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Policy research and energy structure optimization under the constraint of low carbon emissions of Hebei Province in China

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ABSTRACT

As a major energy consumption province, the issue about the carbon emissions in Hebei Province, China has been concerned by the government. The carbon emissions can be effectively reduced due to a more rational energy consumption structure. Thus, in this paper the constraint of low carbon emissions is considered as a foundation and four energies--coal, petroleum, natural gas and electricity including wind power, nuclear power and hydro-power etc are selected as the main analysis objects of the adjustment of energy structure. This paper takes energy cost minimum and carbon trading cost minimum as the objective functions based on the economic growth, energy saving and emission reduction targets and constructs an optimization model of energy consumption structure. And empirical research about energy consumption structure optimization in 2015 and 2020 is carried out based on the energy consumption data in Hebei Province, China during the period 1995-2013, which indicates that the energy consumption in Hebei dominated by coal cannot be replaced in the next seven years, from 2014 to 2020, when the coal consumption proportion is still up to 85.93%. Finally, the corresponding policy suggestions are put forward, according to the results of the energy structure optimization in Hebei Province.

Keywords: China, Economic growth, Energy structure optimization, Genetic algorithm, Hebei Province, Low carbon constraint

1. Introduction

Energy is the material premise of social harmony and economic development in a country, and a substance that human beings depend on for existence. At present, most of the energies we use are non renewable, such as oil, coal, natural gas, etc. However nowadays the world's energy consumption is growing at a rate of 2% per year, and the main consumption is still the traditional fossil fuels such as coal and oil. While in the course of the use of these fossil energies it will usually be accompanied by a large number of sulfur dioxide, nitrogen oxides, carbon dioxide, soot and other pollutants, resulting in serious environmental pollution. Therefore, the rational use of energy has been widely concerned by the international community, and the research on the energy issue has gradually become much more important. In the present situation, the energy problem is not only a short term problem in a country, but a long-term and international problem. Among the world's major energy consuming countries, the fossil energy consumption ratio in China is the highest, so is the consumption. In 2013, the energy consumption growth fell to 4.7% from 7%, which was far lower than 8.6%, the average in ten years, though the economic growth China reported was still as high as 7.7% [1]. The gross domestic product (GDP) energy intensity of China in 2010 was 1.034 tons of standard coal, energy consumption per unit of GDP, and the data was seven times that of Japan, 3.5 times that of the United States and even 1.7 times that of Indonesia which is a developing country. In accordance with the "12th Five-Year planning", the GDP energy intensity of China in 2013 is about 0.94 tons of standard coal every ten thousand yuan. Although the per capita emissions of the United States are gradually decreasing, 16.18 tons every person in 2013 is still much higher than that of other major emitters. The per capita emissions of European Union (EU) is only 40% of the America's, which is 6.57. While China's per capita emissions are relatively low, it has been rising year by year. And the data exceeded the world average level in 2006 and outnumbered that of the EU in 2013, reaching 6.60 t/person. In addition, the carbon intensity in Europe and America, Japan and other developed countries is much lower than other developing countries and it is in the process of the continuous reduction. The carbon intensity in China and Russia declined rapidly but is still much higher than other major emitters

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and the world's average level. Among the six big carbon emitters, the carbon intensity of China is the highest. Compared to the situation in 1990, the data in 2013 has fallen by more than 55% which is 1.85 kg per dollar at the level in 2005. However this data is still 3.2 times that of the world's average, 8.4 times the EU, 7.2 times the Japan and 5.2 times the America. From the above indicators, China is facing a serious pressure to reduce the carbon emissions. Therefore it is necessary to carry out research on the issue of China's energy in order to conserve energy and reduce emissions better. The coal dominated energy structure in China not only caused serious influence upon the ecological environment but also the main reason of the low energy utilization efficiency and poor economic benefits. This unreasonable energy structure has inhibited the development of low carbon economy, which is a sustainable economic development pattern with characteristics of low consumptions, low emissions and low pollutions. The fact is to utilize the technology progress and institution innovation to change the way of energy use, improve energy efficiency and optimize the energy structure.

At present, carbon emissions are getting more and more international attention and many scholars all over the world have analyzed the various influence factors through a series of decomposition models [2-3], including IPAT [4-7] and STAIRPAT model [8-9]. It is believed that the main cause of the carbon emissions growth is the energy consumption rather than economic growth [10-11] and there is a serious structural pollution problem in China's energy development. Xu et al. [12] established the factor decomposition model of the carbon emissions per capita in China with the LMDI model and analyzed the impact of some factors upon the carbon emissions per capita quantitatively, including the energy structure, energy efficiency, economic development and so on. The results showed that the contribution rate of the economic development to China's per capita carbon emissions is growing exponentially. Song et al. [13] construct logarithmic mean weight Divisia index (LMDI), mean-rate-of-change index (MRCI), and Shapley value decomposition models to decompose carbon emissions in Shandong Province, and the result shows that energy consumption structure has certain impact on carbon. Zhang [14] confirmed the impact of energy structure to carbon emissions by calculating the carbon dioxide emissions and the elastic coefficients. Therefore, the key to develop low carbon economy is to adjust the energy consumption structure and reduce the proportion of coal.

The adjustment of energy structure is not only under the constraints of the economic system, including population, economy, industrial structure, energy efficiency, total energy, etc., but also of the energy-saving and carbon emissions under the background of low carbon economy development. Lin et al. [15] constructed the strategic adjustment model of energy structure and considered that optimal energy structure should include energy-saving and carbon emissions constraints and the resulted economic cost to the macroeconomic system. The reasonable and scientific adjustment and optimization to the energy structure is helpful to provide the guidance to realize the goals of energy strategy and energy security in China.

