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Study of System Dynamics on the Equilibrium Development of Ecological and Economic System in Ordos of Inner Mongolia in China¹

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Abstract: Along with the accelerated process of industrialization and urbanization, China is faced with several severe situations, such as resource constraint, environmental pollution and ecological degradation, which now have aroused the attention of Chinese government. Meanwhile, In the process of industrialization, resource industry has made a great contribution to national economic development, making the resource based cities become the main body of resource supply. After a large-scale of mining exploitation on resource, the resource based cities in China always encountered unsustainable development, the problems of exhaustion of resources, irreversible damage of ecological environment and difficulty of urban renaissance all resulted in the economic stagnation. However, as one of the typical resource based cities in China, Ordos had more than ten years of rapid economic growth oriented by mining industry. Therefore, how to avoid the tragedy of other resource exhausted cities and maintain the fast economic growth with a sustainable development strategy is becoming one of the most important issues. In this paper, based on the analysis of the Ordos city economic, resource and environment subsystem development status, several ecological and economic systems development issues of the city are revealed. Specifically, these include the significant gap between the rich and the poor, irrational industrial structure, sustainable exploitation pressure of resources and environmental pollution. In Ordos city, the economic development depends on exploitation of coal resource. However, the exploitation process results in water shortage and environmental pollution. In order to realize the sustainable development of ecological economic system, a system dynamics model, which coordinates the subsystems of economy, resources and environment, is constructed and resource utilization efficiency, environmental protection and economical development are considered as systemic parameters to forecast the development trend of Ordos city. Then, sustainability of four development modes are compared via setting its control parameters together with a introduced resource-environment loss rate. Finally, we make a conclusion that the Harmonious development-oriented mode makes the GDP growing moderately and the economic losses of resources and environment destruction are under control and the losses decrease gradually, which accords with the requirements for sustainable development, realizing the benign balance between the economic benefit and ecological benefit.

Key words: Ordos, Ecological economic system, System dynamics, Equilibrium development, Policy simulation

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1 Introduction

Ordos is a typical resource based city. By 2009, The National Development and Reform Commission of China (NDRC) declared that there are 44 resource-exhausted cities in China, which accounted for 37% of the total number of resource based cities. The resource based cities always face the economic stagnation when resources are exhausted. These cities are lacked of overall planning and have a single industrial structure during the development. Their economic growth mainly depends on the large-scale mining, which eventually led to the exhaustion of the resources, irreversible damage of ecological environment and difficulty of urban renaissance. In order to avoid undergoing the same development way of resource-exhausted cities, resources cities, in the stage of growth, should have an advanced plan to coordinate the balance between economical growth and ecological protection. So far, Ordos city had more than ten years of rapid economic growth and people's living standard is in the front row of China. Therefore, how to maintain the fast economic growth with a sustainable development strategy is becoming one of the most important issues.

2 Characters of Study Area

Ordos city is located in the southwest of Inner Mongolia Autonomous Region and belongs to the Ordos Plateau Hinterland. Bordered by Shanxi, Shaanxi and Ningxia provinces, the city is about 400 km long and 340 km wide, with a total area of 86752 square kilometers. The region has rich mineral reserves and is one of the most important national energy bases¹.

2.1 The Current Situation of the Economic Subsystem

Ordos takes the National Western Development as a great opportunity to exploit its resource and has achieved the great-leap-forward development of economy and society. Since 2005, the average annual growth rate is 23.4%. In 2010, the Gross Domestic Product (GDP) of Ordos reached 264.3 billion yuan. In term of industrial structure, the industrial output accounts for more than 90% of GDP and the proportions of second

¹ http://www.ordos.gov.cn/english/eeds2/201207/t20120724_656109.html

industry are stably between 55% to 60%². Coal mining makes up more than 40% contribution to the city's national financial income. However, the heavy industries oriented by resources, did not fully push forward other industries on the transition process from profit to industrial capital so that the other industries are lack of science and technology. This results a barrier to turn the economic benefits into social benefits and comprehensive regional economic health. Furthermore, the urbanization rate of Ordos is above 70% by 2011. The annual disposable income of urban residents is 28986 yuan and the net income of farmers is 9982 yuan¹, which illustrate that the people's living standards in Ordos have been significantly improved.

2.2 The Current Situation of the Resource Subsystem

Ordos city has rich reserves of underground energy minerals. The exploitation and utilization of mineral resources has promoted the mining industry into forceful development. The potential economic value of energy minerals, non-metallic mineral, salt chemical and building materials accounts for more than 52% of that of the Inner Mongolia Province. Abundant coal reserves make the Ordos an extra large thermal coal of high quality and coal liquefaction base with annual production capacity of 100 million tons³. With the gradual expansion of four big industries, specifically, coal mining, coal-fired electricity, chemical and high load industries, the consumption of mineral resources will increase sharply and the city will get great pressure on resource exploitation.

2.3 The Current Situation of the Environment Subsystem

Ordos city has rich natural resources, but a fragile ecological environment, dry climate and serious desertification. The large-scale industrial activities have resulted in negative external effects on ecological environment, for example, the air pollution came from the coal industry. In 2010, the emission of industrial smoke is 104000 tons while the emission of SO₂ is 226000 tons², beyond the emission limits of Inner Mongolia. Furthermore, the process of coal mining and preprocessing had produced a

² Bureau of statistics in Ordos city. Ordos statistical yearbook 2003-2011[M].BeiJing: China statistical publisher.

