



# System dynamic modeling and scenario simulation on Beijing industrial carbon emissions

Lei Wen<sup>†</sup>, Lu Bai, Ernv Zhang

*Department of Economics and Management, North China Electric Power University, Baoding, Hebei 071003, China*

## ABSTRACT

Beijing, as a cradle of modern industry and the third largest metropolitan area in China, faces more responsibilities to adjust industrial structure and mitigate carbon emissions. The purpose of this study is aimed at predicting and comparing industrial carbon emissions of Beijing in ten scenarios under different policy focus, and then providing emission-cutting recommendations. In views of various scenarios issues, system dynamics has been applied to predict and simulate. To begin with, the model has been established following the step of causal loop diagram and stock flow diagram. This paper decomposes scenarios factors into energy structure, high energy consumption enterprises and growth rate of industrial output. The prediction and scenario simulation results shows that energy structure, carbon intensity and heavy energy consumption enterprises are key factors, and multiple factors has more significant impact on industrial carbon emissions. Hence, some recommendations about low-carbon mode of Beijing industrial carbon emission have been proposed according to simulation results.

**Keywords:** Industrial carbon emissions, Scenario simulation and prediction, System dynamics

## 1. Introduction

The mitigation of carbon emissions and other greenhouse gases has come to the forefront of policy debates taking place on the international and national level [1]. China, as the second largest economy and the biggest contributor of carbon emissions in the world, prefers to implement its national commitment by low-carbon city policy [2].

China's economy was dominated by the industrial sector, and carbon emissions in industrial sector shares large proportion in total carbon emissions in China. As the largest emitter of carbon dioxide, China's carbon emissions are 1.78 billion tons in 2007 [3]. What's more, in our country, approximately 70% of total carbon emissions and energy consumption are from industrial sector. However, the average proportion of industrial value added in the gross domestic product (GDP) was 40.2% during 1978-2012 [4]. In China, the development of economic needs industry's drive, but the carbon emissions problems that industrial development brings in are also need to be solved.

Beijing, as a cradle of modern industry and the third largest metropolitan area in China, is experiencing increasingly prosperous industrial civilization [5]. However, the increasing industrial car-

bon emissions will continue to exert far-reaching influences on the environment quality, so adjusting the policy about reducing CO<sub>2</sub> emissions in industry sector is of great significance [6]. Up to now, Beijing has been sticking to the developing guideline focusing on industrial projects, Foreign Direct Investment absorption and export value while emphasizing the development of high and new technology. With much more energy-saving steps and emission-cutting measures vigorously implemented, Beijing is possible to explore greater carbon emissions abatement potential.

This paper attempts to conduct an in-depth research on impact factors of industrial carbon emissions and scenarios simulation under various emission-reducing policies orientations thus proving reference for thorough decision-making.

System dynamics (SD) offers a novel and key approach for above-mentioned issue, for the reason of considering causal relation and structure decision behavior from the system interior microscopic structure [7]. In views of carbon emissions' increasing concern, numerous and outstanding approaches have been applied for this issue. Typically, Qi Cui et al. [8] implemented both Meta-analysis method and multi-factor variance analysis (ANOVA) to identify necessary impact factors on carbon emissions, which cause remarkable variations of estimations. Similar to Qi Cui, Fan



This is an Open Access article distributed under the terms of the Creative Commons Attribution Non-Commercial License (<http://creativecommons.org/licenses/by-nc/3.0/>) which permits unrestricted non-commercial use, distribution, and reproduction in any medium, provided the original work is properly cited.

Copyright © 2016 Korean Society of Environmental Engineers

Received April 1, 2016 Accepted June 29, 2016

<sup>†</sup> Corresponding author  
Email: 307353121@qq.com  
Tel: +86-15933987143

et al. [9] decomposed impact factors of carbon emission intensity by using adopted adaptive Divisia weighting method, whose findings show the crucial position of energy intensity and energy structure. Besides, from the point of empirical study on highway construction, Wang et al. [10] proposed a relatively empirical method to estimate CO<sub>2</sub> emissions. However, lack of dynamic nature and regardless of actual influencing degree is the reason behind their inaccuracy and restricted application. [11] SD is applied to address complex systemic problems with the combination of quantitative and qualitative methods, based on feedback control theory, using computer simulation technology as its measure. Fong et al. [12] introduced SD model as a modeling and simulation methodology for long-term urban decision-making based on variation tendency prediction of carbon emissions under various policy focus in discrepant cities. In another study, Richardson and Pugh put forward the essential viewpoint of SD, namely dynamic behavior is a consequence of system structure. [13] Obviously, SD features more advantages especially in addressing carbon emission issues, due to the connection with observable patterns of a system to micro-level structure and decision making process. [14] Additionally, SD has been applied to a wide range of domains, including corporate planning and policy design, public management and policy, energy and environment, theory development in the natural and social sciences and supply chain management [15-19].

In this paper, SD model is employed in a realistic case study (Beijing, China), with the help of Vensim software, to quantitatively simulate and analyze industrial carbon emissions from 2005 to 2013. Model validity test is carried out by history test and then simulation model is used to forecast gross value of industrial output and total carbon emissions in 2014-2020. SD simulation model is proposed to construct a reasonable structure of Beijing industrial carbon emissions thus meeting emission reduction targets [20]. With regard to the preceding argument, this paper seeks to make progress in two directions.

From the scientific point of view, for the complexity and uncertainty of industrial carbon emissions system, it is difficult to fully solve the problem by only quantitative or qualitative analysis. Hence, simulation method that combined with quantitative and qualitative analysis has been proposed to solve such problem. What's more, we choose Beijing industrial carbon emissions as a case study and the established model also can be applied to other cities, such as Tianjin, Shanghai. The case study chosen in this paper has been the subject of previous work and represents the high level of industry in China. No industrial carbon emissions have been performed thoroughly as this paper in a SD way.

From the empirical point of view, in order to manage industrial carbon emissions while achieving better environmental objectives, alternative strategies could be taken. But the difficulty is in knowing whether the alternative strategies are effective and what the influence for the future are. Therefore, the present study is to explore these issues by simulating different scenarios. The results will provide a promising basis for decision-making to governmental policy-making.