Musgrove [16] analyzed the structure of the Australian energy system to minimize costs during 1980-2020 using the MARKAL model. Xudong et al. [17] demonstrated the necessity and potential of energy structure optimization and proposed countermeasures to adjust China's energy structure from the perspective of low carbon combined with the actual situation of China's development, which could provide energy security for the good operation of the national economy and promote China move to a low-carbon society. Su et al. [18] introduced the life-cycle theory into the urban energy structure optimization model and established a multi-objective planning model through the calculation of the influence factors of various pollutants to the environment. The result indicated that the environmental impact introduced into the optimization model of energy structure is useful to do a reasonable and effective configuration of urban energy and balance the development between environment and energy economic. Gao et al. [19] applied the portfolio theory to China's energy structure optimization model and attempted to use the learning curve to consider the characteristics of renewable energy cost and the fossil energy cost increased with the passage of time, which was utilized to optimize China's overall energy system. And the result showed portfolio theory can effectively solve China's energy structure optimization problem. Liu et al. [20] established a mathematical model of dynamic energy system based on superior control theories, and analyzed the superior strategy for the replacement of renewable energy on fossil energy.

As a large province of energy consumption in China, the environmental problems in Hebei Province have been paid great attention by the government, among which the haze problem is the first to bear the brunt. The main formation reason of the haze pollution in Hebei Province is carbon dioxide, sulfur dioxide and other polluting gases emitted by coal combustion thus excessive dependence on the energy supply of coal has a huge influence to the haze pollution. Optimization of energy consumption structure is the necessary means to control the serious pollution of the haze, and the rational energy consumption structure can achieve energy saving and emission reduction at the greatest degree.

Currently the domestic and foreign scholars mainly estimate the impact of the changes of the energy structure upon the macroeconomic system and environment but rarely study the contribution of energy structure adjustment to the realization of the low carbon economy and whether the emission reduction target could be completed under the premise of the economic growth. Therefore we use the mathematics planning method to construct an energy consumption structure optimization model. The objective functions of the model are minimizing the energy investment cost and carbon trading cost. Furthermore the economic growth and the carbon intensity are considered as the constraints. Then the energy consumption structure in Hebei Province is simulated and optimized, which could province guidance for the government to the energy development planning and the emission reduction commitments.

2. Analysis of Energy Consumption Structure in Hebei Province

2.1. Energy Profile and Related Policies in Hebei Province

Over the years, the coal consumption in Hebei Province has been ranked at the top and the carbon dioxide emissions are high as well. The total energy consumption in 2013 was 311.7036 million tons of standard coal and 88.67% was the coal consumption, which accounted for a large proportion while the proportion of oil, natural gas and primary power occupied was 7.36%, 2.19% and 1.78% respectively, indicating an unsustainable energy structure. In the same year the carbon dioxide emissions was 223.0251 million tons which accounted for about 8.5312% of the total national carbon dioxide emissions. All of these phenomena have been paid close attention by the government of Hebei Province which hopes to reduce carbon dioxide emissions through the adjustment of energy consumption structure.

In order to optimize the energy structure and ease the bottleneck effect of energy to economic development, "Twelfth Five Year development plan in new energy industry" [21] was formulated by the government of Hebei Province in 2010, and the document puts forward that 1) by the year 2015, the proportion of new energy (excluding hydro-power) in the primary energy consumption should reach 5%, 2.6% more than that in 2010; 2) 12 million tons of standard coal should be saved and more than 0.3 million tons carbon dioxide emissions be reduced every year; 3) the proportion of the new installed energy power generation equipment among all the power installed capacity should reach 15%, increased by 7.5% in 2010; 4) ten green energy demonstration counties and 100 green energy demonstration townships should be built; 5) six or more new energy equipment manufacturing enterprises whose annual sales revenue is over 10 billion yuan should be established etc.

2.2. Energy Consumption Structure of Hebei Province

Since 1995, the energy consumption in Hebei Province has been growing rapidly along with the rapid economic development, which increased to 302.5021 million tons of standard coal in 2010 from 88.9241 million tons of standard coal in 1995. And the proportion of coal in total energy consumption has been always more than 85% while oil has remained at about 8%. In addition, the proportion of natural gas from 1995 to 2008 had been below 1% but exceeded 1% from 2009 to 2013 and showed an upward trend; while that of the renewable energy has been in a state of low level, more than 1% in the year 2011 and 2013 [22].

The main energy resources consumed in Hebei Province contain coal, petroleum, natural gas, primary power and other resources, among which the first four account for almost the total energy consumption. Therefore, this paper selects these four energies as the main analysis object of the energy structure adjustment. The main energy consumption of the four types of energy during the period 1995-2013 is shown in Fig.1, from which it can be seen that coal has been the main part of energy consumption and the consumption of natural gas and primary power are rising year by year.

2.3. Carbon Dioxide Emissions in Hebei Province

With the rapid growth of economy in Hebei Province, the energy consumption is increasing, so are the carbon dioxide emissions. The carbon dioxide emissions of China and Hebei from 1995 to 2013 are listed in Table 1, and it is shown that emissions of China rise to 2,614.2392 million tons in 2013 from 875.8393 million tons in 1995 and Hebei, from 64.8454 to 223.0251 million tons. It is calculated that the proportion of the carbon dioxide emissions which Hebei province has among China is always around 7% and proportion is on the rise and occupies a large share [22].

