INTRODUCTION

With the increasing environmental pollution caused by China's economic development, China urgently needs to accelerate the process of clean energy supply and deepen the adjustment of industrial structure to achieve sustainable development. At the same time, ensuring sufficient, stable, and continuous supply of energy resources is a strategic requirement for economic and social development. As a high-quality clean energy, natural gas can not only provide power for...
stable economic growth, but also improve environmental quality. The current growth in demand for natural gas in China's economic development has exceeded its own production capacity. Based on the security of natural gas resource supply, this paper studies the dual goals of economic growth and environmental improvement from the perspective of the optimal allocation of natural gas resources on the demand side.

In recent years, China's environmental pollution problems have become more serious, especially the continuous deterioration of the quality of the air environment. Heavy pollution has seriously affected social production and people's lives. In January 2013 alone, the direct losses caused by haze in the eastern urban areas were 23 billion yuan, and the annual number of premature deaths caused by air pollution in China was 350,000-500,000. China's coal-based energy consumption structure and the rapid development of heavy chemical industries are the main reasons for the deterioration of China's atmospheric environmental quality. During the “Twelfth Five-Year Plan” period, although China's coal consumption accounted for a decline in the proportion of total energy consumption, the proportion in 2015 was still as high as 63.7%. Industrial waste gas emissions are considered to be one of the main causes of atmospheric environmental pollution. The emissions of industrial waste gas pollutants (sulfur dioxide and nitrogen oxides) accounted for the national atmosphere discharge of pollutants from 2000 to 2015 were maintained at more than 80%. In general, in order to achieve sustainable economic, social, and environmental development and fundamentally curb the emission of pollutants, we must continue to deepen industrial restructuring, increase the proportion of the tertiary industry, and vigorously develop natural gas, wind, solar, hydro, geothermal, nuclear energy, etc, clean energy.

The importance of energy supply security is becoming increasingly prominent. Energy is an indispensable material foundation for economic development and plays an important role in maintaining and improving people's living standards and ensuring the normal operation of modern society. At present, the global mining industry has been in a period of in-depth adjustment. The imbalance of supply and demand of mineral resources, the failure of the pricing mechanism, and the frequent adjustment of mining policies have made the security of global mineral supply resources an important international issue that has attracted the attention of various countries. As an important mineral resource, energy supply security issues deserve attention. As the second largest economy in the world, China is not only a major producer of energy resources, a major consumer country, and a major trading country, but also a major force in the transformation of the global supply and demand of energy resources. Therefore, it is China's strategic needs for development to ensure that energy resources are adequate, stable, and sustainable.

Natural gas resources are the most realistic choice for clean energy supply. Natural gas is a high-quality, high-efficiency, and clean energy. Compared with coal, natural gas has a higher unit calorific value. It emits sulfur dioxide and nitrogen oxides under the same heat generation conditions, in which coal is 67 times and 16 times that of natural gas. The “Energy Production and Consumption Revolution Strategy (2016-2030)” (Fa Basis [2016] No. 2795) clearly states that clean energy will become the mainstay of China's incremental energy, with natural gas consumption accounting for about 15% of total energy consumption. At present, due to the low technological maturity and equipment manufacturing capacity, and high production costs, the development utilization rate of most clean energy including wind energy, solar energy, geothermal energy, and nuclear energy is low, and the market size is small. China Statistical Yearbook only publishes consumption data of natural gas resources for clean energy consumption. Since 2000, China's natural gas consumption has grown at an annual rate of more than 10%, far exceeding the GDP growth rate during the same period. In 2015, natural gas consumption was nearly 200 billion cubic meters, accounting for 5.5% of total energy consumption. However, the growth of natural gas domestic production cannot meet the demand for the increase in consumption, and the gap between China's natural gas supply and demand has been increasing. Since 2013, China's external dependence on natural gas has been above 30%.

Facing the contradiction between the increasing demand for natural gas and insufficient domestic natural gas resource supply capacity, from the perspective of natural gas resource supply, due to the difficulty of exploiting natural gas resources in China and the high technical requirements, it is difficult for domestic output to increase significantly in the short term. Due to high external dependence and serious energy security risks, this paper mainly studies from the perspective of optimizing the allocation of natural gas resources on the demand side, through the optimization of natural gas consumption structure to achieve the triple goals of security of natural gas supply, stable economic growth, and improvement of the quality of the atmospheric environment so as to ensure the sustainable growth of China's economic and social environment.

There is a little research on the optimal allocation of natural gas resources, and there are many researches on the optimal allocation of water resources. This paper draws on the research ideas and methods of the published optimal allocation of resources. Babel constructed the model and collaborated with the policymakers to optimize the distribution of water resources among different consumer sectors, taking into account socioeconomic, environmental, and technological factors. Hansen applied multiobjective optimization configuration model to manage groundwater resources. Li and Guo proposed an optimal allocation model for water...
resources under unknown conditions, and conducted case studies on the Minqin area of Gansu, China, to explore how to maximize the economic, social, and ecological benefits. Al-Zahran17 established a multiobjective optimization model for water resources management in Riyadh, Saudi Arabia. Alizadeh18 conducted an empirical study by applying the multiobjective optimization configuration model to groundwater resources in Damj, Fayes Province, Iran. Perry19 applied the multiobjective optimization model to manage natural resources.

