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Optimization Research of Energy Structure in Hebei Province

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Abstract

In the case of excessive energy consumption and energy consumption structure is irrational in Hebei Province, energy structure optimization has become increasingly important. This paper establishes a multi-objective decision model of energy structure optimization through regression analysis by collecting large amounts of data of energy consumption and energy-related investments and pollution control over the years, through a comprehensive and systematic analysis of the model, then using genetic algorithms to solve the model, the result verifies the validity of the method. Finally, the paper analyzes the result and clarifies the future direction of development of the energy structure in Hebei Province.

***Keywords**: Hebei province, energy structure, multi-objective optimization, regression analysis, genetic algorithm*

1. Introduction

With the rapid consumption of energy, the environmental problems are paid more and more attention. Therefore, how to ensure stable economic development under the premise of reducing carbon dioxide, nitrogen dioxide and other polluting gases has become the world's focus of research and study. To optimize the energy structure has important theoretical and practical significance to conserve the energy. This paper is example on Hebei Province whose energy structure is irrational, which is through regression analysis to establish energy structure optimization model, then use genetic algorithm to solve and analyze, proving the genetic algorithm is effective to solve the multi-objective optimization problem.

The idea of Multi-objective optimization was germinated in 1776 on the utility theory in economics research. In 1896, economist V. Pa-reto first proposed a multi-objective programming problem in the study of the economic balance which introduced the concept of the so-called Pareto optimal solution [1, 2]. In addition, in 1927, the research with regard to ordered space theory by mathematician F. Hausdorff provides a theoretical tool to the development of multi-objective planning [3, 4]. In 1947, J.Von Neuman and O. Morgenstern mentioned the multi-objective decision problem in the writings of game theory which raises the attention to the multi-objective optimization of people.

Energy structure optimization is also a multi-objective optimization, the optimization of energy structure for the sustainable development of the energy sector as well as social stability has important practical significance. Optimization of energy structure has been studied by many scholars, therefore, there are many methods, the focus of research questions and the data structure is different, the method selected is different.

Gao, X. C and Wu, Y. P [5] first established energy structure Logistic model, using statistical test estimation, economic growth coefficients and the amount of maximum gap of coal demand in the model is predicted, taking into account the impact on coal consumption caused by changes in the consumption of oil and gas, it made quantitative analysis for the development trend of the energy structure in the next 20 years, and proposed renewable energy role in improving the energy structure;Xu,X.C and Luo, Q.W [6] considered: using a single prediction model often only reflected the local information in energy systems, the solution to this problem was to conduct more energy forecasting model organic combination, so it can more comprehensive describe the actual operation of the energy system, the predicted result was

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more reliable; Ren, Y [7] considered in the use of fuzzy genetic algorithm to optimize the energy structure, the feasible direction and the idea of membership function mutation were introduced in the genetic algorithm, this can guide individual towards optimal solution regional along the feasible direction, Thereby rapidly approaching the optimal solution set, and examples proved that the effectiveness and feasibility of the model and algorithms for structure prediction of energy.

2. Multi-objective Optimization Model

This paper takes the environment, capital and other limiting factors into the traditional energy related analysis when establishing the multi-objective decision model of energy structure optimization, and takes economic and environmental objectives as the goal of the theoretical model to achieve efficient allocation of resources, thereby reducing pollution emissions.

The objective function uses the consumption of a variety of energy for the decision variables, different units are converted into standard coal, the model takes the minimum investment in energy, the minimum cost of environmental pollution control as the objective function. That:

$$\min f(x) = [f_1(x), f_2(x)] \quad (1)$$
$$f_1(x) = a_1x_1 + a_2x_2 + a_3x_3 + a_4x_4$$
$$f_2(x) = b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4$$

Where: x_1 represents coal consumption, x_2 represents oil consumption, x_3 represents natural gas consumption, x_4 represents renewable energy consumption; a_i (i=1,2,3,4) represents four kinds energy investment costs, b_i (i=1,2,3,4) represents four kinds energy pollution control costs.

Model design is mainly based on the following assumptions:

(1) Taking the coordinated development between energy and economic, environmental as the goal.
(2) The adjustment of energy structure is in the fundamental drivers of investment costs minimized and pollution control costs minimized;
(3) Environmental pollution is mainly to consider SO2 and soot emissions;
(4) It is assumed that energy consumption is growing with economic growth, and ignoring changes in energy efficiency, the impact of economic structural adjustment, the improvement of the management level.

3. The Genetic Algorithm for Solving the Multi-objective Optimization

3.1. Multi-objective Optimization and Genetic Algorithm

Due to genetic algorithm is evolutionary computing operations for the whole group, it focuses on a set of individuals, however ,Pareto optimal solution is also a set in generally, thus it can be expected that the genetic algorithm is an effective means for solving Pareto optimal solution set of multi-objective optimization problems [8-10].

