacity will continue, and it will still face challenges in the future (Wang et al., 2018). In the context of the new normal of economic operation, the removal of coal industry excess capacity has become an important issue and key difficulty in promoting China's economic transformation and upgrade.

To solve the serious overcapacity situation in the coal industry, it is necessary to analyze its driving factors (Wang et al., 2015). Research on the causes of overcapacity can unearth the power source for rational regulation of production capacity. The causes of overcapacity are more complicated. There are hoarding behaviors of enterprises in response to competition (Kalyuzhnova and Vagliasindi, 2006; Sun et al., 2008), excessive competition (Jens, 2010), low-end technology dependence (Botterud and Korpås, 2007), local development impulse, blind investment, redundant construction (Geng et al., 2011) and other factors. The performance evaluation system of the Chinese government has caused vicious competition among local governments, established local protection barriers, and provided various subsidies and other preferential policies for investment (Zhang et al., 2016), thereby exacerbating overcapacity. Due to the non-renewability and finiteness of coal resources, the reserves of coal resources and their endowment pattern directly affect their long-term production capacity

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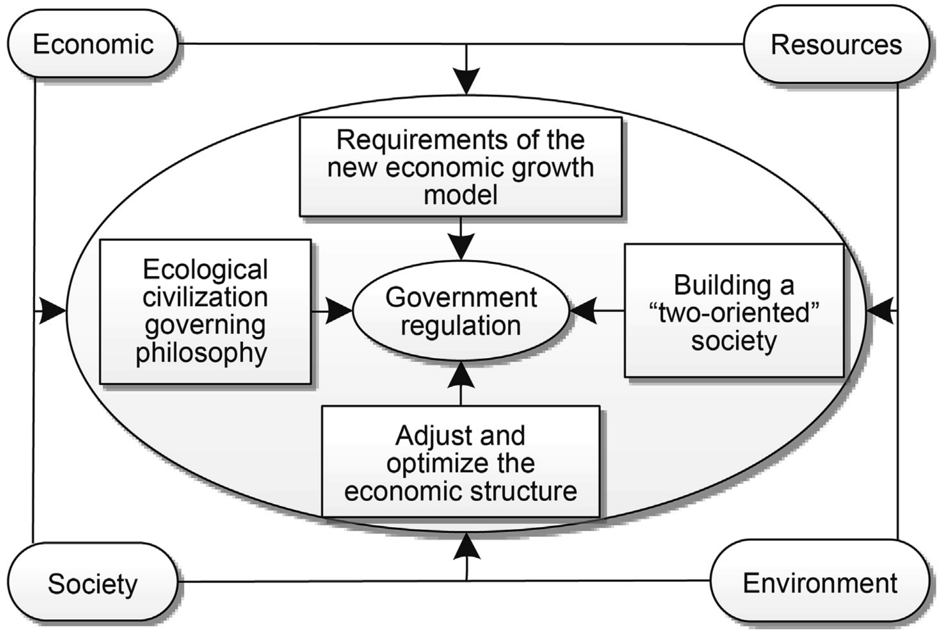

Fig. 1. Driving force of government's coal capacity regulation.

(Calzonetti, 1983; Rodríguez and Arias, 2008). In addition, due to liquidity barriers (Adams, 2010) and institutional barriers (Wang et al., 2014), the coal industry has low entry barriers and high exit barriers, which will also lead to overcapacity. Corporate strategy and government investment incentives will cause natural overcapacity, and demand shocks will cause cyclical overcapacity (Yang et al., 2019a,b). Therefore, policies should be formulated according to the factors that affect the overcapacity. Through an analysis of factors, it is conducive to accurately realize the regulation of the rationalization of production capacity and ensure that policy formulation is feasible. The influencing factors discussed in the literature basically include coal prices, construction industry development, industrial policies, resource endowments, coal production capacity investment, and export fluctuations, which all result in overheated investment and overcapacity (Liu et al. 2016, 2017). In addition, China's foreign direct investment, foreign exports, and technological innovation activities in countries along the "Belt and Road" are more effective in improving energy efficiency (Wu et al., 2020a,b,c). This provides new options for capacity release, which can promote the increase in capacity utilization and effectively alleviate overcapacity.

As an important part of economic transformation, upgrade, and structural adjustment, how to digest and manage overcapacity is an important area that policymakers and academia pay attention. Macro-control is an effective governance mechanism to avoid the trap of overcapacity in China (Dong et al., 2021; Kreindler et al., 2020; Wang, 2020). To maintain scientific coal production capacity construction, the constraints of resources, environment, economy, technology, and safety should be considered comprehensively (Wang et al., 2015; Yang et al., 2019a,b). The capacity regulation of the coal industry will cause a series of chain reactions in the closely related tar, cement, steel, coal power, and thermal power industries (Shi et al., 2018; Hao et al., 2019; Song et al., 2019). The progress and extent of the macro-control of production capacity is the key to whether China's macro-economy can rebound from the bottom. The control measures that can be used include economic control measures, legal control measures, and administrative control measures (Cong et al., 2014). The factors that determine the effect of regulation include economic growth, energy intensity, energy structure, imports, and exports (Wang et al. 2017, 2020). Capacity utilization (Zhang et al., 2016), quota systems (Diana et al., 2017), permit systems (Shi et al., 2020), and international capacity cooperation (Kenderdine and Ling. 2018) can be adopted to reduce capital input (Dixon et al. 2010, 2011) and investment uncertainty (Moret et al., 2020).

It can be seen that discussing control factors and governance mechanisms is the focus of research on coal excess capacity at home and abroad. China's coal production capacity governance must simultaneously face the four pressures of optimizing the production structure, stabilizing development of the macro economy, transforming and upgrading of the industrial structure, and comprehensive upgrading industry technology. In the existing literature, combining the single regulation effect of influencing factors and the regulation effect of the combination of influencing factors to form a regulation mode is still lacking. The contributions of this article are: First, to analyze single regulation effects and potential of key influencing factors; Second, to categorize and form regulation modes and to compare and analyze the effects of different modes on capacity regulation; Third, through the comparative conclusions of the two, to realize empirical support for China's current vigorous promotion of transformation and upgrade.

The article structure is arranged as follows: First, to analyze the driving force of the main regulator and regulating environment; Second, to construct a system dynamics analysis model; Then, to analyze the regulation effects and potential of single regulation and combined regulation policies. Finally, to arrive at the research conclusion of this article.

2. Driving factors of adjustment system

2.1. Driving factors of the main regulator

(1) Government

The strong "visible hand" of China's government is the maker and implementer of macro policies, micro policies, and social service policies for coal production capacity control, and is the source of policy motivation. It has been an effective mechanism of governance to coordinate collective actions of market participants and avoid the overcapacity trap (Dong et al., 2021).

The main driving force for the government to establish a coal production control system to achieve reasonable control of coal production capacity and change to coal utilization methods comes from two external sources (See Fig. 1). From an internal point of view, the scientific development concept, the theoretical connotation, the construction significance, and the construction goals of a "resource-saving, environment-friendly society" and Beautiful China all reflect the government's ecological civilization governance philosophy and adjustments method. At the same time, advancing reform of the coal industry system, improving the environment and energy efficiency (Hao et al., 2020; Wu et al., 2020a,b,c), stimulating the vitality of economic growth, and effectively managing macro-control have become important issues facing the government. From an external perspective, China is at a critical stage of rapid industrialization and urbanization. To promote the transformation of the economic mode of growth and encourage technological innovation, the government must play a role in macro-control and coordinate with stakeholders such as the market and enterprises. The government is facing dual pressures of domestic coal overcapacity and international carbon emission reduction requirements. Various pressures from ecological civilization society, environmental protection, resource conservation, and low-carbon development have prompted the government to seek strategies from the source to cope with reform and sustainable development of the coal industry (Hao et al., 2019).

