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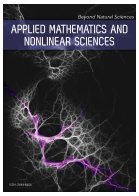

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# Simulation analysis of resource-based city development based on system dynamics: A case study of Panzhihua

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## Abstract

Resources and the environment have always been the two important natural factors that affect people's lives. In recent years, the problem of resources and the environment has increasingly become an important issue that people are concerned about. This study discusses the use and consumption of energy and the impact of environmental pollution on economic development under sustainable economic development. This paper takes Panzhihua as an example to analyze the impact of energy and environment on the economy, and proposes solutions to improve economic development, which is of strategic significance for the future development of Panzhihua City. In this paper, the system dynamics method is used to decompose the Panzhihua large-scale system into three parts and carry out modeling and simulation to explore the connection between them. Based on the data from 2007 to 2015 in Panzhihua City, simulations have been carried out to obtain qualitative and quantitative analysis of certain simulation curves of the energy-environment-economy 3E system (hereinafter referred to as 3E system) from 2007 to 2030 to ascertain the future development pattern of Panzhihua City. The results show that when the 3E system is a coordinated development model, economic development and environmental protection have a good development trend at the same time, which is applicable to the future development of Panzhihua City. This model has good reference suggestions and application prospects for urban development. We want to give Panzhihua City the following suggestions: (1) Continue to focus on the secondary industry and increase competitiveness. (2) Increase the investment funds in environmental protection and achieve sustainable economic development.

**Keywords:** dynamical systems, mathematical model and city development.
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## 1 Introduction

With the continuous development of the times, the economic level has become an important indicator for evaluating the level of development of a city. In the economic development, energy and the environment have played an important role. People's living standards are constantly improving, and the requirements for quality of life are also increasing. The increase of haze has also affected people's daily lives and physical health. The economic benefits and environmental problems brought by the continuous consumption of energy are equivalent existence. For example, although the coal price is relatively low, it will cause serious environmental pollution. In addition, the oil price is high and the resources are scarce, and the complete conversion of production will not be a long-term solution. And with the development of the times, the population growth also affects the economic development. There are intricate and complex relations among energy, environment, and economy. In order to achieve a comprehensive well-to-do society, social progress, and sustainable economic development in the new era China, this issue is what we need to study and solve.

In the early 1980s, China began to introduce the theory and method of system dynamics, and it has been widely applied in the field of sustainable development research. Such as Yang Tongyi of Shanghai [1] and Professor Wang Qipan [2], they think that SD (System Dynamic, abbreviated as SD) research method to deal with complex system problems is a combination of qualitative and quantitative methods of systematic analysis and comprehensive reasoning. Its model simulation is a kind of simulation of structure and function. System dynamics has unparalleled advantages in the study of complex nonlinear systems. The related researchers have applied it to social, economic, commercial, urban construction and even biological and medical research.

In China, for the research of resource-based cities, scholars in China have conducted research on the definition and classification of resource-based cities, analysis of development dilemmas [3], urbanization and ecology [4], employment and transformation [5], and transition mechanisms [6]. Research on sustainable development between resource-based cities' own energy, environment, and economic relations has not been touched at present, especially in the methods and evaluation recognition of resource-based cities in the transformation process are not perfect.

For the Panzhihua City, previous scholars mainly used the methods of shift-share analysis [7], ecological footprint method [8], innovation-driven analysis method [9] and sustainable development system index research method [10] to conduct research. In addition, the research on the output value and pollution of Panzhihua energy is lacking, and the transformation of Panzhihua city is not studied through the system dynamics method. In fact, there is less policy analysis that can be used in Panzhihua City.