This paper is organized as follows. An overview of systematic modeling related to problem identification and model establishment are presented in Section 2, including casual-loop diagram,

stock-flow diagram, equations and validation test which relate to model establishment are present in Section 3. In section 4, we employ the model to predict and simulate scenarios and therefore enabling fulling consideration policy suggestion is proposed consequently. The work closes with the main conclusions in Section 5.

## 2. Model Preparation

### 2.1. Model Description

Industrial carbon emissions stem from the combustion of fossil fuels and industrial production. In consideration of the actual situation of Beijing, the energy balance sheet and the statistical yearbook covering 2005-2013, the paper explores the industrial development on low carbon through establishing a SD model and simulating the real state of carbon emissions.

Energy combustion growth is in urge need of more fossil fuel and raw materials during industrial production, thus stimulating the growth of gross industrial output, energy combustion as well [21]. Hence, we can conclude that economical subsystem of carbon emissions and energetic subsystem of carbon emissions in industry have boosted bilateral ties. Furthermore, population growth and rapid economic development have played a key role in the process of industrial carbon emissions increasing influenced [22]. The model is mainly composed of three subsystems economical subsystem of carbon emissions, energy subsystem of carbon emissions, population subsystem of carbon emissions. Besides, there are causal relationships among the three subsystems and the model can be simulated by their interactions.

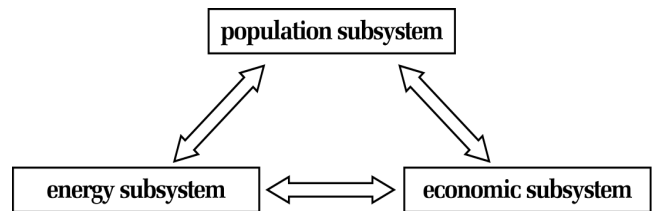


Fig. 1. Industrial carbon emissions system framework in Beijing.

### 2.2. Definite Boundary

The research subject is industrial carbon emissions system in Beijing. After determining the research question and the boundary of the system following the simplified rules, while for model simplification and representation, emissions, generated from production process are not taken into consideration due to the fact of lower emissions level and relative manufacturing technique [23]. According to the principle of system boundary, Beijing industrial carbon emission system should include economic subsystem, energetic subsystem and population subsystem, which constitute the boundary of industrial carbon emissions system. This model is based on the below assumption:

- The total carbon emissions consider the process of fossil fuel consumption merely, regardless of the emissions in the process of industrial production and other sources.

- Beijing's population growth rate keeps stable in the future, which is calculated by the statistics of the discrepancy between birth and death rates.
- The energy structure influence factor is 0.9, reflecting Beijing energy combustion relying on coal.
- We take impact factors of heavy energy consumption enterprises as 0.752, which accounts for the proportion of heavy energy-consumption enterprises.
- Based on the principle of boundary, the key variables which affect the system behaviors and divide the system into three subsystem are as follows,
  - Energy subsystem: carbon emission levels, carbon emissions in the process of fossil fuel combustion and environment quality.
  - Economic subsystem: economic policy, industrial investment in science and technology, production technology in industry, industrial GDP, social and economic development level, and carbon reduction cost.
  - Population subsystem: residents' living standard, gross population and industrial employees.

### 3. Modeling

This paper applies SD model into Beijing's industrial carbon emissions activities and makes a further study of industrial carbon emissions. Based on the statistics of Beijing Statistic Yearbook and Beijing Energetic Balance Sheet, this paper runs the simulated mode of industrial carbon emissions covering 2005-2020 by systematic dynamics software VENSIM. The simulation step size is one year.

It is important to note that the software Vensim® and Stella® are widely adopted by system dynamics models for simulation applications, which provide a user-friendly interface. In addition,

they offer a flexible way to dynamically visualize and communicate how complex systems and ideas really work by building a variety of simulation models from causal loops or stock and flow [24]. In this study, the software Vensim® was employed to the model building of urban traffic's energy consumption and related carbon emissions.

Developed in the mid-1980s, Vensim began to apply in business in 1992. Nowadays, it is widely used in enterprise, science and education. Vensim software can establish SD model by using the graphic and edit language at the same time. The established model features advantages of easy-to-build, what's more, in the modeling process, DYNAMO equations can be edited by operators and it has the function of policy optimization.

#### 3.1. Casual Loop Diagram

The structure of a system in SD methodology is captured by casual loop diagrams, therefore, it is of great importance to construct the appropriate casual loop diagram in a SD manner. Fig. 2 depicts the casual loop diagram of the system.

According to Fig. 2, carbon emissions level is affected by fossil fuel combustion emissions, besides, it contributes to environment quality and carbon emissions reduction investment. What's more, environmental quality can lead to the increase of industrial technology investment and thus to affect production technology and eventually have positive effect on industrial GDP. More found will be invest in industrial science and technology as the industrial GDP's increasing, thus improve energy efficiency. Similarly, increment in industrial GDP will improve social and economic development level. Industrial GDP have positive effect on residents' living standard and thus influence gross population, besides, gross population has positive effect on industrial employment and thus has positive effect on industrial GDP.