The basic structure of the genetic algorithm for solving multi-objective optimization problem is similar to the basic structure of the genetic algorithm for solving single-objective optimization problem. On the other hand, when using genetic algorithms for solving multi-objective optimization problem, it is necessary to consider how to evaluate the Pareto optimal solution, how to design selection operator, crossover operator, mutation operator suitable for multi-objective optimization problem, so the algorithm also has its unique place in the realization [11].

In the implementation of the algorithm, we can do individual selection operator based on the optimization relationship between the various sub-objective function, can do independent operation for each sub-objective function [12]; we also can use niche technology and can also constitute a hybrid genetic algorithm which combining the original multi-objective optimization problem solving methods and genetic algorithm.

There are two methods which are the right weight coefficient variation method and sharing function method to seek the Pareto optimal solution for multi-objective optimization problem by genetic algorithm, the steps of Genetic algorithm optimizing the energy structure is shown in Figure1.

3.2. Genetic Algorithm Matlab Toolbox

In the process of using Genetic algorithm, it must be the preparation of a large number of programs to calculate, we all want to have a ready-made program, and MATLAB genetic algorithm toolbox (GAOT) just to meet this requirement. The called form of its main program ga.m is showed as follows:

[x,fval,reason,output,population] =ga(@fitnessfcn,nvars,options)

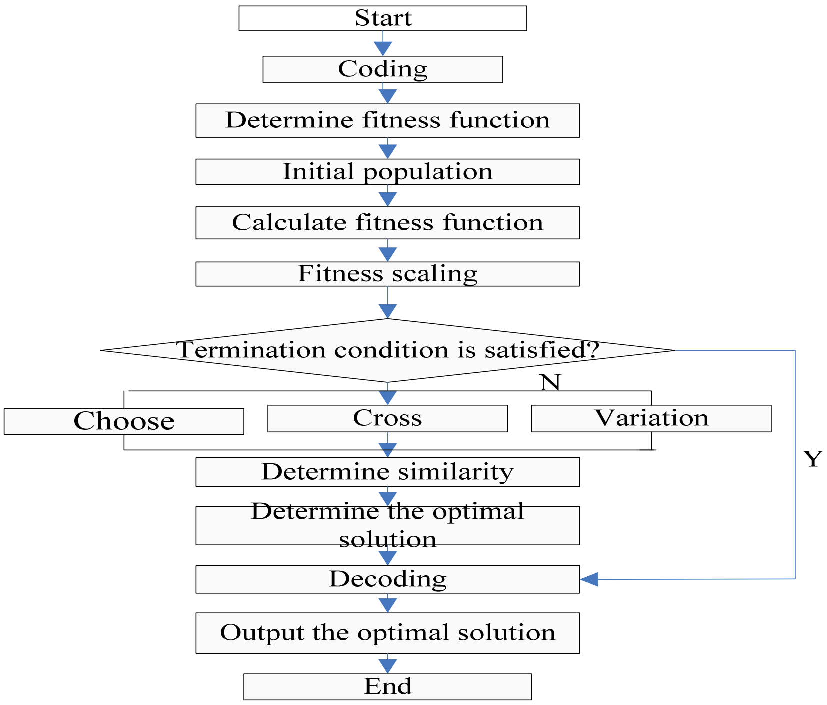

Figure 1. Genetic Algorithm Matlab Implementation Process

4. Empirical Analysis

In this paper, we take Hebei Province as a example, using genetic algorithm for multi-objective optimization model to optimize the energy structure in Hebei Province, the objective function is to minimize energy investment costs and pollution control fee, influencing factors are coal, oil, natural gas and renewable energy.

We use SPSS software to do partial correlation analysis to select sample space of the independent variables, the data are selected from 1980 to 2010 in Hebei Province, and determine the correlation between all kinds of energy and energy investment costs and pollution control costs, Then we obtain regression equation by regression analysis between the four types of energy with two goals, and finally combining with the related constraints, we use the genetic algorithm toolbox to get optimization solutions.

4.1. The Partial Correlation and Regression Analysis

4.1.1. Data Collection

After the model is established, the next step is to select the sample space of the Independent variables, through data analysis, prior to 1999, the growth rate of energy consumption was slow in Hebei Province, but after 1999, energy consumption had rapid growth rate, there is a inflection point in 1999, so we select the 1999-2010 energy consumption in Hebei province as the sample space.

According to the Statistical Yearbook and related information, we can get the energy industry investment in fixed assets, while the cost of pollution control can be calculated by unit energy costs (Table 1) and the annual consumption of various energy, the calculated results are shown in Table 2.

Table 1. Energy Pollution Control Cost Value (yuan / ton of standard coal)

Coal	Oil	Natural gas
117.89	39.94	1.37

Note: Assuming that there is no pollution control fee for renewable energy.