Previous scholars have mainly studied energy and economic issues [11]- [12]. However, under the increasingly severe environmental problems, people began to pay attention to the impact of environmental and energy economic systems [13], started working on sustainable development and bring it into the model for research [14]-[15]. There are currently three models for the study of energy, environment, and economic systems: Markel, multi-objective programming model, and system dynamics model. Since the nonlinear composite structure is to be studied, this article will use the system dynamics model and use feedback from bottom to top to study the relationship between the environment and energy on economic development. It can also clearly show the connection between the internal and external, can explain the trend and strength of the system structure, and at the same time, dynamic simulation analysis can be carried out to explore the connection between the three systems.

This paper uses the combination of theoretical qualitative research and empirical analysis to explore the relationship among the three subsystems of energy, environment, and economy in Panzhihua City. Using system dynamics theory and SD model simulation, combining with the data of National Bureau of Statistics and Panzhihua Yearbook to analyze. And combining with national and Panzhihua policy trend in recent years, the method is introduced into the city to study its matching degree and applicability, and to give policy suggestions for the future development of Panzhihua City as a resource-based city. The solution to the problem is to explore the key factors of the Panzhihua 3E system, so as to establish the SD model, and give strategic policy advice in

light of the current situation.

This article will be composed of two parts, using the material and method and 3E system simulation analysis to complete the Panzhihua City energy-environment-economy relationship research.

## 2 Materials and methods

### 2.1 Research area overview and research methods

#### 2.1.1 Research area overview

Panzhihua is a typical mining energy city. It is also China's first resource development special zone and the vanadium and titanium capital of China. The reserves of titanium, vanadium, and graphite are ranked first in the world, third in the world, and third in China, respectively. It has become the largest production base of vanadium titanium products and vanadium titanium steel in China. The whole area is integrated into the experimental zone for the development and innovation of strategic resources in western Panzhihua and it is speeding up the construction of a world-class vanadium and titanium industrial base. And it has built a domestic first-class ultra-large steel vanadium titanium enterprise group-Panzhihua Iron and Steel. In the inventory of statistical resources at the end of 2015, there were 317.17 million tons of coal, 6318.95 million tons of vanadium-titanium magnetite, 9.78 million tons of associated vanadium, 409.65 million tons of associated titanium ore, 340.56 million tons of flux limestone, 47.87 million tons of metallurgical dolomite, 15.55 million tons of crystalline graphite, 15.49 million tons of diatomite, 20.78 million tons of ink stone and 81.27 million cubic meters of granite are used for decoration. In addition, there are rare precious metals such as chromium, tantalum, niobium, nickel, copper, lead, zinc, manganese and platinum. Many of the projects are listed by the World Record Association as the highest in the world.

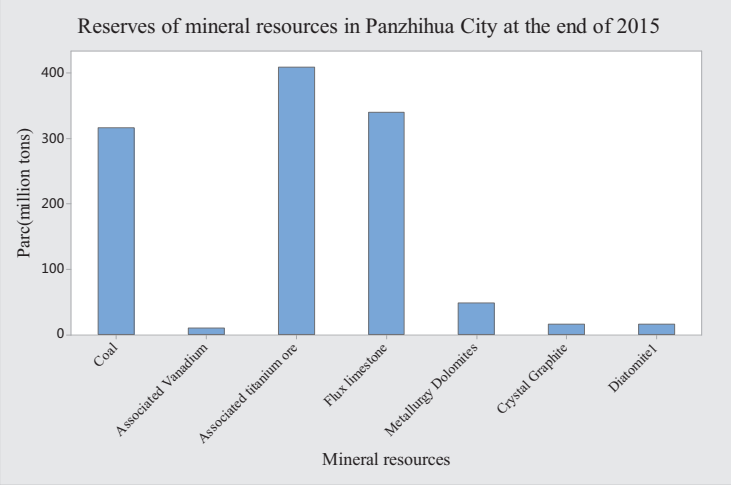


**Fig. 1** Reserves of mineral resources in Panzhihua City at the end of 2015

In 2015, the regional GDP reached 87.085 billion yuan, an increase of 9.3%, and ranking seventh in the province. The added value of the primary industry was 2.94 billion yuan, an increase of 4.5%, and the contribution rate to the economic growth was 1.6%, stimulating the economic growth by 0.1 percentage points. The added value of the secondary industry was 64.309 billion yuan, an increase of 9.6% and the contribution rate to the economic growth was 79.4%, pulling the economic growth by 7.4 percentage points. The added value of the tertiary industry was 19.836 billion yuan, an increase of 8.8%, and the contribution rate to the economic growth