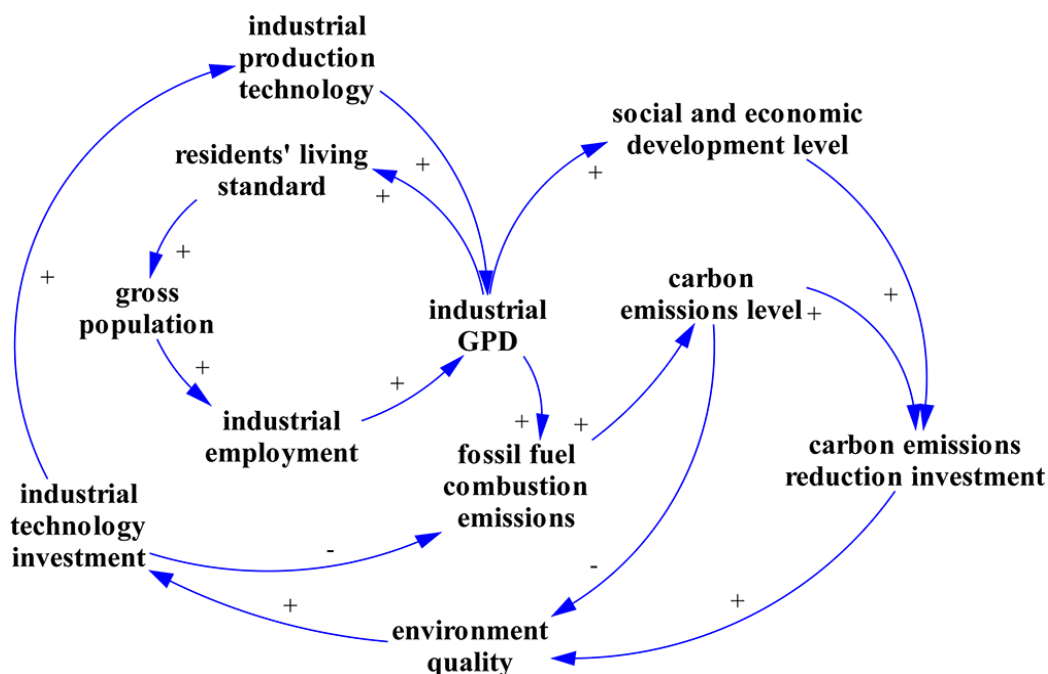


Fig. 2. Industrial carbon emissions system causality diagram.

The main feedback circulates as follows in SD language. There in, arrows represent relation variations among variables. The direction of the influence lines displays the direction of the effect. The sign “+” or “-” at the upper end of the influence lines exhibits the sign of the effect. A “+” sign and A “-” sign respectively dictate the same direction variation and opposite variation.

(1) Industrial GDP → + residents’ living standards → + gross population → + industrial employment → + industrial GDP

(2) Industrial GDP → + social and economic development → + carbon emissions reduction investment → + environment quality → + industrial technology investment → + industrial production technology → + industrial GDP

(3) Carbon emission level → + carbon emissions reduction investment → + environment quality → + industrial technology investment → - fossil fuel combustion emissions → + carbon emission level

(4) Carbon emission level → - environment quality → + industrial technology investment → - fossil fuel combustion → + carbon emissions level

(5) Industrial GDP → + fossil fuel combustion emissions → + carbon emissions level → - environment quality → + industrial technology investment → + industrial production technology → + industrial GDP

### 3.2. Stock-flow Diagram

We only understand the tendency of industrial carbon emissions development in Beijing, and there is no necessity of including accurate data, so the non-critical factors do not take into

consideration. System boundary determination principles urge the modeling to comply with the base hypothesis, meanwhile not including all realistic factors [25]. We formulate the influence of the population, GDP and fossil fuel combustion on the industrial carbon emissions in the proposed SD model by the following equations as Vensim programming.

Gross value of Industrial output increase at the expense of energy consumption and it is the driving force of GDP growth. GDP per capita is generally calculated by the following equation, namely  $\text{GDP per capita} = \text{GDP} / \text{population}$ ; Compared with that, the target performs huge impact on decision making process. When GDP per capita is less than the target, the government put much priority on industrial development; While, higher GDP per capita has positive effect on the progress of energy efficiency improvement. Carbon intensity, which determines the difference of carbon intensity and target, depends on total carbon emissions and industrial output and serve as a crucial environmental protection index of industrial development. Fig. 3 depicts the stock flow diagram in Beijing industrial carbon emissions.

The structure of a SD model contains stock (state) and flow (rate) variables. Stock variables are the accumulations (i.e. GDP) within the system. The flow variables represent the flows in the system (i.e. GDP increment), which result from the decision-making process. The other parameters are auxiliary (i.e. GDP growth rate) variables or constant (i.e. Initial GDP). Variables that we focused on in Beijing industrial carbon emissions are as following:

*Total population*: simulation of Beijing population according

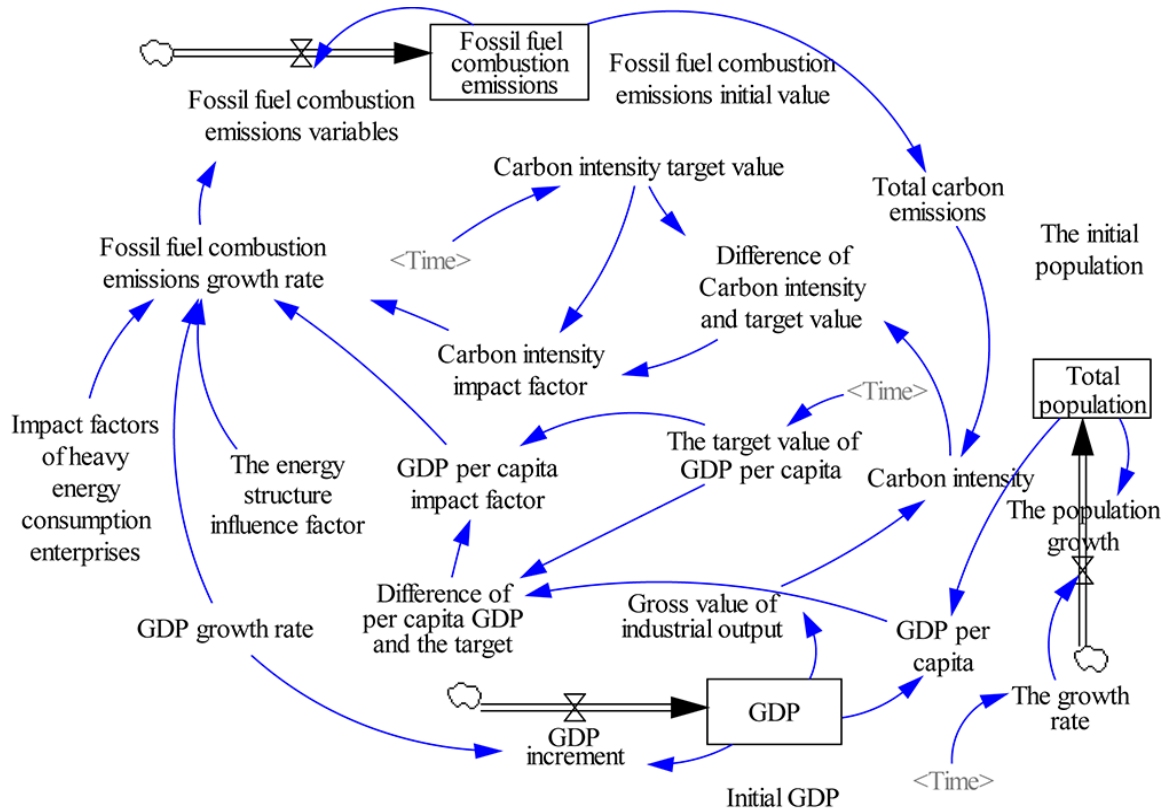


Fig. 3. Industrial carbon emissions system stock flow diagram in Beijing.