4.1.2. Multiple Regression Analysis

Before Multiple Regression analysis ,this paper has done partial correlation analysis for the data which are standardized based on Table 2, The results prove energy investment costs and pollution control costs have a strong positive correlation with four types of energy.

In the present study, we assume linear regression model between random variables y (energy investment costs and pollution control costs) and four types of energy x1, x2, x3, x4 :

$$y=\beta 0+\beta 1x1+\beta 2x2+\beta 3x3+\beta 4x4+\varepsilon \quad (2)$$

Where: β0, β1, β2, β3, β4 are the five unknown parameters, β0 is called the regression constant, β1, β2, β3, β4 are called regression coefficients. y is referred to the variable which is interpreted (the dependent variable); x1, x2, x3, x4 are general variables which can be accurately measured and controlled, it is called the explanatory variables (independent variables). ε is the random error, usually assumed that:

$$\begin{cases} E(\varepsilon)=0 \\ \operatorname{var}(\varepsilon)=\sigma^2 \end{cases}$$

Table 2. The Total Investment and Pollution Control Fee Unit: Million Tons of Standard Coal

	Energy Consumption	Coal	Oil	Natural gas	Renewable energy	Energy Investment (million)	Pollution control costs(million)
1999	9379.27	8442.28	844.13	82.54	10.32	1097900	1029088
2000	11195.71	10181.38	914.69	94.04	5.60	1668200	1236944
2001	12114.29	11125.76	898.88	84.80	4.85	915200	1347633
2002	13404.53	12214.21	1092.47	93.83	4.02	809400	1483695
2003	15297.89	14193.38	992.83	100.97	10.71	887600	1713050
2004	17347.79	15810.78	1389.56	130.11	17.35	963100	1919610
2005	19835.99	18213.41	1477.78	121.00	23.80	1903100	2206367
2006	21794.09	19961.21	1665.07	146.02	21.79	2680800	2419930
2007	23585.13	21783.23	1620.30	160.38	21.23	2572600	2632959
2008	24321.87	22451.52	1622.27	228.63	19.46	7578100	2711916
2009	25418.79	23514.92	1578.51	307.57	17.79	7314500	2835641
2010	27531.11	24901.89	2029.04	396.45	203.73	9406800	3017267

So the multiple linear regression equation between energy investment costs (y1), pollution control costs (y2) and four types of energy is:

$$y=\beta 0+\beta 1x1+\beta 2x2+\beta 3x3+\beta 4x4 \quad (3)$$

Accordance with the data which are which are standardized based on Table 2 ,we can do regression analysis, the regression equation are showed below (because the limited space to the article, this is no longer showing the calculation process).

$$y1=7.247+0.32x1+0.191x2+1.878x3+0.391x4 \quad (4)$$

$$y2=4.869+0.973x1+0.026x2+0.014x4 \quad (5)$$

4.2. Constraint Condition

According to the model design which talked about the optimization goals, we can see that by 2015, the province's total energy consumption of 293 million tons of standard coal, meanwhile the Energy Plan requires that the share of coal energy in the energy consumption structure in Hebei Province should be drop to less than 85%,The share of renewable energy important should be increased to more than 6%, sulfur dioxide emissions to less than 1,255,000 tons. So we can get the constrained multi-objective programming model.

$$\begin{aligned}
&\min f1(x)=7.247+0.32x1+0.191x2+1.878x3+0.391x4\\
&\min f2(x)=4.869+0.973x1+0.026x2+0.014x4\\
&s.t.\ xi\geq 0;\\
&27531.11\leq \sum xi\leq 29300\\
&x1/\sum xi\leq 0.85\\
&x4/\sum xi\geq 0.06\\
&20\ x1+ 1.05x2+ 0.21x3\leq 125500.
\end{aligned}$$

4.3. The Operational Results and Analysis

4.3.1. The Operational Results

The constrained multi-objective optimization programming model of energy structure has been obtained in 4.2, the next step is to use genetic algorithm GOAT programming [13-15] to solve the model. The program is operated in matlab software, the result is showed in Figure 2.

