Simulation and Optimization of Coal Consumption Policy in Beijing-Tianjin-Hebei and Its Surrounding Areas

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Abstract: Taking coal consumption in beijing-tianjin-hebei and its surrounding areas as the research object, based on the analysis of the system structure, coal consumption is taken as the main control factor and integrated into the economic-social-environmental System dynamics model, taking GDP growth rate, population growth rate, R & D input intensity and environmental control investment as control parameters, four policy combination scenarios were set up to simulate coal consumption and air pollutant emission in beijing-tianjin-hebei and its surrounding areas. The results show that the total coal consumption and sulfur dioxide emission are 385.319 million tons and 1313.08 million tons respectively in the middle-high-high scenario and 24.59% and 32.29% respectively in the middle-middle scenario and the high-middle-middle scenario, the ratio of high-high-high scenario decreased by 6.73% and 6.23% respectively, and the system reached the optimal state. Therefore, the total coal consumption control in this region must take the strengthening of environmental regulation as the grasp, increase r & D input, and maintain a reasonable economic and population growth rate.

Keywords: Beijing-tianjin-hebei and surrounding areas; coal consumption; system simulation

1. Introduction

As a basic strategic resource, energy consumption plays an important supporting role in China's economic and social development. And energy consumption is a "Double-edged sword". Unreasonable energy consumption structure brings huge pressure to the ecological environment, in particular, the excessive use of coal-based one-off fossil energy has become a major cause of frequent haze in China in recent years, which has seriously affected the health of residents and the sustainable development of the economy and society. To control the total amount of coal consumption and reduce the impact of coal consumption on the atmospheric environment has become an urgent problem to be solved. In response, the state has issued a series of policy documents, including "Ten measures to prevent and control air pollution" and "Three-year action plan to win the battle to defend the Blue Sky", in which the control of total coal consumption is taken as the main means to control air pollution. However, under the high-intensity policy impetus from top to bottom, due to ignoring the level and level of economic and social development in various regions, the coal consumption control appears the "One-size-fits-all" problem and the "Isolated island" phenomenon, such as the enterprises simply shut down but the transformation is insufficient, the energy substitution is direct and crude, and the effect of each government is different. Coal consumption control is a complex systems engineering, involving many aspects of the economy and society, the study of coal consumption control has become an academic focus area. The current research focuses on the driving factors of coal consumption, the quantitative relationship between coal consumption and air pollutants, the relationship between coal consumption and economic growth, and the total amount control. Previous studies have shown that there is a coupling and coordination relationship between coal consumption and the three systems of economy, society and Environment [1], and the change of total coal consumption is the result of the interaction of many factors [2]. The control of total coal consumption should be taken into account comprehensively from such factors as economic development level [3-4], industrial structure [5], coal price [6], and technology application [7]. The control of the total coal consumption should be based on the prediction of the total coal consumption. At present, the research on the prediction of the total coal consumption mainly concentrates on the level of national [8], provincial [9] and some big cities [10], Some scholars also predict the total coal consumption in different industries [11]. The energy consumption elasticity coefficient method [12], grey system theory [13] and BP Model [14] are adopted in the research methods, and the feedback effect on coal consumption is analyzed with the aim of ecological environment [15]. Through literature review, it is found that the existing research mainly focuses on the relationship between coal consumption and single influencing factor, but the change of total coal consumption is the result of the joint action of many factors, the study of single influencing factor cannot reasonably explain the change trend of total coal consumption. In this paper, based on the ecological constraint red line, the threshold of coal consumption is measured by the System dynamics model, the main driving factors of coal consumption are clarified by the sensitivity analysis method, the precision of prediction is improved, and the policy combination of coal consumption control is selected to provide decision-making basis for coal consumption control in beijing-tianjin-hebei and its surrounding areas.

2. Research Methods and Data Sources

2.1 Correlation thinking of SD model of coal consumption system

The sustainable economic development of Beijing-tianjin-hebei and its surrounding areas cannot be separated from the energy support with coal as the core, and the excessive consumption of coal leads to the continuous deterioration of atmospheric environment. This kind of important energy element cannot be simply regarded as the exogenous variable of ecological environment, but should be regarded as the main control factor in the process of ecological environment optimization. This paper deconstructs the coal consumption subsystem from the aspects of domestic coal and industrial coal, and develops an “Economic-social-environmental” model with coal consumption as the main controlling factor. In this model, besides considering the transfer and allocation of production factors such as capital and labor force, and the dynamic process of social and economic development such as industrial development, the coal consumption driven by industrial production, life and ecological environment is further simulated.

On the coal consumption subsystem and the “Economy-society-environment” system connection (Figure 1), first, the rapid economic development will form a huge demand for coal, including industrial coal, domestic coal and so on. Second, sustained economic growth and rapid urbanization put pressure on the coal consumption system, and the response of the coal consumption system to this may ultimately affect the sustainable development of the economy. The industrial production process with coal as the main energy source will produce a large number of waste gases containing harmful substances, and the daily use of coal by residents will also produce certain waste gases, these gases, if left untreated, will have a negative impact on the sustainable development of the economy, society and the environment. Third, good coordination can be formed between high-quality economic development, urbanization process and coal consumption system. As a result of social and economic development, increased investment in environmental protection treatment and technological progress, the efficiency of coal use will be enhanced, thereby contributing to the reduction of coal demand, while the continuously improved exhaust gas purification technology will protect the atmospheric environment, the negative feedback effect of environmental system on coal consumption system is weakened to some extent. This virtuous circle process provides energy guarantee for the healthy and stable development of economy, society and Environment. Therefore, the coal consumption subsystem is directly related to the “Economy-society-environment” system in Beijing-tianjin-hebei and its surrounding areas through the important variables such as the output value of coal secondary sector of the economy, the rural population, the urban population and the emission of sulfur dioxide, which indicates the degree of air pollution.