to the growth rate

*GDP*: simulation of Beijing GDP according to *GDP growth rate*

*Total carbon emissions*: this is our main focus that indicates the industrial carbon emissions in Beijing according to *Fossil fuel combustion emissions*.

*Industrial carbon emissions intensity*: carbon emissions that industrial output per unit generates.

Based on the statistics of Beijing Statistic Yearbook and Beijing Energetic Balance Sheet during 2005-2013, this paper runs the simulated mode of industrial carbon emissions covering 2005-2020 by SD software VENSIM. The simulation step size is one year.

According to the industrial carbon emissions system stock flow diagram in Beijing, this paper constructs the system model of the main variables and the formula is as follows.

### 3.3. Validity Test

For the sake of objectivity and scientific of simulated model, there is a necessity to perform validity tests of total population, industrial carbon emissions and industrial carbon intensity. The model validity test is proposed by the approach of history test. Table 2, Table 3 and Table 4 illustrate the validity test results of simulation from 2005 to 2013. Through the comparison with historical data

**Table 1.** Mainly Equations in System Dynamic Model

No.	Name	Equation
1	Carbon intensity	= Total carbon emissions*1000/Gross value of industrial output
2	Carbon intensity impact factor	= IF THEN ELSE(Difference of Carbon intensity and target value/Carbon intensity target value >= 0, 0.3, 0.2 )
3	Carbon intensity target value	= 80.2505 - 0.039726*Time
4	Difference of Carbon intensity and target value	= Carbon intensity-Carbon intensity target value
5	Difference of per capita GDP and the target	= GDP per capita-The target value of GDP per capita
6	Fossil fuel combustion emissions	INTEG (Fossil fuel combustion emissions variables, Fossil fuel combustion emissions initial value)
7	Fossil fuel combustion emissions growth rate	SQRT((1-Carbon intensity impact factor)*GDP per capita impact factor)*SQRT(1-The energy structure influence factor))*GDP growth rate*Impact factors of heavy energy consumption enterprises
8	GDP per capita	= GDP/Total population
9	Fossil fuel combustion emissions variables	= Fossil fuel combustion emissions growth rate*Fossil fuel combustion emissions
10	GDP	= INTEG (GDP increment,Initial GDP)
11	GDP increment	= GDP growth rate*GDP
12	Gross value of industrial output	= -7.844e-007*SQRT(GDP) + 0.1756*GDP + 377.5
13	The population growth	= The growth rate*Total population
14	The target value of GDP per capita	= 5049*Time-1.0075e + 007
15	Total population	= INTEG (The population growth, The initial population)

**Table 2.** The Validity Test of Total Population Simulation in 2005-2013

(Unit:104 people)

Year	2005	2006	2007	2008	2009	2010	2011	2012	2013
Simulated population	1,574.8	1,637.2	1,702.1	1,769.6	1,839.7	1,912.7	1,988.5	2,067.3	2,149.3
Actual population	1,538	1,601	1,676	1,771	1,860	1,962	2,019	2,069	2,115
Error(%)	2.39	2.26	1.56	0	1.09	2.51	1.51	0.08	1.62

**Table 3.** The Validity Test of GDP in 2005-2013

(Unit: 106 yuan)

Year	2005	2006	2007	2008	2009	2010	2011	2012	2013
Simulated GDP	7,214	8,227	9,383	10,702	12,153	13,921	15,877	18,108	20,653
Actual GDP	6,969	8,117	9,846	11,115	12,206	14,113	16,252	17,879	19,501
Error (%)	3.51	1.35	4.71	3.72	7.45	7.41	4.7	1.28	5.91

**Table 4.** The Validity Test of Total Carbon Emissions in 2005-2013

(Unit: 104 tons)

Year	2005	2006	2007	2008	2009	2010	2011	2012	2013
Simulated Total carbon emissions	5,854	6,120.91	6,422.73	6,823.89	7,132.24	7,364.92	7,741.94	8,151.95	8,446.13
Actual Total carbon emissions	5,854	6,259	6,663	6,708	6,965	7,372	7,416	7,924	8,143
Error (%)	0	2.21	3.61	1.73	2.40	0.10	4.40	2.88	3.72



from 2005 to 2013, results show that the population factor, industrial carbon emissions and industrial carbon intensity are all simulated well holding errors less than 10% and eventually pass the validation test. Namely, the system dynamic simulation modeling is effective thus providing the possibility of simulation scenario and prediction.

## 4. Results and Discussion

### 4.1. Prediction

Through simulation study of industrial carbon emission system in Beijing, this paper summarizes the simulation data of total population, total industrial carbon emissions and total industrial carbon emissions from 2005 to 2020. Fig. 4, Fig. 5 and Fig. 6 demonstrate the simulated results of total population, total industrial carbon emissions and total industrial carbon emissions respectively. The results show that, total population of Beijing keeps increasing smoothly with a total population exceeding 25 million in 2020; total carbon emissions keep increasing gradually at a low speed; industrial carbon emissions intensity decreases sharply. As a conclusion, although total carbon emissions of Beijing keep increasing for population growth and economic development, industrial carbon emissions intensity tends to decline due to energy

structure adjustment and strict regulation towards high-consumption enterprise [26].