(2) Coal enterprises

Coal enterprises are the main bearers of policy and the direct role of coal production capacity control. The various coal production control policies and measures promulgated and implemented by the government need to be transmitted to the coal enterprises, who ultimately undertake them in practice. The driving force for coal enterprises to realize the transformation from a traditional development model to a scientific development model mainly includes corporate interests, market demand, policy promotion, technological progress, and ecological environment constraints.

According to the description in Fig. 2, the driving force for change in coal enterprises is the result of the combined effects of the interests of enterprises, market demand, government policy promotion, technological advancement, and environmental protection constraints. Corporate interests are among the most important positive internal driving factor for the reform of coal companies. The three positive driving forces of policy promotion, market demand, and technological progress, and the negative driving force of environment constraints, jointly act on internal factors to promote the reform of coal enterprises (Cong et al., 2014).

2.2. Driving factors of regulating environment

In the process of promoting the regulation of coal production capacity, the development of the coal industry is not only restricted by its own development, but also driven and restricted by external forces or constraints such as economic development, social progress, environmental protection, and resource conservation (Zhang et al., 2018; Yang et al., 2019a,b). Each subsystem of the coal production capacity control system represents the orientation of a control policy and corresponds to a control mode (See Fig. 3).

Economic growth constitutes the basic driving force for the sustainable and healthy development of the coal industry. It is also an important goal for the government and enterprises to regulate production capacity at this stage. Ensuring stable and rapid economic growth is a prerequisite for promoting scientific and technological progress, improving production efficiency, and optimizing industrial structure (Mu et al., 2018).

Structural adjustment can provide continuous follow-up power

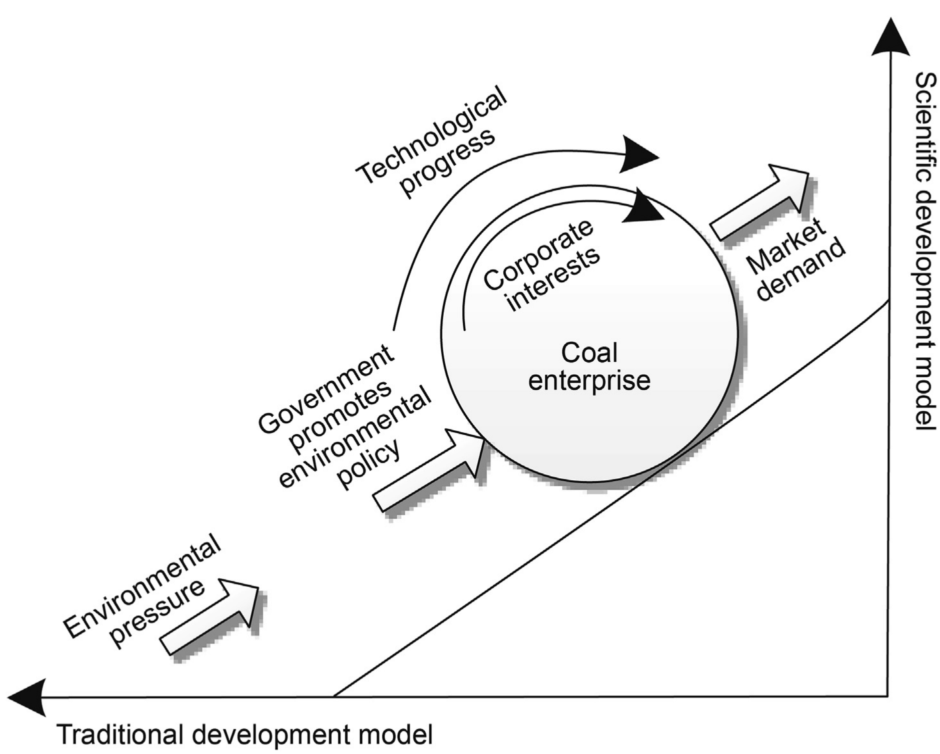

Fig. 2. Driving force for the reform of coal enterprise development mode.

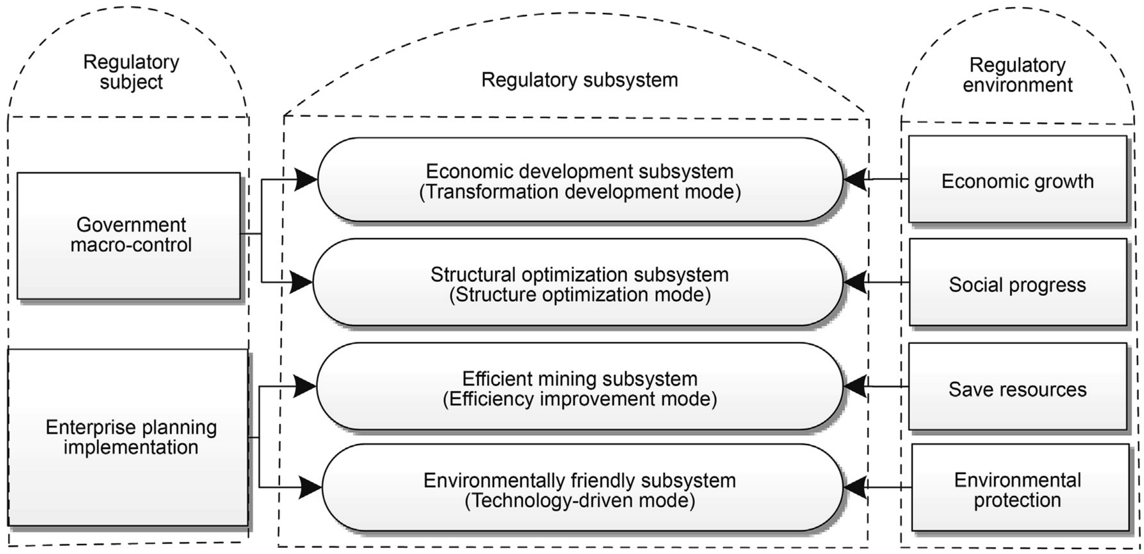

Fig. 3. The corresponding relations among the main body, environment, and subsystems.

for the healthy development of the coal industry and the sustainable growth of the national economy. The energy structure is gradually optimized from fossil energy to non-fossil energy, which can effectively promote the realization of the transformation of energy production and utilization. In short, economic growth provides economic support for structural adjustment, and structural adjustment, in turn, provides development stamina for economic growth. The two interact as cause and effect.

Achieving efficient coal mining is an indirect driving force for alleviating resource and environmental constraints and optimizing energy production and consumption structure. It is also an endogenous driving force for economic growth. On one hand, the government needs to increase investment in scientific and technological research and development. On the other, enterprises need to tap the potential of energy science and technology in practice, improve the efficiency of coal production and utilization, and use the unlimited potential of science and technology to alleviate the constraints of limited recoverable coal resources.

Environmental friendliness is a negative constraint on the current excessive production and consumption of coal. Enhancing environmental constraints and improving the mining area environment can not only alleviate and improve the depletion of coal resources and the serious damage to the environment, but also increase the cost of coal production and use, and realize the “reverse force” of backward coal production capacity.

3. Construction of system dynamics model

3.1. System boundary definition

Accounting for the impact of economic growth, social progress, resource conservation, and environmental protection, four subsystems of economic growth, structural optimization, efficient mining, and environmental friendliness have been established. The economic growth subsystem mainly considers the impact of GDP and population growth on energy and coal demand (Wang et al., 2018; Mu et al., 2018). The structural optimization subsystem mainly considers the effect of social progress and energy technology on energy consumption structure. The efficient mining subsystem mainly analyzes the relationship between coal resource reserves and green and efficient coal mining (Cong et al., 2014). The environmentally friendly subsystem mainly analyzes the relationship between carbon emission constraints and coal production and consumption (as shown in Fig. 4). The four subsystems directly or indirectly affect coal production capacity through factors such as coal demand, coal supply, coal price, market expectations, production capacity investment, industry benefits, and mining environment (Yang et al., 2018, 2019b).