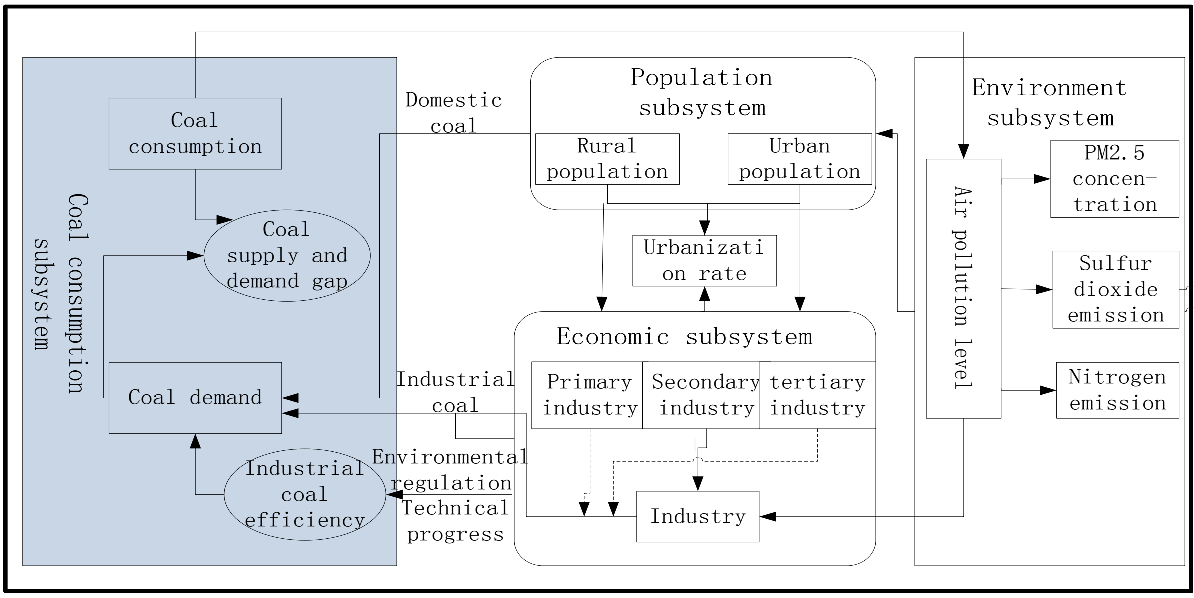

Figure 1. Logical relation between coal consumption subsystem and “Economy-society-environment” system

2.2. Data sources

In this paper, 28 cities in Beijing, Tianjin and Hebei and their surrounding areas are selected as the study area, the economic, social and environmental data of GDP, urban population and SO2 emission were collected from China Urban Statistical Yearbook (2018) and other statistical yearbooks. Data from the coal consumption subsystem are selected from the China Energy Statistics Yearbook (2018). For missing data, such as 2017 industrial value-added coal consumption of 10,000yuan, trend algorithm is used to calculate. SPSS tool was used to fit the main function relations in the model, and Vensim software was used to construct the SD model.

3. Result Analysis

3.1 Simulation model construction and verification

3.1.1 Coal consumption subsystem module

This module mainly simulates the change of total coal consumption (CL-CONSUMPTION) in the study area, assuming that it mainly comes from domestic coal consumption (CL-LIFE) and industrial coal consumption (CL-INDUSTRY). Among them, domestic coal consumption is subdivided into urban and rural domestic coal consumption (CL-UBLIFE, CL-RPLIFE), whose value depends on urban (rural) population (UB-NUMBER, RP-NUMBER), urban (rural) per capita domestic coal consumption (UB-PCL, RP-PCL), and is affected by urban (rural) per capita disposable income (UB-INCOME, RD-INCOME); Industrial coal consumption is the product of industrial GDP (GDP-INDUSTRY) and coal consumption per ten thousand yuan of industrial GDP (DAWL-C&G), which is affected by environmental governance investment (EPI) and science and technology progress factor (SCI-FACTOR); Scientific and technological progress factor is determined by R&D (*R&D-APPORTS*) input and scientific research output (*SR-OUTPUT*). The main formulas among variables of coal consumption subsystem module are shown in Table1, and the logic structure is shown in Figure 2.

Table1. Main equation of coal consumption system

Module	Principal equation
Total coal consumption	*CL-CONSUMPTION=CL-LIFE+CL-NDUSTRY*
Domestic coal consumption	*CL-LIFE= CL-UBLIFE+ CL-RPLIFE* *CL-UBLIFE= UB-NUMBER×UB-PCL* *CL-RPLIFE= RP-NUMBER×RP-PCL* *UB-PCL=UB-INCOME×FACTOR1* *RP-PCL= RD-INCOME×FACTOR2*
Industrial coal consumption	*CL-INDUSTRY=GDP-INDUSTRY ×DAWL-C&G* *DAWL-C&G=SCI-FACTOR×RATIO1*

Note: In the table, FACTOR1 is UB-INCOME's impact actor on UB-PCL, FACTOR2 is RD-INCOME's impact factor on P-PCL, and RATIO1 is SCI-FACTOR's impact factor on *DAWL-C&G*.

