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Research on the Sustainable Development of an Economic-Energy-Environment (3E) System Based on System Dynamics (SD): A Case Study of the Beijing-Tianjin-Hebei Region in China

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Received: 19 August 2017; Accepted: 22 September 2017; Published: 26 September 2017

Abstract: The sustainable development of an economic-energy-environment (3E) system has received increasing attention by the government because it both determines national development and individuals' health at the macro and micro level. In this paper, we synthetically consider various important factors based on analysis of the existing literature and use system dynamics (SD) to establish models of sustainable development of a 3E system. The model not only clearly shows the complex logical relationship between the factors but also reveals the process of the 3E system. In addition, the paper provides a case study of the Beijing-Tianjin-Hebei region in China by using a scenario analysis method. The models proposed in this paper can facilitate an understanding of the sustainable development pattern of a 3E coordination system and help to provide references for policy-making institutions. The results show that the long-term development of the Beijing-Tianjin-Hebei region's 3E system is not sustainable, but it can be changed through the adjustment of the energy structure and an increase in investment in environmental protection, which can improve the environmental quality and ensure continuous growth rather than excessive growth of energy consumption and the gross domestic product (GDP).

Keywords: sustainable development; economic-energy-environment (3E) system; system dynamics (SD); Beijing-Tianjin-Hebei region; China

1. Introduction

Energy is the material basis of economic development; the environment is the carrier of energy and also the space for all kinds of living things. However, with the rapid development of industrialization and economy, the world is being faced with imbalances and challenges of resource depletion and the deterioration of the ecological environment because of unreasonable development of mankind and the use of natural resources, as well as any emissions of pollutants [1,2]. Historical experience shows that energy, the environment, and the economy form an interrelated complex entity. The coordinated development of energy, economical, and environmental subsystems is not only an essential requirement of the sustainable development theory but also an effective way to achieve sustained, steady, and high-speed development of the national economy [3]. How to coordinate the relationship among the economy, energy, and the environment and how to explore their sustainable development have become important problems for the government and academia to solve urgently.

The coordinated relationship among the economy, energy, and environment is shown in Figure 1. Its specific performance is as follows. The environment is the foundation of economic development. The environment, as the material condition of economic and social development, can both promote and hinder the development of economy. Environmental pollution and ecological damage have become important factors that endanger people's health and restrict economic and social development [1]. The economy influences the environment. Economic development has two impacts on the environment. One is positive, that is, the ecological environment is protected, and resources are rationally and continuously used through the coordinated development of the economy and environment [4]. The other is a negative effect, i.e., that inappropriate economic development will lead to the destruction of resources and the ecological environment. Energy is the necessary factor for economic development. Economic development is based on energy, and energy is the material base of economic development [2]. From an economic point of view, the relationship between energy and economic growth is manifested in two aspects. On the one hand, economic growth depends on energy, that is, energy is the most important part of economic growth. On the other hand, the development of energy should be based on economic growth, because economic growth can lead to large-scale development and utilization of energy [5]. However, energy, as an economic motive factor, is also an obstacle. The gradual depletion of energy and the environmental problems caused by energy will seriously hinder economic development [6,7].

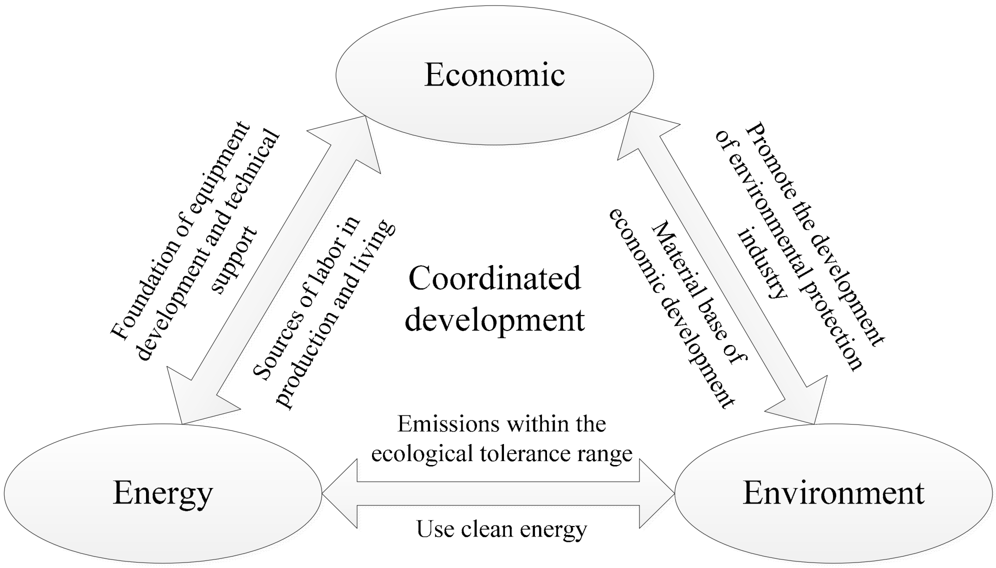

Figure 1. The coordinated relationship among the economic, energy and the environment.

Many scholars have studied the sustainable development of the economic-energy-environment (3E) system as well as its importance. Bozoklu and Yilanci [8] investigated the causal linkage among output and energy consumption and found that income Granger causes energy consumption (conservation hypothesis); in addition, their results reveal that energy consumption Granger generates the income level for the case of 20 Organization for Economic Co-operation and Development (OECD) countries. Pao and Fu [9] found unidirectional causality running from income to energy consumption for Brazil covering the period from 1980 to 2010 based on conventional neo-classical one-sector aggregate production technology. Apergis and Payne [10] investigated the causality of 3E using the vector error correction model (VECM) and found that output, renewable energy consumption, and CO_2 emissions are co-integrated. Tan et al. [11] presented an interactive comparison of different waste to energy scenarios, and the 3E assessment revealed incineration as the superior technology choice when the production of electricity and heat was considered. Yi et al. [12] used 3E to study a novel system combining a dual-gas of coal gasified gas and coke oven gas with the technology of CO_2 recycling into a single gasifier. Adibhatla and Kaushik [13] used 3E to study a conceptual power plant cycle formed by integrating solar energy in a steam cycle of a natural gas-fired combined cycle power plant. Li et al. [14] constructed the system dynamics (SD) model of 3E sustainable development and took China as an example for system simulating and forecasting. Zhang [15] used the theories and principles of SD to determine the key indicators and quantitative relationships among the indicators to establish and test an SD model based on the 3E system. Zhou et al. [16] established a 3E-SD model of Suzhou, setting the energy structure and the environmental investment as the adjusting parameters and designing four developing modes for simulation.

Existing literature uses different methods to study the influential factors of the sustainable development of a 3E system. However, this literature mainly emphasizes the importance of an energy system. Systematic research on the relationship among energy structure, economic development, and environmental pollution is limited, and most studies summarize data or perform qualitative analysis. Some scholars have used econometric methods to study the relationship of elements among energy structure, energy consumption, and the gross domestic product (GDP), but this research lacks further prediction and judgment on the future sustainable development trend of the economy, energy and environment [17–20]. Thus, our goal is to fill this gap. In this paper, we synthetically consider various important factors through analysis of the existing literature and use SD to establish models of sustainable development of a 3E system. The model not only clearly shows the complex logical relationship between the factors but also reveals the process of the sustainable development of a 3E system. In addition, the paper provides a case study of a 3E system of the Beijing-Tianjin-Hebei region in China by using the scenario analysis method. The models proposed in this paper can facilitate an understanding of the sustainable development pattern of a 3E coordination system and help to provide references for policy-making institutions. The structure of this paper is as follows. Section 2 establishes the sustainable development models of the 3E system. Section 3 presents the data analysis and results of simulations. Section 4 is the discussion of different scenarios, and conclusions are presented in Section 5.

2. Methodology

SD is a systems modeling and dynamic simulation methodology for the analysis of dynamic complexities in socio-economic and biophysical systems with long-term, cyclical, and low-precision requirements [21]. Through the complex relationship between the various elements of the system, SD establishes a relatively effective model, which can achieve the predetermined goal and meet the predetermined requirements. Based on the principle of system thinking and feedback control theory, SD helps understand the time-varying behavior of complex systems [22]. A 3E system is a complex, large system which is coupled to many factors, such as the economy, energy, society and environment. From the point of view of system theory, a 3E system is a subsystem of the sustainable development of the national economy, and its internal factors can be intuitively and clearly displayed by SD. Although other types of quantitative modeling can be used for the impact analysis, the SD model, which has the advantage of solving dynamic problems, can better simulate the process of sustainable development of systems [23].

