Dynamic simulation of sustainable development mode in mining area in low carbon environment

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ABSTRACT: *Properly handling and coordinating the relationship between four closely linked factors of population, resources, environment and economy is an important way for better survival and development at this stage. Mineral resources as precious resources of national economy construction, promote the economic prosperity in mining area and social progress through the development and utilization in an appropriate way. The excessive development of mineral resources will result in constant deterioration of ecological environment, gap of people's income and single industrial structure of enterprise, thus the sustainable development in mining area is impossible to be realized. According to dynamic principle, this study divides complex mining system into four subsystems, i.e., society, economy, resource and environment, and sets up a dynamic system model based on operational mechanism chart and cause and effect diagram of each subsystem in mining area; then simulates the model and analyzes the results by applying model validity. Finally a better strategy is obtained to realize sustainable development mode in mining area.*

Keywords: Low carbon environment, Sustainable development, Dynamics, Simulation model

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1. Introduction

With the continuous development of human society and science and technology, mining as a basic industry in our country, plays a more and more important role in the development of national economy. However, many unreasonable problems exist in sustainable development of mining in our country, for instance, waste of available resources in the mining area everywhere. Therefore, resources exploitation at will and irrational utilization in mining area will aggravate the exhaustion of mineral resources, speed up the economic recession in the mining area, even lead to a mass of ecological environmental problems, such as surface collapse in gob, land grab, etc., and aggravation of environmental pollution as a result of emissions of waste water, gas and residue of mining industries, which hinder the development of social economy. Under the influence of those uncertain factors, scholars from various countries have made comments on innovation driving force, countermeasures and development model of the sustainable development in mining area. Zeng et al. [1] pointed out that innovation driving forces for the sustainable development of resource-oriented regional economy are made up of government, society, market and enterprise. Prior et al. [2] put forward that resource supply, demand and environmental policy have a great influence on resource-oriented regional economic development based on technological advances and government regulation. Furthermore, Costa et al. [3-6] indicated that the implementation of environmental policy and ecological technological innovation is conducive to protect the environment and improve the efficiency of resource use so as to realize the regional sustainable development. Moreover, Yang Jian et al. [7] stated that the construction of regional innovation system is the fundamental guarantee of promoting regional sustainable development, which builds innovation management system for talent, knowledge and capital using system dynamics. Taking Wuhan as an example, this study, an innovative research on sustainable development of mining area in a low carbon environment, establishes system dynamics model for sustainable development patterns in mining area, and performs analogue simulation for the dynamic model. Simulation results suggest that the optimal choices of sustainable development mode for the mining area are to develop harmonious population, use resources efficiently, control environmental pollution effectively, implement the ecological system regulation strictly and strengthen the inter-area integrated sustainable development mode vigorously.

2. Overview of Sustainable Development In Mining Area In Low Carbon Environment

2.1 Connotation of sustainable development in mining area

In 1987, the World Commission on Environment and Development (WCED) headed by Brundtland defined the influenced and widely cited sustainable development by authority, i.e., “Sustainable development not only meets the need of modern people, but also is unharmful to the ability of meeting their needs for future generations” [8]. Sustainable development exists in the development process of human society by taking an idea of “good opportunity, favorable geographical location and support from the people”, promoting the effective transformation of scale, structure and function in the mining area, and accelerating the lifestyle from extensive to intensive change, ultimately improving the overall development of economy in mining area and realizing the harmonious development between human and the nature. Embodied in the following aspects:

(1) Sustainable development focuses on a new development concept and development mode;

(2) Sustainable development emphasizes the continuity, stability and sustainability of society, economy, resource and environment in the process of development;

(3) Sustainable development pays attention to the coordinated development of synthetic system between society, economy, resource and environment systems;

(4) Sustainable development is multidimensional. Multi dimensions, such as “time dimension”, “space dimension”, “demand dimension” and “relation dimension” are balanced mutually, that is to say, recent development and long-term development, local development and overall development are united organically;

(5) Sustainable development stresses overall development but not local development.