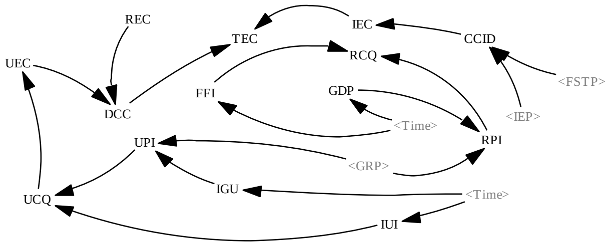

Figure 2. Logical structure of variables in coal consumption subsystem

3.1.2 Economic subsystem module

The construction method of economic, social and environmental subsystem mainly refers to the dynamic model of urbanization system constructed by Gu [16]. The economic subsystem takes the regional GDP as the core variable, which mainly includes the output value of the primary, secondary and tertiary industries (the state variable), the added value of the primary, secondary and tertiary industries (the rate variable) and the industrial added value etc., the logical structure of the variables is shown in Figure 3, which contains the main equations:

GDP of primary industry = INTEG (added value of GDP of primary industry, 5414.12, unit: billion yuan)

Primary industry GDP growth rate = Primary industry GDP growth rate over time table LOOKUP (time)

Secondary sector of the economy GDP = INTEG (secondary sector of the economy, 36,917.7)

Secondary sector of the economy GDP growth rate = Secondary sector of the economy GDP growth rate over time LOOKUP (time)

Tertiary sector of the economy GDP = INTEG (tertiary sector of the economy, 33906.5)

Tertiary sector of the economy GDP growth rate = Tertiary sector of the economy GDP growth rate over time LOOKUP (time)

Industrial value added = Secondary sector of the economy × proportion of industrial secondary sector of the economy

GDP = Primary industry output + Secondary sector of the economy output + Tertiary sector of the economy output

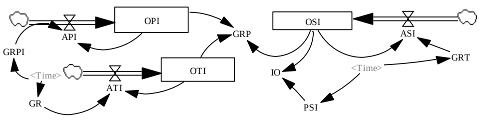

Figure 3. Logical structure of variables in economic subsystem

3.1.3 Social subsystem modules

The social subsystem is divided into the rural population and the urban population, and its change depends on the change of the birth rate and the mortality rate. It is an important indicator of the level of human resources in the region, the development of the national economy and the use of coal energy must serve the population. Accordingly, the total population and its structure also have a profound impact on the total economic output, the total coal consumption and the emission of pollutants.

The social subsystem is composed of the urban population, the rural population, the urban birth rate, the urban mortality rate, the rural birth rate, the rural mortality rate and so on:

Urban population = INTEG (urban population growth-urban depopulation, 10,698.4, in 10,000)

Urban population growth = Urban birth rate LOOKUP (time) × Urban population

Urban population decline = Urban mortality LOOKUP (time) × Urban population

Rural population = INTEG (rural population growth-rural population decline, 8,505.8, units: 10,000)

Rural population growth = Rural birth rate LOOKUP (time) × Rural population

Declining rural population = Rural mortality LOOKUP (time) × Rural population

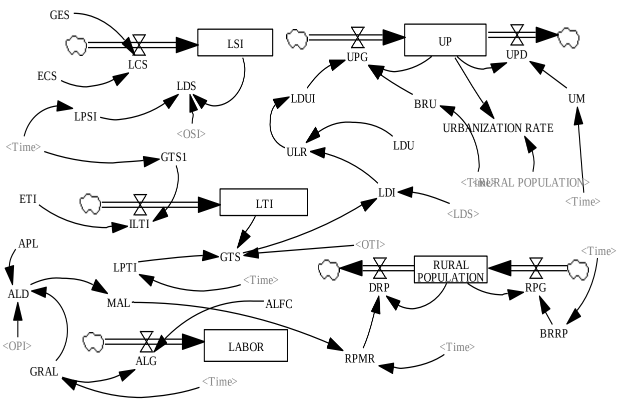

Figure 4. logical structure of social subsystem variables

3.1.4 Environment subsystem module

In the process of forecasting the total coal consumption with the ecological red line constraint method, the ecological environment will be taken as the main index to judge whether the total coal consumption reaches the relative optimum or not. The increase of coal consumption will affect the emission of sulfur dioxide, nitrogen compounds and PM2.5 air pollutants. Considering the authenticity of the data and the uniqueness of the index, the emission of sulfur dioxide is chosen as the core variable in the environmental subsystem, the logical structure of the environmental subsystem variables is shown in figure 5. The main equations include:

Sulphur dioxide emissions = sulphur dioxide production-sulphur dioxide removal

Sulfur dioxide removal = sulfur dioxide production X coal desulfurization efficiency

Coal desulfurization efficiency = Science and technology progress factor × 0.499568(obtained by SPSS Fitting)

Sulfur dioxide production = sulfur conversion of coal LOOKUP (time) × total coal consumption

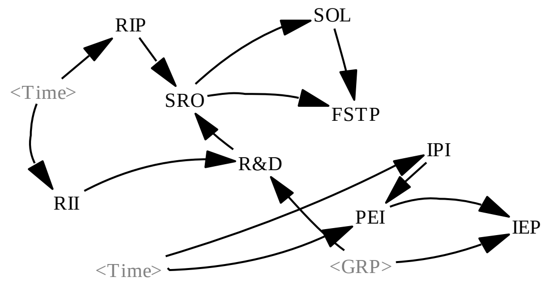

Figure 5. logical structure of environment subsystem variables

3.1.5 Construction of compound system of economy-society-environment-coal consumption

Based on the comprehensive analysis of the causal relationship and the overall structure of the variables, the simulation model of the “Economy-society-environment-coal consumption” system in the study area is constructed by using the statistical data of beijing-tianjin-hebei and its surrounding areas from 2010 to 2017, the coal consumption subsystem is connected with the economic subsystem, the social subsystem and the environmental subsystem through the links of “Industrial added value-industrial coal consumption”, “Urban (rural) population-urban (rural) living coal consumption” and “Total coal consumption-SO2 emission”. The model consists of 84 variables, including 9 state variables, 11 rate variables, and 64 auxiliary variables, it involves the industrial structure, population, environmental regulation and technical progress efficiency which affect the total coal consumption in the study area. The SD model flowchart is shown in Figure 6.