3.2. System causality

(1) Causality of economic growth subsystem. The economic subsystem links economic growth with production consumption, unit capacity investment, coal consumption, coal supply, coal prices, and local government investment, ensuring economic growth is the primary factor influencing the growth of coal demand. At the same time, economic growth has expanded coal supply, expanded coal investment, and promoted an increase in production consumption. When coal is in short supply and a gap between supply and demand occurs, it will further stimulate economic growth and become the driving force for a new round of expansion of coal investment.

(2) Causality of the structural optimization subsystem. The structural optimization subsystem mainly reflects the role of energy technology in the adjustment and optimization of energy structure. This subsystem describes the relationship between energy consumption and the coal supply-demand gap, GDP, industrial production, energy consumption, scientific and technological research and development investment, carbon emissions, energy intensity, and energy structure. On one hand, economic and social progress and industrialization have promoted an increase in energy consumption in production and life, and the total energy consumption has shown a rapid growth trend. On the other, the mode of economic growth has undergone major changes, and government and enterprises have gradually invested in energy technology research and development. The increase in energy technology has promoted the gradual substitution of non-fossil energy to coal energy, reducing total carbon emission and carbon emission intensity, thereby providing a

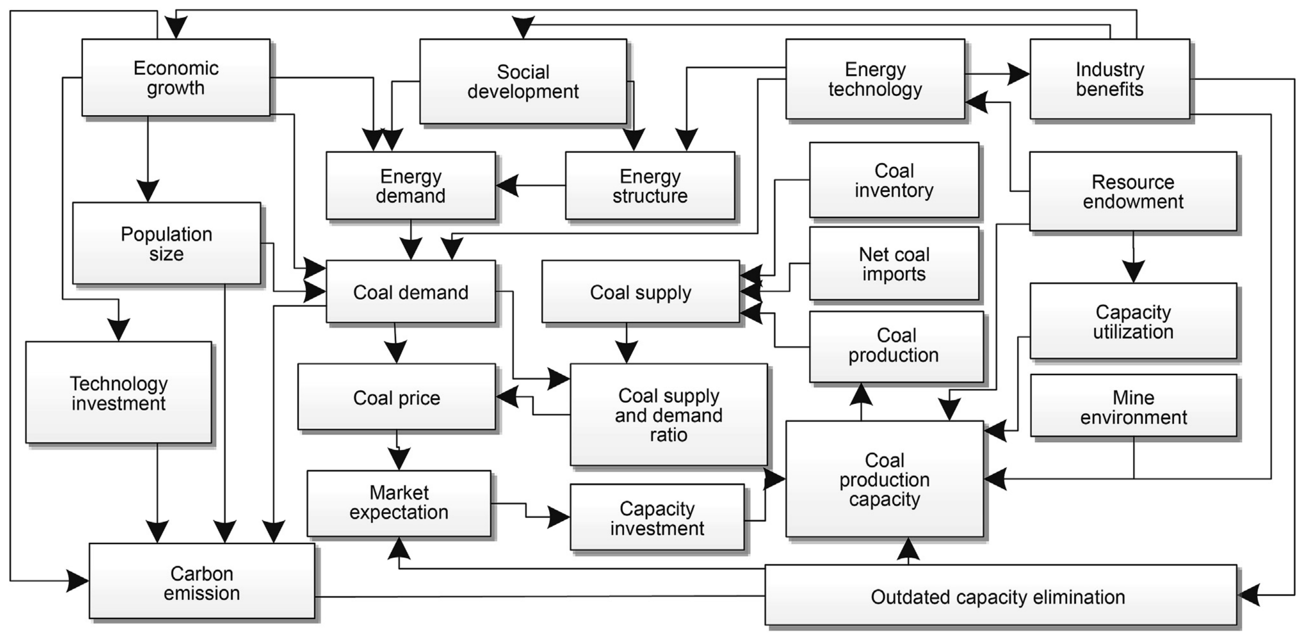

Fig. 4. Dynamic model boundary of coal capacity control system.

continuous impetus for achieving high-quality economic development (Wu et al., 2020a,b,c).

(3) Causality of the high-efficiency mining subsystem. The high-efficiency mining subsystem refers to the relationship between coal enterprises on the basis of limited recoverable coal reserves, exploiting the potential of existing resources, using energy technology to improve mining efficiency, using existing coal resources for production and expansion reinvestment, and other related variables. An efficient mining subsystem construction first begins with the analysis of coal resource reserves, and discusses the impact of the degree of mechanization on the recovery rate and the death rate of one million tons. The increase in recovery rate can effectively reduce the consumption of coal resource mining and the increase in efficiency of coal production capacity will increase coal production, affect coal prices, and stimulate coal investment.

(4) Causality of environmentally friendly subsystems. Coal production and coal mine investment are restricted by policy requirements such as those regarding environment. The environmentally friendly subsystem mainly describes the relationship between GDP, industrial pollution control investment, carbon dioxide emissions, coal production, and coal production capacity. The development of the national economy and the constraints of the ecological environment have increased the environmental protection awareness of coal companies. The increase in investment in the treatment of industrial pollution by coal companies has been internalized as an increase in the cost of coal production, which has played a role in restraining coal investment and reducing both coal capacity utilization and output.

3.3. Flow diagram and variable

(1) Flow Diagram Model

Based on the aforementioned analysis of environmental dynamics and subsystem causality diagrams, an SD model for coal production capacity control is established to analyze the regulatory effects of specific coal production control policies on the four systems. There are five state variables including GDP, total population, coal production capacity, recoverable coal reserves, and total fixed coal assets. The other variables are determined by the five state variables (See Fig. 5). The relationship between variables will be determined by system initialization through historical statistical data and judgment on future trends, combined with measurement and statistical methods.

(2) Data source

The data of the model parameters come from the “China Energy Statistical Yearbook”, “China Coal Industry Yearbook”, “China Environment Statistical Yearbook”, “China Statistical Yearbook”, “China Demographic Yearbook”, “China Fiscal Yearbook”, “China Environment Statistical Yearbook”, “Compilation of Statistics in 60 Years of New China”, “Statistical Yearbook of China's Land and Resources”, “Compilation of Statistics of China's Coal Industry”, and China Economic Network Industry Database.

(3) Determination of variable relationship

Regarding the relationship between variables in the model flow diagrams, guided by historical data from 2000 to 2015, a combination of qualitative and quantitative methods is adopted. Based on the qualitative analysis of logical reasoning to determine the logical relationship between variables, multivariate statistical analysis, trend extrapolation, econometrics, and other quantitative methods determine the relationship between variables.