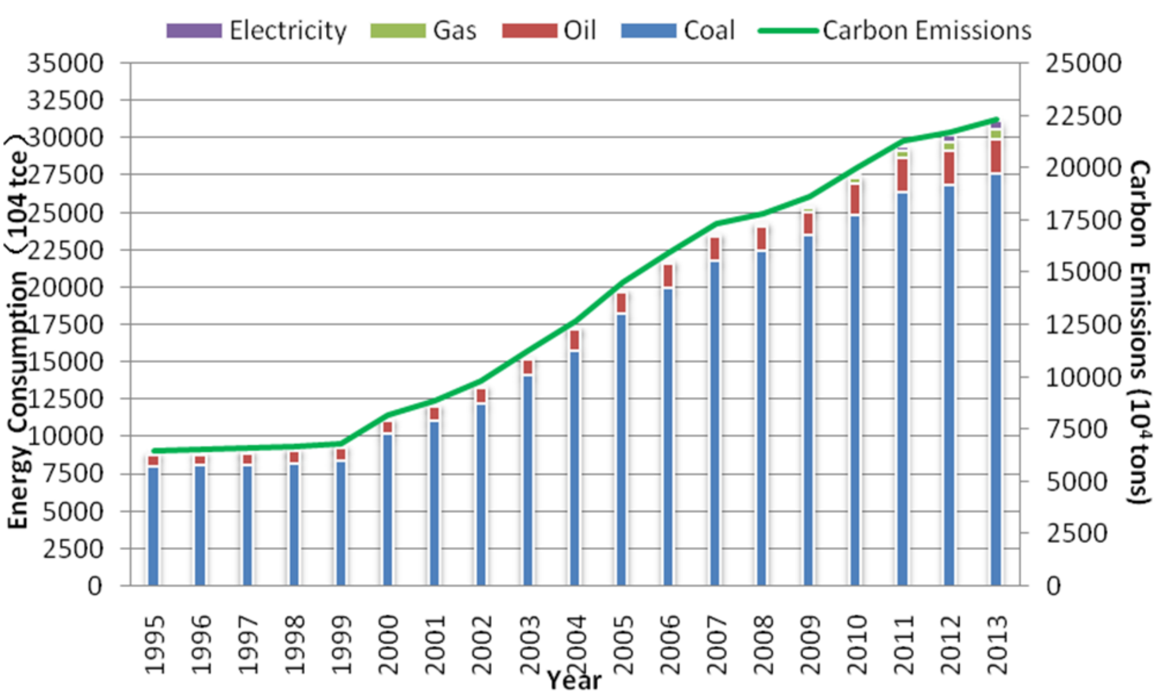

Fig. 1. Energy consumption structure and carbon emissions in Heibei Province.

Table 1. Carbon Dioxide Emissions of Hebei Province and China (million tons)

Year	Hebei	China	Proportion	Year	Hebei	China	Proportion
1995	64.8454	875.8393	7.4061	2005	145.3081	1,713.6523	8.4632
1996	65.1971	900.9906	7.2362	2006	159.5766	1,877.0088	8.5016
1997	65.9057	897.8972	7.3400	2007	173.0009	2,038.0484	8.4886
1998	66.684	897.7982	7.4275	2008	178.3084	2,074.1627	8.5966
1999	68.3976	930.5353	7.3503	2009	186.3564	2,172.6623	8.5773
2000	81.8611	955.3821	8.5684	2010	199.7439	2,295.4755	8.7016
2001	88.7883	999.4915	8.8833	2011	212.9655	2,489.1765	8.5557
2002	98.0932	1,093.2540	8.9726	2012	216.9941	2,543.4022	8.5316
2003	112.3408	1,285.2935	8.7405	2013	223.0251	2,614.2392	8.5312
2004	126.8726	1,499.1130	8.4632				

3. Establishment of a Multi-object Model of Energy Structure Optimization

This paper selects the energy consumption data of Hebei Province from 1995 to 2013 as the basis data and optimizes the energy structure in 2015 and 2020, balancing the energy development in Hebei Province from many aspects. In this paper, the minimum cost of energy consumption and carbon dioxide emissions trading are chosen as objective functions and economic growth, carbon dioxide emissions of per unit GDP, energy supply and non-negativity restriction as constraint conditions, then the multi-objective model of energy structure optimization is constructed.

3.1. The Hypothesis of the Model

In the foundation of the model of China's energy structure optimization model, we need to make some assumptions about the conditions, specifically as follows:

(1) The target of the model is the coordinated development of energy, economy and environment, and the main way to achieve this goal is to optimize the structure of energy consumption.

(2) It is assumed that the China's economy in the future is in a state of growth and along with the growth of energy consumption while the influence of technical innovation, economic adjustment and management level improvement on energy consumption is ignored.

(3) It is assumed that the source and variety of the energy is unchanged and the carbon emission coefficient of the each energy is constant subject to technological progress.

(4) The fundamental factor which promotes the adjustment to energy structure is the minimization of the cost, that is to say, the minimum cost of energy consumption and carbon dioxide emissions trading.

(5) Only the amount of CO_2 emissions produced from fossil fuel burning is considered.

3.2. Objective Function

The decision variables involved in the objective function are the consumption quantity of four kinds of energy: coal (X_1), oil (X_2), natural gas (X_3), primary power including hydro-power, nuclear power, wind power and others (X_4).

(1) The cost of energy consumption

$$\min f_A = \sum_{i=1}^{4} I_i X_i \quad (1)$$

where f_A represents the cost of energy consumption and I_i represents the investment cost per unit of each energy whose measurement unit is yuan / 104 tons of standard coal.