2.2 Basic structure of sustainable development in mining area

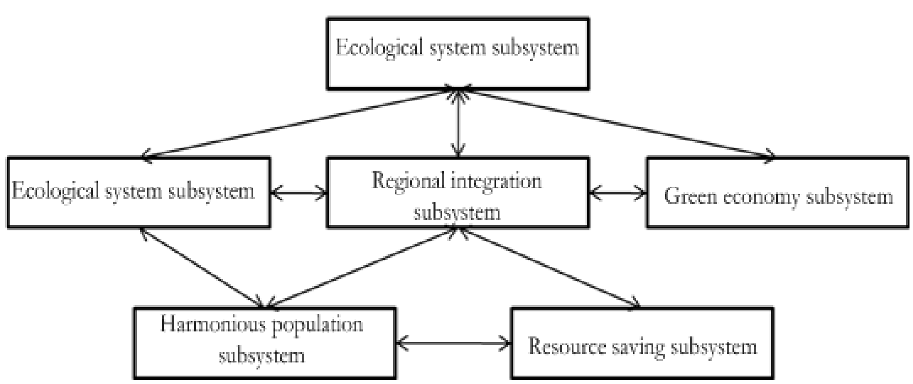

Figure 1. Basic structure of sustainable development in mining area

Sustainable development in mining area mainly explores the relationship between population gross, resource quantity, environmental quality and economic development. Therefore, the system is composed of harmonious population subsystem, resource saving subsystem, green economy subsystem, ecological environment subsystem, innovative ecological system subsystem and regional integration subsystem, and the specific relationship between each subsystem is shown in figure 1.

Structure of sustainable development in mining area is expressed as a dynamic nonlinear function including degree of the harmonious population development, sustainable resources utilization ability, green economy sustainable development level, maximum ecological environment utility level, ecological system regulation strength and regional integration and coordination ability, MSD=F(PHD, RSU, GESD, EEU, EIS, RRH). The system structure of sustainable development in mining area is complex, diverse and unstable due to dynamic and changeable population, resources, environment and regional coordination, and uncertain ecological surveillance easily affected by external environment.

3. Establishment of Dynamic System Model of Mining Area

3.1 Cause and effect relationship

Cause and effect relationship of the system comes into being under the mutual influence of dynamic system, used for expressing the relationship between each variable in the system. Main feedback relationship of sustainable development mode in mining area is acquired as follows through the link of above each subsystem.

(1) Gross domestic product (GDP) increase prompts the strengthened special investment for environmental protection, reduced discharge of the three wastes on account of effective control, declined energy consumption per unit of output, increased total value of output; thereby a positive feedback circuit is formed to ensure the sustainable development of regional environment.

(2) The growing of GDP increases the special investment volume for environmental protection, which gets environmental disruption under control, increases green GDP and feeds obtained ecological benefits back to GDP, to form a positive feedback circuit and ensure the sustainable development of regional economy.

(3) A positive feedback circuit is formed when primary energy consumption increases, energy residual amount and recovery rate decline, energy consumption per unit of output increases, GDP under the same energy level decreases, expenses of special investment for environmental protection and scientific and technological investment is cut down by government, and total primary energy consumption rises continuously. Please refer to figure 2.

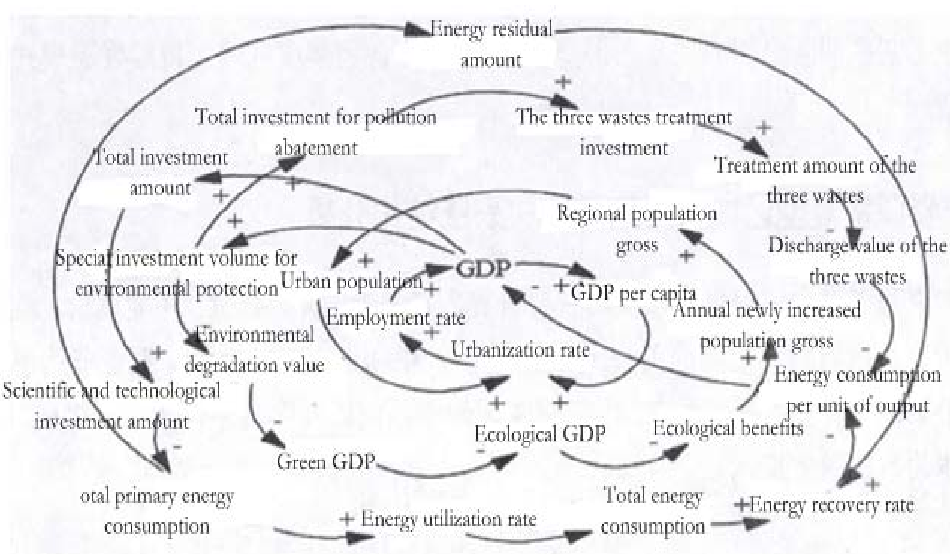

Figure 2. Structure of cause and effect relationship of dynamic sustainable development system in mining area