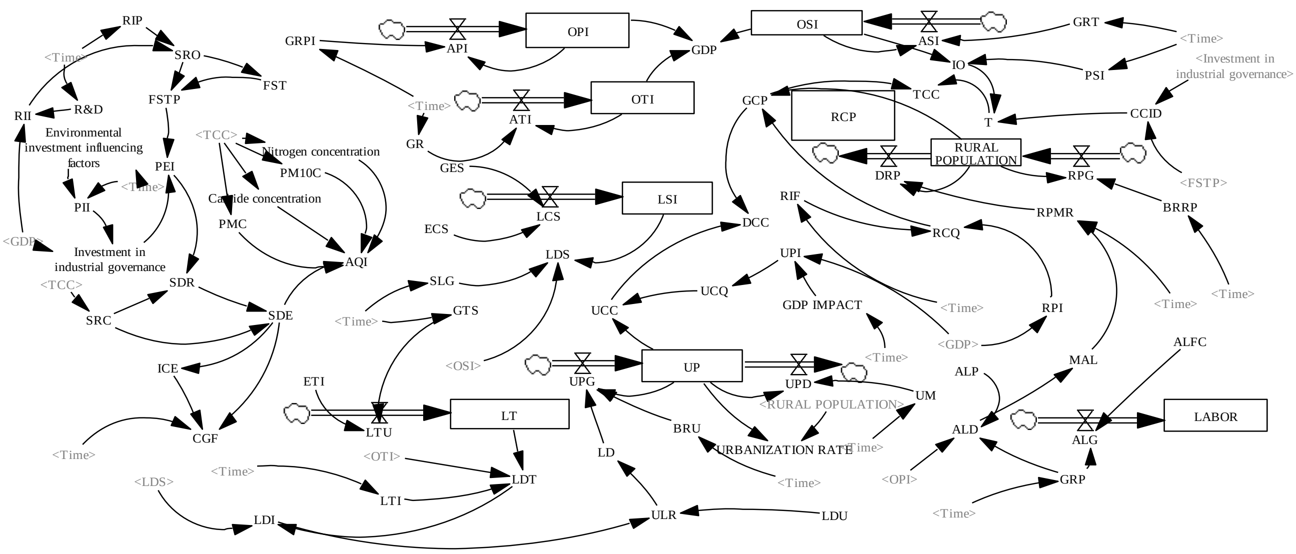

Figure 6. SD model of “Coal consumption-economy-population-environment”

NOTE:
RIP: R&D Input impact factors
CS: Coal shortage
RII: R&D Input intensity
RCC: Rural coal consumption
SRO: Scientific research output
DCC: Domestic coal consumption
UCQ: Urban per capita coal consumption quota
UPI: Urban per capita disposable income
TCC: Total coal consumption
LDU: Labor demand of urban industry in the early stage
DUP: Decreasing urban population
ALP: Agricultural labor productivity
SRC: Sulfur conversion rate of coal
ALD: Agricultural labor demand
ICE: Initial CO2 emissions
GRP: Growth rate of agricultural labor productivity
CGF: CO2 emission growth factor
ALG: Agricultural labor growth
LCE: Labor force coefficient of secondary industry
RCQ: Coal consumption quota in rural areas
SOL: Scientific research output of last year
DRP: Decreasing rural population
FST: Factors of scientific and technological progress
RPI: Rural per capita disposable income
IEP: Impact factors of environmental protection investment
MAL: Migration speed of agricultural labor force
PEI: Proportion of environmental protection investment
GRT: Growth rate of output value of secondary industry
EPI: Environmental protection investment
PSI: Proportion of industry in secondary industry
CCID: Coal consumption of industrial added value
RPG: Rural population growth
SDP: Sulfur dioxide production
RPMR: Rural population migration rate
GRP: wth rate of output value of primary industry
FSTP: Factors of scientific and technological progress
SDE: Sulfur dioxide emissions
RCP: Regional coal production
ETI: Employment coefficient of tertiary industry
BRRP: Birth rate of rural population
LTI: Labor growth in the tertiary industry
OTI : Output value of tertiary industry
TLR: Third industry laborer Yield growth rate
LDI: Labor demand of urban industry
CDE: Coal desulfurization efficiency
SFR: Sulfur dioxide removal
GRT: Growth rate of output value of tertiary industry
GES: Growth rate of employees in the secondary industry
ECS: Employment coefficient of secondary industry
SLG: secondary industry Labor productivity growth rate
GTS: Growth rate of employees in the tertiary industry
LTI: Labor force in the tertiary industry
LDT: Labor demand of the tertiary industry
API: Added value of primary industry
ATI: Added value of tertiary industry
LCS: Labor force coefficient of secondary industry
LDS: Labor demand of secondary industry
UCC: Urban coal consumption
OPI: Output value of primary industry
OSI: Output growth of secondary industry
OTI: Output growth of tertiary industry
LSI: Labor force of secondary industry
UPD: Urban population decline
BRU: Birth rate of urban population
UDG: Urban industrial labor force Demand growth factor
GCP: Growth rate of coal production
APG: Annual coal production growth
UEC: Urban energy consumption
FFI: Factors affecting farmers' income
TEC: Total energy consumption
IEC: Industrial energy consumption
RCQ: Rural per capita living energy consumption quota
IUI: Influencing factors of urban income
IGU: Influence factors of GDP on urban income
IEP: Investment in environmental protection
FRP: Gross Regional Product
ASI: Added value of secondary industry in
ATI: Added value of the tertiary industry in
IO: Industrial output
IPI: Impact factors of environmental protection investment
PMC: PM2.5 concentration
NC: Nitrogen concentration
CC: Carbide concentration
PM10C: PM10 Concentration
OC: Ozone concentration
PII: Proportion of industrial governance investment

3.1.6 Model checking

The model is tested from two aspects: system flow rate and system sensitivity. On the one hand, the simulation values of key variables from 2010 to 2017 are compared with real historical data to check their relative errors (Table2).Because the "Economy-society-environment" model system related to coal consumption is complex and involves many variables, the key variables are mainly selected in the system storage flow test, this includes 2017 gross regional product, urban and rural population, total coal consumption, total industrial coal consumption and sulfur dioxide emissions. The results show that the average error between the simulated value and the actual value is about 0-4%, which is less than 5%.