There are not many studies on the allocation of natural gas resources in China, and there are many studies on the safety of natural gas supply. Zhang, Hu, and Yang, and others used qualitative analysis methods to study the safety of natural gas supply, taking the status quo of natural gas supply as an entry point.20 They analyzed the existing problems and proposed countermeasures to ensure the safety of natural gas supply. They applied quantitative analysis to develop the index system to evaluate the supply safety of natural gas. The solution options were given after the data were comprehensively evaluated for safety of natural gas supply. Shen21 comprehensively evaluated the five aspects, resource supply, transportation capacity, market conditions, accountability, and emergency management, and building a safety indicator system for urban natural gas supply. Zhang and Huang23 pointed out that natural gas unit production value energy consumption, natural gas import dependence, natural gas domestic production, consumption proportion, and natural gas geopolitical risk will affect the safety of natural gas supply. The evaluation results show that there is potential risk in the current safety situation of China's natural gas supply due to its high dependence on foreign natural gas. This trend is gradually rising, and they proposed to reduce the amount of natural gas imports. Through the analysis of nine important factors, Wang24 built an evaluation index system and they concluded that China needs to increase domestic natural gas supply to make natural gas supply safer. Tian25 based on China's natural gas data from 2006 to 2014 applied analytic hierarchy process and entropy method to build a comprehensive index system to grade natural gas supply safety. Through the establishment of an optimal allocation model of natural gas resources, Fan was able to achieve goals of natural gas resource supply security, economic stability, and improvement of atmospheric environmental quality. Yan26 used the SWOT analysis to eliminate the impact of China's energy security policy. In view of the dual-level and multiobjective characteristics of China's energy-environment-economy (3E) system, Ning27 reviewed the economic development scenario and believed that the "win-win" situation can be achieved to have high-quality economic development breeding good economic effects.

At present, the main body of China's clean energy is natural gas. China can adjust its energy structure to achieve unprecedented economic development and significant environmental improvement. From the perspective of natural gas supply safety, this paper studies the multiobjective optimal allocation of natural gas resources, and comprehensively considers the dynamic relationship among natural gas supply and demand, social and economic development, and environmental quality. It sets environmental quality constraints and natural gas safety supply constraints and adjusts the four policy combinations of energy structure. Finally, Lingo was used to simulate the policy combinations introduced in the model to optimize the structure of natural gas consumption.

2.1 Conceptual model

The economic-environment-natural gas resource multiobjective optimal allocation model established in this study is based on the actual situation of China's natural gas resource supply and demand, social, and economic development and atmospheric environment. Based on the model of Higano and Yoneta28 with reference to other scholars' model improvements,29-32 we use equations to represent the actual situation as much as possible, and use Lingo software, the equation system model written as a programming language for simulation and trial calculations, to find the optimal solution, that is, the policy combination for the optimal allocation of natural gas resources. (a) Assume that the coefficients involved in the whole model are fixed; (b) assume that the model is a closed system, but can import natural gas from abroad, regardless of other
exogenous variables outside the model. The model consists of an objective function and three subsystems. The objective function is the maximization of GDP. The three subsystems are the socioeconomic development system, the natural gas resource supply and demand balance system, and the atmospheric environmental quality constraint system, as shown in Figure 1. The optimal result is to achieve the three goals of safe supply of natural gas resources, stable economic growth, and improvement of atmospheric environmental quality.

The social and economic development system describes the relationship between the input of various industrial capital, natural gas resources, and other factors and social output, and dynamically simulates the future development of social economy through the input-output coefficient. In the natural gas resource supply and demand balance system, the demand for natural gas resources is simulated by the gas demand coefficient (under the premise of natural gas supply safety), the gas structure of the industrial sector is adjusted, and the natural gas emission reduction coefficient is used to simulate the pollution reduction brought by natural gas. The atmospheric environmental restraint system accounts for the emission of pollutants that are metabolized by energy after social and economic activities. Only SO₂ and NOₓ are selected as indicators for the evaluation of pollutants.

In the conceptual model based on economic-environment-natural gas resource allocation, the relationship between the three subsystems is interactive and mutually restrictive. Socioeconomic development consumes natural gas resources and at the same time emits pollutants SO₂ and NOₓ into the atmospheric environment; natural gas resources provide energy support for social and economic development. To reduce SO₂ and NOₓ emissions, it is important to replace traditional energy consumption, and at the same time to restrict the safety constraints of natural gas supply changes in the output value of the industrial sector. While atmospheric environmental constraints set by emission reduction limit for SO₂ and NOₓ, we can restrict the changes in the output value of various industries and also require natural gas resources to replace traditional energy consumption. The model composed of the three subsystems and the objective function is an integrated system. The common goal is to achieve the triple goals of natural gas resource supply security, stable economic growth, and air pollution reduction by optimizing the allocation of natural gas resources.