3.2 System flow chart and main equations

System flow chart

Different from cause and effect relationship diagram, system flow chart displaying the relationship between each variable with different properties can reflect the differences and relations between each variable evidently, while cause and effect relationship diagram is unable to make it. Hence, a system flow chart, i.e., dynamic system simulation model of mining area is set up by subdividing mutual effect of each scalar quantity based on structural relationship of cause and effect relationship diagram, which is capable of describing additive effects of dynamic performance influencing feedback system clearly, distinguishing each variable and building corresponding variable equation. Figure 3 shows the system dynamics model of mining area established in this study.

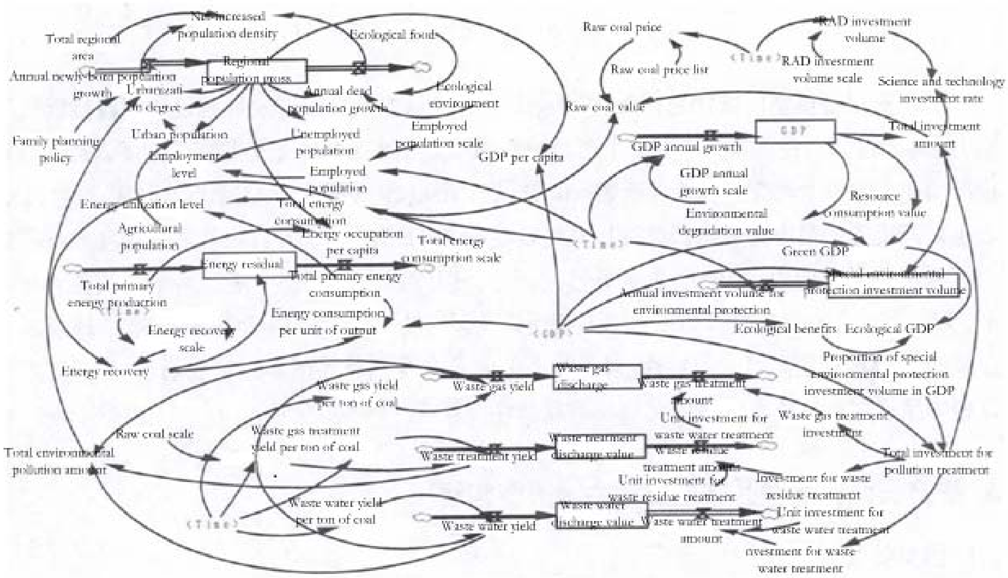

Figure 3. System dynamics model of mining area

Main equations

$$\mathrm{GDP} = \mathrm{INTEG}\,(\mathrm{GDPIV} + \mathrm{GDPAG} * (\mathrm{year} - 2000))$$

$$\mathrm{SEPI} = \mathrm{INTEG}\,(\mathrm{GDPIV} * \mathrm{EPIA} + \mathrm{ACIEP} * (\mathrm{year} - 2000))$$

$$\mathbf{TRP} = \mathbf{INTEG}\,(\mathbf{TRPIV} + \sum_{2000}^{\mathbf{year}} (\mathbf{AAB} - \mathbf{AAD}))$$

$$\mathbf{RAE} = \mathbf{INTEG}\,(\mathbf{AEIV} + \sum_{2000}^{\mathbf{year}} (\mathbf{TPPE} - \mathbf{TPCE}))$$

$$\mathbf{EA} = \mathbf{INTEG}\,(\mathbf{EG} - \mathbf{EP})$$

$$\mathbf{ECPUO} = \frac{\mathbf{TPPE - TPCE}}{\mathbf{GDP}}$$

Notes of equations are:

GDP, GDPIV-GDP initial value, GDPAG-GDP annual growth, SEPI-special environmental protection investment, EPIA-environmental protection investment accounting, ACIEP-annual capital investment for environmental protection, TRP-total regional population, TRPIV-total regional population initial value, AAB-annual amount of birth.

AAD-annual amount of death, RAE-residual amount of energy, AEIV-average energy initial value, TPPE-total primary production of energy, TPCE-total primary consumption of energy, EA-emission of automobile, EG-energy generation, EP-energy processing, SWA-slag waste amount, SWG-slag waste generation.