The sensitivity analysis compares the output of the model by changing the input parameters of the model to determine the influence degree of different independent variables on the dependent variables. A stable and robust SD model is insensitive to changes in input parameters, the sensitivity analysis of the model is mainly to test the sensitivity of the model to the parameter change and to determine the influence degree of each control variable to the target variable. Therefore, the sensitivity of the system is analyzed by increasing or decreasing the value of the key parameter by 10%. The sensitivity analysis model is as follows:

$$S_Q = \left| \frac{\Delta Q_{(t)}}{Q_{(t)}} \cdot \frac{X_{(t)}}{\Delta X(t)} \right| \quad (1)$$

$$S = \frac{1}{n} \sum_{i=1}^{n} S_{Q_i} \quad (2)$$

In formula (1): for the sensitivity of the state variable q to Parameter X, for the values of the state variable q and the parameter X at time t, for the state variable Q and the parameter X at time T. In (2), S is the average sensitivity of the state variable q to the parameter X, and N is the total number of years.

The sensitivity test of "Economy-society-environment-coal consumption" in jing-jin-ji and its surrounding areas is carried out by selecting 10 variables from economic subsystem and social subsystem to test the sensitivity of coal consumption to 10 parameter changes. The results show that the sensitivity of most variables is less than 10%, which shows that the new model of "Economy-society-environment-coal consumption" is insensitive to the change of most parameters and meets the modeling requirements. From the sensitivity of each factor, it can be seen that the degree of the effect of each factor on coal consumption is R&D input intensity, environmental management investment, the proportion of industry in secondary sector of the economy, the growth rate of industrial output value, and the birth (death) rate of population. Therefore, in the process of setting up the parameters of the follow-up scenario model, the situation of coal consumption under different policy conditions is simulated by changing the main variables such as R&D input intensity, environmental management investment, GDP growth rate, and population birth (mortality rate), in order to choose the best policy guidelines.

Through the above system storage flow test and sensitivity test, the "Economy-society-environment" SD model based on coal consumption constraint is judged to have good simulation effect and sufficient stability, it can reflect and simulate the coal consumption in beijing-tianjin-hebei and its surrounding areas.

Table 2. Results of storage flow test and sensitivity analysis of key variables system

Storage flow test		**Sensitivity analysis**		
Variable	Average relative error/%	Variable	Increase sensitivity mean by 10%	Minus 10% sensitivity mean
Gross regional product	2.35	Primary sector of the economy	3.24	3.22
Primary sector of the economy	0.41	Secondary sector of the economy	4.32	4.78
Secondary sector of the economy	2.30	Tertiary sector of the economy	3.89	3.41
Tertiary sector of the economy	3.27	Investment in environmental governance	5.22	5.91
Industrial value added	0.58	R&D input intensity	6.47	6.41
Urban population	1.59	City birth rate	0.41	0.58
Rural population	0.63	Rural birth rate	0.22	1.25
Total coal consumption	1.39	Mortality rate of rural population	1.43	1.34
Domestic coal consumption	0.99	Industry as secondary sector of the economy	6.28	5.83
Industrial coal consumption	2.34	Mortality rate of urban population	0.77	0.36

3.2 Scenario setting and analysis

3.2.1 Scenario parameter setting

Since 2013, the country has carried out industrial transformation and upgrading, from the original “Two, three, one” model to “Three, two, one”, tertiary sector of the economy will replace secondary sector of the economy to become the leading industry of national economic growth, China’s economy has entered a period of structural slowdown. The 13th five-year plan points out that China’s GDP growth rate will remain below 8 percent from 2015 to 2020. According to the parameter setting of Chinese urbanization model constructed by Gu Chaolin [16], the economic growth rate is divided into high and middle scenarios. In the high plan, the growth rate of the output value of the primary, secondary and tertiary industries is set at 4%, 7% and 8% respectively. In the middle plan, the growth rate of the output value of the primary, secondary and tertiary industries is set at 3.5%, 6.5% and 7.5% respectively.

In terms of population policy, according to the trend of birth rate and mortality in the study area over the years, and in combination with the national population development plan (2016-2030) and the regional population development plan, the birth rate is set at 1.6 per thousand for 2018-2020, from 2020 to 2030, the mortality rate was 1.8 per thousand.

According to statistics, the R & D input intensity of “2 + 26” cities in Beijing, Tianjin and Hebei reached 2.73% in 2017, and the R & D input intensity increased by 0.04 percentage points on average from 2010 to 2017. Therefore, in the medium-speed development, R & D input intensity in accordance with the historical trend, with an annual increase of 0.04 percentage points set parameters. At present, the R & D input intensity in developed countries is generally around 3% [17], and the R & D input intensity in Japan is as high as 3.36%, which is the peak of our country in 2030, under the condition of the government supporting the development of R & D and the transformation and upgrading of enterprises, the R & D input intensity is increasing rapidly, and the parameter is set up by 0.055 percentage point every year.