³ http://www.ordos.gov.cn/pub/jjwyh/cygh/201001/20100107_98085.html, 2010.1.7

large number of wastewater. The stripping output has seriously destroyed the water, land and vegetation resources in the mining area⁴. The emissions of industrial wastes have greatly increased with the expansion of resources development and utilization. The transport of resources has caused serious dust pollution along the traffic lines. All of these make the ecological system of drought and desert grassland more fragile.

3 Method and Model Description

3.1 Objectives and Requirements of Modeling

The resource exploitation in Ordos brings economic benefits as well as negative environmental effects and potential risks. Therefore, it is urgently needed to build a systemic analysis model to analyze the risks and negative effects, identify the controlling and influencing factors and then make the improvement policies for balancing economy and environment.

To realize the objectives, it is required that the model built can dynamically and quantitatively simulate the development trend of the system; can reflect the interaction between economical, resource and environmental subsystems; can reveal the key influencing factors for making the improvement policies and also can test the improvement effects to insure the feasibility and effectiveness of the improvement policies⁵.

3.2 System Dynamics Method

According to the above objectives and requirements, we use system dynamics method to build an ecological and economical systemic analysis model. The system dynamics method was created by Forrester of Massachusetts Institute of Technology in the mid-1950s⁶. After decades of development and improvement, the system dynamics model has been widely used in the study of economy, society, ecology and many other

⁴ Hong Galu. Research on the sustainable development of energy economy in Ordos city[D].Minzu University of China.2011.

⁵ Fu Jia Li, Suo Cheng Dong, Fei Li. A system dynamics model for analyzing the eco-agriculture system with policy recommendations. *Ecological Modelling* 227 (2012) 34-45.

⁶ Forrester,J.W.,1958.Industrial dynamics : a major breakthrough for decision makers. *Harvard Business Review* 36(4),37–66.

complex systems⁷⁸. The systemic dynamics model can reveal the dynamic changes, feedback, delay and other processes of a system, and it is characterized by quantifiability and controllability. Therefore, it has a distinct advantage in analyzing, improving and managing the system characterized by long development cycle and complex feedback effects⁹.

3.3 Logical Framework of Modeling

The ecological and economical system in Ordos city is composed of three subsystems: economy, resource and environment. The economic development depends on exploitation of coal resource. However, the exploitation process results in water shortage and environmental pollution. To realize the coordinated development of ecological economic system, resource utilization efficiency, environmental protection and economical development are considered as systemic parameters to forecast the development trend of Ordos city. Repeatedly, these parameters are adjusted to conduct the policy evaluation (Fig. 3.1).

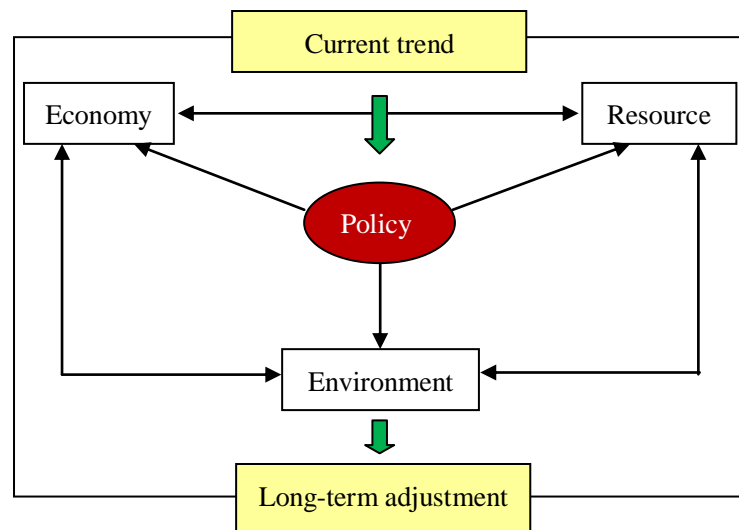


Fig 3.1 Logical framework of modeling

⁷ Wang, Y., Zhang, X., 2001. A Dynamic modeling approach to simulating socioeconomic effects on landscape changes. *Ecological Modelling* 140(1–2):141–162.

⁸ Chang, Y., Hong, F., Lee, M., 2008. A System dynamic based DSSF or sustainable coral reef management in Kenting Coastal zone, Taiwan. *Ecological Modelling* 211(1–2):153–168.

⁹ Tao, Z., 2010. Scenarios of China's Oil Consumption Per Capita (OCPC) Using a Hybrid Factor Decomposition-System Dynamics (SD) Simulation. *Energy* 35(1):168–180.

3.4 Data Sources

The data used in this model mainly come from the “2005-2011 Statistical Yearbook in Ordos City”, 2006-2010 Bulletin of Environmental quality in Ordos City and 2010 Bulletin of Water Resources in Ordos City.

4 Ecological Economic System Dynamics Model in Ordos City

4.1 Model Structure of Economic Subsystem

In the economic subsystem, the industrial investment expands reproduction and realizes the positive feedback of growth in industrial GDP. According to the proportion of industrial GDP, the simulation value of GDP can be calculated. The mining industry refers to coal and non-metallic mining while the non-mining industry refers to the other industries.

GDP index is the direct reflection of the economic value while the net GDP considers the economical losses caused by water shortage and pollution. We choose the growth of industrial GDP as an important indicator to evaluate the industrial GDP. The formation of mining and non-mining industry fixed assets generally needs 3-5 years, therefore, the function between the increase of fixed assets and the fixed asset investment is treated as 3-order delay function. Normally, the life of mining and non-mining industry fixed asset is ten years¹⁰; In addition, in order to simplify the study, the environmental protection investment and water conservancy investment is set 3% respectively. According to the data in the statistical yearbook, the initial value of industrial GDP in 2004 is 16.931 billion yuan. The simulation structure of economic subsystem in Ordos city is shown in figure 4-1.