was 19%, stimulating the economic growth by 1.8 percentage points. Its gross national product is increasing but its magnitude is gradually decreasing. In the specific GDP share of Panzhihua City, the secondary industry accounts for the largest proportion, while the primary industry only has a small proportion.

Similar to most other resource-based heavy industrial cities, Panzhihua has many issues left over from history in environmental protection, and its structural pollution is serious. In order to solve these problems, the "Total Control Plan for the Discharge of Major Pollutants in Sichuan Province during the 11th Five-Year Plan period" stipulated that by the end of 2010, the total sulfur dioxide emissions in Panzhihua City should be controlled within 81,000 tons. To achieve these goals, Panzhihua City has adopted a series of important measures, including the establishment of emission reduction implementation plans and action plans, such as the "Panzhihua Main Pollutant Total Emission Reduction and Implementation Plan" and Panzhihua City's "Main Pollutant Total Emission Reduction Action Plan" in 2008 and 2009. In addition, the total amount of major pollutants control indicators was further decomposed and implemented to enterprises, the municipal governments signed "Panzhihua City's 11th Five-Year Plan major pollutant control responsibilities" with the counties, districts and the major enterprises [16].

### 2.1.2 Research methods

In recent years, the compound control system has obvious advantages in the study of the connection between various relationships. In order to explore the economic development direction of Panzhihua City, this paper selected the energy subsystem and the environmental subsystem in combination with the economic subsystem according to the specific conditions of Panzhihua City to study. Panzhihua is a resource-based city in the western region and has rich mineral resources. At the same time, development also faces environmental damage. The two factors constrain each other, thus affecting economic development. The best model for the development of Panzhihua City in the future should be coordinated development.

System dynamics is not only a discipline of a feedback system that analyzes research information, but also a new comprehensive subject of understanding and solving the intersecting of system problems. It believes that the system's behavior patterns and characteristics mainly depend on its internal dynamic structure and feedback mechanism. Using a combination of qualitative and quantitative methods, the system is modeled and simulated, and the links between various subsystems are studied. However, when establishing a qualitative model of system dynamics, there are basically no fixed rules to follow. The quality of the model built depends largely on the experience of the researcher. Therefore, when modeling system dynamics, we should focus on the causal structure of the model, reflect the true dynamic behavior of the system, and avoid one-sided pursuit of unnecessary complex models [17].

System dynamics' understanding of problems is based on the close interdependence between the behaviors and the internal mechanisms in the system, and through the process of establishing and operating mathematical models, it gradually explores the causes and consequences of changing patterns. System dynamics calls it structure. The use of system dynamics to solve problems consists of three main steps: firstly, a systematic analysis of the research objects in combination with system dynamics theory, principles and methods to identify system variables and boundaries; secondly, analyze the system structure, divide the levels and sub-blocks of the system, determine the overall and local feedback mechanism, and establish a model that meets the mathematical norms; thirdly, simulate and analyze the model [18].

## 2.2 Energy-Environment-Economy system analysis and model establishment in Panzhihua City

### 2.2.1 Analysis of the wholeness of Energy-Environment-Economy system in Panzhihua City

The three subsystems of energy resource, environment and economy restrict and interact with each other to form a large system that affects people's survival and development. This article refers to many sources of literature and concludes that the interaction between the energy, environment, and economic systems affects the overall development of Panzhihua, and that the closed-loop feedback control system can be accurately linked in the three relationships [19]. Only the coordinated development of the three major systems can avoid the

imbalance of any subsystem or the accumulation effect of a certain factor, and avoid the huge changes or even the collapse of the entire system. Panzhihua city as a mining city, the whole city's economic development depends mainly on mining. At the same time, population growth also affects the emergence of environmental problems [20]. We can analyze the current problems and the future direction of development in Panzhihua from it. These can be seen in the simulation of Vensim. The following will be analyzed from the causality diagram and the SD model diagram to draw conclusions.