2.1. Causal Loop Diagrams (CLD) Analysis

As mentioned above, there is a close connection among the subsystems of the 3E system. On the one hand, the economic subsystem puts forward the energy requirements to the energy subsystem, which supplies the required resources to the economic subsystem [4]. On the other hand, the activity of the energy subsystem puts forward the demand for economic products to the economic subsystem, which relies on its own activities to supply these products to the energy subsystem. Although the 3E system can be an independent analysis, it is not a closed system, which cannot be analyzed separately from the large system of the national economy [5]. This study uses causal loop diagrams (CLD) to represent the relations of the SD model, as shown in Figure 2, in which the arrow indicates the relationship between factors and the direction of influence, and the positive and negative sign represents positive or negative correlation, respectively. The theoretical framework is analyzed as follows:

(1) As the largest developing country, China uses secondary industry, that is, industrial development, as the core to attract input and output and promote the development of other industries, thereby stimulating economic development. At the same time, industrial production will lead to energy consumption and high pollution. Thus, this study argues that the subsystems of the 3E system are linked by industrial output values.

(2) Many factors can reflect the economic development of a country from different angles, and the core variable of them is GDP. GDP is an important indicator to measure the overall economic situation of a country or region. Thus, the core evaluation index of the economic subsystem of this research is set to GDP. The core factor of the energy subsystem in this study is set as the energy consumption. GDP growth will directly enhance the investment in energy, and energy supply and demand will also increase, which will lead to a shortage of energy resources. As the energy gap widens, energy policy will be strengthened to reduce energy intensity, thereby reducing energy demand, and thus bridging the energy gap. The development of industry and the growth of energy consumption further aggravate the pollution of the environment; therefore, we use the pollution index to examine the environmental subsystem.

(3) The feedback path of each subsystem of 3E based on the above two points is as follows. Economic subsystem (According to the division of China's National Bureau of Statistics, primary industry is agriculture, forestry, fishery and animal husbandry; secondary industry is mining, manufacturing, electric power, the production and supply of gas and water, construction; and the tertiary industry is the service industry.): The total output value of the secondary industry → GDP → fixed assets investment → the total output value of the primary industry (Q1)/the secondary industry (Q2)/the tertiary industry (Q3) → GDP. Energy subsystem: Total industrial output value → energy investment → energy supply → energy gap → energy policies → energy intensity → energy consumption, and GDP → energy consumption. Environment subsystem: Total industrial output value → energy consumption → energy pollution index → pollution index, and total industrial output value → water pollution/air pollution/solid waste pollution → pollution index.

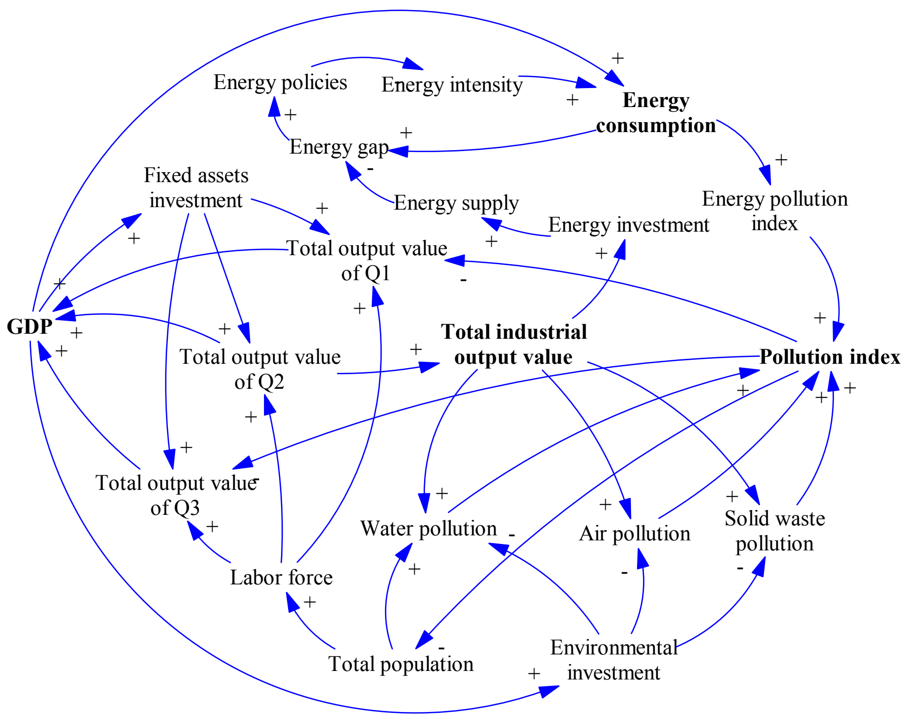

Figure 2. The theoretical framework of the SD model of 3E.

(4) In addition, there is a special cycle, that is GDP → environmental investment → pollution index → total population → the labor force → total output values of Q1/Q2/Q3 → GDP. A change in GDP will affect the environmental investment, thereby affecting the pollution index. The pollution of the environment has a negative impact on people's health; thus, a change in the pollution index will affect the population, thereby affecting the labor force and total output values of Q1/Q2/Q3, eventually further increasing or decreasing GDP.

2.2. Model Design

To facilitate the theoretical study and establishment of the model, there are several assumptions in the process of model establishment: (1) Do not consider energy abandonment, that is, all the new energy power can be consumed. (2) Do not consider the financial gap of investment, that is, the financial sector's investment in environmental protection is adequate. (3) The government can effectively promote the implementation of policies to promote the sustainable development of a 3E system.

Based on the above analysis, we believe that there is a complex nonlinear relationship among energy, economics and the environment. We establish the economic subsystem model, the energy subsystem model, and the environment subsystem model based on the above theoretical framework analysis. This study sets the variables showing the cumulative results to state variables (shown in boxes), the variables showing the changing rate of state variables to rate variables (shown with double triangles), and the rest of the relevant variables to auxiliary variables according to the characteristics of the factors [23]. The stock and flow diagram (SFD) is a good tool for modeling the cause and effect relationships between various components of the SD model. The model design and main formulas are shown as follows.

2.2.1. Economic Subsystem

An SFD of the economic subsystem is established in this paper using Vensim software, as shown in Figure 3. The economic subsystem is the largest in the 3E system, which occupies the leading position in the whole system. The economic subsystem provides a powerful driving force for the entire 3E system from the economy. Economic development is the premise and foundation for the improvement of residents' living and social development. Without the sustained growth of the economy, the whole system will lose its significance. The economic growth of this study is to meet the reasonable needs of people under the restriction of self-control by means of the accumulation of wealth and the expansion of economic scale in a corresponding stage, rather than 'zero growth' by limiting wealth accumulation for ecological protection [24]. The economic subsystem mainly selects GDP as the core variable and is connected with the other subsystems to reflect the system through the industrial output, that is, industrial output and total output values of the secondary industry are connected, thereby affecting the energy and environment subsystem. In this system, economic development is determined by the total economic output of Q1, Q2, and Q3 and interacts with the total population.

There are approximately thirty control functions in this SFD that are used to express the quantitative relationships between parameters. Due to the limited length of the article, only the main formulas and significant functional relationships of the economic subsystem in the flow chart are enumerated, as follows. The expressions for the rest of the basic formulas in the model are given in Appendix A.

$$FZ_{n_1,n_2,n_3} = FI \times FR_{n_1,n_2,n_3} \tag{1}$$

$$Y_{n_1,n_2,n_3} = A \times L_{n_1,n_2,n_3}^{\alpha_1,\alpha_2,\alpha_3} \times K_{n_1,n_2,n_3}^{\beta_1,\beta_2,\beta_3} \times I_{n_1,n_3} \tag{2}$$

$$GDP = Y_{n_1} + Y_{n_2} + Y_{n_3} \tag{3}$$

$$PZ = P \times PR \times PI \tag{4}$$

where n_1, n_2, and n_3 are Q1, Q2, and Q3, respectively. FZ is a fixed output increment. FI is investment in fixed assets. FR is the proportion of fixed assets. Y is the industrial output value. A is a generalized technological progress factor. L is the labor force. K represents fixed assets. α_1, α_2, and α_3 are elasticity coefficients of the labor force of the primary industry, secondary industry, and tertiary industry, respectively. β_1, β_2, and β_3 are elasticity coefficients of fixed assets of the primary industry, secondary industry, and tertiary industry, respectively. I is the index of industrial pollution's impact. PZ is population growth. P is total population. PR is the population growth rate. PI is the index of population affected by pollution.