The National Urban Ecological Protection and construction plan LRB (2015-2020) stipulates Chinahina’s investment in environmental management should reach the target of 3.5%GDP GDP by 2020. According to the data of past years, although the investment in environmental management in beijing-tianjin-hebei and its surrounding areas has increased by about 10% annually, its ratio to the regional GDP shows a fluctuating upward trend, with a high value of 2.15%, which is much lower than the national target. It is predicted that the growth rate of environmental governance investment in beijing-tianjin-hebei and its surrounding areas will be kept between 14-20% in the next few years [18]. Therefore, under the medium and high intensity of environmental regulation, the growth rate of environmental governance investment is 14% and 20% respectively.

3.2.2 Scenario

The SD model of “Economy-society-environment-coal consumption” in beijing-tianjin-hebei and its surrounding areas is simulated by using Vensim PLE [19-22]. The time step is 1 year and the system is simulated for 20 years. In the model, the four control variables (GDP growth rate, population growth rate, R&D input intensity and environmental governance investment) have only one change mode of population growth rate, and the other three variables have two growth modes of medium and high respectively, four control variable combinations altogether have 8 kinds of plans to carry on the scenario simulation to 2010-2030 area coal consumption situation, this article selects 4 kinds of representative plans to carry on the analysis, they are “Medium-medium-medium” (represents medium-speed GDP growth, medium-speed growth in the intensity of investment in R&D, and medium-environment regulation, as below), “Medium-high-high”, “High-medium-medium”, and “High-high-high”, the parameters of the four scenarios are set as shown in table 3. The other four scenarios are not discussed because the simulation results have the same trend with the first four scenarios and the numerical changes are small. Taking the emission of sulfur dioxide in the environmental subsystem as an index to judge the change of coal consumption, so as to find out the influence degree of different policies on the total coal consumption and choose the best policy combination, inorder to control the total coal consumption and optimize the atmospheric environment [23-26].

Scenario 1: Medium-medium-medium

Assuming that the GDP growth rate adopts the medium growth plan, the growth rate of R & D input intensity and environmental investment is in accordance with the medium growth rate [27-28], that is, the growth rate of the output value of the primary, secondary and tertiary industries are 3.5%, 6.5% and 7.5% respectively, R&D investment increased by 0.04% and environmental management investment increased by 14%. The coal consumption in beijing-tianjin-hebei and its surrounding areas from 2010 to 2030 was simulated. As can be seen from table 4 and Figure 4, R & D Investment increased at a medium rate in GDP, under the medium-intensity environment regulation scenario, the total coal consumption in the region reached 541.425 million tons and 510.952 million tons respectively in 2020 and 2030, and the sulfur dioxide emissions reached 2.408.91 million tons and 2.029.03 million tons respectively.

Scenario 2: Medium-high-high

Suppose the GDP growth rate is medium growth, the R&D input intensity increases at a high speed [29-30], and the environmental governance investment increases at a high speed, i.e. the output growth rate of the primary, secondary and tertiary industries is set the same as scenario 1, R&D investment intensity increased by 0.055 percentage points, and environmental management investment increased by 20%. According to table 4 and

Figure 4, the total coal consumption reached 507.982 million tons in 2020 and 385.319 million tons in 2030, sulfur dioxide emissions reached 2,023,450 tons and 1,313,080 tons, respectively.

Scenario 3: high-medium-medium

If the GDP growth rate adopts the high-speed growth plan, the R&D input intensity and the investment amount of environmental management increase in accordance with the medium speed [31-32]. The specific parameters are set as 4%, 7% and 8% of the growth rate of the output value of the primary, secondary and tertiary industries respectively, and 0.04% and 14% of the annual growth of R&D input intensity and environmental management investment respectively. Under this situation, the total coal consumption in the region in 2020 and 2030 reached 554.139 million tons and 547.901 million tons respectively, and the sulfur dioxide emissions reached 2.452.26 million tons and 2.164 million tons respectively.

Scenario 4: High-high-high

Assuming that the GDP growth rate adopts a high-speed growth plan [33-34], the R&D input intensity and the investment in environmental governance all grow at a high speed, that is, the growth rate of the output value of the primary, secondary and tertiary industries is 4%, 7%, 8%, the input intensity of R&D and the investment of environmental management are set up table function with an annual increase of 0.055 percentage points and 20% respectively. Under this situation, the total coal consumption in the region reached 519.905 million tons and 413.128 million tons in 2020 and 2030 respectively, and the sulfur dioxide emissions reached 2.059.84 million tons and 1.400.3 million tons respectively.

Table 3. Coal consumption schemes in Beijing, tianjin, hebei and surrounding areas

Develop-ment scenario	Develop-mentmodel	Time interval	Parameter setting
Scenario 1	Medium-medium-medium	2018-2030	The growth rate of primary industry output value: 3.5% The growth rate of the output value of the secondary industry: 6.5% The growth rate of the output value of the tertiary industry: 7.5% Birth rate:1.6‰ (2018-2020) 1.8‰ (2021-2030) Annual growth rate in R&D investment: 0.04% Annual growth in investment in environmental governance: 14%
Scenario 2	Medium-high-high	2018-2030	The growth rate of primary industry output value: 3.5% The growth rate of the output value of the secondary industry: 6.5% The growth rate of the output value of the tertiary industry: 7.5% Birth rate: 1.6‰ (2018-2020) 1.8‰ (2021-2030) Annual growth rate in R&D investment: 0.055% Annual growth in investment in environmental governance: 20%
Scenario 3	High-medium-medium	2018-2030	The growth rate of primary industry output value: 4% The growth rate of the output value of the secondary industry: 7% The growth rate of the output value of the tertiary industry: 8% Birth rate: 1.6‰ (2018-2020) 1.8‰ (2021-2030) Annual growth in R&D investment: 0.04% Annual growth in investment in environmental governance: 14%
Scenario 4	High-high-high	2018-2030	The growth rate of primary industry output value: 4% The growth rate of the output value of the secondary industry: 7% The growth rate of the output value of the tertiary industry: 8% Birth rate: 1.6‰ (2018-2020) 1.8‰ (2021-2030) Annual growth rate in R&D investment: 0.055% Annual growth in investment in environmental governance: 20%