¹⁰ Hunag Xianfeng. System dynamics study on the coordinated development of Economic-Resource-Environment in Jiangsu Province [D].Jingsu University.2005.

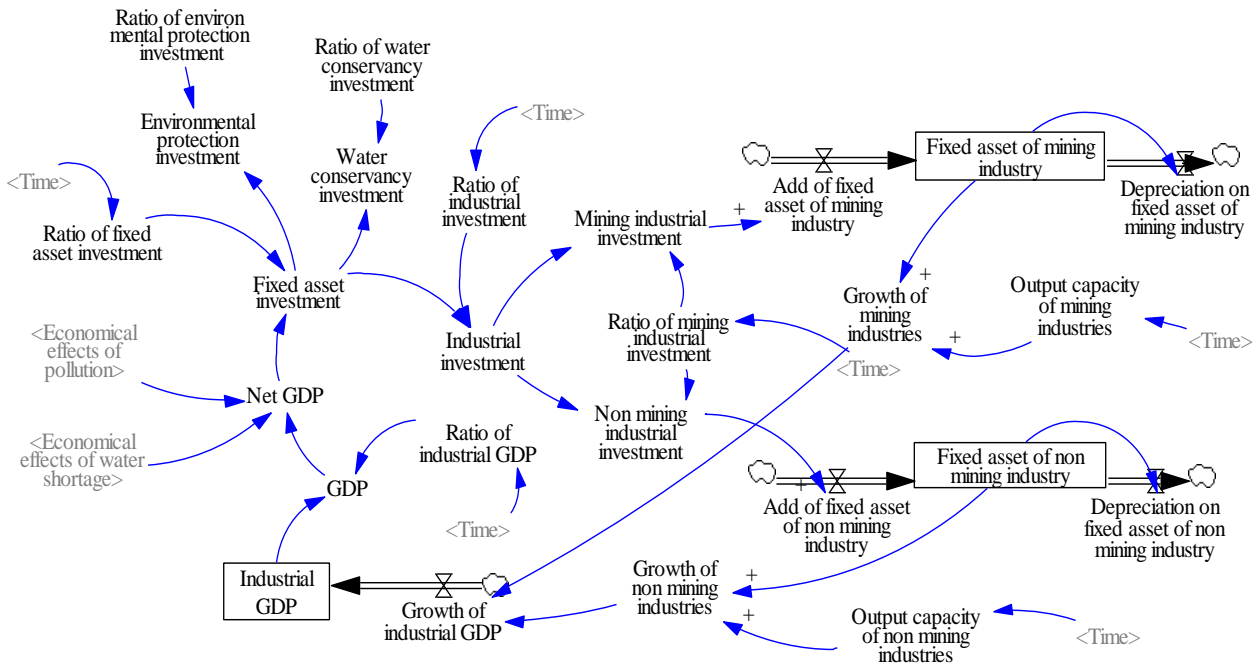


Fig 4-1 Model structure of economic subsystem in Ordos

4.2 Model Structure of Resource Subsystem

In the model of resource subsystem, we mainly discuss relationship between water shortage and GDP¹¹ and the sustainable development of coal resources. Industrial investment, especially the increase of mining investment, speeds up the development of mineral resources industry. On the other hand, the introduction of advanced production technology improves the recovery rate of mining and reduces the loss rate of resource and environment. The decrement of coal reserves is equal to the raw coal output divided by recovery rate. The degree of water shortage is influenced by the consumption and supply of water and water conservancy investment. The water conservancy investment can indirectly ease the water shortage by increasing the water supply, reducing the water wastage, and improving the comprehensive utilization and recycling efficiency of water resources. According to the Bulletin of Water Resources in Ordos City, the annual water supply is 1.6314 billion tons and the exploitable reserves of coal are 149.6 billion tons. The simulation structure of resource subsystem is shown in figure 4-2.

¹¹ He Youshi. Dynamic Simulation and Policy Regulation of the Development of Regional Social and Economic System [M]. Hefei: Publisher of University of Science and Technology of China, 2008.2.

