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The Multi-Objective Programming Model of the Structure of Energy Consumption on China

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Abstract: In this study, we develop a multi-objective programming model of the structure of energy consumption energy consumption, emission of CO_2 to optimize structure of energy consumption. The proportion of non-fossil and natural gas in energy consumption are setted as the objectives, and taking industrial structure and industry expansion as the constraint conditions. Different weight factors are granted to the objectives. The results indicated that taking the reduction of emission of CO_2 as the first place, economic growth as the second and increasing the supply of non-fossil and natural gas in energy consumption as the last will be a good choose.

Keywords: Emission of CO_2, multi-objective programming, the structure of energy consumption

INTRODUCTION

To mitigating climate change, some measures are taken by the countries in the world to reduce emission of the Greenhouse Gasm (GHG). It is a crucial time to develop economic in China, the demand of energy keep rising, in the "Eleventh Five-Year Plan", China government set the target of reducing its unit GDP energy consumption by 20% by the end of 2010. Before the Copenhagen Climate Change Conference 2009, China State Council declared its goal to reduce its unit GDP CO_2 emission by 40-45% by 2020, compared with 2005. In the long-run, the target about emission reduction will achieve mainly through progress in technology and optimization of the structure of energy consumption. Coal provides around 70% of the total primary energy consumption in China, which is the produces the most GHG and most serious pollution to environment, the proportion of coal will remain unchanged for a time, as shown in Fig. 1.

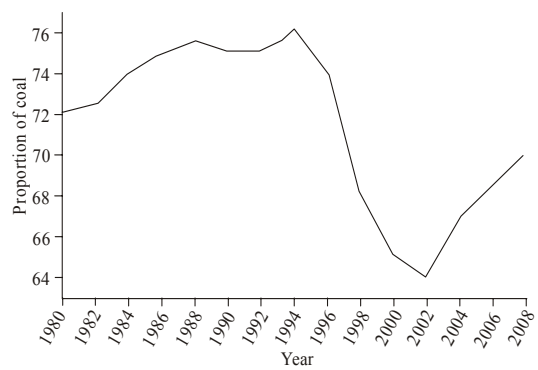

Fig. 1: Trend of propotion of the coal

Many attentions are payed to the optimization of the structure of energy consumption at home and abroad. Hu and Zhou discussed this problem through feasibility from economic and technology. From a global view, Liu think the industrialization and urbanization of China need not only structural adjustment of energy system, but also integrating to economic of the world. Hu and Zhou put forward more attention should be payed to structural adjustment of energy system, diversification of energy was the inevitable choice. From these literatures, there is lack of systematic analysis about integrated economic growth, lower energy consumption and reduce pollutants. Based on the input-output analysis, a multi-objective model is constructed in this paper, tryin41g to solve the contradiction between economic development, environment and resource through adjustment of structure of energy system. Wang *et al*. (2011) have a study of the CO_2 emission, energy consumption and economic growth in China: A panel data analysis. Wenying and Ruina (2010) have a research of the clean coal technology development in China. Han *et al*. (2007) analyze the energy structure, marginal efficiency

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and substitution rate: an empirical study of china. Kraft and Kraft (1978) study the relation between energy and GDP. Shiu and Lam (2004) have a research of the electricity consumption and economic growth in china. Guo and Fu (2009) study the current situation of energy consumption and measures taken for energy saving in the iron and steel industry in China.

In this study, a multi-objective model is developed to optimize the structure of energy consumption. Compared with the expected value, we can see that promise to emission reduction emission of CO_2 can fulfill on the premise of economic development. Policy about the adjustment of structure of energy consumption is suggested as followed: Firstly, we should take the development of economic as the secondary, increasing the propotion of non-fossil and natural gas as the last. Secondly, production and supply of non-fossil should increase; enhance the propotion of power generation of non-fossil. Lastly, insisting on energy strategies of diversification, developing the new pattern of structure of consumption of energy with clean, efficient and diversified.

PROBLEM FORMULATION

Allowing to the target of emission reduction of different stages, from these aspects of economic energy, emission of CO_2, the proportion of non-fossil and natural gas, optimization of the industrial structure is considered to achieve adjustment of structure of energy system.