From the simulation results (Figure 4), it can be seen that the total coal consumption in 2018- 2030 is on a downward trend under the conditions of different GDP growth rate, R & D input growth and environmental regulation, no matter which scenario policy can realize the requirement of "2 + 26" city's negative growth of coal consumption in the future, the trend line of coal consumption and SO_2 emission is as follows: Scenario 3 > Scenario 1 > Scenario 4 > Scenario 2. Scenario 3 total coal consumption and sulfur dioxide emissions are the highest among the four scenarios, but under moderate technological progress and moderate environmental constraints, regional coal consumption decreased from 583,077,000 tons in 2017 to 547,907,000 tons in 2030, an average annual decrease of 0.46 percent; Correspondingly, sulfur dioxide emissions caused by coal consumption decreased from 2,759,340 tons in 2017 to 2,164,090 tons, an average annual decrease of 1.65 percent. Scenario 1 with the same rate of technological progress and environmental regulation as scenario 3, the medium rate of economic development led to a significant decline in total coal consumption, total coal consumption and sulfur dioxide emissions were reduced to 510.952 million tons and 2.029 million tons respectively in 2030, a decrease of 6.74 percent and 6.24 percent respectively compared with scenario 3. Scenario 4 the increase in total coal consumption due to economic growth does not occur as the economy maintains a high growth rate and at the same time increases the speed of scientific and technological progress and environmental regulation, regional coal consumption and sulfur dioxide emissions reached 413.128 million tons and 1.400.3 million tons respectively in 2030, compared with scenario 3 and 1, respectively, a decrease of 24.59%, 19.15%, 35.29% and 30.99%. Scenario 2 under the constraints of medium-speed economic growth, high-speed scientific and technological progress and high-intensity environmental regulation, total coal consumption and sulfur dioxide emissions are far lower than the other three scenarios, with total coal consumption reaching 385.319 million tons in 2030,compared with scenario 3,1 and 4, the emission of sulfur dioxide was reduced by 29.67% , 24.59% and 6.73%,respectively, the emission of sulfur dioxide reached 1.313 million tons in 2030. Compared with scenario 3, 1 and 4, the emission of sulfur dioxide decreased by 39.32%, 35.29% and 6.23% respectively.

Compared with the simulation results of the four scenarios, scenario 3 belongs to the extensive development model. Although it can ensure the higher economic growth, the rate of coal consumption decrease is obviously slowed down due to the positive economic growth, and the total amount of coal consumption and the total amount of sulfur dioxide emissions are significantly higher than other scenarios. Scenarios 1 and 4 can basically guarantee the win-win of economy and environment. The control of total coal consumption and SO2 emission is better than scenario 3, but lower than scenario 2. In scenario 2, coal consumption is obviously restrained because of the increase of R & D input intensity, and this scenario has stronger control of SO2 emission and better protection of air pollution than the other three scenarios.

Table 4. Simulation results of coal consumption prediction in beijing-tianjin-hebei region and surrounding areas

variable	**Medium-medium-medium**		**Medium-high-high**		**High-medium-medium**		**High-high-high**	
	2020	2030	2020	2030	2020	2030	2020	2030
Primary industry output value (current year's price, billion yuan)	7482.33	10544.6	7482.33	10544.6	7627.96	11291.3	7627.96	11291.3
Secondary industry output value (current year price, 100 million yuan)	65714	123354	65714	123354	131714	123354	66956.8	131714
The output value of the tertiary industry (current year's price, 100 million yuan)	92552.6	190754	92552.6	190754	94286.6	203558	94286.6	203558
Gross Regional Product (RMB 100 million)	165749	324663	165749	324663	168871	346563	168871	346563
Rural population (10,000 people)	7327.72	6818.82	7327.72	6818.82	7327.72	6818.82	7327.72	6818.82
Urban population (10,000 people)	15648.4	16737.3	15648.4	16737.3	15648.4	16737.3	15648.4	16737.3
Rural coal consumption (tons)	901.425	1643.05	901.425	1643.05	918.406	1753.88	918.406	1753.88
Urban coal consumption (tons)	1253.09	2625.31	1253.09	2625.31	1276.7	2802.4	1276.7	2802.4
Total industrial coal consumption (tons)	51988	46826.8	48643.7	34263.5	50233.8	34263.5	49795.4	36756.5
Total coal consumption (tons)	54142.5	51095.2	50798.2	38531.9	55413.9	54790.1	51990.5	41312.8
Sulphur dioxide emissions (tons)	240.891	202.903	202.345	131.308	245.226	216.409	205.984	140.03
Sulfur dioxide emission (tons)	7482.33	10544.6	7482.33	10544.6	7627.96	11291.3	7627.96	11291.3