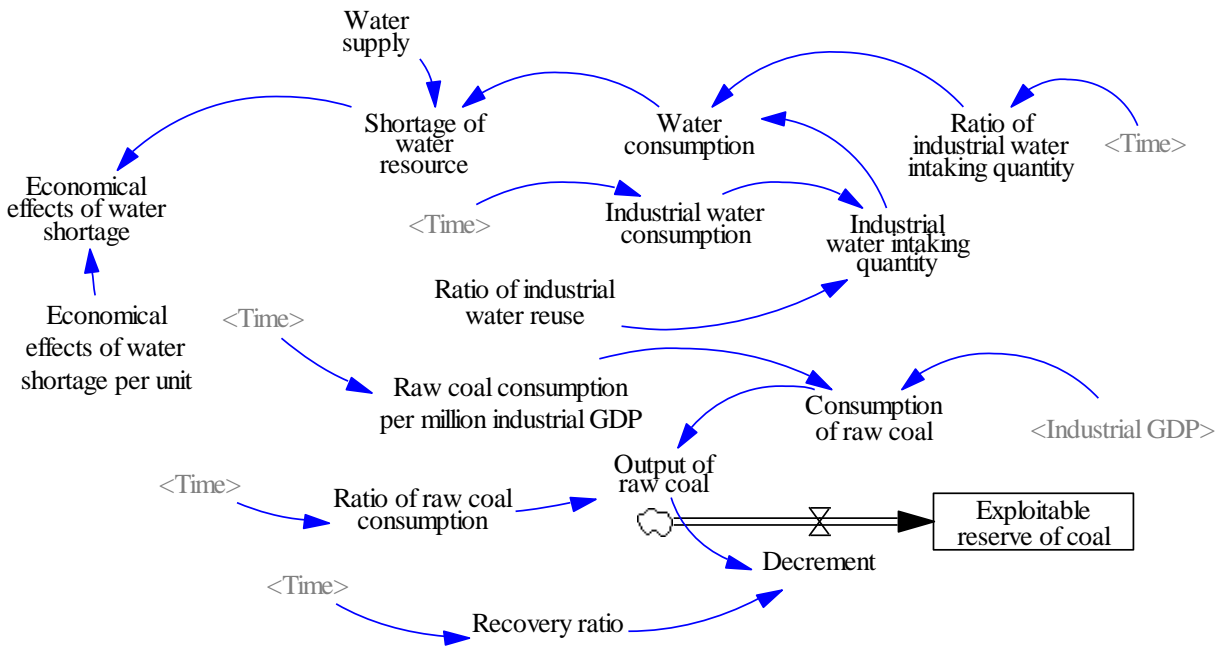


Fig 4-2 Model structure of resource subsystem in Ordos

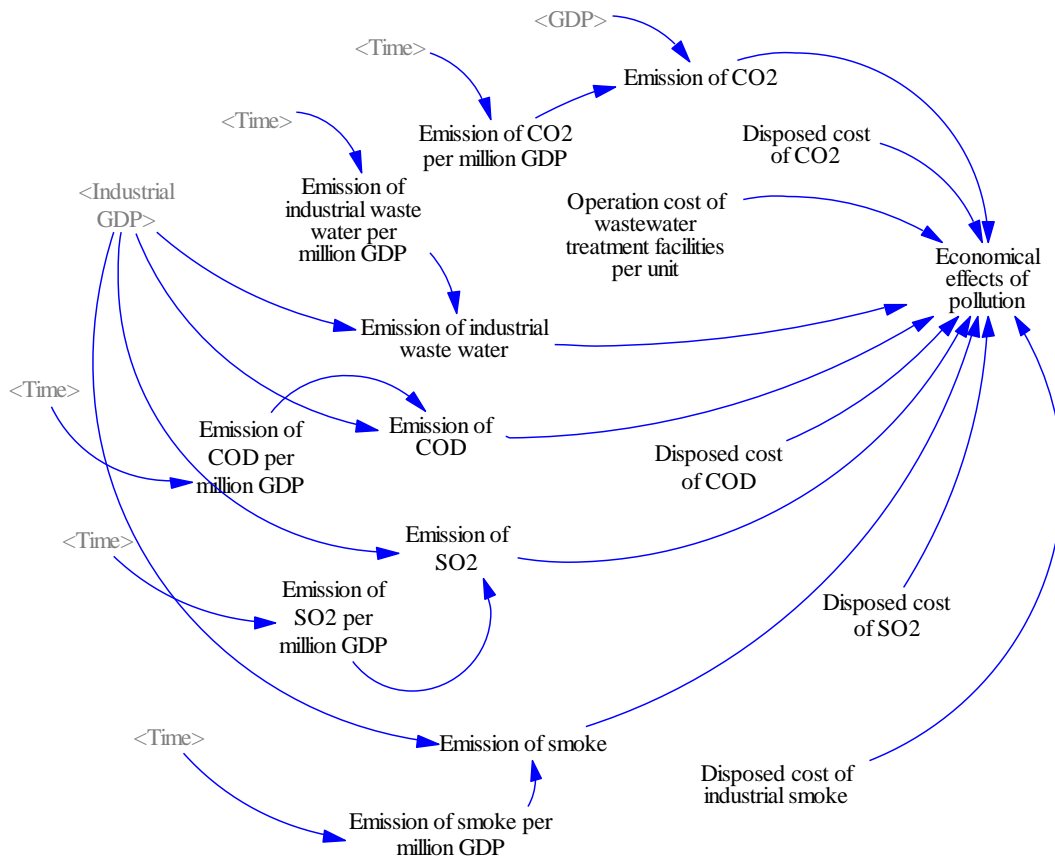


Fig 4-3 Model structure of environment subsystem in Ordos

4.3 Model Structure of Environment Subsystem

The industrial development characteristics of Ordos city shows that the main pollutants are SO₂, CO₂, industrial smoke, industrial waste water, and COD. Pollution generation and handling mechanism decides the pollution level. GDP is used to predict the future generation of industrial pollutants according to their tight connection. Furthermore, the disposed costs can be used to estimate the economic effects of pollution¹². The mining, which causes a great impact on ecological environment, reduces the coal reserves and produces a large number of pollutants¹³. In turn, this will restrict the economic development. The model is shown in figure 4-3.

5 Simulation of Ecological economic System Dynamics Model in Ordos City

5.1 Model Testing

After the model building, we should make sure the dimension consistent on both sides of the equations. The ecological economic system dynamics model of Ordos city has passed the structure adaptability test and validity test after in-situ survey and repeated experiments. Then, the model is validated using the historical date from 2004 to 2010 years. The test result on GDP index of the economic subsystem is listed to demonstrate the process, see table 5-1. The relative error is less than 9% and there is a monotonic relationship between the historical and other simulated variables. Therefore, the ecological economic system dynamics model of Ordos city can effectively reflect the present situation of economy, resources and environment and be used to predict the future development trends.