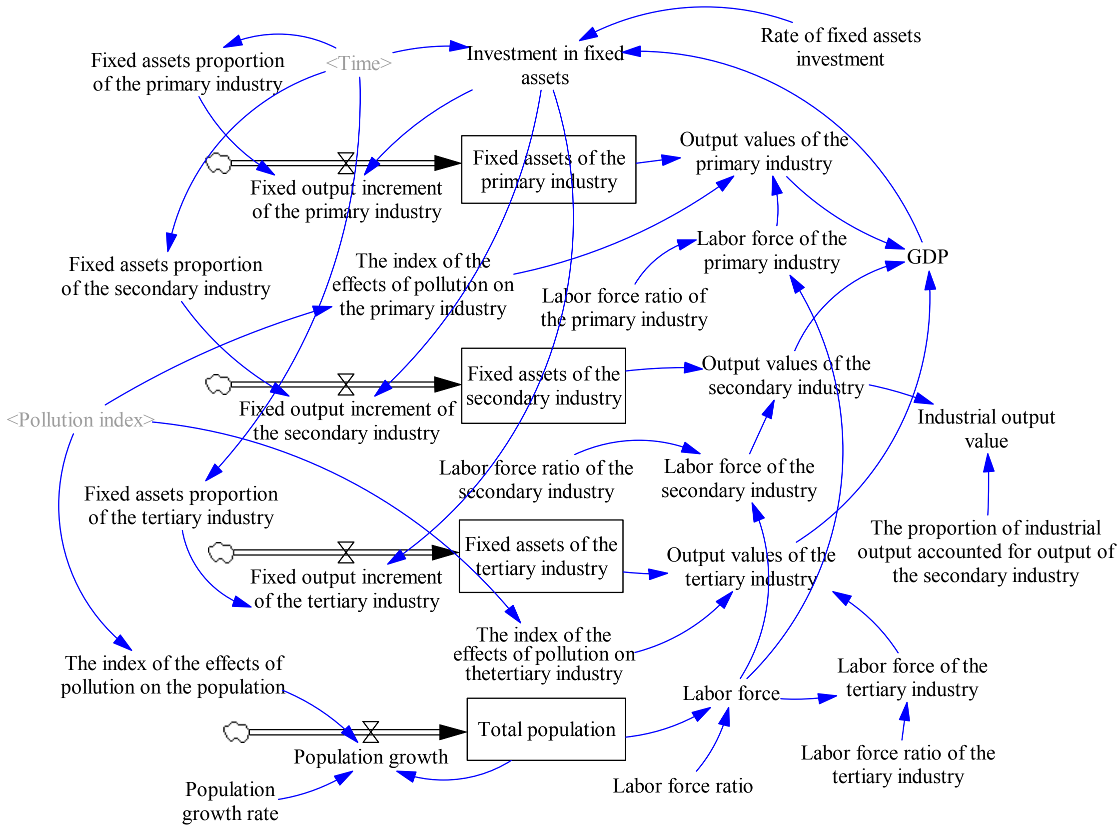

Figure 3. The SFD of the economic subsystem.

The fixed output increment of each industry is shown in Formula (1), which is the total fixed assets investment multiplied by the fixed assets ratio of each industry. The output value of each industry is shown in Formula (2). We set the industrial fixed assets as the internal circulation factors, the labor force as external inputs, and used Cobb-Douglas (CD) function to represent the conversion mechanism of industrial fixed assets investment and output value. In addition, we consider that the output values of Q1 and Q3 industry will be affected by industrial production pollution; thus, the output values of Q1 and Q3 will be multiplied by index I. GDP is the total sum of the output value of three industries, as shown in Formula (3). Population growth is determined by population growth rate and population and is affected by environmental pollution, shown as Formula (4).

2.2.2. Energy Subsystem

An SFD of the energy subsystem is shown in Figure 4. An energy subsystem is a large system including energy development, transformation, supply, storage, regulation, management, and application. Energy is the basis of economic development, so the energy subsystem is also the material base of the system. This system takes the total energy consumption as the primary assessment variable, which is determined by the industrial output value and GDP [6]. Therefore, the economic subsystem and the energy subsystem are connected. The energy pollution coefficient generated by energy consumption connects this system to the environmental subsystem.

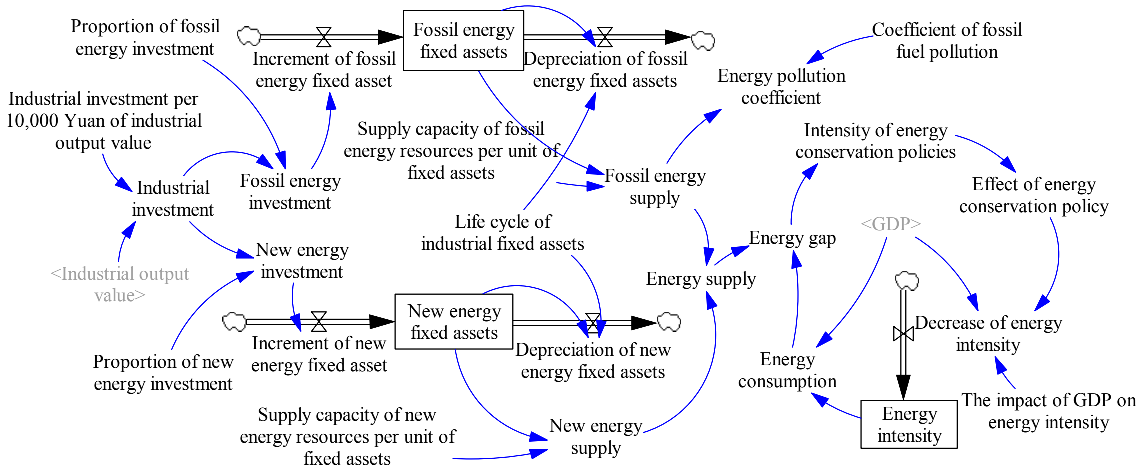

Figure 4. The SFD of the energy subsystem.

From the view of energy development and utilization, energy can be divided into fossil energy and new energy sources. Investment in fossil and new energy fixed assets comes from industrial investment, followed by energy supplies [25]. There is an energy gap when the energy consumption is higher than the energy supply, and it is adjusted by energy policies. The greater the intensity of energy conservation policy, the better the effects of energy conservation policy, which causes a decline in energy intensity and ultimately reduces the energy gap, thereby adjusting the supply and demand of energy [26]. In addition, the energy pollution coefficient will be used to correct the pollution index in the environmental subsystem, which can not only simulate the quality of the environment more accurately but also reflect the influence of the energy structure on the environment. The main formulas are enumerated as follows. The expressions for the rest of the basic formulas in the model are given in Appendix A.

$$EC = EI \times GDP \tag{5}$$

$$IEP = EG \times \varepsilon \tag{6}$$

$$EEP = IEP \times \alpha \tag{7}$$

$$DEI = EEP - GDP \times IEI \times \delta \tag{8}$$

$$EI = \int (-DEI) + EI_0 \tag{9}$$

where EC is energy consumption, EI is energy intensity, IEP is intensity of energy conservation policies, EG is the energy gap, EEP is the effect of energy conservation policy, DEI is a decrease in energy intensity, IEI is the impact of GDP on energy intensity, EI_0 is the initial value of energy intensity, ε, α, and δ are economic parameters.

Energy intensity is the energy consumption per unit of GDP, as shown in Formula (5). The intensity of the energy conservation policy is related to the energy gap, and the greater the energy gap, the greater the intensity of the energy conservation policy, as shown in Formula (6). Similarly, the greater the intensity of energy conservation policies, the greater the effects of energy conservation policies, as shown in Formula (7). An increase or decrease in energy intensity is related to the effect of the energy saving policy and the impact of GDP on energy intensity. If the effect of energy conservation saving is better than that of GDP on energy intensity, the energy intensity will decrease, and vice versa, as shown in Formula (8). Since the decrease of energy intensity in Formula (8) is only a value without showing direction, the expression for energy intensity is shown as Formula (9).

2.2.3. Environment Subsystem

An SFD of the environmental subsystem is shown in Figure 5. The environmental subsystem is the sum of the elements of the earth's surface environment and their correlation. It has the characteristics of self repair within a certain range and can maintain stability. However, once the environment is destroyed and breaks through the threshold range, the system will suffer permanent damage and will produce a series of chain reactions [7]. The environmental subsystem is a constraint system and an evaluation subsystem for the coordinated sustainable development of the 3E system. This system connects with the economic subsystem and environmental subsystem through the industrial output value and energy pollution coefficient, respectively.