Objective functions:

Maximization of economic benefit: The primary aim of optimization of the industrial structure is development of economic, reflecting GDP is the maximum, which can be expressed as $\max iV$, where, i is the sum of row vector when the element is 1.

$$V = (V^E, V^N)^T$$

Minimization of emission of CO_2: Be in short supply of energy, the emission of CO_2 must be get least possible quantity and can be represented as $\min coV$, where co is the coefficient matrices of emission of CO_2 of each department.

Minimization of energy consumption: The industries of high energy consumption are limited, after the adjustment of structure of energy system, energy consumption should get the smallest possible number and can be expressed as $\min eV$, where e is the coefficient matrices of energy consumption of each department.

Table1: The constraints of adjustment between three industries

	2015		2020	
Industry	Upper limit	Top limit	Top limit	Top limit
Primary industry,	8	10	6	8
Secondary industry	45	50	40	45
Tertiary industry	40	47	47	54

Maximization of use of non-fossil and natural gas: The usage of non-fossil and natural gas can reduce emission of CO_2 efficiently, which can be represented as max wV, max gV, where, W and g denotes the row vector of value added each unit of non-fossil and natural gas separately.

Constraints: The adjustment of structure of energy consumption system must be on the relationship Also primary industry, secondary industry and tertiary industry should achieve balanced development. A top limit and upper limit according to the data based on 2005~2009 is setted as Table 1

The expectation of different objectives: When solving the model, the expected value of different objectives need to be setted, in consideration of the actual conditions of China, some expected value about the objectives be setted as followed.

Taking the GDP as the index of measuring the economic benefit, given the average growth rate of GDP is 8% between 2010~2015 and 7.5% between 2015~2020, the aim of GDP in 2015 and 2020 are $GDP_{2010}\times(1+8\%)^5$ and $GDP_{2010}\times(1+8\%)^5 \times (1+7.5\%)^5$. The GDP in the model is denoted by b_1.

Compared with 2005, in 2015 need decreased by 29~31%, 40~45% in 2020, the emission of CO_2 in consumption for living and biological activity are not included. The top limit and upper limit of the emission intensity of CO_2 in the model for each year is denoted by b_2, b_3.

It is targeted to reduce production by 25~28% in 2015 and 30~35% in 2020 calculated by average speed in 10 years. b_4, b_5 is the top limit and upper limit of energy consumption for unit GDP in the model.

Non-fossil mainly include hydro energy and nuclear energy for this paper, because of lack of data of wind energy, biomass energy etc., is 11% in 2015, 15% in 2020. The top limit and upper limit of the proportion of non-fossil in the model is.b_6, b_7.

Table 2: Priority enactment

		Emission		Non-fossil		Natural gas		Consumption of energy	
Priority	GDP	Top	Upper	Top	Upper	Top	Upper	Top	Upper
w_co1	2	1	---	3	4	5	6	7	8
w_co2	2	---	1	3	4	5	6	7	8
w_co3	4	1	---	2	3	5	6	7	8
w_co4	4	1	---	5	6	2	3	7	8

Natural gas is aim to 6.88 and 8.29% in, which is denoted by b_8, b_9 for the top limit and upper limit of propotion of natural gas to total consumption of the energy in the model.

Muti-objective programming model: Based on the discussion of above, a multi-objective programming model is expressed as:

$$
\begin{aligned}
&\min f \\
&\text{st. } iV + d^+_1 - d^-_1 = b_1 \\
&\quad C_0V + d^+_2 - d^-_2 = b_2 \qquad C_0V + d^+_3 - d^-_3 = b_3 \\
&\quad eV + d^+_4 - d^-_4 = b_4 \qquad eV + d^+_5 - d^-_5 = b_5 \\
&\quad \omega V + d^+_6 - d^-_6 = b_6 \qquad \omega V + d^+_7 - d^-_7 = b_7 \\
&\quad gV + d^+_S - d^-_S = b_S \qquad gV + d^+_9 - d^-_9 = b_9 \\
&\quad (I - A)\, A_V V \geq F \\
&\quad u^L_i \leq u_i \leq u^U_i \quad i = 1, 2, 3 \\
&\quad V^L_i \leq V_i \leq V^U_i \quad i = 1, \ldots, 29
\end{aligned}
$$

where, d_i^+, d_i^- stand for positive and negative deviation variables of the constraint of the i objective. u_i denoted the propotion to the GDP for the i industry and L and U is the upper limit and top limit for some index. f is the objective function, which is a weighting function of d_i^+, d_i^-.