(4) Model checking

Through the “Units Check” test, the dimensional consistency test, the structure test, and the system consistency test are carried out to confirm that the structure of the model essentially conforms to the actual situation. The historical data and simulation results are used to perform the error test, and the result shows the relative

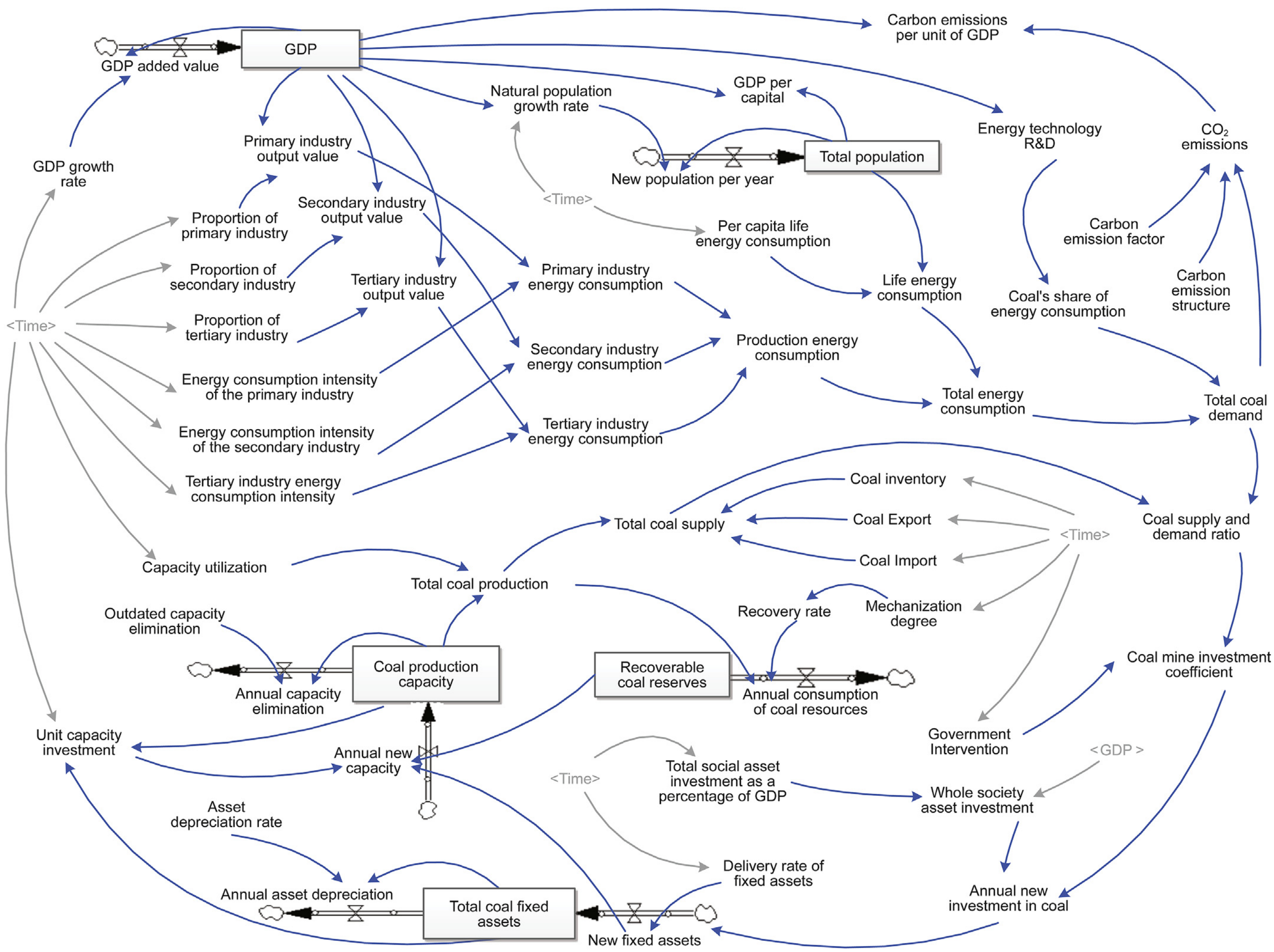

Fig. 5. System dynamics flow diagram of coal production capacity regulation.

error between the simulation values and historical values is within 5%, which has passed the degree of fit test and can be used to simulate coal production capacity control policies.

4. Scenario analysis of regulation policy

4.1. Simulation analysis of single regulation policy

4.1.1. Scene description and parameter setting

Taking 2015 as the base year and 2016–2025 as the inspection period, according to the setting of main parameters in Table 1, this study simulates the effect of a single policy variable on the developmental trend of coal production capacity from 2016 to 2025. The transmission mechanism within the system carries out simulation analysis of the control effect and control feasibility of a single policy of coal production control.

4.1.2. Scenario simulation and control effect

Fig. 6 shows the changes and trends of coal production capacity under various single factors. The total control effect of single-factors on coal production capacity are shown in Table 2.

(1) Effect of economic growth adjustment. According to the calculation results, coal production capacity has been reduced compared to the baseline scenario under the economic growth policy adjustment scenario. During the period from 2016 to 2025, coal production capacity has been reduced by 153.29 million tons, and the reduction has continued to increase. The ability to regulate and control is increasing year by year. It can be seen that an appropriate slowdown in GDP growth can reduce coal production capacity.

(2) Effect of industrial structure. According to the calculation results, during the period from 2016 to 2025, the industrial structure optimization policy scenario has reduced coal production capacity by 418.03 million tons compared with the baseline scenario, and its capacity control capability has shown an increasing trend year by year. It can be seen that the optimization of industrial structure has a significant role in reducing and alleviating overcapacity. Industrial structure optimization can be used as an effective long-term adjustment policy to resolve excess capacity.

Above conclusion are consistent with the research conclusions of Wang et al. (2017, 2019) and Cong et al. (2014) on individual regulatory policies. Both prove that OCE, ET R&D, FDR, CU, EG, CI, and CE are important means of resolved overcapacity. MD and RR have a weak inhibitory effect on overcapacity. In addition, this

Table 1
Main parameters setting.

Parameters	Baseline scenario	Policy scenario
Economic Growth (EG)	2016–2020 is 7%, 2021–2025 is set to 6.5%.	2016–2020 is 6.5%, 2021–2025 is set to 6%.
Industrial Structure (IS)	In 2025, the proportions of primary, secondary, and tertiary industries will be 7%, 36.3%, and 56.7%, respectively.	By 2025, primary and secondary industries will be reduced to 6.5% and 30%, and the proportion of tertiary industry will be 63.5%.
The Delivery Rate of Fixed Assets (FDR)	Reduce the delivery rate of fixed assets to 70% in 2025.	Reduce it to 65% in 2025.
Government Intervention (GI)	The intervention intensity increased linearly from 0.7 in 2015 to 1 in 2020, and gradually decreased to 0 in 2025.	Increase to 0.9 in 2020 and gradually decrease to 0.5 in 2025.
Outdated Capacity Elimination (OCE)	The annual outdated capacity elimination rate is set at 2.726%.	Increase production capacity elimination, set at 3.17%.
Capacity Utilization (CU)	Production capacity comprehensive utilization rate reached 85% by 2025	The production capacity comprehensive utilization rate increased to 95% by 2025.
Recovery Rate (RR)	Reached 85% in 2025	Reached about 90% by 2025.
Mechanization Degree (MD)	80% in 2020, 85% in 2025	85% in 2020, 90% in 2025
Energy Technology R&D (ET R&D)	The coefficient of energy technology R&D investment is 0.022171.	It is increased to 0.025.
Coal Import (CI)	Increase to 300 million tons in 2020 and 350 million tons in 2025.	Increase to 350 million tons in 2020 and 400 million tons in 2025.
Coal Export (CE)	Limit coal exports to less than 5 million tons by 2025.	Control coal export volume below 3 million tons.