SWP-slag waste processing, WWA-water waste amount, WWG-water amount generation, WWP-waste water processing, UR-urbanization rate, UP-urbanization population, ECPUO-energy consumption per unit of output, GGDP-green GDP, EDV-environmental degradation value, RCV-resource consumption value.

4. System Simulation

Taking Wuhan as an example, six indexes of GDP, green GDP, special environmental protection investment, science and technology investment, total environmental pollution, coal occupation per capita are selected to perform analogue simulation and analysis, and establish system dynamics model of sustainable development in mining area. Of them, GDP is the best index measuring local economic condition; green GDP is an index accounting total newly created real national wealth after taking out resource and environmental loss; special environmental protection investment, the total fund paid for protecting resources and controlling environmental pollution is an important index measuring national economy and social development; science and technology investment plays a vital role in improving scientific and technological innovation ability; total environmental pollution is a critical indicator weighing regional sustainable development; coal occupation per capita is a key criterion weighing regional coal sustainable utilization level.

4.1 Model test

Based modeling purpose, system boundary, variables and each correlation coefficient are set in line with the actual situation. To verify the authenticity of Wuhan simulation model, six indexes are performed analogue simulation, and operating results of the model are compared and analyzed as shown in table 1.

Indexes	Objects	2012	2013	2014
GDP (billion RMB)	Simulation value	9387.3	10968.2	12982.1
	Actual value	9475.4	11188	13402
	Relative error (%)	0.93	1.97	3.13
Green GDP (billion RMB)	Simulation value	8395.8	10171.1	12034.6
	Actual value	8306.2	10602.9	11998.7
	Relative error (%)	-1.07	4.24	-0.31
Special investment for environmental protection (billion RMB)	Simulation value	85.3	94.0	99.6
	Actual value	89.0	92.3	104.9
	Relative error (%)	1.88	-1.82	5.11
Scientific and technological investment (billion RMB)	Simulation value	86.4	108.6	110.8
	Actual value	88.1	107.9	116.4
	Relative error (%)	1.88	-0.64	4.84
Total environmental pollution (million tons)	Simulation value	52857	59212	74500
	Actual value	54333	60638	75062
	Relative error (%)	2.79	2.41	0.75
Coal ownership per capita (standard coal per ton /person)	Simulation value	1.72	1.91	2.08
	Actual value	1.79	1.89	2.15
	Relative error (%)	4.07	-1.05	3.37

Table 1. Comparison of actual value and simulation value from 2012 to 2014

oadway 2444 material roadway), deep part is 7446 goof of coal seam 7# in liberation layer. Bottom of 2442 is goof 7444. Average interlayer spacing of coal seam 2# and 7# is 110 m. Arrangement of 2444 work face in clip river coal mine is as Figure. 1

It can be seen from table 1 that relative error of each index controlled within 5% accounts for 94.4% compared with simulation value and actual value, which is considered to have a good fitting degree by test. Therefore, those six indexes can be selected to predict the sustainable development trend of mining area.

4.2 Analysis of analogue simulation

Six indexes of four development modes in mining area are compared in figure (a) and figure (b), and a big difference of GDP and green GDP exists as a result of selecting different development modes. From the perspective of simulation value in 2020, GDP of green development mode increases by 15.8%, which is 1.22 times that of traditional development mode.