We mainly consider water pollution, air pollution and industrial solid waste pollution as environmental pollution products, where water pollution includes sewage and industrial waste water. The amount of chemical oxygen demand (COD) production is the index of water pollution (COD is the amount of redox substance in water samples by using a chemical method for measurement purposes, which is an important and rapidly determined organic pollution parameter in water pollution management). Air pollution mainly refers to sulfur oxides and nitrogen oxides. In the process of economic development, pollution will continue to occur, but at the same time, it will also be dealt with through environmental protection investment. In addition, the model also considers COD and air pollution self purification ability (coefficient of self purification) [27]. The pollution coefficient of the environmental system is finally determined through synthesis of the above process. The main formulas in the model are shown as follows, and the expressions for the rest of the basic formulas in the model are given in Appendix A.

$$ER = W \times \lambda \tag{10}$$

$$W = EPC \times (WP \times I_w + AP \times I_a + SW \times I_s)/((WP + AP + SW)/W_0) \tag{11}$$

where ER is the investment proportion of environmental protection. W is the pollution index. λ is an economic parameter, EPC is the energy pollution coefficient, WP, AP, and SW are the accumulation of water pollution, air pollution, and industrial solid waste, respectively. I_w, I_a, and I_s are the coefficients of water pollution, air pollution, and industrial solid waste, respectively. W_0 is the pollution index of the base year.

The proportion of investment in environmental protection will be affected by environmental pollution, and the higher the pollution index, the greater the proportion of environmental protection investment. Therefore, we set economic parameters to make the proportion of investment in environmental protection change to a certain extent relative to the pollution index, shown as Formula (10). The calculation of the pollution index is the product of the accumulation and coefficient of various pollution types, and it is relative to the base value. As mentioned above, the energy pollution index will be used for the correction of the pollution index. Multiplying the energy pollution index and environmental pollution index generates the pollution index value, as shown in Formula (11).

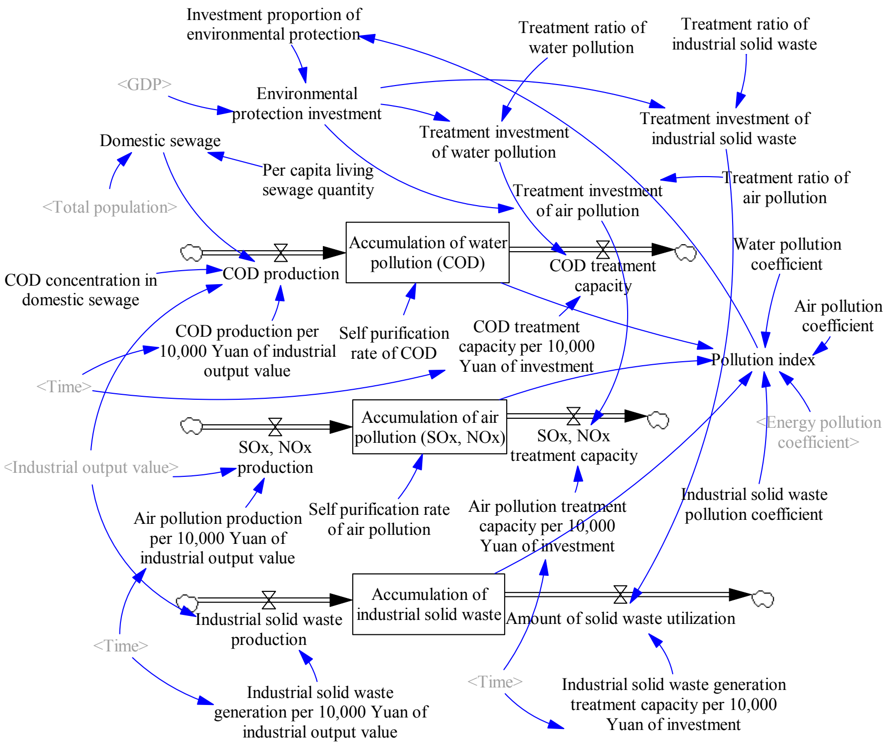

Figure 5. The SFD of the environment subsystem.

2.3. Validation of Dynamic Models

SD models are causal models, suitable for analysis and evaluation of policy in a period of time, rather than a precise numerical prediction at a specific time [28,29]. Consistent with this assertion, the key purpose of our developed SD models is to assist us in the assessment and analysis of the sustainable development of a 3E system. Furthermore, all the models which produce the outcomes based on the right structure should be tested for validity. Without appropriate validity testing of the model, it is difficult for anyone to buy in the claims of the study [30]. Therefore, we followed validation methods and steps that the SD community subjects their models to according to Refs. [31,32]. Both the structural (shown as follows) and behavior validity procedures (shown in the analysis of the results) are applied to SD models. It is noted that the validation methods and steps in Refs. [31,32] are suitable for all SD models and are directly used by us for a certain case study in the following content.

2.3.1. Boundary Adequacy

A boundary is used to determine the endogenous and exogenous variables of the model, which not only helps the model better reflect the problems to be studied, thereby eliminating some irrelevant variables, but also helps readers understand the model more clearly. Figure 6 summarizes the major endogenous and exogenous variables in the models.

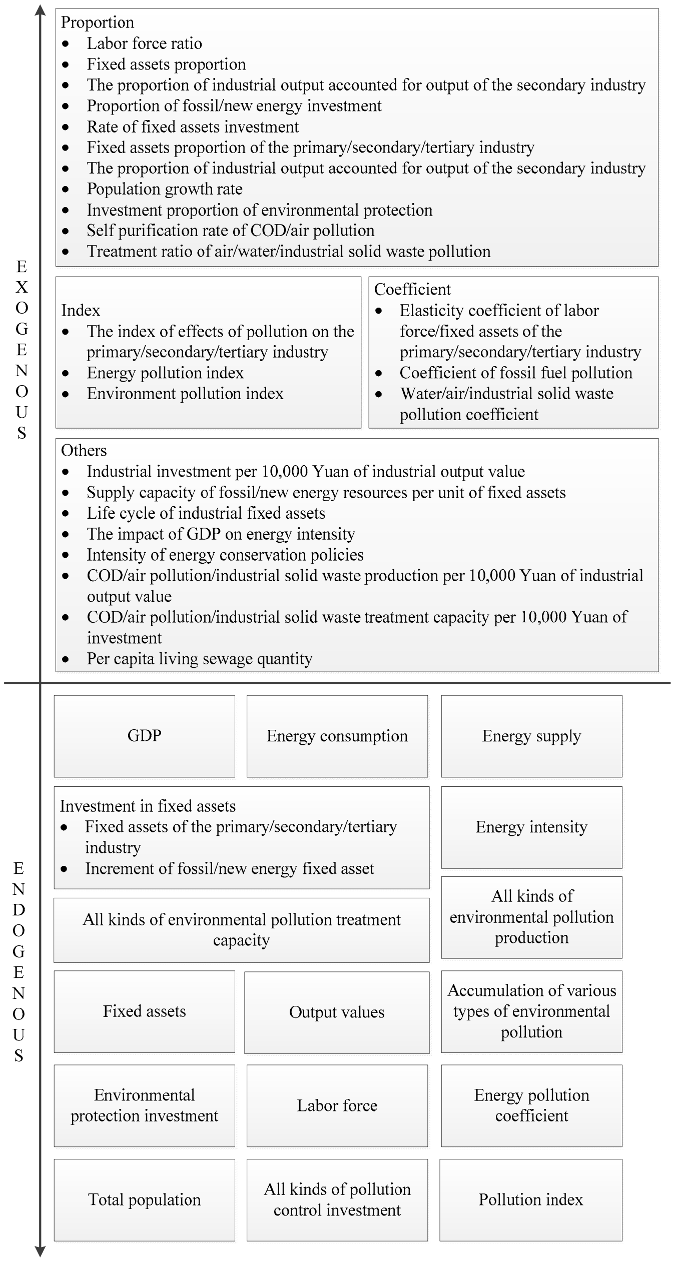

Figure 6. Summary of the model boundaries.

2.3.2. Structure Verification

The structure verification of the models is tested using two aspects. One of them is the specific case—data of the Beijing-Tianjin-Hebei region in China (or available knowledge about the real system) shown in Section 3, and the other are sub-models/structures of the existing models of the domain shown in Table 1.

Table 1. The models' structures adopted from existing work.

Structures/Concepts	Remarks
Economic subsystem [21]	Structural formulation was adopted
Energy subsystem [25,26]	Structural formulation was adopted
Environment subsystem [9]	Causal structure was adopted

2.3.3. Dimensional Consistency

The dimensional consistency test requires testing all mathematical equations in the models and ensuring that the units of variables in each equation are consistent. We used "Unit Test" in Vensim and found that the dimensional consistency passed the test.