(2) The cost of carbon dioxide emissions trading

$$\min f_B = \sum_{i=1}^{4} P \lambda_i X_i \quad (2)$$

where f_B represents the cost of carbon dioxide emissions trading, P represents trading price whose measurement unit is yuan / 104 tons of standard coal and λ_i represents the carbon emission coefficient.

3.3. Constraint Conditions

(1) Economic growth constraint

The energy structure adjustment in China must be carried out under the premise of not affecting the social economic development goals and GDP growth must satisfy the anticipated target set by the country during the study period which is $G_t \geq G$. The transcendental logarithmic production function is used to reflect the demand of economic growth to energy consumption. This function is an elastic production function model and belongs to the quadratic response surface model in structure with characteristics of easy estimation and strong tolerance, which provides support point to analyze the interaction impacts among various input elements and differences of various input of technology progress effectively. Berndt and Wood [23] applied transcendental logarithmic production function to analyze the relationship between energy and non-energy. Although affected by the spatial and temporal factors, scholars differed in different periods in different parts of the conclusions, the researchers were confirmed the feasibility of this function when studied on the aspect of energy substitution, and the expression is as follows:

$$GDP = kF^{\alpha_1} P^{\alpha_2} C'^{\alpha_3} r^{\alpha_4} \quad (3)$$

where $F=f(x_1)$, $P=f(x_2)$, $C=f(x_3)$ and $R=f(x_4)$; $f(x_i)$ is a function of GDP on the independent variable; x_1 is the consumption of coal; x_2 is the consumption of oil; x_3 is the consumption of natural gas; and x_4 is the consumption of primary power.

(2) Carbon dioxide emissions of per unit GDP constraint

$$\frac{\sum_{i=1}^{r} \eta_i X_i}{GDP} \leq m \quad (4)$$

where η_i is the coefficient of carbon dioxide emissions; m is the controlled carbon dioxide emissions of GDP, which can be obtained according to the policy.

(3) Energy demand constraint

As China's energy reserves are limited, the consumption of the various energy is under constraint of the supply of energy.

$$e_t \leq X_i \leq E_i \quad i=1,\ 2,\ 3,\ 4 \quad (5)$$

where e_i and E_i are the lower and upper bound of each energy supply respectively, which can be predicted by historical data.

(4) Non-negativity restriction constraint

$$x_i \geq 0 \quad i=1,\ 2,\ 3,\ 4 \quad (6)$$

where X_i is the consumption of different energy.

3.4. Parameter Design and Data Processing

3.4.1. Investment cost per unit of energy

When the energy consumption cost of Hebei Province is forecast in the future, investment cost per unit of energy rather than energy price is selected and energy import is not taken into account. Then the investment cost per unit of various energy during the period 2015-2020 is shown in Table 2 according to the predicted result of "China Energy Research Report - Regional."

Table 2. The Investment Cost per Unit of Energy (yuan)

	2015	2020
coal	871.8	1,030
oil	4,226	7,890
natural gas	4,226	7,890
primary power	115,000,000	136,000,000

3.4.2. Carbon trading price

Carbon trading is a market mechanism to promote global greenhouse gas emissions reduction, especially the global carbon dioxide emissions, the basic principle of which is a party of a contract can get the amount of greenhouse gas reduction through the payment to the other party and the buyer could achieve the emission reduction targets using the purchased credits for slowing the greenhouse effect. In October 2011, "Notice of the pilot work on carbon emissions trading" [24] was issued by the national development and Reform Commission of China and seven provinces and cities including Beijing, Shanghai, Tianjin, Chongqing, Hubei, Guangdong and Shenzhen were approved to conduct carbon emissions trading pilot work. Taken Beijing and Tianjin and Hebei District into account, this paper chooses the carbon trading price of Beijing as a basis to calculate the cost of carbon trading in Hebei Province.

Due to the trend of the Beijing-Tianjin-Hebei regional integration, the carbon trading price in Beijing is selected as the benchmark of the one in Hebei Province in this paper. Fig.2 is the carbon trading price curve from November 28, 2013 to June 16, 2015 released by the carbon trading center in Beijing. It can be seen from the curve trend that the price of carbon trading is basically about at 50 yuan/t except a sudden change during the period June to August in 2014 when the price rose to 76.83 yuan/t due to the fact that carbon emissions trading pilot areas have entered the first performance period, leading to a rise in carbon trading price. Therefore the carbon trading prices at the beginning of each month are selected as the sample data in this paper to predict the price in future and carbon trading price at the beginning of 12 mon individually per year is averaged as the price of that year in order to calculate the carbon trading cost.

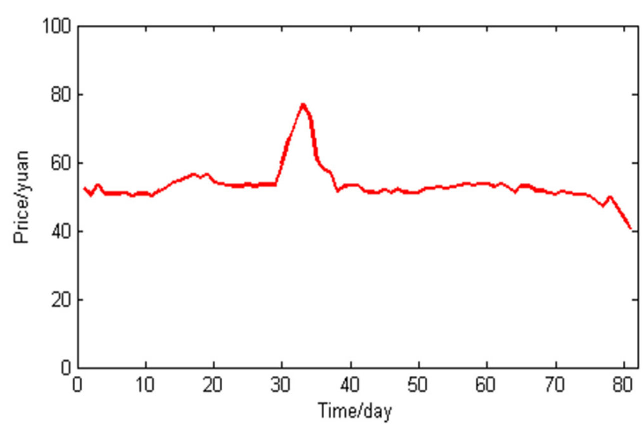

Fig. 2. Carbon trading price curve.