Table 5-1 GDP fitting test of System dynamics

Year	Historical value of GDP (million yuan)	Simulation value of GDP (million yuan)	Relative error (%)
2004	39559.4	39559.4	——
2005	59483	56996.3	-4.18
2006	82251	88424.1	7.51
2007	117316	127116	8.35

¹² XIAO Shi-en, LEI Jia-su. Calculation and Causes of Environmental Pollution Loss in China [J]. China Population, Resources and Environment. Vol.21 No.12 (2011):70-74.

¹³ YAN Jun-yin, ZHAO Guo-jie. Simulating on Ecological & Economic System of Regional Mineral Resources Exploitation. Journal of Natural Resources. Vol.24 No.18 2009(8):1334-1342.

The figure 5-2 illustrates the corresponding development tendencies of industrial investment, mining investment and environmental protection investment and water conservancy investment of Ordos city. The industrial investment and the mining investment continue to rise and grow quite fast while environmental protection investment and water conservancy investment crawl slowly. Therefore, current investment policy is not conducive to sustainable development and will not work in future.

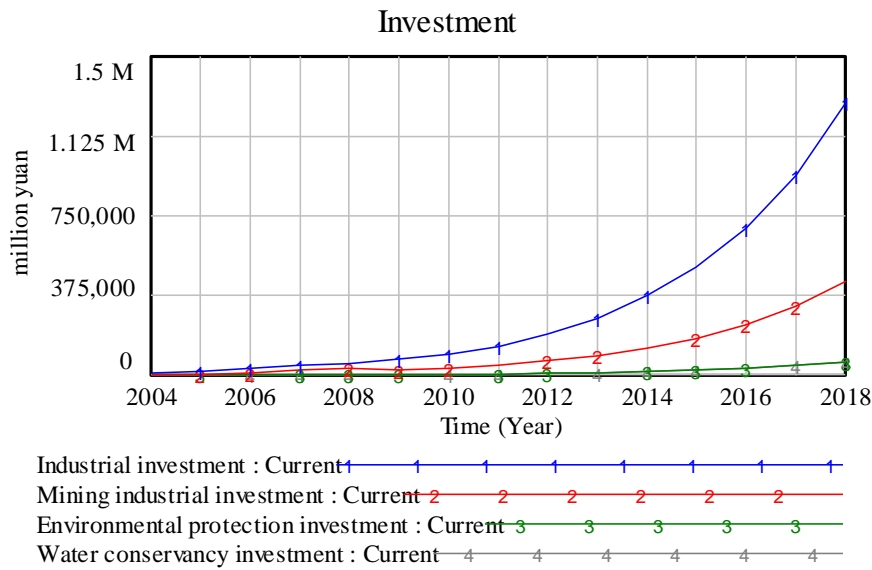


Fig 5-2 The developing trend of investment in Ordos

5.2.2 Results and Analysis of Resource Subsystem

In this section, water shortage, the correspondingly economical effect, raw coal output and exploitable coal reserves are predicted. Ordos is a lack of water resources. Without sufficient of the water conservancy investment, local industry development, which is tightly connected with coal mining, electricity and coal chemical industry, is restricted. The leading industry water requirement of 2010 is 616.103 million cubic meters and will increase to 965.3 million cubic meters in 2015¹⁴. Figure 5-3 shows the water shortage in next 10 years. Figure 5-4 shows its impact on the economy.

Ordos holds 149.6 billion tons proved coal reserves. Its future reserves accounts for about 50% of the Inner Mongolia Province and 16.6% of the whole country. As shown

¹⁴ Li Wei, Liu Yanju, Li Tianwei. Methods and practice on environmental impact assessment for industrial development planning of resource based cities [M]. Chemical Industry Publisher. 2009.01.01.

in figure 5-5, the raw coal production increases year by year. The massive coal exploitation will bring great economic benefit in the short term. Without restriction in coal mining, serious waste will be caused by the low recovery rate. Consequently, the sustainable development is not available and the resource depletion will not be far away, see figure 5-6.