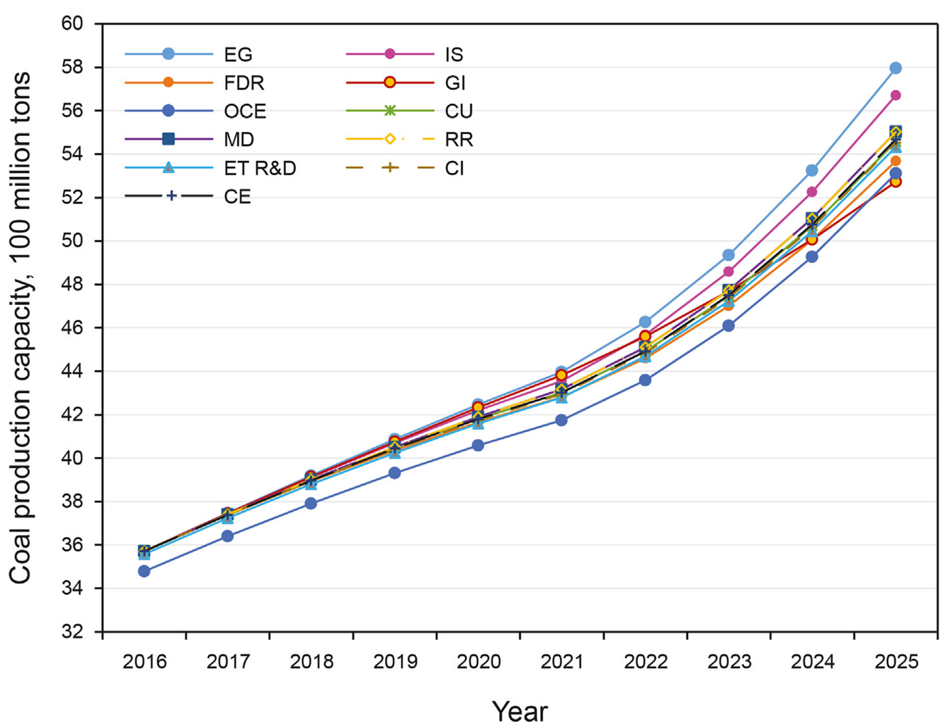

Fig. 6. Comparison of the single-factor effects.

article also analyzes and compares the regulatory effects of industrial structure adjustment and government intervention.

4.2. Scenario analysis of combined control modes

Generally speaking, a single policy measure can play a greater regulatory role in coordination with other measures. According to section 2.1, each subsystem of coal production capacity control represents a type of control policy orientation and corresponds to a control mode. Therefore, to further analyze the policy effects of different coal production capacity control modes, this section sets up policy combination plans for different capacity control modes to reflect the effect of capacity control under the comprehensive use of various parameter adjustments. The coal production capacity control SD model is used for combined policy simulation and comparative analysis Fig. 7.

4.2.1. Scene description and parameter setting

(1) Set the GDP growth scenario.

At present, China's economy is in the "new normal" period of low-speed growth. Based on research results of domestic and foreign research institutions and scholars and the current status of China's economic development, the average annual growth rate from 2016 to 2025 is defined as a high growth rate, medium growth rate, and low growth rate, as shown in Table 3.

(2) Parameter setting of the combination scheme corresponding to the four control modes.

Table 2
Comparisons of regulatory capacity on coal capacity regulation factors.

	EG	IS	FDR	GI	OCE	CU	MD	RR	ET R&D	CI	CE
2016	0.00	0.00	0.00	0.00	−0.93	0.00	0.00	0.01	−0.13	0.00	0.00
2017	0.00	−0.02	−0.02	0.05	−1.00	−0.01	0.01	0.02	−0.17	−0.01	0.00
2018	0.00	−0.06	−0.05	0.15	−1.08	−0.03	0.02	0.02	−0.21	−0.01	0.00
2019	−0.02	−0.12	−0.10	0.30	−1.15	−0.06	0.03	0.03	−0.26	−0.03	0.00
2020	−0.04	−0.22	−0.17	0.51	−1.23	−0.09	0.05	0.03	−0.31	−0.05	0.00
2021	−0.08	−0.34	−0.24	0.77	−1.30	−0.14	0.08	0.04	−0.37	−0.07	0.00
2022	−0.15	−0.50	−0.35	0.65	−1.37	−0.20	0.07	0.04	−0.43	−0.09	0.00
2023	−0.25	−0.70	−0.52	0.16	−1.44	−0.27	0.02	0.05	−0.50	−0.11	0.00
2024	−0.40	−0.95	−0.74	−0.72	−1.52	−0.35	0.07	0.06	−0.59	−0.13	0.00
2025	−0.60	−1.27	−1.03	−1.98	−1.60	−0.45	0.10	0.07	−0.69	−0.15	0.00
Total	−1.53	−4.18	−3.22	−0.11	−12.6	−1.59	0.43	0.37	−3.67	−0.65	−0.01

Note: "-" indicates a reduction and "+" indicates an increase in coal production capacity.

(3) Effect of coal investment adjustment. The investment efficiency of the coal industry is measured by the rate of fixed asset delivery. It can be seen from the simulation results that the reduction in the delivery rate of fixed assets can effectively reduce coal production capacity. According to the calculation results, the policy scenario of the fixed asset delivery utilization ratio during the period from 2016 to 2025 has reduced coal production capacity by 321.65 million tons compared with the baseline scenario.

(4) Effect of government intervention. The government's intervention and adjustment are mainly performed through national macro-control, increasing efforts to rectify coal production capacity from the source, strictly controlling production capacity reconstruction, and achieving strict control and strict control of the construction of new coal production capacity. From the simulation results, it can be seen that the policy scenario has reduced coal production capacity by 11.18 billion tons compared with the baseline scenario. This shows that the adjustment of the intensity of government intervention can reduce coal production capacity to a certain extent, but the impact is limited. The government's use of interventions to adjust coal production capacity should pay attention to reality. On the basis of respecting market rules, the government should use administrative interventions cautiously, and use economic and legal means to assist coal production control.

(5) Effect of eliminating backward production capacity. According to the comparison of the calculation results, the coal production capacity under the policy scenario of eliminating backward production capacity has dropped significantly compared with the baseline scenario, and its capacity control effect has an obvious growth trend from 93 million tons in 2016 to 160 million tons in 2025. During the inspection period from 2016 to 2025, the total coal production capacity was reduced by 1261.45 million tons. It can be seen that speeding up the elimination of outdated production capacity is a powerful policy measure for resolving coal overcapacity. A large number of policy documents issued by the state have repeatedly emphasized that it is determined to eliminate a batch of outdated production capacity and prevent both redundant construction and blind expansion of outdated production capacity. This is accomplished by digesting a batch of production capacity, transferring a batch of production capacity, integrating a batch of production capacity, and ultimately eliminating a batch of production capacity.

(6) Effect of production capacity utilization. Through simulation, it is found that coal production has been reduced by 1.14276 million tons in the context of capacity utilization efficiency policy adjustment. Coal production has also been increased by 158.61 million tons compared with the baseline scenario. The increase in capacity utilization has significantly reduced coal production, and its positive effect on coal production is far greater than its negative effect on coal production capacity.

(7) Effect of coal technological progress. Two indicators of mechanization and recovery rate are used to measure the progress of coal production technology. After simulation, it is found that the increase in mechanization and recovery rate has promoted the growth of coal production capacity to a certain extent. The root cause lies in the specificity of coal industry assets and the formation of relatively high fixed assets. In addition to the long-term dependence on low-end technology in the coal production process, there has been an obvious technology lock-in effect in coal production and the degree of mechanization of coal production and mining. There is a negative correlation between production rate and capacity utilization. According to the calculation results, the two have cumulatively increased coal production capacity by 43.01 million tons and 36.75 million tons, respectively, during the inspection period when compared to the baseline scenario.

(8) Effect of energy technology R&D. The proportion of energy technology R&D investment in GDP is a key indicator to evaluate the energy technology investment level. According to the calculation results, the policy scenario of energy technology R&D investment during the period from 2016 to 2025 will reduce coal production capacity by 367.48 million tons compared with the baseline scenario. It shows that the implementation of the increasing energy technology investment policy has effectively restrained the growth of coal production capacity, which is an effective coal production control measure.

(9) Effect of coal import and export. According to the calculation results, during the period from 2016 to 2025, the coal import and export policy scenario has reduced coal production capacity by 66.69 million tons when compared with the baseline scenario, and this effect is increasing year by year. It can be seen that by encouraging coal imports and restricting coal exports, the regulatory path can reduce domestic excess production pressure, reduce domestic coal production, and effectively control the excessive growth of coal production capacity. This is a more effective coal production control measure.

The baseline scenario (A0), the transformational development scenario (A1), the structural optimization scenario (A2), the energy efficiency improvement scenario (A3), and the technology-driven scenario (A4) are set for the trend changes of 10 policy variables from 2016 to 2025 Tables 4-8.