3.4.3. Coefficient determination of transcendental logarithmic production function

In this paper, the data of GDP, coal consumption, oil consumption, natural gas consumption and primary power consumption from 1995 to 2013 in Hebei province are obtained from the "Hebei Province Statistical Yearbook 2014" [22]. In order to establish the production function models between GDP and the above main factors, the data from 1995 to 2012 are taken as the fitting data in this paper and the data in 2013 as the test data to prove the validity of the models. The process is conducted with the SPSS statistics software and the specific results are as follows:

The fitting equation between GDP and coal consumption is

$$F = -9773.229 + 4.714\times10^{-9}X_1^3 - 1.82\times10^{-4}X_1^2 + 2.827X_1 \quad (7)$$

The fitting equation between GDP and oil consumption is

$$P = 933.093 - 6.287\times10^{-7}X_2^3 + 0.007X_2^2 - 1.04X_2 \quad (8)$$

The fitting Eq. between GDP and natural gas consumption is

$$C = -8.163.045 + 3.47\times10^{-4}X_3^3 - 0.413X_3^2 + 182.916X_3 \quad (9)$$

The fitting Eq. between GDP and primary power consumption is

$$R = -4202.804 + 4823.338\ln X_4 \quad (10)$$

And in order to observe the fitting conditions visually and intuitively, the four fitting curves are drawn, shown in Fig. 3.

In order to verify the correctness of the built models, F-test and Significance test are carried out and the results are shown in Table 3.

Under the significance level of 0.05, the F test of these equations is passed and all the significance levels are less than 0.05 which indicates that the four equations are significant. Thus, X_1, X_2, X_3, X_4 is taken into the corresponding fitting equation respectively to get the estimated values of F, P, C and R and the following equation can be obtained through taking the logarithm of the logarithmic production function.

$$\ln GDP = \ln k + \alpha_1 \ln F + \alpha_2 \ln P + \alpha_3 \ln C + \alpha_4 \ln R \quad (11)$$

Using the SPSS software to establish a multiple linear regression equation, the following expression is obtained.

$$\ln GDP = -0.007 + 0.863\ln F + 0.181\ln P - 0.026\ln P - 0.019\ln R \quad (12)$$

And the specific test results are shown in Table 4.

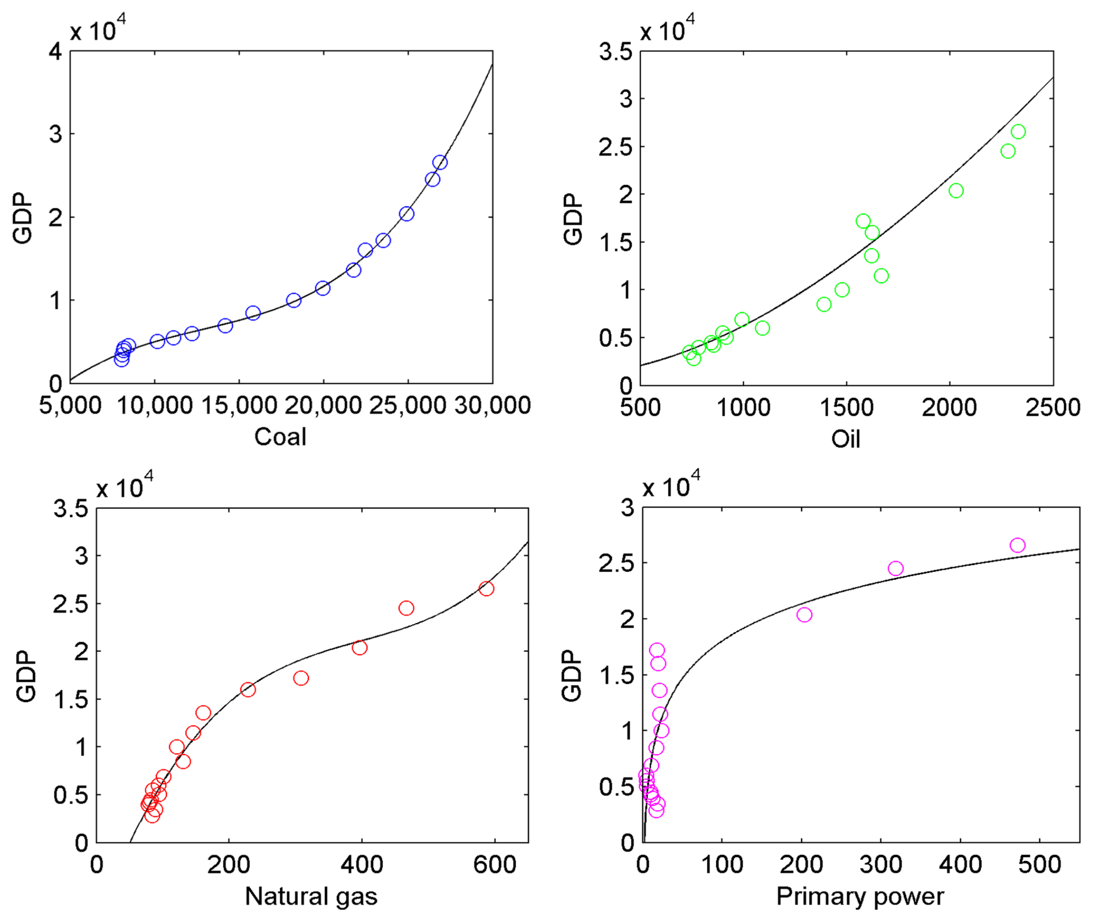

Fig. 3. Four fitting curves.