2.3.4. Parameter Verification

The selection of parameter values determines the validity and feasibility of the model outcomes. The values in this study are sourced from existing knowledge and numerical data from the case—study of the Beijing-Tianjin-Hebei region in China. A detailed description is given in Section 3.

2.3.5. Extreme Condition Test

We set the proportion of coal, oil, natural gas and new energy power to gradually decrease to 0 as an extreme condition. The simulation results show that GDP, total energy consumption and the pollution index gradually decrease to 0. This reveals that the output of the models is in line with the actual situation under extreme conditions, and the models we produced pass the extreme condition test, and their validity is ensured.

2.3.6. Structurally Oriented Behavior Test

In this test, the official dataset from 2006 to 2015 and the results of the model can be compared to test the robustness of the model. We use a reality check to validate and verify our model. The results are shown in Table 2. It is obvious that the MAPEs (mean absolute percentage errors) are all limited into a relative small interval (0–3%). Consequently, the historical trend is successfully reproduced by our SD model.

In summary, the structure of the SD models of the 3E system is exposed to all six tests for overall structural validity. Based on these evaluations, we have strong confidence in the credibility of our scenario-based conclusions.

Table 2. Model reality check.

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	MAPE
GDP (10^8 Yuan)	24,048	28,706	33,845	36,910	43,732	52,074	57,348	62,472	66,474	69,359	-
simulation results	23,349	28,183	33,277	36,175	42,832	51,336	56,825	62,167	65,946	68,226	1.57%
Energy consumption (Million tons of standard coal)	319.68	345.83	358.11	376.41	410.6	438.39	453.55	465.22	482.96	503.37	-
simulation results	311.83	334.26	345.72	370.31	400.42	432.94	446.26	457.24	479.66	495.43	2.02%
Energy intensity (Tons of standard coal/10^4 yuan)	1.329	1.205	1.058	1.02	0.939	0.842	0.791	0.745	0.727	0.726	-
simulation results	1.3355	1.186	1.0389	1.0237	0.9349	0.8433	0.7853	0.7355	0.7274	0.7262	0.70%

3. Case Study

The Beijing-Tianjin-Hebei region is the most dynamic economic zone in northern China [33]. It contributed to 10.1% of China's GDP in 2016 and is considered the main development region in China's 13th Five-Year Plan [34]. However, due to the rapid economic development, population, and increased energy consumption in recent years, air pollution has progressively become a serious problem [35]. Rapid economic expansion and urbanization have caused this region to suffer extremely frequent and severe haze events. Seven out of the ten cities with the worst air quality were located in this region, and the proportion of days that did not satisfy the national standard of air quality is as high as 47.6% in Beijing-Tianjin-Hebei urban agglomeration [36].

The development of the Beijing-Tianjin-Hebei region is unbalanced, and there is a phenomenon of 'three highs and one low'. 'Three high' refers to the high total energy consumption and the high proportion of the secondary industry, which accounts for the excessive proportion of total energy consumption [37]. 'One low' refers to the low efficiency of energy utilization, which directly leads to excessive waste of energy and serious environmental pollution and restricts the development of the regional economy of the Beijing-Tianjin-Hebei region [35]. In response to the above problems, the Chinese government attaches great importance to the coordinated and sustainable development of energy, economics, and the environment in the Beijing-Tianjin-Hebei region. Therefore, this study uses SD models to study the sustainable development pattern of the 3E coordination system in the future development of the Beijing-Tianjin-Hebei region.

3.1. Data

To facilitate the study of the dynamic development, the temporal resolution of the model needs to be small. This study assumes that the step size is 1 month. SD's simulation time for the country's energy and economic systems is generally 10 years because the policy environment in 10 years is relatively stable, thus this study assumes that the simulation time is 10 years, that is, 2016 is the base year for simulation, and the simulation time is from 2016 to 2025. The main historical data relate to 2006–2015. The data resources are the *China Statistical Yearbook*, *Chinese Energy Statistics Yearbook*, *China Environmental Statistics Yearbook*, *Beijing Statistical Yearbook*, *Tianjin Statistical Yearbook*, *Hebei Economic Yearbook* and *China Technology Statistical Yearbook*. The parameter values of models are obtained using the following methods: (1) Some parameter values can be determined directly through yearbook data, such as population and investment in fixed assets. (2) Some variables need to be calculated (the average value) by using historical statistics, such as population growth, the proportion of industrial output accounted for output of the secondary industry, and per capita living sewage quantity. (3) The coefficient and economic parameter values are determined by logic inference based on historical data and model run tests, such as coefficients of energy pollution and environmental pollution and the elasticity coefficient. (4) Some variables need to be subjected to regression analysis of their historical data through the metering method to predict their future data, such as industrial investment per 10,000 Yuan of industrial output value and production of various pollutants per 10,000 Yuan. (5) For some variables that change over time, their values are determined by table functions in Vensim, such as fixed asset investment rates, labor force ratios, and the proportion of fossil and new energy investment. The values of each parameter are shown in Tables 3–5.

Table 3. The values of the economic subsystem.

Parameter	Value	Unit	Method of Calculation
GDP	74,612.6	Hundred million Yuan	Direct determination
Total population	11,204.9	10,000 people	Direct determination
Investment in fixed assets	54,430.8	Hundred million Yuan	Direct determination
Labor force ratio	[1] of Appendix B	-	Table function
Rate of fixed assets investment	[2] of Appendix B	-	Table function
Labor force ratio of the primary industry	38.1%	-	Average value
Labor force ratio of the secondary industry	34.8%	-	Average value
Labor force ratio of the tertiary industry	27.1%	-	Average value
Fixed assets proportion of the primary industry	8.1%	-	Average value
Fixed assets proportion of the secondary industry	56.8%	-	Average value
Fixed assets proportion of the tertiary industry	35.1%	-	Average value
The proportion of industrial output accounted for output of the secondary industry	91.4%	-	Average value

Table 3. *Cont.*

Parameter	Value	Unit	Method of Calculation
Population growth rate	4.96%	-	Average value
Elasticity coefficient of labor force of the primary industry	−0.673	-	Logical inference
Elasticity coefficient of labor force of the secondary industry	0.544	-	Logical inference
Elasticity coefficient of labor force of the tertiary industry	0.659	-	Logical inference
Elasticity coefficient of fixed assets of the primary industry	0.341	-	Logical inference
Elasticity coefficient of fixed assets of the secondary industry	0.468	-	Logical inference
Elasticity coefficient of fixed assets of the tertiary industry	0.325	-	Logical inference

Table 4. The values of the energy subsystem.

Parameter	Value	Unit	Method of Calculation
Industrial investment per 10,000 Yuan of industrial output value	[3] of Appendix B	Million tons of standard coal/10^8 Yuan	Metering method
Proportion of fossil energy investment	[4] of Appendix B	-	Table function
Proportion of new energy investment	[5] of Appendix B	-	Table function
Supply capacity of fossil energy resources per unit of fixed assets	54,716	Million tons of standard coal/10^8 Yuan	Average value
Supply capacity of new energy resources per unit of fixed assets	78,352	Million tons of standard coal/10^8 Yuan	Average value
Life cycle of industrial fixed assets	20	Year	Average value
The impact of GDP on energy intensity		-	Logical inference
Intensity of energy conservation policies	[6] of Appendix B	-	Table function
Coefficient of fossil fuel pollution	0.67	-	Logical inference

Table 5. The values of the environmental subsystem.