### 4.2. Scenario Simulation and Policy Suggestions

According to the “twelfth five-year” plan and long-term development strategy of Beijing, Beijing will adjust the energy structure, but also adjust the industrial structure, reducing the proportion of high energy consumption enterprises. Therefore, three scenarios were set up, which were single factor, double factors, three factors. This paper carries out a simulation analysis of energy structure, high energy-consuming enterprises and carbon intensity, and then discusses the influence on total carbon emissions caused by these three variables. According to the construction goal of low carbon city in Beijing city, we can distinguish better emission-reduction strategy and avoidable deficiency by changing parameters thus providing different simulated scenarios. Table 4 shows the declining trend of carbon intensity in changing scenario.

#### 4.2.1. Single impact factor analysis

##### • Impact factors of heavy energy consumption enterprises

In this section, we focus on Impact factors of heavy energy consumption enterprises, its initial value is 0.752, Fig. 5 shows the simulation results while the impact factors varies from 0.7 to 0.8.

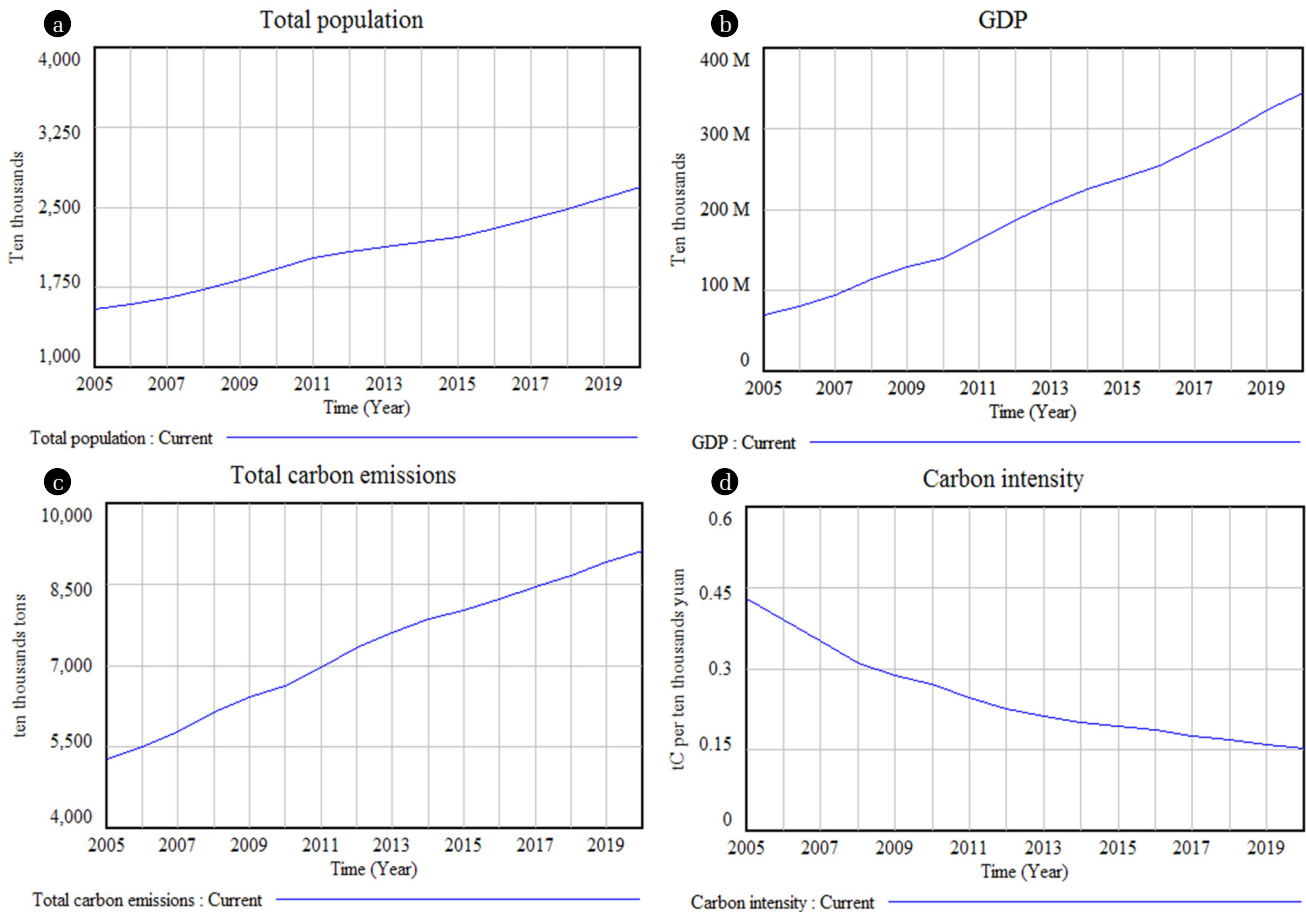


Fig. 4. Prediction results in Beijing industrial carbon emissions system.

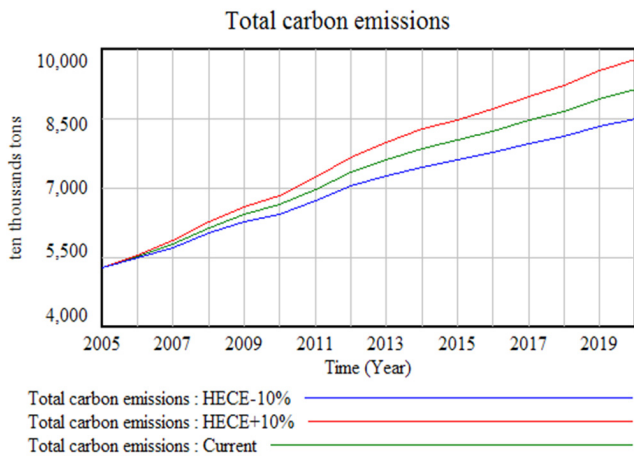


Fig. 5. The impact of heavy energy consumption enterprises on total carbon emissions.

As is shown in Fig. 5, the heavy energy consumption enterprises increase and total carbon emissions will increase. Similarly, carbon emissions will decrease with the impact of high energy consumption enterprises. Therefore, reducing the heavy energy consumption enterprises 10% can reduce carbon emissions by about 7.5%.

#### • Carbon intensity impact factor

Then, we focus on Carbon intensity impact factor, the equations in the model as shown below:

$\text{Carbon intensity impact factor} = \text{IF THEN ELSE}(\text{Difference of Carbon intensity and target value} / \text{Carbon intensity target value} \geq 0, 0.3, 0.2)$

We decrease/increase Carbon intensity impact factor by 10% and simulation results are depicted in Fig. 6.