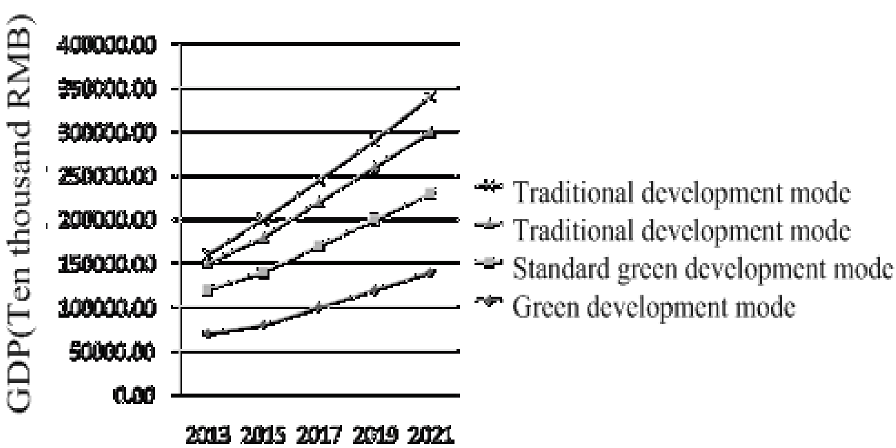

Figure a. GDP comparison

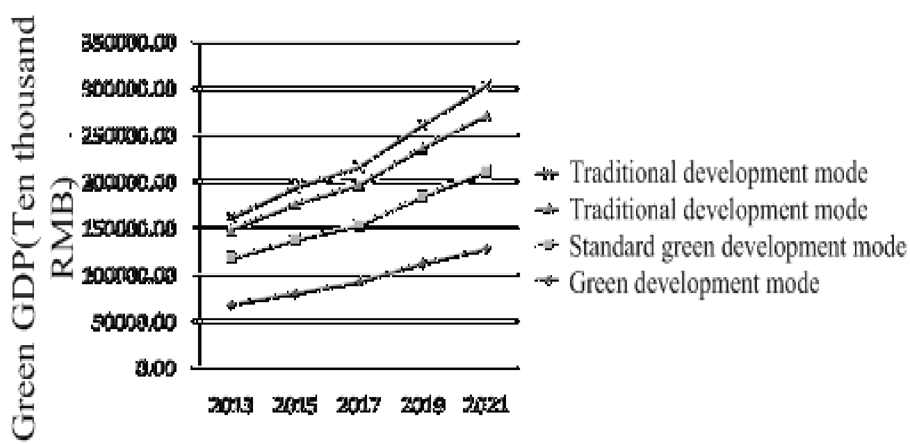

Figure b. Green GDP comparison

From figure (c) and (d), special environmental protection investment and science and technology investment of green development mode are far more than other three development modes. By analyzing 2022, 156 million RMB is invested additionally by selecting green development mode, and green development mode is 1.34 times that of the traditional development mode in total science and technology investment.