2.2 Data sources and policy combinations

The data sources of this paper are from “2012 China Input-Output Table,” “China Energy Statistics Yearbook 2013-2018,” “China Environmental Statistics Yearbook 2013-2018,” and so on. The other part is based on the original statistical data, and the demand coefficient in the model is calculated as indirect data.

This paper proposes four combination strategies. The first is the safety constraints of natural gas supply. The second is

FIGURE 1 Conceptual model based on economic, environmental, and natural gas resource allocation
the adjustment of energy structure. The third is the optimization of natural gas consumption structure. The fourth is the constraint of air pollution discharge. The policy mix is shown in Table 1:

(1) Natural gas supply safety constraints

The natural gas supply safety constraint refers to the domestic sustainable and stable natural gas source in the long term, including domestic production and foreign imports. Under the premise of neglecting the short-term price fluctuation of natural gas resources, the model considers the domestic production of natural gas resources, the foreign natural gas imports, and the ratio between the two, as well as the domestic sector consumption of natural gas structure and the impact of natural gas on reducing atmospheric pollutant emissions. In the “13th Five-Year Plan for Natural Gas Development,” domestic natural gas production will reach 207 billion cubic meters in 2020, and the average annual growth rate of natural gas production during the 13th Five-Year Plan period is 9%. We set the average annual growth rate of natural gas production in 2021-2025 to 10% due to enhanced natural gas supply. The average annual growth rate of China’s imported natural gas reached 30% in 2010-2015, but since the new LNG receiving stations in Jiangsu Donggang and Northeast China were put into operation in 2011, natural gas imports surged, which has increased for 5 years. The average growth rate of natural gas after 2011 is 15%, and it is very stable. Then, this paper sets the average annual growth rate of China’s imported natural gas in 2016-2025 to 15%.

(2) Energy structure adjustment

The “Revolutionary Strategy for Energy Production and Consumption (2016-2030)” proposes that clean energy is the main contributor to the main body of China’s energy increase, and 15% of energy consumption is contributed by natural gas resources. In the context of this policy, based on the total energy consumption of coal, oil, and natural gas in current social and economic activities, the future new energy consumption will be supplied by natural gas. The advantages of natural gas consumption in reducing atmospheric pollutants will be used to achieve atmospheric pollution reduction targets.

(3) Optimize the consumption structure of natural gas

At present, the efficiency of the use of natural gas resources in different industries varies greatly. For example, every 100 million yuan of output produced by the oil and natural gas extraction industry consumes 1.002 million cubic meters of natural gas, while every 100 million yuan of output produced by the transportation, warehousing, and postal industries consumes 249,000 cubic meters of natural gas, and every tertiary industry except transportation, warehousing, and postal industry consumes only 19,000 cubic meters of natural gas for every 100 million yuan of output. Therefore, the policy meaning of optimizing the structure of natural gas consumption is to increase gas consumption and usage proportion for those with high-efficiency industries so as to increase industrial output under other conditions unchanged.

(4) Air pollution emission constraints

According to the “13th Five-Year Plan,” the air pollution emission restriction policy refers to the cumulative reduction of SO2 and NOx emissions by 15% in 2015-2020 and the reduction of SO2 and NOx by 20% in 2020-2025(Chinese 13th Five-Year Plan in 2015-2020). This constitutes the constraint target of air pollution reduction.

In summary, the overall connotation of the policy portfolio set in this study is based on the future annual growth rate of domestic natural gas production and foreign imports. The total annual domestic and foreign natural gas supply is calculated, which is the red line of the policy for the safety of natural gas supply. Natural gas consumption is restricted by the policy red line, adopting new energy sources, adjusting the energy structure by natural gas supply, and combining natural gas consumption structure optimization to guide more limited natural gas resources to

| Policy number | Policy name                        | Policy connotation                                           |
|---------------|-----------------------------------|--------------------------------------------------------------|
| 1             | Natural gas supply safety constraints | Natural gas consumption does not exceed total natural gas allocation |
| 2             | Energy structure adjustment        | New energy is supplied by natural gas                        |
| 3             | Optimization of natural gas consumption structure | Increased natural gas consumption in sectors with high natural gas resource consumption efficiency |
| 4             | Air pollution emission constraints | SO2 and NOx emission reductions are in line with government emission targets |

TABLE 1 Policy combinations for multiobjective optimization of natural gas resources
be consumed in industries with high natural gas utilization efficiency and emission reduction effects. The goal is to achieve stable economic growth under the constraints of air pollution emissions.

2.3 | Configuration model

According to the latest input-output table, this paper uses 2012 as the base year to simulate the supply and demand trends of China's natural gas resources in 2013-2025, China's social and economic development trends, and the improvement trend of atmospheric environmental quality, including the simulated China's economic development trends between 2013 and 2017 compared with actual data to verify the accuracy of the model application.