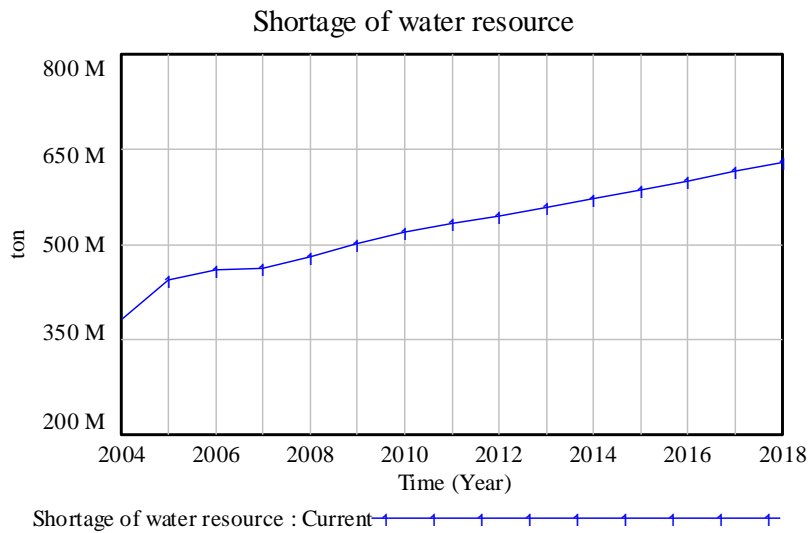


Fig 5-3 The trend of water shortage in Ordos

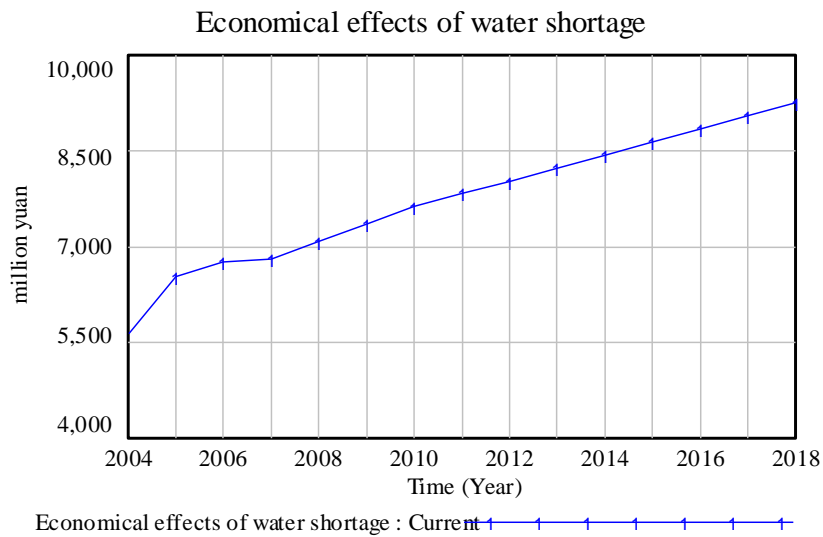


Fig 5-4 Economical effects of water shortage in Ordos

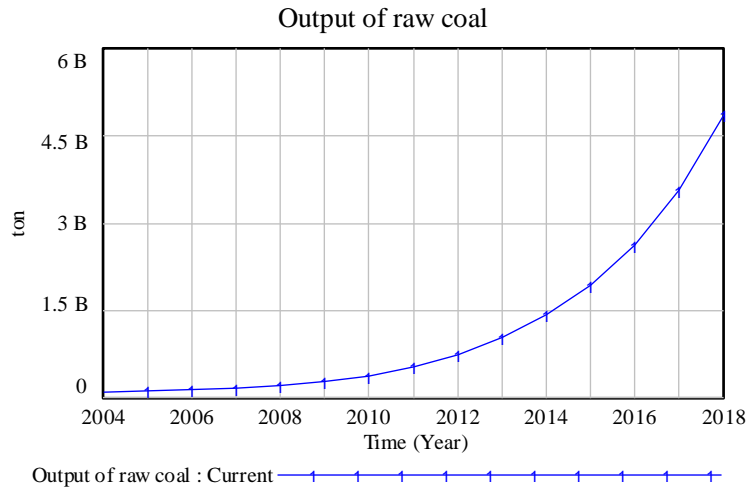


Fig 5-5 Output of raw coal in Ordos

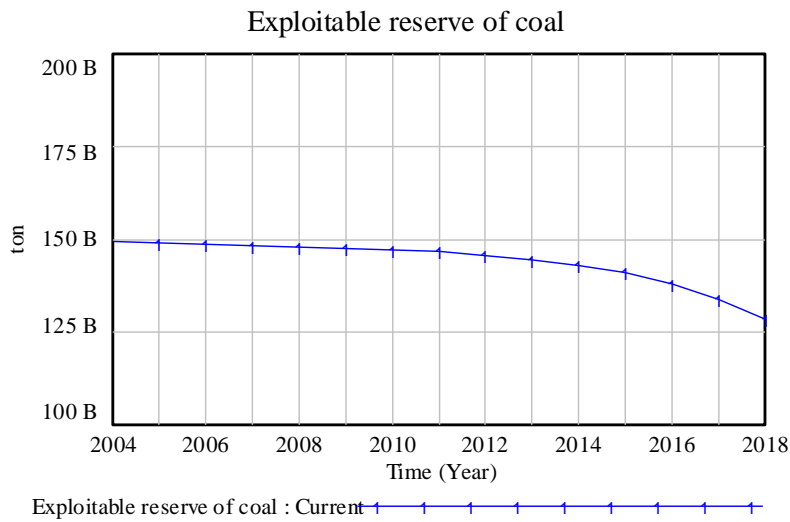


Fig 5-6 The Change on the exploitable reserve of coal in Ordos

5.2.3 Results and Analysis of Environment Subsystem

In this section, the same model parameters are used to predicate the emissions of COD, industrial SO₂, industrial smoke, CO₂, industrial waste water and the economical effect of pollutant in environment subsystem. Figure 5-7 and figure 5-8 show that the pollutant emissions increase year by year while the emissions of industrial waste water and COD do not increase a lot. The correspondingly economical losses are shown in 5-9. Actually, the solid wastes of the coal mining, such as coal gangue, slag, etc., which are neglected in this simulation, will cause extra cost. The uncontrolled industrialization will damage the environment a lot in near future.