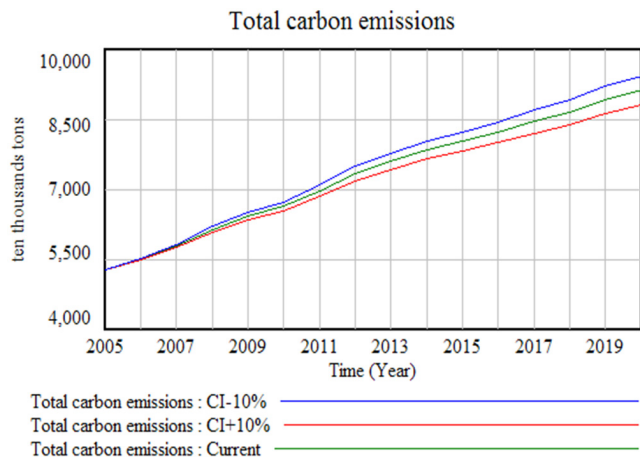


Fig. 6. The impact of carbon intensity on total carbon emissions.

From this Fig. 6, the carbon intensity increases and the total carbon emissions are reduced. Similarly, when the carbon intensity is reduced, carbon emissions are increasing. It can be seen the impact of carbon intensity decreased by 10% and carbon emissions increased by 3.5%.

#### • The energy structure influence factor

Hence, we focus on energy structure influence factor, its initial value is 0.9, Fig. 7 shows the simulation results while the impact factors varies from 0.85 to 0.95.

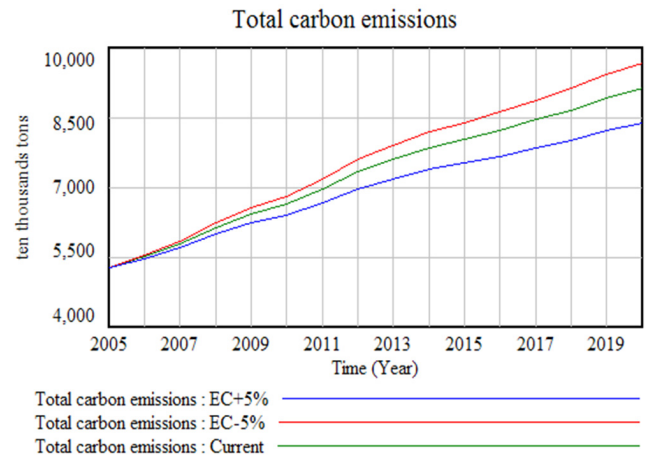


Fig. 7. The impact of energy structure on total carbon emissions.

In Fig. 7, the influence of energy structure increased by 5% is greater than it reduced by 5%. It can be seen the energy structure increased by 5% and carbon emissions reduced by 8%. On the contrary, the energy structure reduced by 5% and carbon emissions increased by 5.8% in 2020.

It can be seen from the single factor analysis, the energy structure has a maximum influence on industrial carbon intensity of Beijing, followed by heavy energy consumption enterprises and the final is carbon intensity. It is also related to the change of the industrial output value and energy structure factor, which reflects the main direction of adjusting energy structure will become the main direction of Beijing industrial emission reduction.

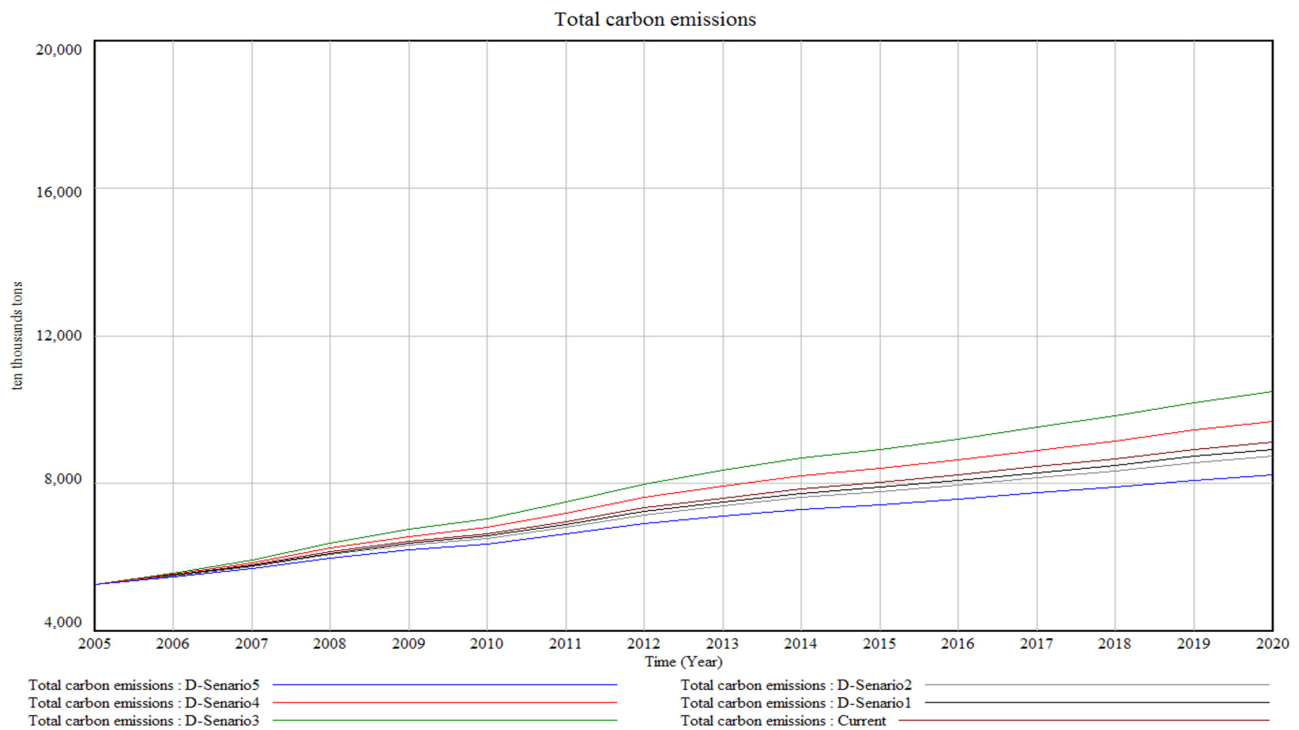
#### 4.2.2. Double-factor scenario analysis

In this section, we mainly analyze the influence of two factors on the industrial carbon emissions in Beijing. The variable factors are: Impact factors of heavy energy consumption enterprises, Carbon intensity impact factor and Carbon intensity impact factor. We set up five scenarios according to the change and the results of the simulation as shown.