One of the methods of solving the multi-objective programming is setting priority for each objective in advance. If reduction of emission of CO_2 is preferred and top limit and upper limit of the emission is setted, four different weights w_co1, w_co2, w_co3 and w_co4 are considered under this priority, the meanings of every weight are showed by Table 2.

The function f can be expressed separately under four weights as follows:

w_co1 $$f = p_2(d_1^+ + d_1^-) + p_1 d_2^+ + p_3 d_4^+ + p_4 d_5^- + p_5 d_6^+ + p_6 d_7^- + p_7 d_8^+ + p_8 d_9^-$$

w_co2 $$f = p_2(d_1^+ + d_1^-) + p_1 d_3^- + p_3 d_4^+ + p_4 d_5^- + p_5 d_6^+ + p_6 d_7^- + p_7 d_8^+ + p_8 d_9^-$$

w_co3 $$f = p_4(d_1^+ + d_1^-) + p_1 d_2^+ + p_2 d_4^+ + p_3 d_5^- + p_5 d_6^+ + p_6 d_7^- + p_7 d_8^+ + p_8 d_9^-$$

w_co4 $$f = p_4(d_1^+ + d_1^-) + p_1 d_2^+ + p_3 d_4^+ + p_4 d_5^- + p_2 d_6^+ + p_3 d_7^- + p_7 d_8^+ + p_8 d_9^-$$

RESULTS

The analysis of results of the model in 2015: Given the average growth rate of GDP is 8% between 2010~2015, the total amount of GDP in 2015 is 461700.2 million yuan RMB. Under this circumstance, the emission of CO_2 should control between 81350 and 84310 billion tons .The consumption of energy is 351201~363311 10^2 ton tce, the propotion of non-fossil and natrual gas will be 3.87 and 6.88%, reaching 13593~14062 10^2 ton tce and 24155~24988 10^2 ton tce separately.

The optimal result of model is listed as the Table 3 and 4.

From these results, the values of objective are declining in some degree, the rate of descent of the propotion of coal, petroleum and coke decrease, the variation scope of the propotion of natural gas, hydropower and thermal power increase.

The analysis of results of the model in 2020: Given the average growth rate of GDP is 8% between 2010~2015, the average growth rate of GDP is 7.5% between 2015~2020, the total amount of GDP in 2020 is 662830.32 million yuan RMB. Under this circumstance, the emission of CO_2 should control between 9347 and 10197 billion tons .The consumption of energy is 456808~452036 10^2ton tce, the propotion of non-fossil and natural gas will be 5.28 and 8.29%, reaching 23858~25693 10^2 ton tce and 37458~403401^0 ton tce separately。 The optimal result of model in year 2020 is similar to 2015, so the detail analysis is omitted.

CONCLUSION

In this study, a multi-objective model is developed to optimize the structure of energy consumption. Compared with the expected value, we can see that promise to emission reduction emission of CO_2 can fulfill on the premise of economic development. Policy about the adjustment of structure of energy consumption is suggested as followed: Firstly, we should take the reduction of emission of CO_2 as the primary target, development of economic as the

Table 3: Optimal result of model in 2015

Priority	GDP/10^4 yuan	Consumption of energy/10000-ton tce	Emission of CO_2 /10^2 ton	Consumption of non-fossil/10000-ton tce	Consumption of natural gas/10000-ton tce
w_co1	4617001796	354493	8431	9611	10978
w_co2	4617001796	343653	8254	9113	10338
w_co3	4832997857	355433	8431	9928	11130
w_co4	4704526424	355022	8445	9101	22233

Table 4: Optimal result of model in 2015 unit: percentage

Priority	Coal	Crude oil	Natural gas	Hydropower	Thermal power	Product oil	Coke	Heat	Gas
w_co1	-3.45	0.00	-2.21	-0.18	0.10	0.19	0.92	2.09	-1.05
w_co2	-2.83	0.00	-4.01	-0.14	0.16	0.27	1.33	2.73	-0.65
w_co3	-3.37	0.00	0.00	-3.15	-0.15	2.89	0.01	0.03	1.78
w_co4	-4.16	-0.02	0.00	0.00	-3.94	-0.07	3.91	-0.04	-0.21

secondary, increasing the propotion of non-fossil and natural gas as the last. Secondly, production and supply of non-fossil should increase; enhance the propotion of power generation of non-fossil. Lastly, insisting on energy strategies of diversification, developing the new pattern of structure of consumption of energy with clean, efficient and diversified.

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