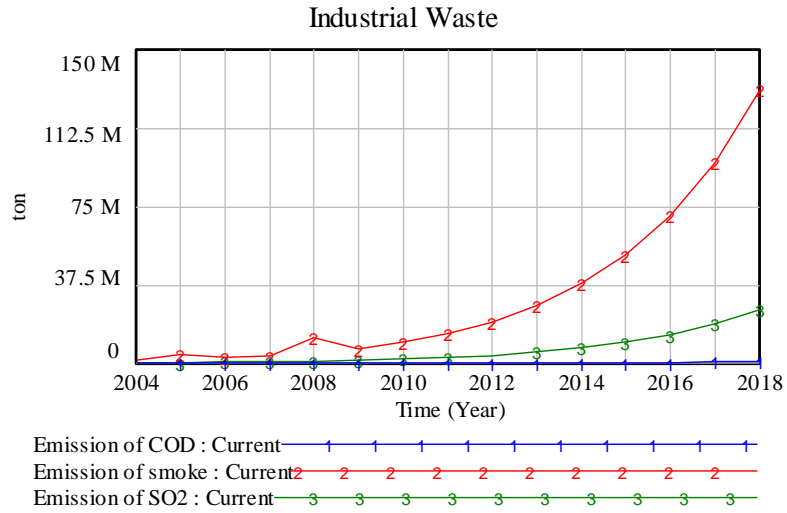


Fig 5-7 The developing trend of COD, industrial SO₂ and industrial smoke in Ordos

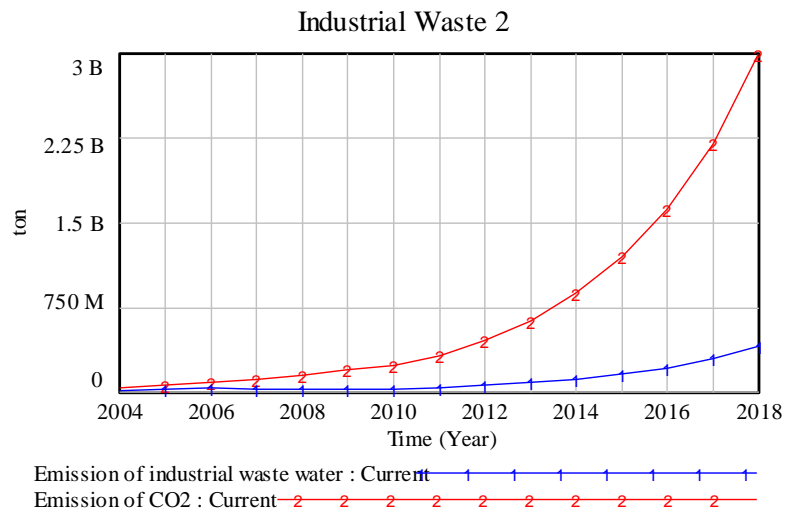


Fig 5-8 The developing trend of CO₂ and industrial waste water in Ordos

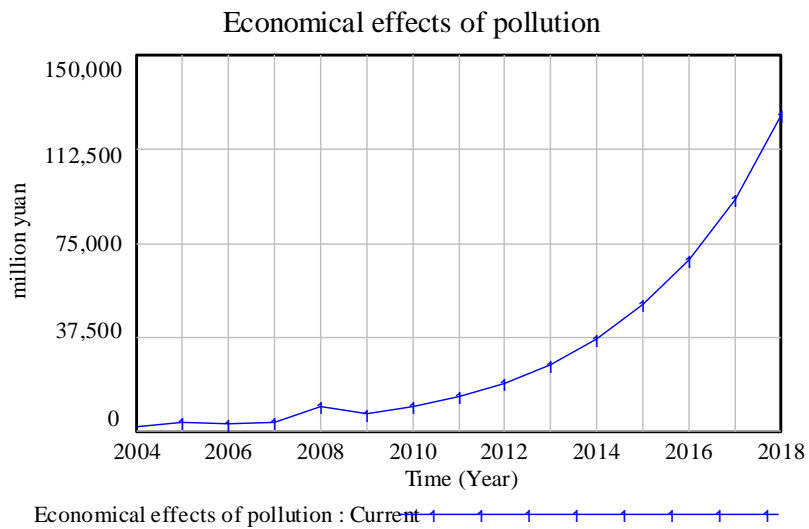


Fig 5-9 Economical effects of pollution in Ordos

6 Policy Adjustment for Ecological Economic System in Ordos City

The simulation results are almost consistent with the real situation in Ordos city. In this case the development is not sustainable. Therefore, control parameters are used to predict the results of different decision alternatives.

6.1 Control Variables and Setting of Operation Mode

Based on the principle of regulation and controlling¹¹ and the reality of economy, resources and environment in Ordos city, the controlling parameters are adjusted to analyze the four development modes. These parameters are listed in table 6-1, specifically, these include ratio of environmental protection investment, ratio of water conservancy investment, ratio of industrial investment, and ratio of mining industrial investment on economic subsystem; ratio of industrial water reuse, and recovery ratio on resource subsystem; emission of CO₂ per million GDP, emission of COD per million GDP, emission of SO₂ per million GDP and emission of smoke per million GDP on environment subsystem. Four operation modes are set for these parameters, specifically, these are Real evolution type, Resource leading type, Environment protection type and Harmonious development type.

Table 6-1 Control variables and setting of operation mode

Subsystems	Parameters	Unit	Real evolution type	Resource leading type	Environment protection type	Harmonious development type
Economic subsystem	Ratio of environmental protection investment	%	3	3	3.6	3.5
	Ratio of water conservancy investment	%	3	3	3.6	3.5
	Ratio of industrial investment	%	64	67	64	65
	Ratio of mining industrial investment	%	34.27	38	34.27	22.85
Resource subsystem	Ratio of industrial water reuse	%	61.33	61.33	75	75
	Recovery ratio	%	65	65	68	68
Environment subsystem	Emission of CO ₂ per million GDP	ton/million yuan	961	961	836	865
	Emission of COD per million GDP	ton/million yuan	0.63	0.63	0.54	0.56
	Emission of SO ₂ per million GDP	ton/million yuan	14.92	14.92	13	13.43
	Emission of smoke per million GDP	ton/million yuan	71.53	71.53	68	70

(1) Real evolution type is based on the real data and current policies and the simulation results are shown in chapter 5.2.