2.3.1 | Objective function

The Chinese economy pursues the maximization of GDP while meeting the requirements of natural gas supply security and environmental protection. The objective function is to maximize the regional economic production (GDP). At the same time, based on the current national debt interest rate, the social annual discount rate of 0.04 is set, which is the basis for vertically comparing economic variables in different periods.

\[
\text{MAX} \sum_t \frac{1}{(1 + \rho)^{t-1}} \text{GDP}(t) \quad (t = 1, 2, \ldots, 13) \quad (1)
\]

\[
\text{GDP}(t) = \sum_i v_i \cdot x_i(t) \quad (2)
\]

In Equation 1, GDP\( (t) \) is the \( t \)-period of China's GDP. The base period is 0. The simulation period is 1-13. \( \rho \) is the social discount rate, the reference is government bond interest rate of 0.04.

In Equation 2, \( X_i(t) \) is the gross value of the \( t \)-period of industry \( i \). \( V_i \) is the value-added rate of industry \( I \), where \( i \) takes values from 1 to 13. There are 13 departments used in this paper. They are agriculture, forestry, animal husbandry, fishery and water conservancy, oil and gas extraction, other extractive industries, petroleum, coking and nuclear fuel processing, chemical, nonmetallic minerals, metal smelting and rolling processing, other manufacturing, electricity, thermal production and supply, gas and water production and supply, construction, transportation, warehousing and postal services, and other tertiary industries.

2.3.2 | Supply and demand balance system for natural gas resources

(1) Balance of supply and demand of natural gas resources

In order to ensure the sustainable development of the social economy, the natural gas supply in each period should be greater than the demand for natural gas.

\[
\text{GST}(t) \geq \text{GDT}(t) \quad (3)
\]

In Equation 3, GST\( (t) \) is the total supply of natural gas resources in period \( t \). GDY\( (t) \) is the total demand for natural gas resources in period \( t \).

(2) Supply of natural gas resources

China's natural gas resource supply is divided into two parts: domestic production supply and foreign supply.

\[
\text{GST}(t) = \text{GP}(t) + \text{GI}(t) - \text{GE}(t) \quad (4)
\]

In Equation 4, GP\( (t) \) is the production of natural gas resources in period \( t \). GI\( (t) \) is the amount of natural gas resources supplied by foreign countries. GE\( (t) \) is the amount of natural gas resources exported in period \( t \).

(3) Demand for natural gas resources

China uses natural gas mainly for industrial and civil natural gas. The demand for industrial gas is determined by the industrial output in the social economy and the set industry demand coefficient. The gas consumption of residents is determined by the national fixed population and the demand coefficient of residential gas.

\[
\text{GDT}(t) = \text{GID}(t) + \text{GHD}(t) \quad (5)
\]

\[
\text{GID}(t) = \sum_i g_i \cdot x_i(t) \quad (6)
\]

\[
\text{GHD}(t) = g_e \cdot p(t) \quad (7)
\]

In Equation 5, GID\( (t) \) is the demand for natural gas resources by residents in the industrial sector in the \( t \)-th period and GHD\( (t) \) is the demand for natural gas resources by residents in the \( t \)-th period. In Equation 6, \( g_i \) is the industry demand coefficient. In Equation 7, \( g_e \) is the coefficient of demand for residential gas and \( p(t) \) is the population of China in the \( t \)-th period.
2.3.3  Atmospheric environment restraint system

(1) SO₂ emissions

Under the energy structure in which natural gas resources are not optimally allocated, the amount of SO₂ emitted by industrial production of social and economic activities is determined by the output value of various sectors and the SO₂ emission coefficient; the same amount of SO₂ emissions from residents is determined by the national population and its SO₂ emission coefficient. The reduction in SO₂ emissions after the use of natural gas resources depends on the total demand for natural gas resources and the SO₂ emission reduction coefficient of the industry and residents.

\[
TP_{SO₂} = IP_{SO₂}(t) + HP_{SO₂}(t)
\]

\[
TP_{SO₂}(t+1) \leq TP_{SO₂}(t) \times (1 - a\%)
\]

\[
IP_{SO₂}(t) = \sum_i ep_{SO₂}^i \cdot x_i(t) - \sum_i rp_{SO₂}^i \cdot (g_i \cdot x_i(t) - x_i(0))
\]

\[
HP_{SO₂} = ep_{SO₂}^h \cdot p(t) - rp_{SO₂}^h \cdot ge \ast (p(t) - p(0))
\]

In Equation 8, TP_{so₂}(t) is the total amount of SO₂ emissions in the t-th period. IP_{so₂}(t) is the SO₂ emissions from industrial sector in the t-th period. HP_{so₂}(t) is the emissions of SO₂ from residents’ lives in the t-th period. In Equation 9, a is the percent of the average annual reduction in total SO₂ emissions. In Equation 10, ep_{so₂}^i is the SO₂ emission coefficient of the industry, and rp_{so₂}^i is the emission reduction coefficient of SO₂ after the consumption of natural gas in the industry. In Equation 11, ep_{so₂}^h is the SO₂ emission coefficient of residents’ living, and rp_{so₂}^h is the emission reduction coefficient of SO₂ after residents consume natural gas.