(3) Control plan combination

According to three GDP growth scenarios, benchmark scenarios, and four types of control models, fifteen coal production control proposals have been produced, as shown in Table 9.

4.2.2. Scenario simulation and control effect comparison

(1) Energy consumption

From the results of total energy consumption, under various economic growth rates, the total energy consumption shows slow upward trend, and its annual growth rate shows an obvious downward trend, indicating that various policy adjustment scenarios have played a positive role in effectively controlling energy consumption (Table 10). When the economy is growing at a low speed, the decline of the total energy consumption of D11 ~ D15 is the largest, while D31 ~ D35 shows a continuous upward trend when the economy is growing at a high speed. The total energy consumption of the benchmark scenario under various economic growth rates is greater than that of the other four scenarios, while the transition development scenarios (D12, D22 and D32) under various economic growth rates are the lowest. Thus, by optimizing and adjusting the three-industry structure, limiting the blind increase in coal fixed asset investment, and speeding up the elimination of outdated production capacity, the effect on reducing production energy consumption and total energy consumption was significant thereby adjusting coal production capacity. It is an effective coal production adjustment measure.

(2) Carbon emissions

From the results of CO_2 emissions, total CO_2 emissions shows slow upward trend under various economic growth rate, and the

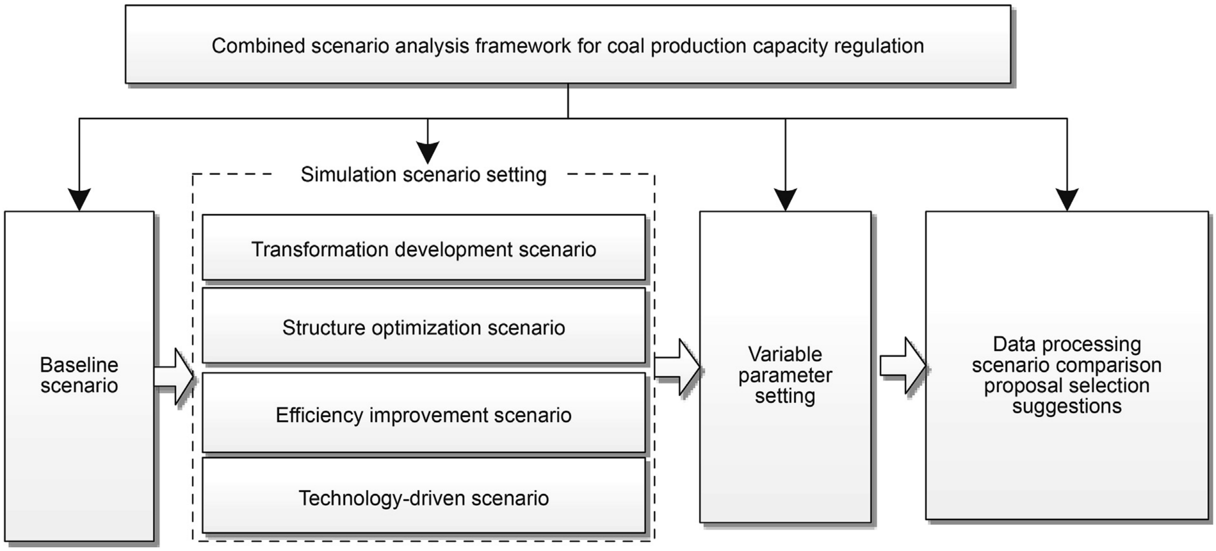

Fig. 7. Combinations scenario analysis frame of coal production capacity regulation.

Table 3
Growth rate of GDP in different scenarios.

Scenario	Low-speed scenario	Medium-speed scenario	High-speed scenario
2016–2020	5.5%	6.3%	7.1%
2021–2025	4.8%	5.6%	6.4%

Table 4
Baseline scenario settings (A0).

Parameters	Trend
IS	In 2025, the proportions of the primary, secondary, and tertiary industries will be 7%, 36.3%, and 56.7%, respectively.
FDR	Fixed delivery rate of will reduce to 70% in 2025.
GI	Government intervention intensity will increase linearly to 1 in 2020 and gradually decrease to 0 in 2025.
OCE	Outdated capacity elimination rate is set at 2.726%.
CU	Capacity utilization rate will reach over 85% by 2025, realizing the effective allocation of production factors in the coal industry.
RR	Recovery rate will reach 85% in 2025.
MD	Mechanization degree will reach to 80% in 2020 and 85% in 2025.
ET R&D	Energy technology R&D investment coefficient is 0.022171.
CI	Coal imports will increase to 300 million tons in 2020 and 350 million tons in 2025.
CE	Coal exports limit to less than 5 million tons by 2025.

Table 5
Transformational development scenario settings (A1).

Parameters	Trend
IS	The proportions of the primary, secondary, and tertiary industries in 2025 will be 6%, 35%, and 59% respectively.
FDR	Reduce the delivery rate of fixed assets to 68% in 2025.
OCE	“Document 7” identified that starting from 2016, about 500 million tons of production capacity will be withdrawn in the next 3–5 years, and the annual elimination rate is set at 3.6% accordingly.

Table 6
Optimization structure scenario settings (A2).

Parameters	Trend
CI	Increase to 350 million tons in 2020 and 400 million tons in 2025.
CE	Implement coal export control and control coal export volume below 3 million tons.

annual increase in CO_2 emissions shows a clear downward trend, indicating that various policy adjustment scenarios have played an active role in effectively controlling carbon emissions. The technology-driven scenario (D15, D25, D35) has the lowest CO_2 emissions under three economic growth scenarios, followed by the transitional development scenario (D12, D22, D32). Under low economic growth, the lowest CO_2 emissions in 2020 and 2025 are 6.718 billion tons and 7.149 billion tons, respectively. The analysis

Table 7
Energy efficiency scenarios settings (A3).

Parameters	Trend
MD	Increase to 95% in 2020 and 100% in 2025.
RR	The recovery rate is set to increase by 5% on the original basis.

shows that due to the increased investment in energy science and technology under the technology-driven scenario, the proportion of coal in primary energy consumption has been effectively adjusted, which directly feeds back to coal consumption demand, improves coal utilization efficiency, and reduces total coal demand. As a result, the reduction of CO_2 emissions in the technology-driven scenario is more pronounced than in other scenarios. In addition, the transformational development scenario reduces energy consumption by optimizing the three major industrial structures, and then acts on the total energy consumption and total coal demand through a feedback loop to reduce CO_2 emissions.

(3) Energy consumption structure

From the results of energy consumption structure, coal resources will remain dominant in the future. According to Table 10, the proportion of coal in energy consumption in the technology-driven scenario has been further optimized compared with other control modes. The coal demand structure has reached 53.03%, 51.73%, and 50.36%, respectively, compared with the baseline, structural optimization, and energy efficiency improvement scenarios. It is reduced by 9.24–12.96% in comparison. This is primarily due to the increased investment in energy technology under the technology-driven situation, which has played an important role in the conservation of coal resources and the clean utilization of coal.

(4) CO_2 emission intensity

From the results of CO_2 emission intensity, under various scenarios it shows a clear downward trend. Especially, the downward trend of the technology-driven policy scenario is the most obvious. In 2020, the CO_2 emission intensity will reach 0.69 tons/10,000 yuan. In 2025, the CO_2 emission intensity of 2.18 tons per 10,000 yuan was reduced by 68.34%, which exceeded expectations to achieve the relative reduction target of 40%–45%.

(5) Coal supply and demand

Under the three economic growth rate scenarios, the change trend of coal supply is relatively stable, but the change trend of coal demand is obviously different, the coal demand is the lowest when the economy is growing at a low speed, and the largest when the economy is growing at a high speed, this leads to an expanding trend of supply and demand gaps in the scenario of rapid economic growth, which is not conducive to the control of coal production capacity. Coal consumption demand can be effectively controlled by

Table 8
Technology-driven scenarios settings (A4).