As can be seen from Fig. 8, the carbon emissions of scenario 5 is the smallest, which can be reach 8,230.48 ten thousand tons by 2020. Inversely, Scenario 3 has a highest carbon emissions are 10,485 ten thousand tons by 2020. Meanwhile increasing the carbon intensity and reducing the impact factors of high energy consumption enterprises is also very obvious for reducing carbon emissions. We can see from the double factor analysis, increasing carbon intensity impact factor, that is increasing the carbon emissions per unit of industrial GDP, and reducing the impact factors of high energy consumption enterprises can significantly reduce carbon emissions. Similarly, the amount of carbon emissions in the scenario 1, 2, 4 is 8,925.97, 8,742.47, 9,678.81 ten thousand tons. Compared with scenario 1 and 2, in the case of maintaining high energy consumption enterprises, increasing the impact factor

**Table 5.** Simulated Double-factor Scenarios Setting

Scenario pattern	Character description (impact factors)
Changing scenario 1	Impact factors of heavy energy consumption enterprises decreases by 10% at 0.652; carbon intensity impact factor keep constant; factor of energy structure decreases by 10% at 0.8.
Changing scenario 2	Impact factors of heavy energy consumption enterprises decreases by 10% at 0.652; carbon intensity impact factor decreases by 10%; factor of energy structure decreases keep constant at 0.9.
Changing scenario 3	Impact factors of heavy energy consumption enterprises keeps constant at 0.752; carbon intensity impact factor decreases by 10% ; factor of energy structure decreases by 10% at 0.8.
Changing scenario 4	Impact factors of heavy energy consumption enterprises keeps constant at 0.752; carbon intensity impact factor increases by 10% ; factor of energy structure decreases by 10% at 0.8.
Changing scenario 5	Impact factors of heavy energy consumption enterprises decreases by 10% at 0.652; carbon intensity impact factor increases by 10%; factor of energy structure keeps constant at 0.9.

**Fig. 8.** Simulated double-factor scenarios variations in total carbon emissions.**Table 6.** Simulated Third-factor Scenarios Setting

Scenario pattern	Character description (impact factors)
Changing scenario 1	Impact factors of heavy energy consumption enterprises decreases by 10% at 0.652; carbon intensity impact factor decreases by 10%; factor of energy structure increases by 5% at 0.95.
Changing scenario 2	Impact factors of heavy energy consumption enterprises increases by 10% at 0.852; carbon intensity impact factor by 10%; factor of energy structure decreases by 5% at 0.85.

of the energy structure and reducing the carbon intensity of the factors can reduce carbon emissions. The purpose of double-factor analysis is to provide a more comprehensive reference for the government to formulate policies, especially when the government can only weigh two factors.

#### 4.2.3. Third-factor scenario analysis

This section mainly analyzes the influence of three factors on

the industrial carbon emissions in Beijing. The variable factors are: Impact factors of heavy energy consumption enterprises, Carbon intensity impact factor and Carbon intensity impact factor. We consider two extremes in the third-factor scenario analysis. Results of scenario simulation are shown in the table.

As is shown, the carbon emissions of scenario 1 are the smallest, which can be reached 7,685.34 ten thousand tons by 2020. It reduces 1,427.35 ten thousand tons compared with Current



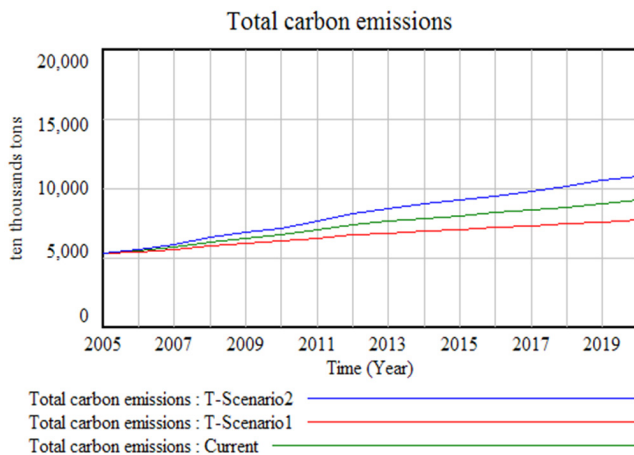


Fig. 9. Simulated third-factor scenarios variations in total carbon emissions.

scenario. The scenario 2 has a highest carbon emissions and its carbon emissions will achieve 10,874 ten thousand tons at the end of 2020. It increases 1,751.31 thousand tons compared with Current scenario. There is a difference of 3,178.66 tons of carbon emissions. It is clear that the Beijing industry has a lot of space and potential from the analysis of simulated third-factor.

## 5. Conclusions

The objective of this paper is to identify simulated-variation tendency of industrial carbon emissions system under various policy focus and provide emission-cutting recommendations relatively. SD, which based on the cause-and-effect analysis and feedback loops structures, has been proposed as a new thought to solve complexity and uncertainty problems. The approach is illustrated by a realistic case study (Beijing, China), conceived to be a brick to attack a jade. This paper has established a SD model to analyze the Beijing industrial carbon emissions system. Furthermore, the proposed model also can be used to understand the long-term behavior of a system under various situations. Eventually, this paper concludes with scenario-simulated data of industrial carbon emissions and emission-reducing policy recommendations under different development strategies in Beijing. As above-mentioned, we can draw the following conclusions and recommendations.

- Beijing can achieve the carbon emissions reduction goals in 2020 under current economic development situation, and the industrial emission reduction space is large. It even can be as high as 70%, taking into account the agriculture, service, transportation and other industries emission reduction space is small. So Beijing can appropriately increase the industrial emission reduction efforts to achieve carbon emissions targets.