Table 3. Model Validations

Function	F	C	P	R
F statistics	1639.960	103.922	206.398	47.549
Sig.(0.05)	0	0	0	0.000004

Table 4. Model Validation

Test index	R^2	F statistics	Sig.
Value	0.989	284.294	0

It can be shown that $R^2 = 0.989$, implying the fitting effect is good and the significance level is less than 0.05 at the significance level of 0.05, which shows that the equation is significant. In summary, the regression model of the logarithmic production function is feasible and the expression of GDP on F, P, C, R is as follows.

$$GDP = 0.993F^{0.863}\ P0.181\ C^{-\ C0.026}\ R^{-\ 0.019} \tag{13}$$

The data of the various energy consumptions in 2013 are substituted into the Eq. (13) and the forecast value of GDP can be obtained, which is 2,808.976 billion yuan. While the actual value is 2,830.141 billion yuan and the absolute error is 0.007478, showing a high accuracy. According to the guiding ideology and overall deployment in “government work report” of Hebei Province in 2013 and the goal of “Twelfth Five Year Plan” [21], the economic growth from 2013 to 2020 are divided into two stages for the purpose to improve the reliability and accuracy of forecasting. Consequently, the economic growth rate from 2013 to 2015 is set 8.5% and 7% from 2016 to 2020 and the forecast planning values of GDP of Hebei Province in 2015 and 2020 are listed in Table 5.

Table 5. Planning Values of GDP in Hebei Province

Year	2013	2015	2020
GDP(108 yuan)	28,301.41	33,317.13	46,728.99

3.4.4. Carbon dioxide emissions of per unit GDP constraint

The carbon dioxide emissions of per unit GDP refers to the amount of carbon dioxide emissions emitted to produce ten thousand yuan GDP and this indicator can reflect China's actual economic development and greenhouse gas emission level more scientifically with the combination of gross national income that reflects the true level of the national economic development and national welfare. The lower the value is, the lower the carbon dioxide is produced when one unit of GDP is produced in a certain country. Thus the index could represent the country's energy saving level well and that’s why many countries and international organizations use the carbon intensity to measure the level of the energy saving and emission reduction in a region.

Table 6. Planning Values of Carbon Dioxide Emissions of per Unit GDP in Hebei Province

Year	2015	2020
Planning values (10^4 t / 10^8 yuan)	2.911588	2.66326

In the reference to the "Twelfth Five Year Plan of energy saving and emission reduction in Hebei province" [25] released in March 2012 and “2009 report on China's sustainable development strategy” [26], by 2015, the carbon dioxide emissions of per unit GDP should decline by 19% compared with that in 2010 while by 2020 even decline by 50% compared with that in 2005. Therefore, the planning values of carbon dioxide emissions of per unit GDP are shown in Table 6.

3.4.5. Energy demand constraint

The upper limit and lower limit data of various energy demand in 2015 and 2020 is predicted according to the energy report of Hebei provincial government and the original total demand data of coal, oil, natural gas and primary power during the period 1995-2013 from statistical yearbook of Hebei Province, as shown in Table 7.

Table 7. Energy Consumption Demand (million tons/standard coal)

Year	Coal		Oil		Natural gas		Primary power	
	Lower Limit	Upper Limit	Lower Limit	Upper Limit	Lower Limit	Upper Limit	Lower Limit	Upper Limit
2015	268.61	289.31	25.675	27.633	5.9624	6.8667	6.834	8.301
2020	300.77	336.21	29.864	32.318	6.969	8.7106	13.528	15.36

4. Energy Structure Optimization and Result Analysis in Hebei Province

4.1. The Establishment of the Multi-objective Optimization Model

In order to eliminate the big coefficient difference of the objective function, the normalization method is used in this paper to normalize the coefficient of each objective function and the normalized formula is shown below:

$$\lambda_j = \alpha_j \sum_{i=1}^{4} \alpha_i \quad j = 1,\ 2,\ 3,\ 4 \tag{14}$$

where λ_j represents the value after the normalization and α_i represents original value of the coefficient.

4.2. Genetic Algorithm for Multi-Objective Optimization Problem

Genetic algorithm (GA) is a highly parallel, random and adaptive search algorithm designed by professor John H. Holland [27, 28] from American Michigan Ann University which draws lessons from natural selection, genetic variation and evolutionary mechanism in biological world with characteristics of the simplicity, strong robustness and fit for parallel processing so that this algorithm can be used to solve a variety of complex optimization problems. The basic operation of GA can be divided into three parts: the selection operation, crossover operation and mutation operation. In this paper, the tool “gamultiobj” accompanied with Matlab2014b is used to solve the multi-objective optimization problem and the Pareto solutions of the multi-objective optimization