### 2.2.2 Causality diagram

This article refers to many reference materials on the construction model of the economic, energy, and environmental (3E) systems [21]- [22]. The subjective thinking of the researcher combined with the development and change laws of Panzhihua City and use the combination of qualitative and quantitative analysis to build a causality diagram of the coordinated development of energy-environment-economy system in Panzhihua City, among which there are multiple feedback relationships. According to the system dynamics modeling ideas, establishing an effective causality network is the premise and key to carry out system simulation research.

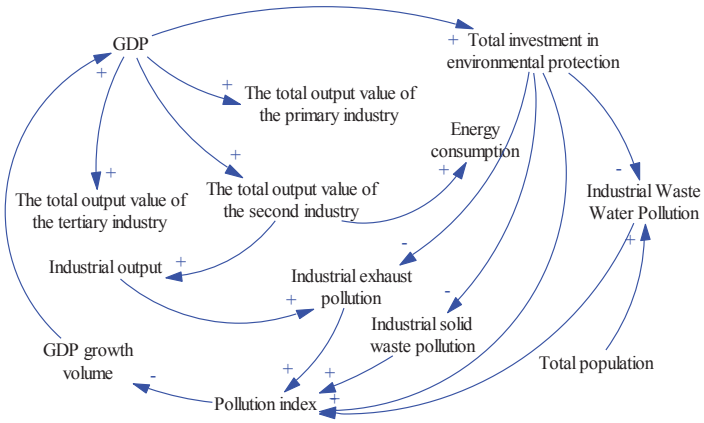


**Fig. 2** Causality diagram

(1) Energy subsystem causality diagram model. It is mainly composed of energy consumption and mainly affected by the positive feedback of the total value of the secondary industry. The secondary industry has the largest industrial output value and the greater the energy consumption. It plays a pivotal role in the entire system.

(2) Environmental subsystem causality diagram model. It consists of industrial waste gas pollution, industrial solid waste pollution, and industrial waste water pollution. On the one hand, the impact of total investment in environmental protection in the economic subsystem has a negative effect on industrial waste gas pollution, industrial solid waste pollution, and industrial waste water pollution. The growth of the three wastes also increases the pollution index, which in turn affects the economic subsystem.

(3) Economic subsystem causality diagram model. It consists of regional GDP, environmental protection investment, and GDP growth. Among them, the positive feedback of the main secondary industry's total value to the energy subsystem and the negative feedback of the environmental protection investment to the environmental subsystem make the entire system enter the loop.

### 2.2.3 3E system inventory and flow chart

### 2.2.4 Model checking

The test of the model is to compare the matching degree between the model and the reality. Because the model has a certain degree of subjectivity, and the reality is often very complex, we can consider that the model is also a microcosm of reality under certain conditions. Therefore, in order to prove the validity of the model,