(2) NOₓ emissions

It is completely consistent with the emission SO₂ determinants of Equation 1 and will not be described here.

\[
TP_{NOₐ}(t) = IP_{NOₐ}(t) + HP_{NOₐ}(t)
\]

\[
TP_{NOₐ}(t+1) \leq TP_{NOₐ}(t) \times (1 - b\%)
\]

\[
IP_{NOₐ}(t) = \sum_i ep_{NOₐ}^i \cdot x_i(t) - \sum_i rp_{NOₐ}^i \cdot (g_i \cdot x_i(t) - x_i(0))
\]

\[
TP_{NOₐ} = ep_{NOₐ}^h \cdot p(t) - rp_{NOₐ}^h \cdot ge \ast (p(t) - p(0))
\]

In Equation 12, TP_{NOₐ}(t) is the total amount of NOₓ emissions in the t-th period. IP_{NOₐ}(t) is the NOₓ emissions from industrial sector in the t-th period, and HP_{NOₐ}(t) is the amount of NOₓ from residential source in the t-th period. In Equation 13, b is the percent of the average annual reduction in total NOₓ emissions. In Equation 14, ep_{NOₐ}^i is the NOₓ emission coefficient of the industry, and rp_{NOₐ}^i is the emission reduction coefficient of NOₓ after industrial consumption of natural gas. In Equation 15, ep_{NOₐ}^h is the NOₓ emission coefficient of the resident’s life, and rp_{NOₐ}^h is the NOₓ emission reduction coefficient after the residents consume the natural gas.

2.3.4  Social and economic development system

(1) Balance of industrial output

\[
X_i(t) \geq A \ast X(t) + C(t) + I(t) + NE(t)
\]

\[
C(t) = a \ast p(t)
\]

In Equation 16, \( X_i(t) \) is the total value of industry \( i \) production in the t-th period, \( A \) is the coefficient matrix of input and output, \( X(t) \) is the matrix of the total industrial production value in the t-th period, \( C(t) \) is the t-th period industrial consumption matrix, \( I(t) \) is the t-th period industrial investment matrix, and \( NE(t) \) is the t-th period industry net export matrix. In Equation 17, \( a \) is the per capita consumption coefficient.

(2) Social population growth

\[
p(t+1) = (1 + gr) \ast p(t)
\]

In Equation 18, \( gr \) is the natural growth rate of China’s population.

(3) Industry growth restrictions

\[
X_i(t) \leq a_i \ast k_i(t)
\]

\[
k_i(t+1) = k_i(t) + I_i(t+1) - d_i \ast k_i(t)
\]

In Equation 19, \( a_i \) is the capital output coefficient of industry \( i \), and \( k_i(t) \) is the total capital industry \( i \) in the t-th period. In Equation 20, \( I_i(t) \) is the investment amount of industry \( i \), and \( d_i \) is the social depreciation rate of industry \( i \).
2.4 Model evaluation

This paper examines the reliability and effectiveness of the model. The test of model reliability uses sensitivity analysis to analyze the key factors such as the industrial value-added rate of the objective function in the model, the gas demand coefficient of the constraint function, and the air pollution emission coefficient. By comparing the simulated data with the actual data of 2013-2018, we found that the relative error between the simulation result and the actual data is less than 3%. That is, the change trend of the simulation result is consistent with the actual data, and the results of other variables are similar. This implies that the model is reliable. The verification of the model fit to the GDP is presented in Table 2.

Based on the above verification results of model reliability and effectiveness, the dynamic empirical model of economic and environmental sustainability under China’s natural gas supply security constraints is reliable and effective. This model can reflect China’s natural gas resource utilization, social and economic development, and status and trends of environment development and pollution improvement.

3 RESULTS AND DISCUSSION

3.1 Dynamic scenario analysis

This paper sets three scenarios, which are the baseline scenario, the improvement scenario, and the enhancement scenario. The policy combinations in different scenarios are shown in Table 3.

This paper uses Lingo software to simulate the above three scenarios, and analyzes and compares various feasible solutions of China’s social and economic development, natural gas resource utilization, and environmental improvement under the three scenarios. It can screen out the best scenario for China’s natural gas resource utilization, social and economic development, and environmental improvement.

| Year | Year 2012 constant price Actual GDP value (100 million yuan) | Simulated GDP (100 million yuan) | Relative error (%) |
|------|---------------------------------------------------------------|----------------------------------|-------------------|
| 2013 | 582 291                                                       | 573 775                          | 1.4               |
| 2014 | 624 769                                                       | 612 504                          | 1.9               |
| 2015 | 667 976                                                       | 651 054                          | 2.5               |
| 2016 | 725 549                                                       | 705 960                          | 2.7               |
| 2017 | 804 660                                                       | 786 153                          | 2.3               |
| 2018 | 882 655                                                       | 857 941                          | 2.8               |

TABLE 2 Result of simulated data fit to GDP

3.1.1 Scenario analysis of China’s social and economic development

The scenario analysis of China’s social and economic development mainly considers China’s total GDP and the trend of GDP during the simulation period.