Parameter	Value	Unit	Method of Calculation
COD production per 10,000 Yuan of industrial output value	[7] of Appendix B	Ton/10,000 Yuan	Metering method
Air pollution production per 10,000 Yuan of industrial output value	[8] of Appendix B	Ton/10,000 Yuan	Metering method
Industrial solid waste generation per 10,000 Yuan of industrial output value	[9] of Appendix B	Ton/10,000 Yuan	Metering method
COD treatment capacity per 10,000 Yuan of investment	[10] of Appendix B	Ton/10,000 Yuan	Metering method
Air pollution treatment capacity per 10,000 Yuan of investment	[11] of Appendix B	Ton/10,000 Yuan	Metering method
Industrial solid waste generation treatment capacity per 10,000 Yuan of investment	[12] of Appendix B	Ton/10,000 Yuan	Metering method
Per capita living sewage quantity	53.5	Ton/Person	Average value
Investment proportion of environmental protection	2.8%	-	Average value
COD concentration in domestic sewage	350	-	Average value
Self purification rate of COD	39.2%	-	Average value

Table 5. *Cont.*

Parameter	Value	Unit	Method of Calculation
Self purification rate of air pollution	24.7%	-	Average value
Treatment ratio of water pollution	19.6%	-	Average value
Treatment ratio of air pollution	33.6%	-	Average value
Treatment ratio of industrial solid waste	46.8%	-	Average value
Water pollution coefficient	0.35	-	Logical inference
Air pollution coefficient	0.81	-	Logical inference
Industrial solid waste pollution coefficient	0.66	-	Logical inference

3.2. Simulation Results

Real data were used to simulate the development of the 3E system of the Beijing-Tianjin-Hebei region, and the results are as follows. The simulation results of GDP, energy consumption, and energy intensity are shown in Appendix C. They show that the GDP of the Beijing-Tianjin-Hebei region continues to grow, while GDP growth declines gradually. GDP reaches a maximum value of 11.63 trillion Yuan in 2024 and then begins to decline, reaching 11.43 trillion Yuan in 2025. According to Formulas (7) and (8), the energy intensity gradually increases because the effect of energy conservation saving is weaker than that of GDP on energy intensity; thus, the energy consumption of the Beijing-Tianjin-Hebei region continues to grow rapidly, reaching 1256.95 million tons of standard coal in 2025.

The simulation results of fossil energy supply, new energy supply, and the energy gap are shown in Figure 7. It shows that, on the one hand, as GDP continues to grow, energy investment grows, so fossil energy and new energy supplies continue to grow; however, the increase in fossil energy and new energy supplies gradually decreases with slower annual GDP growth. According to the data, the proportion of new energy investment gradually increases, and the proportion of fossil energy investment gradually decreases, but the latter is always higher than the former. Thus, the fossil energy supply is always higher than the new energy supply, but its growth rate is lower than that of the new energy supply, i.e., 510 and 443 million tons of standard coal in 2025, respectively. On the other hand, during the period from 2016 to 2018, the energy gap gradually decreases and tends to 0, and energy supply and demand gradually balance. However, from 2019, as the annual energy supply increments gradually decrease while energy consumption increases rapidly, the energy gap gradually increases and becomes faster and faster, reaching 304 million tons of standard coal in 2025.

The simulation results of the accumulation of water pollution, air pollution, industrial solid waste, and the pollution index are shown in Table 6. With the development of the economy and the continuous growth of energy, the production of various pollutants increases annually, and the pollution coefficient gradually increases, reaching 71.32 in 2025.

Based on the above results, the current development of the 3E system of the Beijing-Tianjin-Hebei region is uncoordinated. The reasons are that, on the one hand, although new energy power proportion gradually increases, fossil energy power proportion gradually decreases, but fossil energy supply is always higher than new energy supply, resulting in the rapid growth of energy consumption and energy pollution. On the other hand, the coefficient of pollution continues to increase as the annual amount of pollution treatment is less than the amount of pollution produced. This affects people's health, thereby affecting the population, the labor force, and effective working life, thus reducing the speed of economic development and GDP. Beijing-Tianjin-Hebei region's economic development growth rate gradually declines, and energy consumption continues to grow, resulting in a gradual reduction in the use of energy resources, as well as high pollution under the current development. Thus, it is difficult to achieve the sustainable development of the 3E system.

Table 6. The simulation results of the accumulation of water pollution, air pollution, industrial solid waste, and the pollution index.

Year	Accumulation of Water Pollution (10^4 Ton)	Accumulation of Air Pollution (10^4 Ton)	Accumulation of Industrial Solid Waste (10^4 Ton)	Pollution Index
2016	147,992	124.9	31,953	31.95
2017	154,474	130.4	33,352	34.82
2018	161,280	136.1	34,822	37.98
2019	168,426	142.2	36,365	41.47
2020	175,930	148.5	37,985	45.32
2021	183,808	155.2	39,686	49.56
2022	192,081	162.1	41,472	54.23
2023	200,767	169.5	43,347	59.38
2024	209,888	177.2	45,317	65.06
2025	219,464	185.3	47,384	71.32

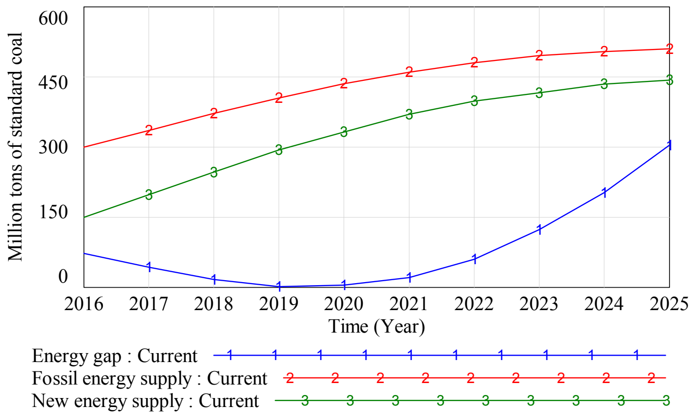

Figure 7. The simulation results of the fossil energy supply, new energy supply, and the energy gap.

4. Discussion

To compare and discuss 3E development of the Beijing-Tianjin-Hebei region under energy and environmental policies, this study selects three indexes of fossil energy power proportion, new energy power proportion, and the investment proportion of environmental protection as control variables. Different values of these variables are set to obtain various simulation scenarios, thereby simulating different development patterns of the Beijing-Tianjin-Hebei region. In this section, we assume four scenarios of development patterns: the present development pattern, the energy structure adjustment pattern, the environmental protection pattern, and the coordinated development pattern of energy and environment. The simulation results are shown as Figure 8. The analysis of the 3E system under the four patterns is as follows:

(1) The present development pattern: The analysis is the same as the results of Section 3.

(2) The energy structure adjustment pattern: This pattern focuses on the adjustment of energy structure and hopes to alleviate environmental pressure through the increase of the proportion of new energy investment in industrial production. We use table functions to adjust the proportion of fossil and new energy power investment to 45% and 55%, respectively, in 2025. The proportion of investment in environmental protection remains at 2.8%. Under the energy structure adjustment pattern, GDP will increase annually to 12.97 trillion Yuan in 2025. The GDP growth rate is higher than that of the present development pattern, which is about 6%. With the development of the economy, energy consumption and the pollution index continue to grow, but they decrease to 9.87 trillion Yuan and 56.86, respectively, in 2025 compared with the present development pattern due to the considerable increase in new energy consumption. The quality of the environment will be improved, and the 3E system will be sustainably developed.

(3) The environmental protection pattern: This pattern emphasizes the impact of increased investment in environmental protection on environmental quality improvement. Under the premise of rapid development of industries and constant energy consumption structure, we use the table function to advance the investment proportion of environmental protection to 4% and 6% when the pollution index reaches 40 and 60, respectively. The results show that GDP, energy consumption, and the pollution index continue to increase. GDP further increases to 14.11 trillion Yuan compared to that of the energy structure adjustment pattern, and energy consumption and the pollution index further decrease to 8.97 trillion Yuan and 52.03 in 2025, respectively. The GDP growth rate is about 7.2%. It shows that the quality of the environment will be improved, and the 3E system will be sustainable developed.

(4) The coordinated development pattern of energy and environment: Integrated energy structure adjustment and environmental protection policies; this pattern not only requires rapid economic development but also pays attention to the use of clean energy and the increase of the environmental investment proportion. That is, the proportion of fossil and new energy power investment is adjusted to 45% and 55%, respectively, and the investment proportion of environmental protection increases to 4% and 6% when the pollution index reaches 40 and 60, respectively. Under this pattern, GDP will maintain rapid growth, with an average growth rate of 9.4%, and reach 17.96 trillion Yuan in 2025. The total energy consumption will further reduce, reaching 8.15 trillion Yuan in 2025. Environmental quality will improve even more, and pollution index reduce to 47.62 in 2025. In summary, this pattern has the best comprehensive benefits and is an ideal pattern for the sustainable development of Beijing-Tianjin-Hebei region's 3E system.