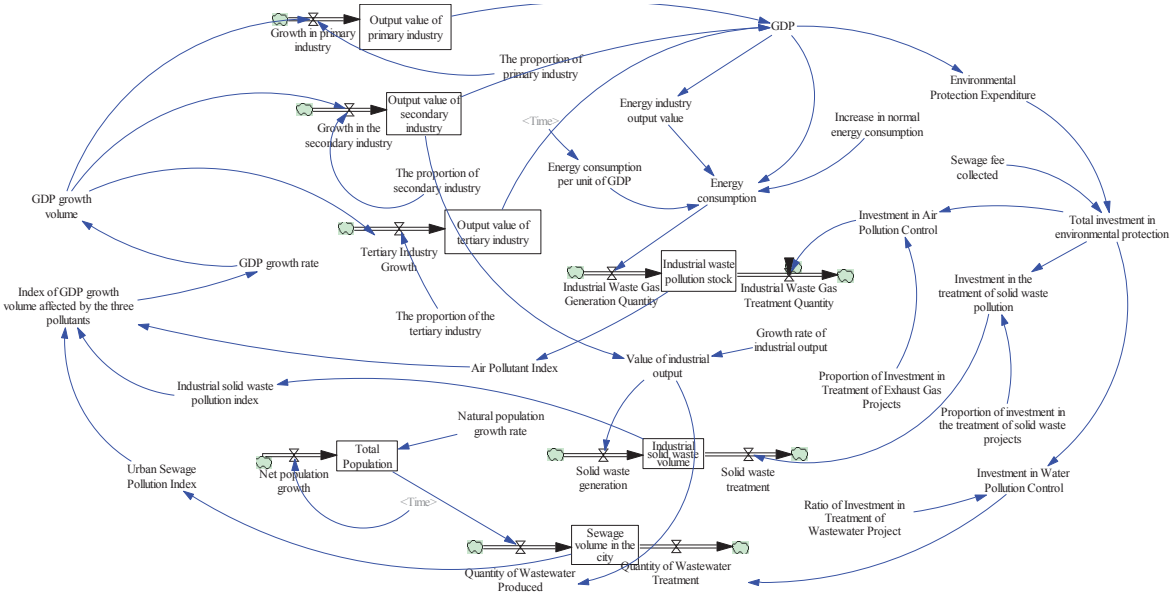


**Fig. 3** 3E system inventory and flow chart

the test is also conducted to determine whether the model conforms to the actual trend and development, so that the research is more persuasive. This article uses the historical test method, which means that taking any historical time node as the starting point in the scope of the entire study, using the model to simulate the model and comparing the existing historical data with the simulated data. In the system dynamics model, when the error is within 10%, the model is considered to have passed the historical test.

Through the reference model, we enter the historical data from 2007 to 2014 to compare. It can be found that the operation of the model is basically stable. Only a very few values exceed 10%, indicating a good fit between simulated and actual values.

## 3 An empirical analysis of 3E system simulation in Panzhihua City

### 3.1 Parameter establishment and equation

#### 3.1.1 Parameter establishment

In system dynamics, the most important party is information feedback. The model's behavior patterns and main results depend mainly on the parameter values. Another feature of system dynamics is that the accuracy requirements of data and parameters is not very high, and it has a certain subjectivity of modelers. Constructing a model is a prerequisite for simulation, and the establishment of a model needs to be based on the acquisition of parameters. The feedback mechanism of the 3E system in resource-based cities is very complex. Many parameters cannot be expressed with accurate data and most of the data are difficult to obtain. Therefore, we select the variables that have important influence on the state variables and rate variables and that are relatively easy to obtain data as the main research object of the model.

The data in this paper are mainly from the "Panzhihua Yearbook" (2007-2015) prepared by Panzhihua City People's Government, the data disclosure of the Statistics Bureau of Panzhihua City, and the statistics of the National Bureau of Statistics. This article mainly uses the following methods for statistical analysis of data:

(1)Simple linear regression. Using Matlab and other statistical software to carry out simple linear regression and obtain the relationship between two to three indicators. (2)Table function method. Using the inter-parameter

equation in Vensim to establish the table function and then the connection between the two indicators is obtained. In addition, due to the lack of data, some of the data were analyzed by fitting.