- Reducing the proportion of Beijing industrial high energy consumption enterprises is the key element of achieve the carbon emissions reduction target. So Beijing can achieve carbon emissions targets only by reducing the proportion of Beijing industrial high energy consumption enterprises and maintaining a steady GDP growth rate.

- Although the impact factor of the energy structure is small,

but it is still very important to reduce carbon emission reduction targets. Reducing the proportion of coal in energy consumption can effectively accelerate the carbon emission intensity decreased.

- Besides, air quality in Beijing is promising to be ameliorative through a mass of measures, like reducing the carbon emissions, planting the vegetation that can absorb more carbon dioxide, expanding the proportion of the tertiary industry, reducing the proportion of cement, steel and other energy-intensive industries and improving the level of manufacturing industry modernization.

- Finally, there is a necessity to adjust the energy structure, to promote low-carbon technologies development and management methods optimization positively and to select a path of low-carbon economic development.

This paper provides a research way of thinking to SD applied in the carbon emissions study. In view of China's low carbon economic develop, in the later study, the SD method can be used in construction, transportation and other aspects of the low carbon study. Nevertheless, a number of refinements and model extensions are required for future consideration: (1) In the process of calculating industrial carbon emissions, we only consider the carbon emissions stem from production process, emissions that generate from productive corporate activities were not taken into consideration, such as emissions from the production movement; (2) in this study, only macro economic factors were considered for decomposition analysis. If the different decomposition analyses can be conducted at the sector level, the results will become more robust and reliable for sustainability policy making.

## Acknowledgements

This work is supported by the Fundamental Research Funds for the Central Universities (No. 12ZX12).

## References

1. Walther GR, Post E, Convey P, et al. Ecological responses to recent climate change. *Nature* 2002;416:389-395.
2. Ford A. System dynamics and the electric power industry. *Syst. Dynam. Rev.* 1997;13:57-85.
3. He J. Analysis of CO<sub>2</sub> emissions peak: China's objective and strategy. *Chinese J. Popul. Resour. Environ.* 2014;12:189-198.
4. Ouyang X, Lin B. An analysis of the driving forces of energy-related carbon dioxide emissions in china's industrial sector. *Renew. Sust. Energ. Rev.* 2015;45:838-849.
5. Ma C, Zhang GY, Zhang XC, et al. Simulation modeling for wetland utilization and protection based on system dynamic model in a coastal city, China. *Procedia Environ. Sci.* 2012;13: 202-213.
6. Yin Y, Xu W, Zhou S. Linking carbon sequestration science with local sustainability: An integrated assessment approach. *J. Environ. Manage.* 2007;85:711-721.
7. Barth M, Boriboonsomsin K. Energy and emissions impacts of a freeway-based dynamic eco-driving system. *Transport. Res. D-Tr. E.* 2009;14:400-410.
8. Cui Q, Yang J, Dong W. Determinants of the variance of estima-

- tions on China's carbon emission: Based on meta-analysis. *Energy Procedia* 2014;61:1150-1162.
9. Fan Y, Liu LC, Wu G, et al. Changes in carbon intensity in China: Empirical findings from 1980-2003. *Ecol. Econ.* 2007;6:683-691.
10. Wang X, Duan Z, Wu L, et al. Estimation of carbon dioxide emission in highway construction: A case study in southwest region of China. *J. Clean. Prod.* 2014;103:705-714.
11. Wang C, Chen J, Zou J. Decomposition of energy-related CO<sub>2</sub> emission in China: 1957-2000. *Energy* 2005;30:73-83.
12. Fong WK, Matsumoto H, Lun YF. Application of system dynamics model as decision making tool in urban planning process toward stabilizing carbon dioxide emissions from cities. *Build. Environ.* 2009;44:1528-1537.
13. Richardson GP, AL Pugh. Introduction to system dynamics modeling. Portland (OR): Productivity Press; 1981.
14. Hassan QU, Baek SS. How to do structural validity of a system dynamics type simulation model: The case of an energy policy model. *Energ. Policy* 2010;38:2216-2224.
15. Homer JB, St. Clair CL. A model of HIV transmission through needle sharing. A model useful in analyzing public policies, such as a needle cleaning campaign. *Interfaces* 1991;21:26-29.
16. Ford A, Lorber HW. Methodology for the analysis of the impacts of electric power production in the West. Paper read at Environmental Protection Agency Conference on Energy/Environment II; 1977.
17. Abada I, Briat V, Massol O. Construction of a fuel demand function portraying interfuel substitution, a system dynamics approach. *Energy* 2013;49:240-251.
18. Akkermans H, Bogerd P, Vos B. Virtuous and vicious cycles on the road towards international supply chain management. *Int. J. Oper. Prod. Man.* 1999;19:565-582.
19. Qudrat-Ullah H. Green power in Ontario: A dynamic model-based analysis. *Energy* 2014;77:859-870.
20. Ford A, Bull M. Using system dynamics for conservation policy analysis in the Pacific Northwest. *Syst. Dynam. Rev.* 1989;15:1-16.
21. Luo D, Hu Z, Choi DG, et al. Life cycle energy and greenhouse gas emissions for an ethanol production process based on blue-green algae. *Environ. Sci. Technol.* 2010;44:8670-8677.
22. Vafa-Arani H, Jahani S, Dashti H, et al. A system dynamics modeling for urban air pollution: A case study of Tehran, Iran. *Transport. Res. D-Tr. E.* 2014;31:21-36.
23. Qudrat-Ullah H. On the validation of system dynamics type simulation models. *Telecommun. Syst.* 2012;51:159-166.
24. Feng YY, Chen SQ, Zhang LX. System dynamics modeling for urban energy consumption and CO<sub>2</sub> emissions: A case study of Beijing, China. *Ecol. Model.* 2013;252:44-52.
25. Anand S, Vrat P, Dahiya RP. Application of a system dynamics approach for assessment and mitigation of CO<sub>2</sub> emissions from the cement industry. *J. Environ. Manage.* 2006;79:383-398.
26. Sterman JD. An integrated approach to the economic long wave. *Working paper* 1983;17:104-131.