Parameters	Trend
ET R&D	Increase the proportion of energy technology R&D investment in GDP, and set the coefficient of energy technology R&D investment to 0.025.

Table 9
Coal capacity regulatory policy combinations.

Scenario	Mode				
	Proposal				
	Baseline Scenario	Transformation Development	Structure Optimization	Improve Energy Efficiency	Technology-driven
Low-speed scenario	D11	D12	D13	D14	D15
Medium-speed scenario	D21	D22	D23	D24	D25
High-speed scenario	D31	D32	D33	D34	D35

Table 10
Scenario analysis of total energy consumption and carbon emission.

Scenario	Proposal	Total energy consumption (100 million tons)		CO_2 emissions (100 million tons)		Proportion of coal in energy consumption (%)		Carbon emission per unit GDP (tce/10,000 yuan)	
		2020	2025	2020	2025	2020	2025	2020	2025
Low-speed scenario	D11	48.19	56.51	69.60	75.17	60.54	55.75	0.72	0.61
	D12	47.69	55.20	68.88	73.42	60.54	55.75	0.72	0.59
	D13	48.19	56.51	69.60	75.17	60.54	55.75	0.72	0.61
	D14	48.19	56.51	69.60	75.17	60.54	55.75	0.72	0.61
	D15	48.19	56.51	67.18	71.50	58.43	53.03	0.70	0.58
Medium-speed scenario	D21	48.91	59.57	70.36	77.60	60.29	54.59	0.72	0.59
	D22	48.41	58.19	69.64	75.80	60.29	54.59	0.71	0.58
	D23	48.91	59.57	70.36	77.60	60.29	54.59	0.72	0.59
	D24	48.91	59.57	70.36	77.60	60.29	54.59	0.72	0.59
	D25	48.91	59.57	67.86	73.53	58.15	51.73	0.69	0.56
High-speed scenario	D31	49.65	62.79	71.12	79.97	60.04	53.38	0.72	0.58
	D32	49.14	61.33	70.39	78.12	60.04	53.38	0.71	0.57
	D33	49.65	62.79	71.12	79.97	60.04	53.38	0.72	0.58
	D34	49.65	62.79	71.12	79.97	60.04	53.38	0.72	0.58
	D35	49.65	62.79	68.55	75.44	57.86	50.36	0.69	0.55

Table 11
Scenario analysis of total coal supply-demand and investment of energy technology.

Scenario	Proposal	Coal demand (100million tons)		Coal supply (100million tons)		GDP (trillion yuan)		Energy technology investment (trillion yuan)	
		2020	2025	2020	2025	2020	2025	2020	2025
Low-speed	D11	29.17	31.50	41.98	53.11	96.28	124.18	1.92	2.54
	D12	28.87	30.77	39.83	49.88	96.28	124.18	1.92	2.54
	D13	29.17	31.50	42.45	53.51	96.28	124.18	1.92	2.54
	D14	29.17	31.50	41.98	53.11	96.28	124.18	1.92	2.54
	D15	28.15	29.97	41.73	52.56	96.28	124.18	2.20	2.89
Medium-speed	D21	29.49	32.52	42.03	53.80	97.74	130.92	1.96	2.69
	D22	29.18	31.77	39.88	50.54	97.74	130.92	1.96	2.69
	D23	29.49	32.52	42.50	54.19	97.74	130.92	1.96	2.69
	D24	29.49	32.52	42.03	53.80	97.74	130.92	1.96	2.69
	D25	28.44	30.82	41.77	53.22	97.74	130.92	2.23	3.06
High-speed	D31	29.81	33.52	42.08	54.50	99.21	137.97	1.99	2.85
	D32	29.50	32.74	39.93	51.22	99.21	137.97	1.99	2.85
	D33	29.81	33.52	42.55	54.89	99.21	137.97	1.99	2.85
	D34	29.81	33.52	42.08	54.50	99.21	137.97	1.99	2.85
	D35	28.73	31.62	41.82	53.90	99.21	137.97	2.27	3.24

controlling economic growth expectations, taking measures to transform and upgrade, optimizing structure, improving energy efficiency, and developing technology. From the perspective of coal demand, under the scenarios of low and medium economic growth, the total coal demand is effectively controlled. Especially, the coal demand of the technology-driven mode is the smallest, reaching 2.815 billion tons, 2.844 billion tons, and 2.873 billion tons, respectively, in 2020, which are significantly reduced compared to the other scenarios. Because of its scenario settings, the efficiency of coal utilization can be improved and coal consumption relatively reduced when the input of energy technology increases. From the perspective of coal supply, China's total coal supply in 2020 under the transitional development scenario will be 3.893 billion tons, 3.988 billion tons, and 3.993 billion tons, respectively. Which are significantly reduced compared to the other scenarios. The reduction is largely due to the reduction of economic growth expectations and the strengthening of total coal demand control Table 11.

(6) Changes in coal production capacity

To reflect the effect of capacity control under various schemes, the twelve scenarios represented by the transformational

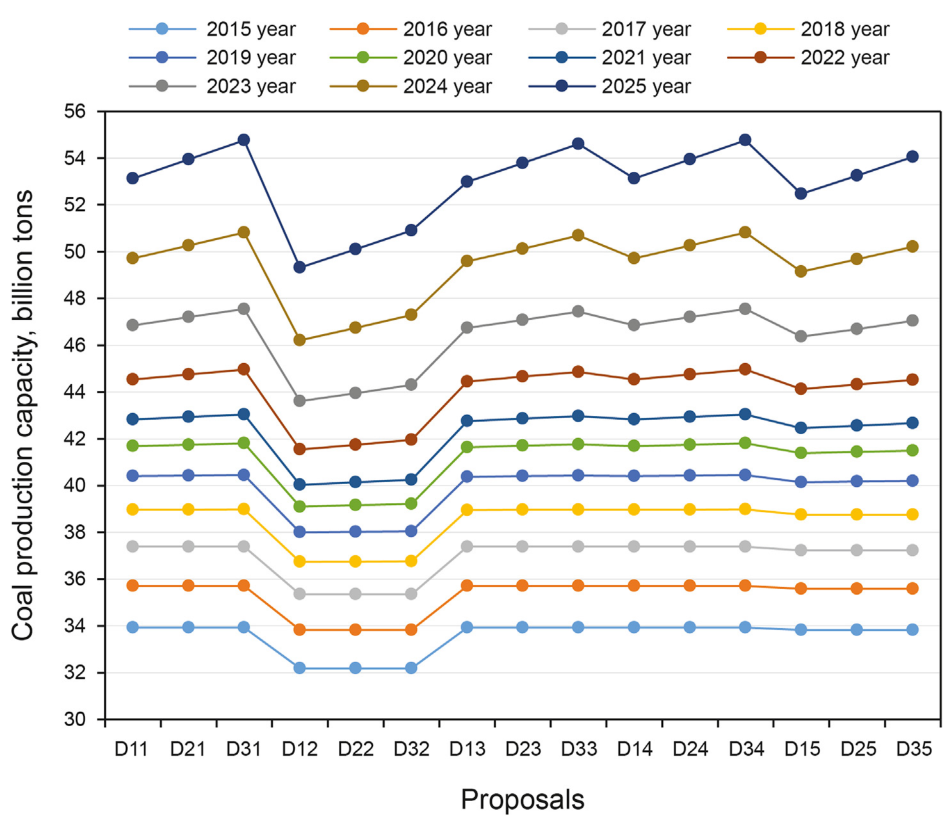

Fig. 8. Comparison of coal production capacity in various scenarios.