### 3.1.2 Basic equations of parameters in SD model

The basic equations of this model are as follows:

*(1)FINAL TIME=2022*

*Units: Year*

*The final time for the simulation.*

*(2)The increment of GDP=GDP growth rate*100*

*(3)Index of GDP growth volume affected by the three pollutants=0.003*Air Pollution Index+0.00036*Industrial Solid Waste Pollution Index+0.0056*Urban Sewage Pollution Index*

*(4)The increment of the primary industry=The increment of GDP*The proportion of the primary industry*

*(5)The increment of the secondary industry=The increment of GDP*The proportion of the secondary industry*

*(6)The increment of the tertiary industry=The increment of GDP*The proportion of the tertiary industry*

*(7)Output value of the primary industry=INTEG (The increment of the primary industry, 13.01)*

*(8)Output value of the secondary industry=INTEG (The increment of the secondary industry, 240.59)*

*(9)Output value of the tertiary industry=INTEG (The increment of the tertiary industry, 72.47)*

*(10)GDP=Output value of the primary industry+Output value of the secondary industry+Output value of the tertiary industry*

*(11)Energy consumption=GDP*Energy consumption per unit of GDP*(1+ Increase rate of normal energy consumption)*(0.002* Output value of energy industry)*

*(12)Environmental Protection Expenditure=10.491-0.0042*GDP*

*(13)Investment in Air Pollution Control=Proportion of investment in waste gas treatment projects*Total investment in environmental protection*

*(14)Industrial waste gas pollution quantity=INTEG (Industrial Waste Gas Generation Quantity-Industrial Waste Gas Treatment Quantity, 146)*

*(15)The amount of industrial solid waste=INTEG (The amount of solid waste production-The amount of solid waste treatment, 2026.06)*

## 3.2 SD model simulation results

Using the above models to simulate the energy, environment, and economic systems in Panzhihua City. The values of exogenous variables and parameters were based on data from 2007 to 2015 in Panzhihua City. Taking 2007 as the base year, step length is 1 year, and the time boundary is from 2007 to 2030. And we take the proportion of investment in waste gas treatment projects, the proportion of investment in solid waste treatment projects, the proportion of investment in wastewater treatment projects, the proportion of the primary industries, the proportion of the secondary industries, and the proportion of the tertiary industry as variables, through continuous adjustment to determine the development direction of Panzhihua City. The following are divided into two situations: They are the current development model and the coordinated development model.

**Situation 1: Current development model**

According to the original development direction, we will continue to develop and maintain the status quo unchanged.

**Situation 2: Coordinated development model**

The coordinated and comprehensive development of economy, energy and environment makes the proportion of investment in waste gas treatment projects, the proportion of investment in solid waste treatment projects and the proportion of investment in wastewater treatment projects changed to 60:5:35, and the proportion of the primary industry, the proportion of the secondary industry and the proportion of the tertiary industry changed to 1:90:9.

The following are the simulation results for some of the indicators in the two cases:

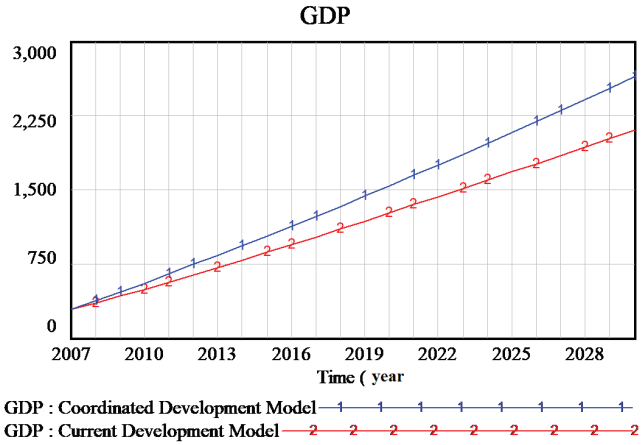


**Fig. 4** GDP simulation value(One hundred million yuan)

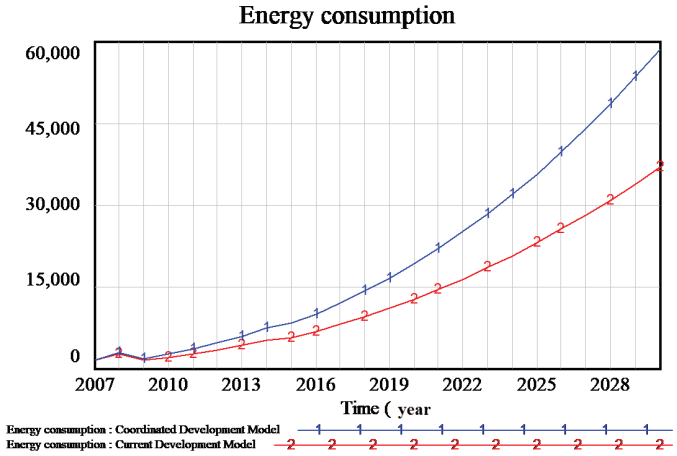


**Fig. 5** Energy consumption simulation value(10,000 tons of standard coal)

### 3.3 Analysis of simulation results

The simulation of situation 1 shows that in 2030, the GDP will reach 211.046 billion yuan, the amount of GDP growth will be 8.775 billion yuan, the industrial output value will be 25.732 billion yuan, the air pollution index will be 94.4925, the industrial solid waste pollution index will be 102.921, and the urban sewage pollution index will be 101.578. In this situation, there is room for further improvement in Panzhihua in terms of economic development and pollution treatment. Under future policies and social constraints, this development will have certain drawbacks in the future.

The simulation of situation 2 shows that in 2030, the GDP will reach 264.075 billion yuan, the amount of GDP growth will be 11.632 billion yuan, the industrial output value will be 40.371 billion yuan, the air pollution index will be 91.7934, the industrial solid waste pollution index will be 101.947, the urban sewage pollution index will be 101.059. In case 2 the GDP of the model has increased significantly, the amount of pollutants