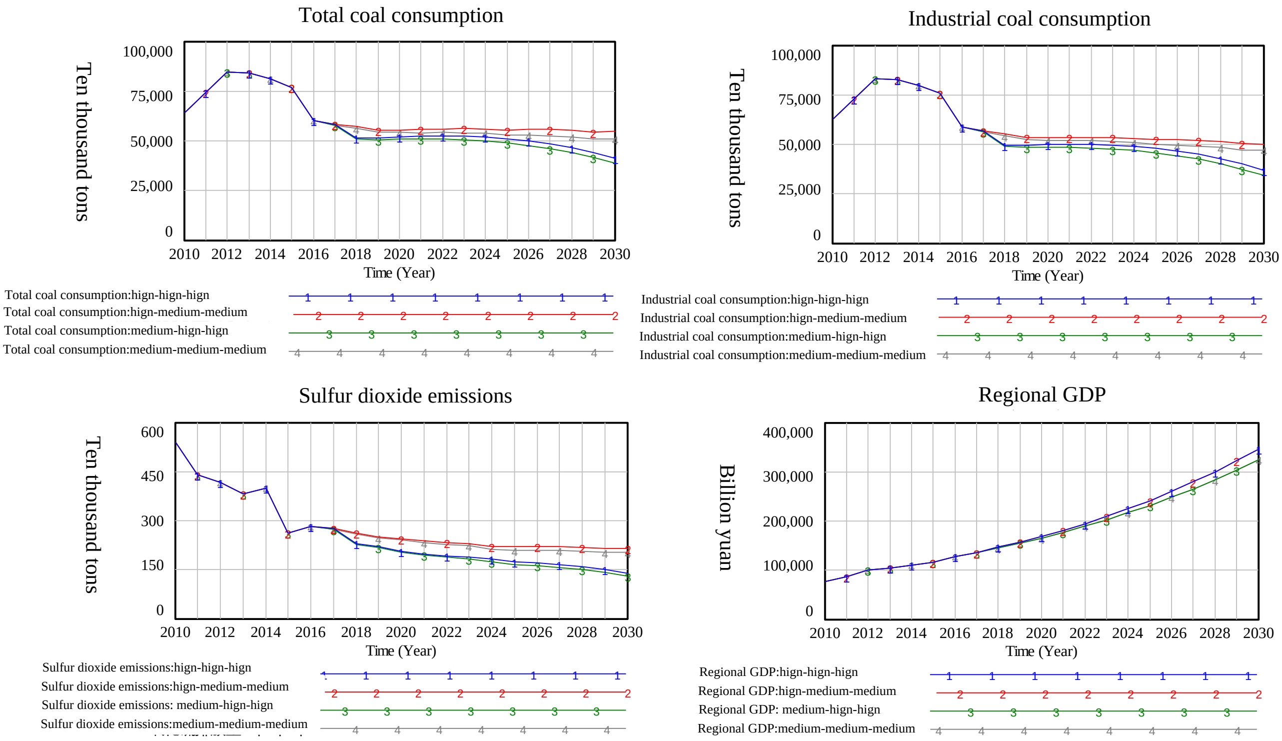

Figure 7. Simulation results of each index in the SD model

4. Conclusion and Discussion

4.1 Conclusion

The test of the system storage flow and the sensitivity analysis show that the SD model of "Economy-population-environment-coal consumption" in beijing-tianjin-Hebei and its surrounding areas has good simulation results and Operability, it also proves that total coal consumption control plays a key role in the process of environmental optimization.

In the future, the optimal development pattern of beijing-tianjin-hebei and its surrounding areas may be scenario 2 (middle-high-high), with emphasis on strengthening R&D investment and environmental regulation. In 2020, the total coal consumption in beijing-tianjin-hebei and its surrounding areas was 500,173,000 tons, with the output value of each industry increasing by 3.5%, 6.5% and 7.5% respectively, the R&D input intensity increasing by 0.55% a year, and the investment in environmental management increasing by 20% a year, 366.467 million tons in 2030, 2.023.45 million tons of sulfur dioxide emissions in 2020 and 1.313.08 million tons in 2030. The scenario will not only contribute to ensuring stable and high-quality economic development and population growth, it also realizes the protection and optimization of the ecological environment.

When the coal consumption efficiency is fixed, the industrial development becomes the more obvious coal consumption regulating factor than the population growth by affecting the two main coal consumption channels of domestic coal and industrial coal; Under the condition that the situation of social and economic development is kept certain, strengthening the environmental regulation of enterprises by the government, improving the efficiency of industrial use of coal, can effectively reduce the level of coal consumption, thereby reducing the emission of sulfur dioxide and other waste gases in the region, to realize the coordinated development of economy and environment.

4.2. Discussion

In the process of sustained economic growth, Beijing-tianjin-hebei and its surrounding areas need to face up to the increasingly severe reality of huge coal consumption and serious air pollution. Based on the analysis of the simulation results under different policy combinations, the following policy suggestions are put forward: 1) In Beijing-tianjin-hebei and its surrounding areas, strengthen the scientific delimitation of high-energy private enterprises and high-energy state-owned enterprises, and restrict the development of high-coal private enterprises, through the establishment of strict industry standards, reduce coal consumption quotas and other ways to reduce industrial use of coal. 2) Increase the investment of R&D funds, encourage the R&D personnel to carry out R&D on desulfurization technology, and give certain preferential tax policies to the enterprises that actively optimize the production process and speed up the utilization of desulfurization equipment. 3) While maintaining a reasonable economic growth rate, we will reduce the proportion of secondary sector of the economy, vigorously support the development of the tertiary sector of the economy, and promote the transformation of the economic development pillar from heavy chemical industry to high and new technology industries, tourism and other tertiary sector of the economy industries. It is necessary for beijing-tianjin-hebei and its surrounding areas to study the harmonious relationship among regional economy, society, environment and coal consumption.

The SD model of “Economy-society-environment-coal consumption” constructed in this paper, although it mainly uses regional scale data and parameters, in theory the coupling relationship between economy, society, environment and living coal consumption, industrial coal consumption in the study area and the logic of cause and effect cycle can be based on the framework of the basic concepts determined in this paper, according to the actual characteristics of the study area, the parameter setting can be adjusted flexibly so as to carry out multi-scenario simulation in other regions and the whole country.

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