(2) Resource leading type aims to develop the resource industries. To boost local economic development, the feedback loop effect of economic subsystem should be strengthened. After repeated testing, we reset the ratio of industrial investment and ratio of mining investment respectively as 67% and 38% while other parameters remain unchanged.

(3) Environment protection type aims to protect the resources and environment. According to the Environmental Planning of 2011 to 2015 in Ordos city, indicators of environmental protection investment, water conservancy investment, industrial water reuse and recovery rate are raised while the pollution emission are reduced, see table 6-1.

(4) Harmonious development type aims to achieve coordinated development between environmental protection and economy growth. To balance both, environmental protection investment and water conservancy investment are raised, mining investment is lowered as 22.85%, and industrial investment is slightly raised. Accordingly, industrial water reuse and recovery rate indicators rise and indicators of emission of CO₂ per million GDP, emission of COD per million GDP, emission of SO₂ per million GDP and emission of smoke per million GDP fall, see table6-1.

6.2 Policy Adjustment and Analysis

The loss rate of resources and environment¹³ is used to measure the regional sustainable development. The formula is described as the difference between GDP and net GDP divided by GDP. A lower loss rate of resources and environment means a less of resources shortage and environmental pollution and a better policy effect (see table 6-2).

(1) The average resources and environment loss rate of Real evolution type from 2008 to 2018 is 0.0482, which is the largest of the four types. Obviously, current structures of investment and industries, resource consumption speed, exploitation efficiency and environmental emission level will cause great economic losses. Although, the loss rate of resources and environment gradually declines, showing that this type has a certain level self improvement. As the values of GDP and net GDP are minimum, this develop mode is not a suitable.

(2) Resource leading type holds the highest and fastest growing GDP and net GDP. Although the exploitation of resources makes a great contribution to economic growth, the coal reserves drop down significantly and economic losses caused by the pollution reaches the maximum. The average of loss rate of resources and environment is 0.0463, which means that the faster the economy develop, the more consumption on resources and the much more damage on ecological pollution.

(3) Environment protection type's GDP and net GDP are smaller than Resource leading type and Harmonious development type. In this case, the government will invest more on environmental protection, energy conservation and emission reduction, etc., and relatively reduce the investment on resources exploitation. Consequently, the coal reserves decline relatively slow, the water gap narrows down and the pollutant emissions become controllable. The average of loss rate of resources and environment is 0.0379, which is the smallest of the four types. Although this mode is the most environmentally friendly, the relationship between economy and environmental protection is not balanced well and the improvement of the ecological value is not enough to promote the development of the whole society.

(4) Harmonious development holds a relatively reasonable growth rate. Its GDP and net GDP are lower than the resource leading type and higher than others from 2008 to 2018. The average of loss rate of resources and environment is 0.0387, which is slightly higher than that of environmental protection type. In this case, the economic losses of resources and environment destruction are under control and the losses will decrease gradually.

Table 6-2 Comparison of loss rate of resources and environment in four development types

Year	Real evolution type			Resource leading type			Environment protection type			Harmonious development type		
	GDP	Net GDP	loss rate of resources and environment	GDP	Net GDP	loss rate of resources and environment	GDP	Net GDP	loss rate of resources and environment	GDP	Net GDP	loss rate of resources and environment
2008	1673	1531	0.0853	1983	1821	0.0815	1734	1628	0.0613	1734	1628	0.0613
2009	2172	2054	0.0544	2707	2570	0.0504	2272	2191	0.0356	2272	2191	0.0356
2010	2890	2738	0.0528	3700	3518	0.0493	3043	2927	0.0379	3043	2927	0.0380
2011	3958	3764	0.0489	5090	4855	0.0462	4184	4033	0.0359	4184	4029	0.0370
2012	5550	5296	0.0458	7117	6805	0.0438	5878	5668	0.0357	5878	5662	0.0368
2013	7745	7408	0.0435	9814	9401	0.0421	8214	7922	0.0355	8214	7914	0.0366
2014	10660	10214	0.0418	13473	12924	0.0408	11318	10919	0.0353	11334	10922	0.0364
2015	14519	13929	0.0406	18454	17719	0.0398	15433	14891	0.0352	15483	14923	0.0362
2016	19690	18908	0.0397	25264	24277	0.0391	20956	20222	0.0350	21064	20304	0.0361
2017	26733	25690	0.0390	34657	33322	0.0385	28484	27491	0.0349	28636	27607	0.0359
2018	36415	35013	0.0385	47618	45803	0.0381	38834	37483	0.0348	38908	37514	0.0358
Average			0.0482	Average		0.0463	Average		0.0379	Average		0.0387

7 Conclusion and Discussion

The Harmonious development type makes a rational allocation of fixed asset investment on environmental protection, water conservancy, industry and coal mining. The economic losses of environment destruction are under control and the Ordos city will finally achieve a balance between economic benefit and ecological benefit. According to the simulation results, we come up with the proposals that the Ordos city should adjust the economic growth rate appropriately; optimize the industrial structure and take a new road to industrialization; improve the efficiency of resource utilization and rationally exploit natural resources; increase the investment on environmental protection and carry out the construction of ecological civilization.