(1) Scenario analysis of total GDP

Due to the different policy combinations, there are differences in the cumulative total of China’s GDP in 2013-2025 in the three scenarios. Under the baseline scenario, the cumulative total GDP in 13 years is 1164 trillion yuan, which is the lowest in the three scenarios. Under the improvement scenario, the cumulative total GDP in 13 years is 1193 trillion yuan. In the enhanced scenario, the cumulative total GDP is 27 000 billion yuan higher than the baseline scenario, which is 2 trillion yuan lower than the improvement scenario, as shown in Table 4. This shows that combining energy structure adjustment with natural gas consumption structure optimization is conducive to achieving the dual goals of economic growth and environmental improvement. However, it is the price to pay for achieving the goal of reducing air pollution.

(2) Scenario analysis of GDP change trend

Based on three different policy combinations, the trend of GDP change under three scenarios is simulated and presented in Figure 2.

Starting from the change of GDP growth rate in 2013-2025, the average GDP growth rate in the baseline scenario is 7.04%, the improvement scenario is 7.54%, and the strengthening scenario is 7.52%, indicating that the three scenarios are in line with the current situation of China’s economic growth. According to the specific analysis, the GDP growth rate of the baseline scenario is the lowest, and the GDP growth rate is even below 6% in 2025. As a comparison, the GDP growth rate of the improvement scenario and the enhanced scenario maintains an upward trend, with data exceeding 7%, indicating that if it only depends on spontaneous...
industrial restructuring, it cannot balance the two objectives of improving the quality of the atmospheric environment and economic growth.

### 3.1.2 Scenario analysis of China's natural gas resource utilization

Based on the annual average growth rate of natural gas production mentioned in the “13th Five-Year Plan for Natural Gas Development” and the 2012 natural gas production given by the National Bureau of Statistics, the data of 2013-2025 natural gas production are obtained. The data show under the three scenarios natural gas supply is safe, and this confirms the validity of the model assumptions. Consider the total consumption of natural gas resources in 2013-2025 under the three scenarios. The consumption under the baseline scenario is 1683.2 billion cubic meters, the situation consumption is 2304.7 billion cubic meters, and the consumption under the enhanced scenario is 2289.9 billion cubic meters, as shown in Table 5.

In the baseline scenario, the consumption of natural gas resources is the smallest. Improving the situation and strengthening the situation will increase the total consumption of natural gas resources. This is because natural gas is responsible for the consumption of new energy. Consumption of natural gas resources can not only bring economic growth, but also improve the environment to some extent. In the enhanced scenario, the economic aggregate has decreased compared with the improvement scenario. This shows that in order to better improve the atmospheric environment, it is impossible to replace traditional energy consumption only by consuming clean energy, and it can only be at the expense of economic growth.

From the perspective of the average consumption intensity of natural gas in 2013-2025, the average consumption intensity under the three scenarios is 145 000 cubic meters/100 million yuan, 191 000 cubic meters/100 million yuan, and 190 000 cubic meters/100 million yuan. In the past 13 years, natural gas accounted for the proportion of total energy consumption is also shown in Table 6. The baseline scenario was the lowest. In contrast, the improvement scenario was the highest, which indicates that the improvement scenario has better energy consumption structure optimization effect.
3.1.3 | Scenario analysis of the status quo of atmospheric environment improvement in China

From 2013 to 2025, China's SO\textsubscript{2} emission intensity under the baseline scenario is 17.7 tons/100 million yuan, the improvement scenario is 17.6 tons/100 million yuan, and the enhanced scenario is 17.4 tons/100 million yuan. The NO\textsubscript{x} emission intensity under three scenarios is 18.4 tons/100 million yuan, 17.9 tons/100 million yuan, and 17.9 tons/100 million yuan, as shown in Table 7. Under the improvement scenario and the enhanced scenario, the emission of atmospheric pollutants has decreased compared with the basic scenario. Although the emission intensity under the enhanced scenario is lower than the improvement scenario, the emission intensity and the improvement scenario are almost the same, but this is at the expense of economic growth, so the improvement scenario is the optimal improvement result of the emission intensity.

### TABLE 5 Scenario analysis of total natural gas utilization in China in 2013-2025

| Scenario             | Total natural gas consumption (100 million cubic meters) |
|----------------------|---------------------------------------------------------|
| The baseline scenario| 16 832                                                   |
| The improvement scenario| 23 047                                                  |
| The enhancement scenario| 22 899                                                  |

### TABLE 6 Scenario analysis of China's natural gas utilization intensity and proportion of energy consumption in 2013-2025

| Scenario             | Natural gas utilization intensity | Natural gas accounts for the proportion of total energy consumption |
|----------------------|----------------------------------|---------------------------------------------------------------------|
| The baseline scenario| 14.80%                           | 10.01%                                                              |
| The improvement scenario| 19.20%                          | 23.80%                                                              |
| The enhancement scenario| 19.20%                           | 23.80%                                                              |

3.2 | Results analysis

Among the three scenarios, the baseline scenario has low socioeconomic efficiency, and the enhanced scenario requires consumption of economic growth as a cost to reduce limited pollutant emissions, while the improvement scenario enables the socioeconomic under the premise of meeting the set environmental pollution limits and natural gas supply security to maximize the growth. Below we will analyze the trend of China's natural gas resource supply and demand, social and economic development trends, and the improvement of atmospheric environment.