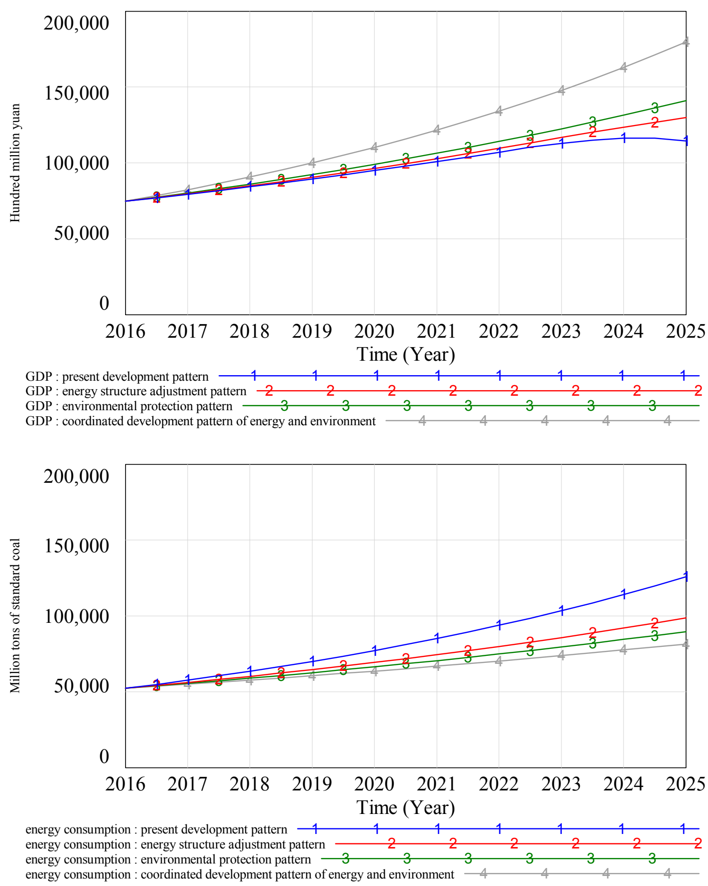

Figure 8. *Cont.*

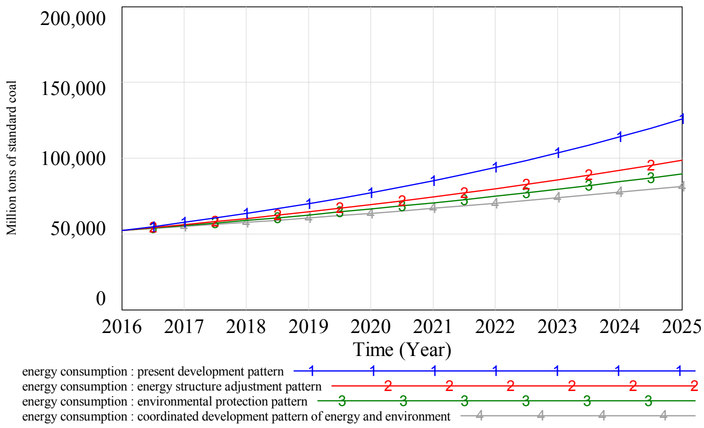

Figure 8. The simulation results of various scenarios.

5. Conclusions

The Chinese government is paying increasing attention to the sustainable development of 3E because it realizes the common development of the national economic progress, the rational use of energy, and environmental protection. This paper uses SD to establish models of sustainable development of the 3E system, analyzes the relationship among economics, energy, and the environment, and takes the Beijing-Tianjin-Hebei region of China as an example to study its development under different scenarios combined with the actual data. The results show that (1) The models designed in this study can effectively reveal the process of sustainable development of the 3E system and forecast the development trend in the future, thus helping to provide references for policy-making institutions. (2) The long-term development of Beijing-Tianjin-Hebei region's 3E system under the present pattern is not sustainable. In the present pattern, the energy consumption of the Beijing-Tianjin-Hebei region continues to grow rapidly. The excessive energy consumption causes more serious environmental pollution, thereby affecting people's health and the labor force, and the effective working time decreases, after which the GDP decreases, which is not conducive to economic development. (3) The government could promote the sustainable development of the 3E system through the adjustment of energy structure and an increase in investment in environmental protection, which can not only improve the environmental quality, but also ensure continuous growth rather than excessive growth of energy consumption and GDP.

This paper notes some limitations that need to be improved upon. Future studies will consider more realistic factors, such as inflation and import and export capital, to generate a more scientific and accurate simulation of the sustainable development of the 3E system. In addition, there are some assumptions in this study, and scholars can further study the ways to solve energy abandonment of the Beijing-Tianjin-Hebei region to effectively increase investment in environmental protection and to ensure cooperation among regional governments.

Acknowledgments: This paper is supported by the National Natural Science Foundation of China (No. 71573084).

Author Contributions: Yi Zuo and Ying-ling Shi conceived and designed the experiments; Yu-zhuo Zhang performed the experiments; Yi Zuo and Yu-zhuo Zhang analyzed the data; Yi Zuo wrote the paper.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

All the formulas of SD are as follows:

[1] Accumulation of air pollution (SO_x, NO_x) = INTEG ((SO_x, NO_x production − SO_x, NO_x treatment capacity) × (1 − Self purification rate of air pollution), 124.9)

[2] Accumulation of industrial solid waste = INTEG (Industrial solid waste production − Amount of solid waste utilization, 31,953)

[3] Accumulation of water pollution (COD) = INTEG ((COD production − COD treatment capacity) × (1 − Self purification rate of COD), 147,992)

[4] Air pollution coefficient = 0.81

[5] Air pollution production per 10,000 Yuan of industrial output value = −0.004 × (Time − 2016) + 0.0187

[6] Air pollution treatment capacity per 10,000 Yuan of investment = 0.006 × (Time − 2016) + 0.0012

[7] Amount of solid waste utilization = Treatment investment of industrial solid waste × Industrial solid waste generation treatment capacity per 10,000 Yuan of investment

[8] COD concentration in domestic sewage = 350

[9] COD production per 10,000 Yuan of industrial output value = −1.314 × (Time − 2016) + 26.25

[10] COD production = Domestic sewage × COD concentration in domestic sewage + COD production per 10,000 Yuan of industrial output value

[11] COD treatment capacity per 10,000 Yuan of investment = 0.364 × (Time − 2016) + 19.57

[12] COD treatment capacity = COD treatment capacity per 10,000 Yuan of investment × Treatment investment of water pollution

[13] Coefficient of fossil fuel pollution = 0.67

[14] Decrease of energy intensity = Effect of energy conservation policy − GDP × The impact of GDP on energy intensity × 1.2 × 10^{-5}

[15] Depreciation of fossil energy fixed assets = Fossil energy fixed assets/Life cycle of industrial fixed assets

[16] Depreciation of new energy fixed assets = New energy fixed assets/Life cycle of industrial fixed assets

[17] Domestic sewage = Per capita living sewage quantity × Total population × 10^4

[18] Effect of energy conservation policy = Intensity of energy conservation policies × 1.1

[19] Energy consumption = Energy intensity × GDP

[20] Energy gap = Energy consumption − Energy supply

[21] Energy intensity = INTEG (Decrease of energy intensity, 0.7)

[22] Energy pollution coefficient = Coefficient of fossil fuel pollution × Fossil energy supply

[23] Energy supply = Fossil energy supply + New energy supply

[24] Environmental protection investment = GDP × Investment proportion of environmental protection

[25] Fixed assets of the primary industry = INTEG (Fixed output increment of the primary industry, 12,563.5)

[26] Fixed assets of the secondary industry = INTEG (Fixed output increment of the secondary industry, 51,584.9)

[27] Fixed assets of the tertiary industry = INTEG (Fixed output increment of the tertiary industry, 27,543.7)

[28] Fixed assets proportion of the primary industry = 0.081

[29] Fixed assets proportion of the secondary industry = 0.568

[30] Fixed assets proportion of the tertiary industry = 0.351

[31] Fixed output increment of the primary industry = Investment in fixed assets × Fixed assets proportion of the primary industry

[32] Fixed output increment of the secondary industry = Fixed assets proportion of the secondary industry × Investment in fixed assets

[33] Fixed output increment of the tertiary industry = Fixed assets proportion of the tertiary industry × Investment in fixed assets

[34] Fossil energy fixed assets = INTEG (Increment of fossil energy fixed asset-Depreciation of fossil energy fixed assets, 5483)

[35] Fossil energy investment = Industrial investment × Proportion of fossil energy investment

[36] Fossil energy supply = Supply capacity of fossil energy resources per unit of fixed assets × Fossil energy fixed assets

[37] GDP = Output values of the primary industry + Output values of the secondary industry + Output values of the tertiary industry

[38] Increment of fossil energy fixed asset = Fossil energy investment × 10^4

[39] Increment of new energy fixed asset = New energy investment × 10^4

[40] Industrial investment per 10,000 Yuan of industrial output value = −0.031 × (Time − 2016) + 0.911

[41] Industrial investment = Industrial investment per 10,000 Yuan of industrial output value × Industrial output value × 10^4

