Potential Study on Carbon Emission Reduction and Energy Saving of Guangdong Province based on Sensitivity Analysis

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Abstract: Based on input-output table and energy consumption balance sheet of Guangdong Province in 2012, this paper formulates non-competitive energy input-output table of Guangdong Province, and calculates energy consumption intensity, carbon intensity and sensitivity coefficient of carbon emission reduction and energy saving of various departments. By applying sensitivity coefficient model to the analysis of carbon emission reduction and energy saving fulfillment under the carbon emission reduction and energy saving measures during the 12th Five-Year Plan in Guangdong Province, conclusions are drawn that the devotion of energy structure optimization, industrial restructuring and higher energy efficiency level to energy saving respectively mount to 13.1%,8.20%and 78.7%, while to carbon emission reduction mount to 15.2%,7.85%, and76.9%. Generally speaking, the reduction of 18.7% in energy consumption intensity and 20.4% in carbon emission intensity can basically meet the requirements of the carbon mission reduction and energy saving goal during the 12th Five-Year Plan.

Introduction

Guangdong Province is an economy-prosperous province and one of the largest energy consumption districts nationwide. In 2010 the overall primary energy consumption of Guangdong Province reached 26344.85 10^4 t tce, ranking the forefront in China [1].As the initial pilot area of carbon emission reduction and energy saving, the goal has been made that Guangdong Province should reduce the energy intensity and carbon intensity respectively by 18% and 19.5% prescribed by the 12th Five-Year Plan[2].To realize the objective, Guangdong Province has conducted planning and deployment in aspects of energy structure reformation, energy saving management, energy utilization efficiency promotion and new energy development and utilization [3]. Will the implementation of those measures meet the requirements of the carbon emission reduction and energy saving and total energy consumed control? Which measures are proved to be the most effective? Those questions are what the paper attempts to solve.

Various cases have been analyzed both at home and abroad on carbon emission amount calculation and influence factors of carbon emission reduction, such as carbon emission amount calculation from the angle of production department and its end use [4-6], carbon emission influence factor analysis [7-9], sensitivity analysis of technical input coefficient which affects the calculation accuracy of carbon emission amount [10,11]. There are also some Guangdong Province carbon

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emission pertinent researches. For instance, ZengXuelan[12] has conducted research on the carbon emission reduction potential and solutions of Guangdong Province during the 12th Five-Year Plan period, whose calculation method was relatively rough; Song Peishan[13]has utilized input-output analysis to calculate the direct carbon emission and hidden carbon emission intensity of various industries and departments of Guangdong Province; Bian Jing [14]calculated the carbon emission intensity of various industries and departments in Guangdong Province from 2000-2010, and constructed carbon emission factorization model by means of LMDI to measure the contribution rate of energy structure, energy efficiency and economic development. This thesis, by means of the established energy input-output table, based on the calculation of energy consumption intensity and carbon emission intensity, has innovatively applied the sensitivity analysis model to work out the sensitivity coefficient of various energy saving and carbon emission reduction measures in the energy consumption intensity and carbon emission intensity of Guangdong Province, and then analyzes the feasibility of the energy saving and carbon emission reduction goal as well as the methods and potentials combined to the various measures in the 12th Five-Year Plan, aiming to provide reference to the government's energy decisions.

Method and data

The energy input-output table

Structure In this research,only energy consumption and carbon emission took place in the range of Guangdong province were taken into account, so the non-competitive input-occupy-output model by Chen Xikang[15] was used as reference.The structure of the input-output table was shown as table 1.

Table 1 Non-competitive input-output table

	Intermediate input	Final demand	Total output and import
Intermediate input			
Domestic products	x^D_{ij}	f^D_{ij}	x_i
Imports	x^M_{ij}	f^M_{ij}	m_i
Initial input	v_j		
Total input	xj		
Energy consumption	n_{kj}		

The selection of departments. According to the characteristics of the input-output table of 42 departments in Guangdong Province and its energy balance sheet, main sectors were selected as farming, husbandry, fishery, industry, construction, transportation, storage, post, retail trade, hotel, and restaurants and other service trades, altogether seven types. Based on the key departments of energy saving and carbon emission reduction of Guangdong Province, industrial departments were divided into 25 trades, which can be seen in Table 2.

Table 2 Departments selected

Order	Department	Order	Department
1	Farming, Forestry, Animal Husbandry and Fishery	16	Manufacture of General-purpose and Special-purpose Machinery
2	Mining and Washing of Coal	17	Manufacture of Transport Equipment
3	Extraction of Petroleum and Natural Gas	18	Manufacture of Electrical Machinery and Equipment
4	Mining and Dressing of Metal Ores	19	Manufacture of Communication Equipment, Computers and Other Electronic Equipment
5	Mining and Dressing of Nonmetal Ores and Other Ores	20	Manufacture of Instruments and Meters
6	Manufacture of Food and Tobacco	21	Handicraft and Other Manufactures
7	Textile Industry	22	Recycling and Disposal of Waste
8	Manufacture of Textile Garments, Footwear and Leather, Fur, Feather, Down and Related Products	23	Manufacture of Metal Products, Machinery and Equipment Maintenance
9	Manufacture of Furniture, Timber Processing, Bamboo, Cane, Palm Fiber& Straw Products	24	Production and Supply of Electric Power and Heat Power
10	Papermaking, Printing& Manufacture of Cultural, Educational and Sports Articles	25	Production and Supply of Gas
11	Petroleum Refining, Coking, and Nuclear Fuel Processing	26	Production and Supply of Water
12	Manufacture of Chemical Products	27	Construction
13	Nonmetal Mineral Products	28	Transport, Storage and Post
14	Smelting and Pressing of Metals	29	Wholesale, Retail Trade and Hotel, Restaurants
15	Metal Products	30	Other sectors

Energy variety

According to the various energy in the energy use balance sheet, there are four major types, coal, petroleum, natural gas, electricity power and heat, and others. the coefficient of converting into standards of various energy can be consulted in the Energy Statistical Yearbook. Total final consumption of the 7 sectors was calculated in Table 3 .