3.2.1 | China's natural gas resource supply and demand trend analysis

After the introduction of four portfolio policies, domestic natural gas production has gradually surpassed demand in 13 years. The efficiency of China's use of natural gas has increased significantly, reducing the dependence of China's natural gas on foreign countries and improving supply security. The proportion of natural gas in the total energy consumption has increased significantly, and China's energy consumption structure and sectoral gas distribution structure have been continuously optimized, basically achieving the goal of optimal allocation of natural gas resources.

(1) Research on the trend of China's natural gas resource supply security
According to actual data and simulation results, natural gas consumption in 2013-2025 jumped from 148.2 billion cubic meters to 217.1 billion cubic meters in 2025. During the same period, the production volume jumped from 115.8 billion cubic meters to 333.4 billion cubic meters. The growth rate of natural gas production (8%) has been higher than the growth rate of consumption (4%). In 2013-2017, natural gas production is less than consumption, but the gap between the two is gradually decreasing. In 2018-2025, natural gas production is overconsumption, and the difference between the two is increasing, indicating that China’s natural gas resource supply is becoming more and more secure. In 2018, China does not need to import natural gas resources from abroad to meet natural gas consumption demand, as shown in Figure 3.

(2) Research China’s natural gas resources accounting for total energy consumption

In 2013-2025, China’s natural gas consumption per unit of GDP fell from 258 000 cubic meters/100 million yuan to 156 000 cubic meters/100 million yuan. The proportion of natural gas consumption in total energy consumption rose from 5.4% to 7.8%. As shown in Figure 4, it is shown that the combination of the four policies has led to increased natural gas consumption in sectors with high gas use efficiency.

In 2013-2025, the proportion of coal, oil, and electricity consumption in total energy consumption is declining, but coal is still the main source of energy power, accounting for more than 60%. Natural gas consumption rose from 5.4% to 7.8%, as shown in Figure 5, which optimizes the energy consumption structure, provides incentives for economic development, and improves the quality of the atmospheric environment.

(3) Research on the trend of China’s natural gas consumption structure

In 2013-2025, the proportion of industrial gas consumption in total natural gas consumption remained above 80%. Industrial gas continues to rise (slightly declined in 2015), from 119.2 billion cubic meters to 186.3 billion cubic meters in 2013-2025; residential gas consumption has also increased from 29 billion cubic meters to 30.8 billion cubic meters. But, residential gas consumption accounts for total natural gas consumption dropped from 19.6% to 14.2%, indicating that natural gas plays an increasingly important role in industrial production.

3.2.2 Analysis of China’s social and economic development trends

According to the simulation results, after introducing the policy mix of energy structure adjustment and natural gas consumption structure optimization, the three industrial structures were accelerated and optimized. The contribution of the tertiary industry to GDP accounted for 55.8%. The second industry has high internal efficiency and low pollution. The increase in enterprises has promoted the development of social economy.

(1) Research on the growth trend of China’s economic aggregate

During the simulation period, China’s GDP continued to rise, from 57 trillion yuan to 139 trillion yuan, more than doubled. The annual GDP growth rate in 2016 fluctuated, but
it increased steadily in 2017-2025 (7.5%-8.5%). This indicates that the Chinese economy continues to grow steadily in an environment of sluggish international economic environment, in line with the prejudgment of experts and scholars on China's macroeconomy, as shown in Figure 6.

(2) Research on the trend of China's industrial structure

In 2013-2025, China's primary industry dropped 4.1 percentage points from 9.4% to 5.3%, the secondary industry decreased by 6.3 percentage points from 45.1% to 38.8%, and the tertiary industry increased by 10.3 percentage points from 45.5% to 55.8%. In the 13 years simulated in this paper (2013-2025), China accelerated the optimization of three industrial structures and promoted the rapid growth of China's economy, as shown in Figure 7.

3.2.3 Analysis of China's atmospheric environment improvement trend

(1) Trends in total emissions of atmospheric pollutants

China's SO₂ emissions have decreased from 19.54 million tons in 2013 to 12.64 million tons in 2025, a cumulative reduction of 35.3% of emissions, an average annual reduction
of 3.6% of emissions, which is in line with the model's target setting, and is in line with the national environmental protection situation. Among them, China's industrial emissions continued to decline, from 17.48 million tons to 10.58 million tons in 2013-2025, and the emissions as comparative residents remained unchanged (2.06 million tons), as shown in Figure 8.

China's NOx emissions plummeted from 21.92 million tons in 2013 to 12.59 million tons. Compared with changes in emissions, the rate of decline was even greater, with a cumulative reduction of 42.6% of emissions, with an average annual reduction of 4.5% (shown in Figure 9).