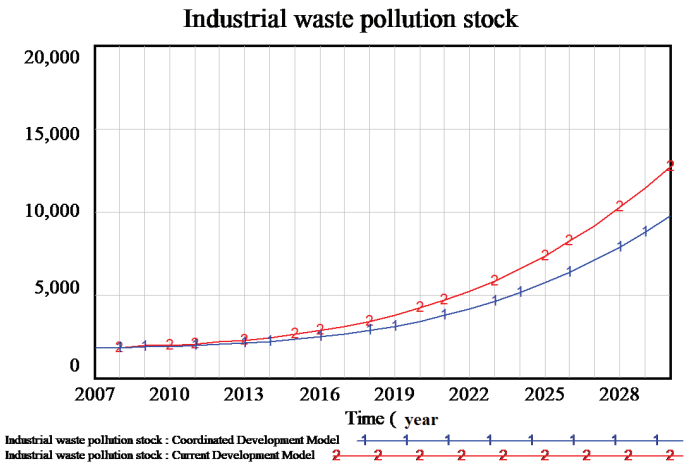


**Fig. 6** Industrial waste gas pollution quantity analog value(100 million cubic meters)

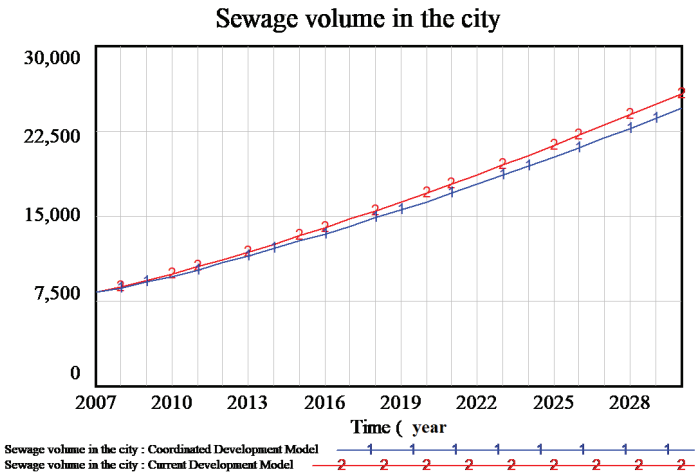


**Fig. 7** Urban sewage volume simulation value(10,000 tons)

has gradually decreased, and energy consumption has also increased a lot. The coordinated development model can also reduce pollution emissions and save energy while ensuring that the economy has certain development, so this model still has advantage. From the domestic perspective, major national strategies such as the "13th Five-Year Plan" period, "The Belt and Road Initiative", and comprehensive innovation and reform tests have entered a period of full implementation and effect transformation, and the stable and better trend of industrial economy has not changed. This brings opportunities to the industrial development of Panzhihua. At the same time, Panzhihua City's "13th Five-Year Plan" also mentioned that industrial production should continue to grow, and the level of energy conservation, emission reduction and resource utilization should be improved. This is in line with the trend of development in the coordinated development model simulated in this paper. Therefore, the energy-environment-economic development model in Panzhihua City is the optimal future development model.

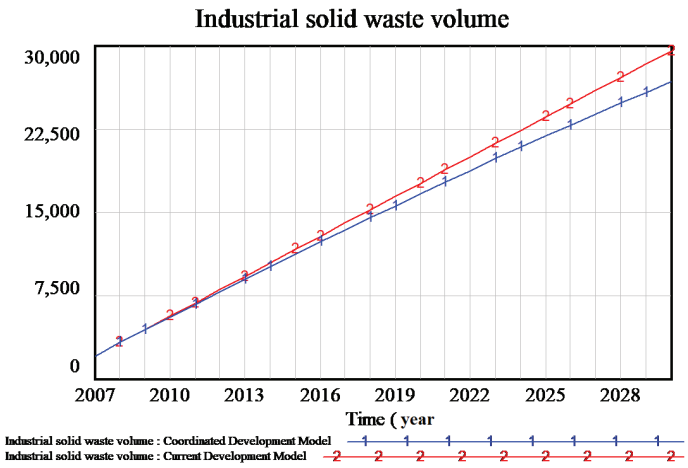


**Fig. 8** Industrial solid waste pollution volume simulation value(10,000 tons)

## 4 Conclusion

In this paper, the principle of system dynamics is used to construct the SD model. Through the simulation of Vensim software and the combination of qualitative and quantitative methods, the development of the energy-environment-economy system in Panzhihua City is analyzed and two kinds of situations are simulated. Finally, we come to the following conclusions:

Situation 2 meets the development trend of Panzhihua City. For the resource-based cities such as Panzhihua, it is necessary for the environmental protection and development to go hand in hand, we cannot pollute first and then handle the environmental issues. This is a considerable burden for the future development, so we must emphasis on the importance of environmental protection. The government should increase its investment in environmental protection governance. If we find that the total investment in environmental protectionis declining, it will not only increase environmental problems, but also make it difficult to develop economically. At the same time, we must concentrate our energy on developing one place while developing the economy, make full use of our own resources, and we must also keep up with the times and develop in an integrated and coordinated way. It is necessary to raise the standards of pollutant discharge, give enterprises the limited conditions and strictly abide by this regulation. We should pay close attention to and study new energy and new technologies in a timely manner, improve the utilization rate of resources, reduce the amount of pollutants discharge and take the road of sustainable development. In addition, we should also respond to national policies in a timely manner, so as to timely adjust economic structure and environmental investment structure, and timely respond to different situations. The Panzhihua City can use this article as a basis to adjust the structure, increase investment in the secondary industry, increase investment in environmental governance, and adjust the proportion of investment in pollution control to make more investment for air pollution treatment, while not neglecting the treatment of other pollution. For the better and faster development of the Panzhihua City in the future, the three systems of energy-environment-economic influence each other to ensure the energy environment and the social economy realize the sustainable development at the same time. And then we need to make overall plans and take all factors into consideration, so as to achieve overall sustainable development.

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