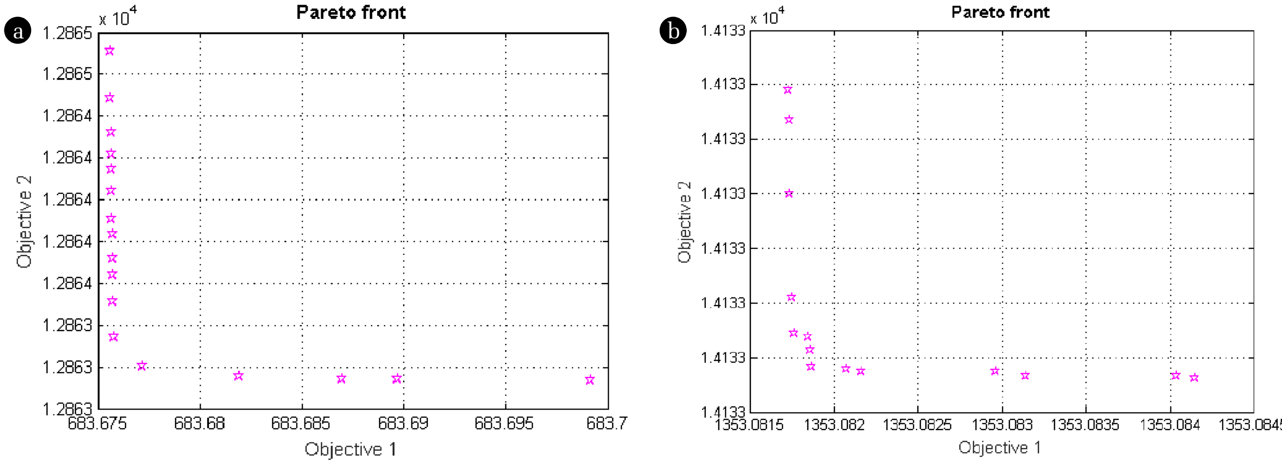

Fig. 4. Pareto optimal solution of the multi-objective optimization. (a) is the energy structure optimization results of 2015, and (b) is the results of 2020.

Table 8. The Energy Structure Optimization Results

Year	Total energy (million tons)	Proportion of coal	Proportion of oil	Proportion of natural gas	Proportion of primary power
2015	327.2403	87.69%	8.35%	1.84%	2.12%
2020	370.6453	85.93%	8.49%	1.93%	3.65%

are obtained after the inputs of objective function and constraint conditions. The optimization results are shown in Fig. 4.

4.3. Result Analysis on the Energy Structure Optimization in Hebei Province

According to the energy structure optimization model in this paper, the energy structure optimization results of Hebei Province in 2015 and 2020 are obtained, as shown in Table 8.

(1) The energy consumption of Hebei province in 2013 is 311.7036 million tons of standard coal including coal, oil, natural gas and primary power the proportion of which are 88.67%, 7.36%, 2.19% and 1.78% respectively and the GDP is 2,830.141 billion yuan and the carbon emission intensity 0.788 tons of ten thousand yuan. While under the goal of low carbon the energy consumption in 2015 is 327.2403 million tons/standard coal and the proportion of the four energies is 87.69% and 8.35%, 1.84% and 2.12%. Then the carbon emission intensity is 0.6992 tons/10^4 yuan, 11.27% lower than that in 2013. By 2020, 370.6453 million tons of standard coal will be consumed, specifically speaking 85.93% coal, 8.49% oil, 1.93% natural gas and 3.65% primary power. And the carbon emission intensity will be 0.5446 tons/10^4 yuan, declined by 22.1% compared that in 2015.

(2) In terms of the optimization process, the guiding ideology to optimize the energy structure at the cost of cutting down the GDP proposed by the government fully plays a role during the period 2010-2020 because the downward trend of the carbon emission intensity is significant, as shown in Fig. 5. Because Hebei Province has been always a province with the major energy consumption of coal in recent years, the energy consumption structure with coal as the main body cannot still be quickly changed even with the slower growth rate of GDP. The proportion of coal accounted for the total energy consumption dropped to 87.69% in 2015 from 88.67% in 2013 under the constraint of low carbon target while by 2020 the proportion reaches 85.93%, which is a smaller decline.

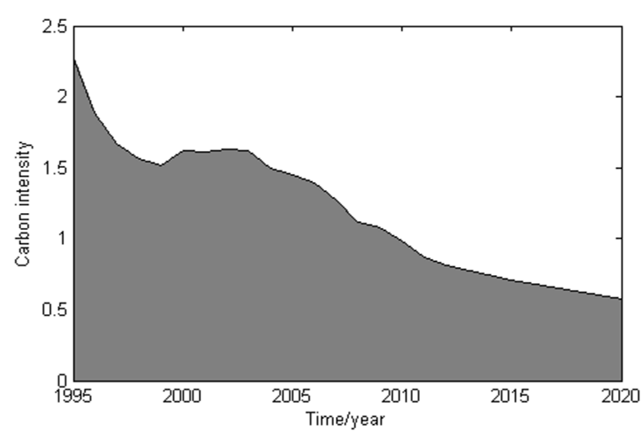

Fig. 5. Carbon emission intensity curve.

(3) Due to the slowdown in GDP growth, the growth rate of energy consumption in Hebei Province also drops a lot, as shown in Fig. 6. The energy consumption growth speed has slowed a lot since 2010 compared to that in 2000-2010. Although coal still occupies the dominant position of the energy consumption, the proportion of clean energy is increasing year by year from 1.78% in 2013 to 2.12% in 2015 and by 2020 the proportion will reach up to 3.65%. Most of this is that the government is also aware of the beneficial effects of clean energy to the environment.

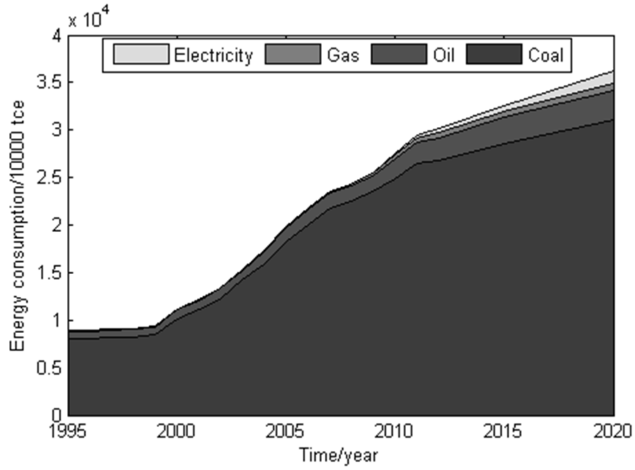

Fig. 6. Composition graph of energy consumption.