(2) Trends in the intensity of atmospheric pollutant emissions

The emission intensity of atmospheric pollutants has dropped sharply from 34.0 tons/100 million yuan in 2013 to 9.1 tons/100 million yuan in 2025, and the emission intensity has decreased by 29.1 tons/100 million yuan. This indicates that China's atmospheric environment has improved significantly, as shown in Figure 10.

4 | CONCLUSION AND SUGGESTIONS

1. Based on the input-output theory and the material-energy-value balance theory, the Chinese natural gas multi-objective optimal allocation model of objective function, natural gas resource supply and demand balance, social economic development, and atmospheric environment constraint module is constructed. The overall target of the model is to maximize GDP, while the simulation goal is to achieve the optimal economic growth of natural gas resource supply security and atmospheric environmental quality improvement.

2. This study uses Lingo software to simulate by introducing the policy combination of natural gas supply safety constraints, energy structure adjustment, natural gas consumption structure optimization, and air pollution emission constraints. The experimental results show that the policy combination set in this paper can realize the optimal and balanced development of natural gas resource supply security, social economic growth, and environmental improvement.

3. Based on 2012, the simulation period is 2013-2025, and Lingo is used to simulate the policy combinations in order to select the optimal scenario. Through the sensitivity analysis, the actual data and simulation data of 2013-2018 are compared. It is found that the relative error between the simulation results and the actual results is less than 3%, indicating that the constructed multiobjective optimization configuration model is reliable and effective. The model can reflect the development status and trends of China's natural gas resource utilization, social economic development, and environmental pollution improvement.

4. The experimental results show that by 2025, China's natural gas production will be 333.4 billion cubic meters, and the consumption will be 217.1 billion cubic
meters. The output will gradually exceed the demand, indicating that the natural gas use efficiency is significantly improved, and China’s natural gas dependence is gradually reduced. The proportion of natural gas consumption in total energy consumption rose from 5.4% to 7.8%, accounting for a significant increase in the proportion, optimizing the energy consumption structure, and providing natural gas for economic development. The total GDP is 139 trillion yuan, with an average annual growth rate of 7.5%. The contribution of the tertiary industry to GDP accounts for 55.8%, indicating that China has accelerated the optimization of its three industrial structures and promoted the stable growth of China’s economy. China’s SO₂ emissions decreased from 19.54 million tons in 2013 to 12.64 million tons in 2025. China’s NOₓ emissions plummeted from 21.92 million tons in 2013 to 12.59 million tons, and the emission intensity of atmospheric pollutants was reduced from 34.0 tons/100 million yuan in 2013 to 9.1 tons/100 million yuan in 2025, indicating that China’s atmospheric environment has improved significantly.

5. Based on the simulation results of different policy combinations in the optimal scenario in the multiobjective optimization allocation model of China’s natural gas resources, this study provides policy recommendations for China’s natural gas resource allocation, industrial structure adjustment, and air pollution reduction. In terms of total supply allocation, natural gas supply has steadily increased from 148.2 billion cubic meters in 2013 to 217.1 billion cubic meters in 2025. In terms of optimizing natural gas resource consumption structure, we recommend to increase natural gas consumption for chemical industry and oil and gas extraction industries, other tertiary industries, other manufacturing industries, and residential sectors from 2013 to 2025, and reduce the consumption of natural gas in the production and supply of electricity and heat, and the nonmetallic mineral manufacturing industry. In terms of the adjustment of industrial structure, we recommend to reduce the output value of high emissions of air pollution, and increase the output value of low-pollution and high-efficiency industries, and focus on the development of other tertiary industries and other manufacturing industries. In terms of air pollution reduction, we recommend to increase the production and supply of gas and water to the chemical industry, oil and gas extraction industry, other manufacturing industries, other extractive industries, and six sectors including agriculture, forestry, animal husbandry, and fisheries to reduce air pollution emissions.

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CONFLICT OF INTEREST

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ORCID

Yangqiu Wang https://orcid.org/0000-0002-8919-1987
Pengtai Li https://orcid.org/0000-0002-4398-3583

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**AUTHOR BIOGRAPHIES**

**Yanqiu Wang** (PhD, Northeast Petroleum University, PRC) is a professor of Business Management at the Northeast Petroleum University. She taught in Northeast Petroleum University in 2003. She received her PhD in Industrial Management from University of Science and Technology Beijing in 2013. She went to the United States in November 2017 as a visiting professor at University of Louisiana at Lafayette. She has published more than 30 academic articles or papers in various journals, and she has been involved in many research projects with governments and attended many different local and international conferences. Her current research interests focus on eco-efficiency, energy consumption, and energy efficiency.

**Zhiwei Zhu** (PhD, University of Louisiana at Lafayette) is a professor of Operations Management at the University of Louisiana at Lafayette. He received his PhD in Industrial Management from Clemson University in 1989. Since then, he has been teaching Operations Management and Business Statistics at ULL. He is active in providing consulting services to local businesses in areas of inventory management, project management, quality insurance, scheduling, and business strategies. He has published more than 50 academic articles on various journals. His current research interests focus on knowledge management, inventory management, and quality insurance.

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