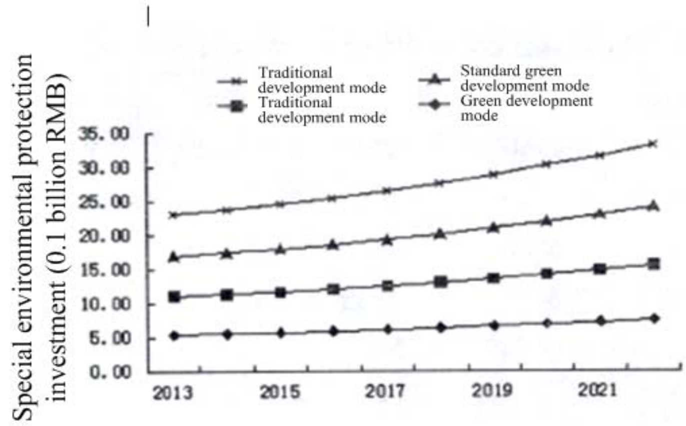

Figure c. Comparison of total special environmental protection investment

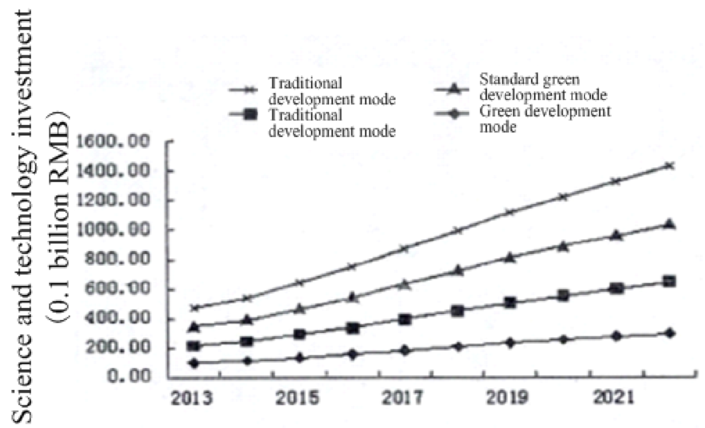

Figure d. Comparison of total science and technology investment

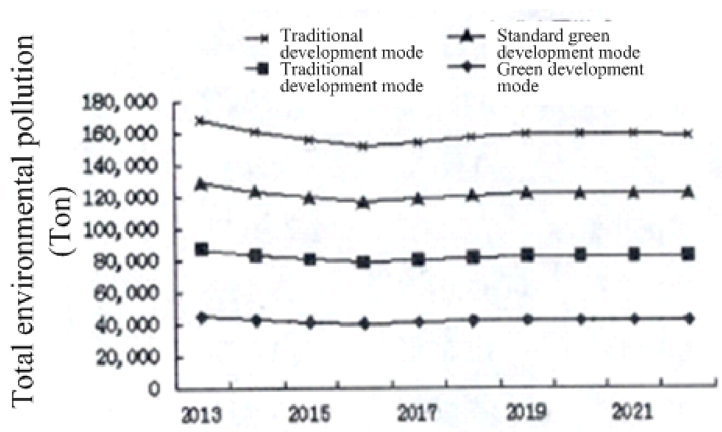

Figure e. Comparison of total environmental pollution

As to figure (e) and figure (f), the simulation results of total environmental pollution and coal occupation per capita, traditional development mode has higher total pollution amount and less coal occupation per capita. Moreover, with the increase of population and consumption of coal resource, coal occupation per capita declines year after year, but total pollution amount rises each year

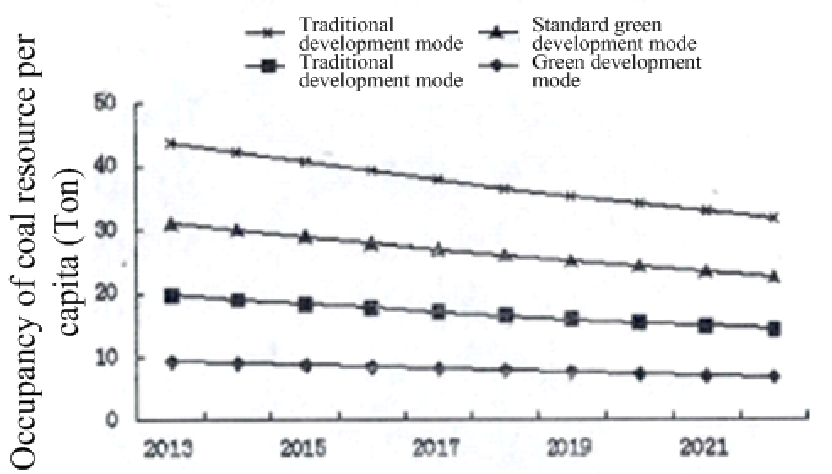

Figure f. Comparison of coal occupation per capita

In conclusion, traditional development mode is featured by maximum source consumption and total pollutant discharge, and lowest energy recovery rate and economic development; resource consumption level and environmental pollution degree under standard development mode are improved to some extent, but still not reach the optimum; standard green development mode connects the limitations of resources with the destruction of environment organically, but ignores the goal of maximizing capital efficiency; green development mode conforming to future economic development trend maximizes the ecological capital, intensifies efficient low carbon resources and realizes the development mode of resource saving friend-environment type with three low and one high. Thus, green development mode is the best choice for sustainable development in mining area.

5. Conclusion

To sum up, first is to adjust overall development strategy in mining area, characterized by minimum resource consumption, lowest environmental pollution, most advanced equipment and technology, most reasonable special environmental protection investment scale, best regional cooperation level and most outstanding knowledge overflow effect, in order to achieve “three low and one high” green development level.

Second is to control total environmental pollution effectively. By choosing green development mode, the simulation values of total environmental pollution in 2013 and 2022 are 3.89 and 3.66 billion tons respectively, fell by nearly 6% year-on-year. Hence, to ensure the sustainable development in mining area, advanced technologies and equipments, rational investment level and sound environmental protection and law knowledge are supposed to be adopted to control total environmental pollution effectively. Generally speaking, special environmental protection investment is hysteretic, but has good late environmental effect in the long term.

Third is to reduce energy consumption per unit of output. Energy consumption per unit of output of Wuhan in 2011 was 10,400 tons of standard coal/0.1 billion RMB. Known from simulation value in 2022, energy consumption per unit of output of traditional, standard, standard green and green development mode is 7400, 4200, 2700 and 2100 tons of standard coal/0.1 billion RMB respectively, and green development mode is a quarter of traditional development mode only. Therefore, reducing energy consumption per unit of output is the important way of realizing the sustainable development in mining area.

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