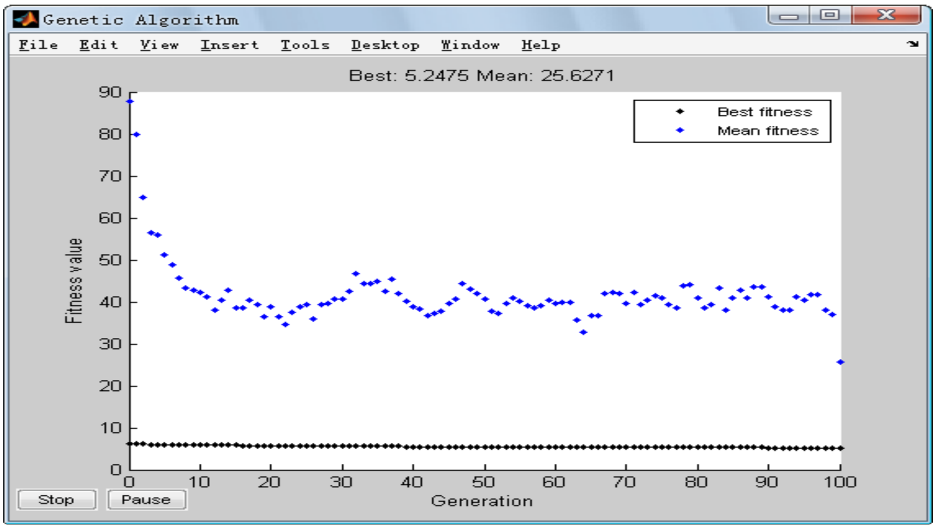

Figure 2. The Best and Average Values of Each Generation Adapted Function

The results are processed after 100 times iteration, we can get:

$x1=24406.9, x2=1699.4, x3=703.2, x4=2490.5$

4.3.2. Analysis of the Results

That is, by 2015, the predicted optimal energy consumption proportion in Hebei Province: coal accounts for 83.3%, oil accounts for 5.8%, natural gas accounts for 2.4%, renewable energy accounts for 8.5%. It can be seen from the simulation results:

Gradual decline in the proportion of coal in the total energy consumption, it will decrease from 90.45% in 2010 to 83.3% in 2015, but with the increasing costs of coal-fired pollution control and pollution emissions restrictions, the increase of coal consumption show slow. Because of the power initial investment is high, in the near future it is difficult to compete with thermal power from the economic consideration. The coal, which is in the dominant position in Hebei energy consumption will not be much change, this is consistent with the energy resources characteristic in our province, the key is to attach importance to the development of large-scale thermal power units, to improve the efficiency of coal use,and to strengthen the development of clean coal technology to control environmental pollution.

Oil consumption has declined, while the proportion of natural gas is rising slowly, which is likely due to the rising of oil prices in global and taking into account the costs of pollution, etc. But in the Hebei, oil and gas resources are relatively scarce, oil dependence on foreign had reached 57.81 percent in 2010, the gap of the oil and gas energy supply and demand in the future will be widened, energy security issues should be on the agenda.

The next five years, the primary power (hydropower, nuclear power, wind power) will be in the stage of rapid development, the proportion in the total energy consumption will increase from 0.74% in 2010 to 8.5% in 2015. the primary power as an alternative energy is starting to show its important role.

Overall, the energy consumption structure in Hebei Province is becoming more and more rational, and we can clearly see the trend of energy development in Hebei Province: Energy structure will have a diversified structure transition which dominated by coal will take hydro, nuclear, wind and other renewable energy as an important alternative energy,moreover, the result is consistent with the energy planning objectives, it proves that the applicability of a genetic algorithm for solving multi-objective optimization model.

4.3.3. Energy Development Strategy in Hebei Province

Through the above analysis, the suggestions of energy development countermeasures in Hebei are as follows:

(1) Development of renewable energy and optimizing energy structure

To solve the energy problem, we must vigorously develop renewable energy, energy structure is adjusted to the coexistence of diverse energy of renewable energy, natural gas, oil and coal instead of coal-dominated energy structure. Renewable energy are wind, geothermal, solar and biomass in Hebei. Wind energy resources in Hebei province is very rich, while geothermal resources, solar energy resources, biomass is also rich, the further development of renewable energy, which requires preferential policy support, but also need strong financial support,financial capital securities,foreign and private capital to actively enter, can effectively promote the new energy and renewable energy industries.

(2) Promoting wind power nuclear power development actively,achieving the substitute of coal and electricity.

There is a fivefold increase of electricity consumption in Hebei nearly 20 years, mainly coal-fired power, which not only transferred a lot of coal, make a great impact on the energy security, but also cause serious pollution to the environment. Wind power, nuclear power technology is mature, and the pollution of renewable energy is small, there been large-scale application in some developed countries, Hebei should seize the opportunity to accelerate the introduction of nuclear power technology and digestion,and promote the construction of wind power vigorously, optimize the power structure.

In short, optimizing energy structure is an important guarantee to achieve energy saving. Strengthening wind, solar, biomass, geothermal and other renewable energy development and utilization is the long-term measures to deal with the increasingly serious energy and environmental problems in Hebei Province.

5. Conclusion

This paper establishes objective optimization model for optimizing the energy structure based on energy investment cost minimization and pollution control costs minimization, and uses genetic algorithm to solve it. As can be seen from the application of the model, optimized energy structure better reflects the Energy Plan target of Hebei Province, it is in line with the actual requirements, which shows that the model has a strong practical value.

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