[42] Industrial output value = Output values of the secondary industry × The proportion of industrial output accounted for output of the secondary industry

[43] Industrial solid waste generation per 10,000 Yuan of industrial output value = −0.021 × (Time − 2016) + 1.143

[44] Industrial solid waste generation treatment capacity per 10,000 Yuan of investment = 0.015 × (Time − 2016) + 0.711

[45] Industrial solid waste pollution coefficient = 0.66

[46] Industrial solid waste production = Industrial solid waste generation per 10,000 Yuan of industrial output value × Industrial output value × 10^4

[47] Intensity of energy conservation policies = Energy gap × 3 × 10^{-4}

[48] Investment in fixed assets = GDP × Rate of fixed assets investment

[49] Investment proportion of environmental protection = Pollution index × 9 × 10^{-3}

[50] Labor force of the primary industry = Labor force × Labor force ratio of the primary industry

[51] Labor force of the secondary industry = Labor force × Labor force ratio of the secondary industry

[52] Labor force of the tertiary industry = Labor force × Labor force ratio of the tertiary industry

[53] Labor force ratio = WITH LOOKUP (Time, ([(2016,0.67) − (2025,0.63)], (2016,0.668), (2017,0.665), (2018,0.661), (2019,0.654), (2020,0.646), (2021,0.631), (2022,0.63), (2023,0.628), (2024,0.626), (2025,0.621)))

[54] Labor force ratio of the primary industry = 0.381

[55] Labor force ratio of the secondary industry = 0.348

[56] Labor force ratio of the tertiary industry = 0.271

[57] Labor force = Total population × Labor force ratio

[58] Life cycle of industrial fixed assets = 20

[59] New energy fixed assets = INTEG (Increment of new energy fixed asset-Depreciation of new energy fixed assets, 1914)

[60] New energy investment = Industrial investment × Proportion of new energy investment

[61] New energy supply = Supply capacity of new energy resources per unit of fixed assets × New energy fixed assets

[62] Output values of the primary industry = 0.037 × Fixed assets of the primary industry$^{0.341}$ × Labor force of the primary industry$^{-0.673}$ × The index of the effects of pollution on the primary industry

[63] Output values of the secondary industry = 0.113 × Fixed assets of the secondary industry$^{0.468}$ × Labor force of the secondary industry$^{0.544}$

[64] Output values of the tertiary industry = 0.084 × Fixed assets of the tertiary industry$^{0.325}$ × Labor force of the tertiary industry$^{0.659}$ × The index of the effects of pollution on the tertiary industry

[65] Per capita living sewage quantity = 53.5

[66] Pollution index = Energy pollution coefficient × (Accumulation of air pollution (SO_x, NO_x) × Air pollution coefficient + Accumulation of industrial solid waste × Industrial solid

waste pollution coefficient + Accumulation of water pollution (COD) × Water pollution coefficient)/((Accumulation of industrial solid waste + Accumulation of water pollution (COD) + Accumulation of air pollution (SO_x, NO_x))/28)

[67] Population growth rate = 0.0496

[68] Population growth = Population growth rate × The index of the effects of pollution on the population × Total population

[69] Proportion of fossil energy investment = WITH LOOKUP (Time, ([(2016,0.62) − (2025,0.51)], (2016,0.75), (2017,0.73), (2018,0.72), (2019,0.7), (2020,0.69), (2021,0.66), (2022,0.64), (2023,0.62), (2024,0.59), (2025,0.57)))

[70] Proportion of new energy investment = WITH LOOKUP (Time, ([(2016,0.62) − (2025,0.51)], (2016,0.25), (2017,0.27), (2018,0.28), (2019,0.3), (2020,0.31), (2021,0.33), (2022,0.36), (2023,0.38), (2024,0.41), (2025,0.43)))

[71] Rate of fixed assets investment = WITH LOOKUP (Time, ([(2016,0.66) − (2025,0.75)], (2016,0.658), (2017,0.664), (2018,0.673), (2019,0.686), (2020,0.695), (2021,0.712), (2022,0.724), (2023,0.733), (2024,0.736), (2025,0.741)))

[72] Self purification rate of air pollution = 0.247

[73] Self purification rate of COD = 0.392

[74] SO_x, NO_x production = Industrial output value × Air pollution production per 10,000 Yuan of industrial output value × 10^4

[75] SO_x, NO_x treatment capacity = Air pollution treatment capacity per 10,000 Yuan of investment × Treatment investment of air pollution

[76] Supply capacity of fossil energy resources per unit of fixed assets = 54,716

[77] Supply capacity of new energy resources per unit of fixed assets = 78,352

[78] The impact of GDP on energy intensity = WITH LOOKUP (Time, ([(2016,0.62) − (2025,0.51)], (2016,1), (2017,1.1), (2018,1.2), (2019,1.4), (2020,1.5), (2021,1.6), (2022,1.7), (2023,1.8), (2024,1.9), (2025,2)))

[79] The index of the effects of pollution on the population = Pollution index × 8.5×10^{-3}

[80] The index of the effects of pollution on the primary industry = Pollution index × 3×10^{-3}
The index of the effects of pollution on the tertiary industry = Pollution index × 5×10^{-3}

[81] The proportion of industrial output accounted for output of the secondary industry = 0.914

[82] Total population = INTEG (Population growth, 11,204.9)

[83] Treatment investment of air pollution = Environmental protection investment × Treatment ratio of air pollution

[84] Treatment investment of industrial solid waste = Environmental protection investment × Treatment ratio of industrial solid waste

[85] Treatment investment of water pollution = Environmental protection investment × Treatment ratio of water pollution

[86] Treatment ratio of air pollution = 0.336

[87] Treatment ratio of industrial solid waste = 0.468

[88] Treatment ratio of water pollution = 0.196

[89] Water pollution coefficient = 0.35

Appendix B

[1] ([(2016,0.67) − (2025,0.63)], (2016,0.668), (2017,0.665), (2018,0.661), (2019,0.654), (2020,0.646), (2021,0.631), (2022,0.630), (2023,0.628), (2024,0.626), (2025,0.621))

[2] ([(2016,0.66) − (2025,0.75)], (2016,0.658), (2017,0.664), (2018,0.673), (2019,0.686), (2020,0.695), (2021,0.712), (2022,0.724), (2023,0.733), (2024,0.736), (2025,0.741))

[3] Energy consumption per 10,000 Yuan of industrial output value = −0.031 × (Time − 2016) + 0.911

[4] ([(2016,0.62) − (2025,0.51)], (2016,0.75), (2017,0.73), (2018,0.72), (2019,0.70), (2020,0.69), (2021,0.66), (2022,0.64), (2023,0.62), (2024,0.59), (2025,0.57))

[5] ([(2016,0.62) − (2025,0.51)], (2016,0.25), (2017,0.27), (2018,0.28), (2019,0.30), (2020,0.31), (2021,0.33), (2022,0.36), (2023,0.38), (2024,0.41), (2025,0.43))

[6] ([(2016,0.62) − (2025,0.51)], (2016,1.0), (2017,1.1), (2018,1.2), (2019,1.4), (2020,1.5), (2021,1.6), (2022,1.7), (2023,1.8), (2024,1.9), (2025,2.0))

[7] COD production per 10,000 Yuan of industrial output value = −1.314 × (Time − 2016) + 26.25

[8] Air pollution production per 10,000 Yuan of industrial output value = −0.004 × (Time − 2016) + 0.0187

[9] Industrial solid waste generation per 10,000 Yuan of industrial output value = −0.021 × (Time − 2016) + 1.143

[10] COD treatment capacity per 10,000 Yuan of investment = 0.364 × (Time − 2016) + 19.57

[11] Air pollution treatment capacity per 10,000 Yuan of investment = 0.006 × (Time − 2016) + 0.0012

[12] Industrial solid waste generation treatment capacity per 10,000 Yuan of investment = 0.015 × (Time − 2016) + 0.711

Appendix C

Table A1. The simulation results of GDP, energy consumption, and energy intensity.

Year	GDP (10^8 Yuan)	Energy Intensity (Tons of Standard Coal/10^4 Yuan)	Energy Consumption (Million Tons of Standard Coal)
2016	74,613	0.700	522.29
2017	79,233	0.727	575.82
2018	84,140	0.755	634.85
2019	89,351	0.783	699.92
2020	94,885	0.813	771.66
2021	100,761	0.844	850.75
2022	107,001	0.877	937.96
2023	112,654	0.918	1034.10
2024	116,252	0.981	1140.09
2025	114,283	1.100	1256.95

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