In addition, the development of clean energy is limited and the growth rate is slow because of the fact that the large investment cost and a long investment recovery period of clean energy (for example the wind power, hydro-power, nuclear power, etc.) result in a long loss state of enterprises and most clean energy companies rely on the government policy support. The growth rate of oil consumption is relatively flat as well, the proportion of which increases to 8.35% in 2015 and 8.49% by 2020 from 7.36% in 2013, affected by the constraints of resource reserves and exploration and development in China and the international petroleum security guarantee.

(4) As shown in Fig. 7, the amount of carbon dioxide emissions in the period 2013-2020 tends to be gentle compared with that during 2000-2013. The energy structure in Hebei Province is improved and tends to rationalize under the constraint of low carbon target which transits from the current structure dominated by coal to a diversified energy structure using renewable energy including hydro-power, nuclear power, wind power and others as an important alternative energy. Therefore, the work of this paper provides scientific theoretical basis for the energy planning problem and environmental protection issue in Hebei Province.

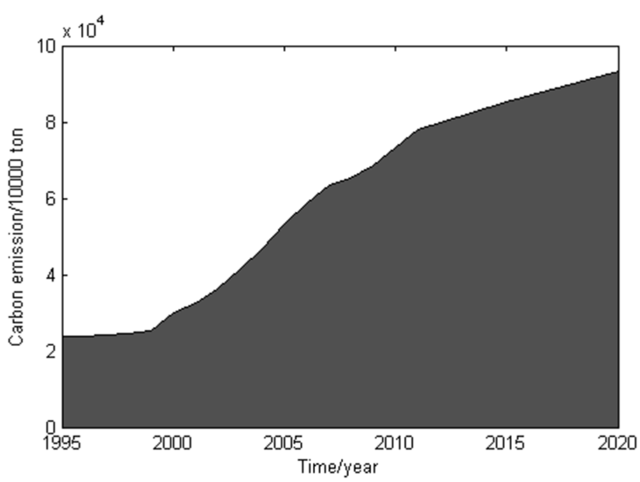

Fig. 7. Area chart of carbon dioxide emission.

5. Conclusions

The multi objective optimization model under the low carbon target is constructed in this paper with the objective function of minimum energy investment cost and carbon trading cost, taking the economic growth of GDP, carbon dioxide emissions of per unit GDP, energy supply constraints into account. Then transcendental logarithmic production function is used to establish the nonlinear function of GDP on coal consumption, oil consumption, natural gas consumption and primary power consumption, respectively, carrying out the energy structure optimization of Hebei Province in 2015 and 2020. The optimization results show that the coal dominated energy consumption structure of Hebei Province is difficult to change in a short period of time although there is a growing trend of clean energy, but the growth speed is slow. The reason of the growth is mainly because of the government policy while the slow speed is also highly correlated with the characteristics of clean energy industry itself.

Optimizing the energy structure is an important guarantee for the realization of energy saving, consumption reduction and energy conservation and sustainable development of economy. Strengthening the development and utilization to wind, solar, biomass, geothermal and other renewable energy, increasing natural gas in intensity and accelerating the technology import and research of nuclear are all benefit to reduce the direct use of coal and realize the diversification of energy structure, which are the long-term measures to deal with the increasingly serious energy and environmental issues and the inevitable course for the sustainable development of Hebei Province. Therefore, the following suggestions are put forward according to the characteristics of the energy consumption structure in Hebei Province:

(1) In the premise that the coal dominated energy consumption structure of Hebei Province cannot be changed in a short time, the government should vigorously promote energy-saving technologies to improve energy utilization efficiency such as carbon capture and storage technology, and the coal pyrolysis technology etc. Besides, more investments in energy saving and continuous optimization and updating to energy-saving equipment are encouraged. Most of the coal consumption in Hebei Province is from the power generation of the thermal power plant and coal burned by residents. The coal-fired power plants should be encouraged to adopt advanced coal processing equipment and scientific coal processing technology to reduce the pollution gas produced by coal combustion and be rewarded for doing these things. For residents, the government needs to vigorously promote clean energy such as natural gas and electricity consumption.

(2) The adjustment and optimization to the industrial structure in Hebei Province needs to reduce or restrict the development of high energy consumption industry and vigorously promote low energy consumption industry development simultaneously, so as to achieve the sustainable development of energy, economic and environment. Hebei Province is a province with prominent heavy chemical industry and consumes huge energy. Besides, the contribution rate of the second industry reached 52% among the total economic output, far higher than the national level. Therefore, the government needs to develop a series of energy-saving emission

reduction policies through the use of administrative, economic, science and technology and other comprehensive measures to increase efforts to eliminate backward high energy consumption and high pollution industry including the iron and steel, cement, coke, thermal power and paper industry. And the government also needs to vigorously promote the energy-saving and emission reduction, strive to optimize the industrial structure, strengthen the management of government at all levels to avoid the neglect of the adjustment and optimization to energy structure caused by the blind pursuit of GDP growth.

(3) The clean energy should be vigorously promoted to develop. Because the investment of clean energy (such as electricity, water, electricity, nuclear power, etc.) is huge and the investment recovery period is long, making the enterprises remain the loss state in a long term, which limits the development of clean energy. Therefore, the government of Hebei Province should strengthen management to clean energy companies and develop a series of effective policies. For example, appropriate subsidy system and the implementation of low interest rate to the financing of clean energy constructions is benefit to promote the healthy development of clean energy.

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