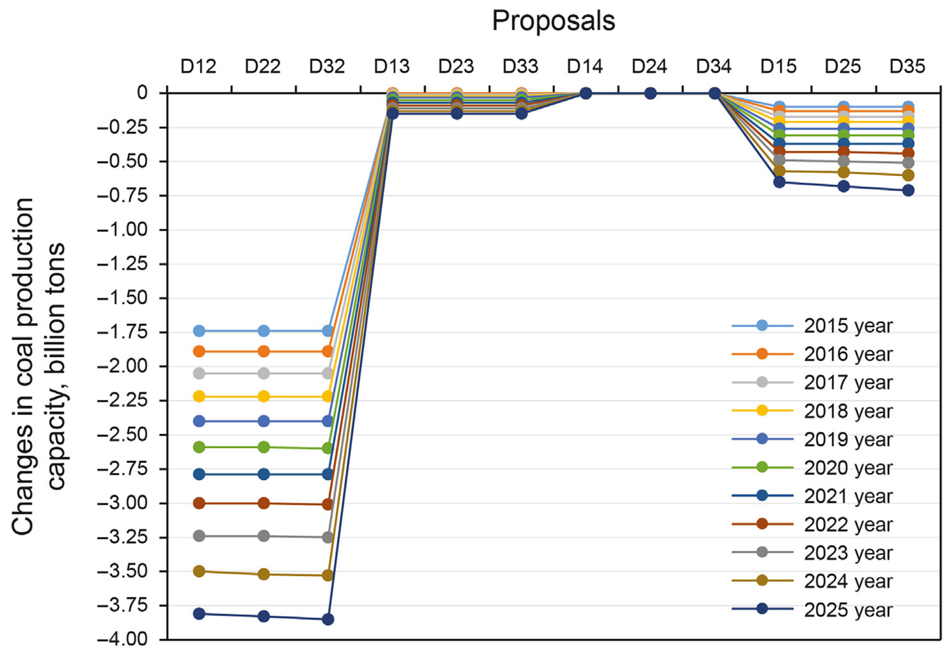

Fig. 9. Comparison of regulatory potential in various scenarios.
Note: "-" in the figure indicates a reduction in coal production capacity.

development, structural optimization, energy efficiency improvement, and technology-driven scenarios were compared with the three baseline scenarios to analyze the capacity control potential of comprehensive adjustment of factors. As is shown in Figs. 8 and 9.

According to the results, China's coal production capacity continues to show an overall growth trend under the control scenario. However, compared with the baseline scenario, the coal production capacity growth rate of each control scenario under the combined effect of factors has been significantly eased. In terms of the horizontal comparison of regulatory potential, the five programs under rapid economic growth show that the intensity of capacity control is significantly better than other programs. In terms of the vertical comparison of regulatory potential, the transformational development mode (D12, D22, D32) under various economic growth development have the greatest potential for capacity regulation, followed by technology-driven, structural optimization, and energy efficiency improvement mode. The contribution of each element of the transformational development mode is much greater than that of other mode.

Based on the above results, energy consumption, coal demand, coal supply, and coal production capacity will increase from 2016 to 2025 with the increase in economic growth and under different economic growth scenarios. The higher the GDP growth rate, the greater the growth. Obviously, this has further verified that GDP growth is the main driving force for the growth of coal resource consumption. The four control modes have played a significant role in regulating the excessive growth and investment in coal production capacity and the slowing of coal demand's growth rate.

From the comparison of the control potential of the four control modes, the transformational development mode has the most obvious inhibitory effect on capacity growth. The technology-driven mode is second in suppressing the growth of coal production capacity, and the third is the structural optimization mode. It shows that the promotion of coal enterprise reform and reorganization, industrial structure adjustment, layout optimization, transformation and upgrading, and other policy measures have significant comprehensive effects on the coal production capacity control system. The regulation and control effect of scientific and technological progress has gradually emerged and has accumulated strength with the implementation of policies. This shows that to maximize scientific and technological power and realize optimization and adjustment of coal production capacity from a macro level, it is necessary to gradually realize the economic growth model driven by the input of labor, capital, and other factors, to the benefit-driven economic growth model, and then to the economic growth model driven by technological innovation. The efficiency improvement model has no obvious effect on suppressing production capacity and has no obvious emission reduction effect. This conclusion is consistent with the single regulation policy because the asset specificity of coal production, the existence of technology lock-in effect, the level of mechanization, and the recovery rate are production-side control measures that have played a certain role in promoting the growth of coal production capacity. Their control effects are largely reflected in the improvement of production-side efficiency. Thus, it is necessary to increase corresponding taxes or financial policies linked to the two indicators, increase investment costs, and strengthen external management. In this manner, the excessive growth of ineffective low-end production capacity is restrained while improving production efficiency.

5. Conclusion and discussion

(1) The use of single capacity control policies, such as reducing economic growth, optimizing industrial structure, encouraging coal import, limiting coal export, improving mechanization, recovery rate and capacity elimination rate, increasing energy technology research and development and appropriate government intervention, is conducive to controlling the excessive growth of coal production capacity. However, there are obvious differences in their effect: OCE> IS> ET R&D> FDR> CU> EG> CI> GI> CE> RR> MD. Among them, OCE, IS, ET R&D, FDR, CU, EG, CI, GI, and CE are negatively correlated with coal production capacity, which are important means of resolved overcapacity and have

relatively strong in capacity control. However, MD and RR are positively correlated with coal production capacity, and its control effect is relatively small. The main reason for the difference is that China's coal industry is largely affected by national policy plans such as supply-side structural reform and economic structure adjustment, restrictive policies related to state power have far greater control over capacity than the market and the company's own regulatory actions.

(2) The four combined regulation modes of transformational development mode, structural optimization mode, energy efficiency improvement mode and technology-driven mode have played a significant role in regulating the excessive growth of coal production capacity and investment in new capacity, and slowing down the growth rate of coal demand. Because the combined control model can form a complementary mechanism, the control effect of its coal production capacity is far greater than the use of a single control policy and control model.

(3) The transformational development mode has the best effect in controlling total energy consumption, adjusting coal supply, and restraining the excessive growth of coal production capacity, while the technology-driven mode has the best effect in reducing total carbon emissions and controlling coal demand. Therefore, these two control modes should be used first. On the one hand, adjusting the industrial structure, restricting blind investment, and accelerating the elimination of backward production capacity, realizing the regulation of energy consumption and energy supply, and promoting the rational optimization of coal production capacity. On the other hand, increase investment in energy technology, and promote the conservation and clean use of coal resources.

According to the conclusions, realizing reasonable regulation of coal production capacity requires attention on the comprehensive application of regulation modes and methods, and the establishment of an interactive policy regulation system for coal production capacity.

(1) Realize coal demand-side macro management through industrial structure optimization, economic growth adjustment, and appropriate government intervention. Support the new industrial system and the tertiary industry. Realize the optimization and upgrade of the industrial structure. Appropriately reduce the economic growth rate, ensure steady economic development, control the total coal demand within a reasonable range, ensuring strict market access, project approval, environmental standard protection, and appropriate government intervention from the source of coal mine investment.

(2) Further implement macro-control measures such as horizontal and vertical coal resource integration and corporate mergers and reorganizations. Establish an exit mechanism for outdated production capacity and strengthen the elimination of outdated production capacity. Establish a coal investment restraint mechanism to guide enterprises to invest rationally reduce coal production capacity investment increments, and optimize investment structure.

(3) Adopt coal import quota measures to reduce imports, reduce the gap between coal supply and demand, provide full play to the multiplier effect of coal imports on production capacity control, and achieve a balance of coal supply and demand with dynamic control.

(4) Promote supply-side reform of the coal industry, increase investment in energy technology, attach importance to energy technology progress, provide full play to potential existing resources, use energy technology to realize green and ecological coal production and utilization, and improve coal production efficiency and utilization effectiveness.

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