The carbon emission coefficient for the 4 types of energy were taken as the following values[14,12]: coal 2.8145 (t/t tce), petroleum products 2.1484 (t/t tce), nature gas for 1.6434 (t/t tce),electricity 2.4567(t/t tce).

Table 3 Total finial consumption of 7 Sectors (10^4ttce)

Energy	Agriculture, Forestry, Animal Husbandry, Fishery	Industry	Construction	Transport, Storage and Post	Wholesale, Retail Trade and Hotel, Restaurants	Other Services	Residential Consumption
Coal	43.79	4868.95	2.23	1.73	59.26	0	118.52
PetroleumProducts	166.43	2376.4	526.79	2731.68	351.39	92.47	1407.44
Nature Gas	0	455.05	0	0	97.09	0	161.6
Electricity, Heat and others	272.77	10708.41	199.43	234.16	879.79	1479.65	2371.6

Departments Distribution of Import Commodities

Based on "proportion equivalent method", assume that the use ratio of import and redeployed products from various intermediate user departments and final user departments equals the use ratio of domestic products, and decompose the total import and redeployed commodities of various departments to establish (import, redeployed) non-competitive input-output table [13].

Energy use distribution of industrial sectors

Guangdong Statistical Yearbook has counted the total energy consumed by various industrial sectors (by standard coal), and consumption of raw coal and electricity. Based on the above statistics, and the RAS method, the column aim vector refers to terminal energy total consumption of various industrial sectors, the row aim vector refers to the total consumption of various industrial energy, and initial condition refers to conusmption distribution ratio of various enegry in various industrial sectors,by numerous iterative operation, total energy consumption of different fuel type in various industrial sectors in Guangdong Provicne can be calculated.

Modeling

Standard model

Row model

$$X=(I-A)^{-1}F\ . \tag{1}$$

$$A=\{a_{ij}\},(i,j=1,2,...,n).$$

$$. \tag{2}$$

Column Model

$$X=(I-)^{-1}V. \tag{3}$$

In the equations, X refers to the total output vector of each department, F refers to the final consumption vector of each department, A refers to the direct consumption coefficient matrix,

refers to the diagonal matrix generated by the intermediate input rate vector, and V refers to value added vector of each department.

Energy consumption and carbon emission model

Based on production

C=CT.V . (4)

N=NT.V . (5)

. (6)

. (7)

. (8)

=. (9)

Based on final use

$C=CT'.(I-A)^{-1}F$. (10)

$N=NT'.(I-A)^{-1}F$. (11)

. (12)

. (13)

In the above equations, C and N refer respectively to the CO_2 emission vector and energy consumption vector of Guangdong Province; CT and NT refer to energy consumption and CO_2 emission vector per unit added value of each department; CT' and NT' refer to energy consumption and CO_2 emission vector of per unit output value of each department; nj and cj refer to total energy consumption of various energy and CO_2 emission; ek refers to the CO_2 emission coefficient of the Kth energy; n_{kj} refers to the Kth energy quantity of each department.

Sensitivity calculation model

=* . (14)

=* . (15)

In the above equations, indicates the carbon emission percent change (%) caused by ifactor;indicates the energy consumption emission percent change (%) caused by i factor;、 indicate the sensitivity coefficient of carbon emission and energy consumption to factor i; indicates the level of change of certain factor(%) (such as GDP growth rate, energy restructuring rate, industry restructuring rate, energy consumption change rate and final demand change rate, etc.)

Results and discussion

Energy consumption and carbon emission in 2012

In 2012, the total energy consumption of Guangdong Province amounts to 29600 10^4 t tce, energy consumption per GDP 0.534 t Tec/10^4 Yuan (value of that year), CO2 emission 58550 10^4 t tce, carbon emission of ten thousand Yuan GDP 1.056t, indicating a decrease of 10.4% in energy consumption and 12.6% in carbon intensity compared to the year 2010. The end-user energy consumptions are as follows: coal(17.21%), petroleum(25.85%)，natural gas(2.41%), and electricity power and others (54.53%) . The energy consumption percentage of the primary industry, secondary industry and the tertiary industry are respectively 1.89%,74.91%,and 23.20%, with the carbon emission percentage of 1.82%, 75.78%, and 22.40%. The top five energy consuming departments are Nonmetal Mineral Products, wholesale and retail trade, hotel and restaurants, production and supply of electricity power and heat, chemical products, metal smelting and pressing, accounting for 22.15% in added value, and 43.28% in energy consumption. Direct and total energy intensity, direct and total carbon emission intensity of each department are shown in Figure 1.

As can be seen from Fig.1, the departments with direct and total energy intensity, direct and total carbon emission intensity ranking the top are Nonmetal Mineral Products, Production and Supply of Water, Production and Supply of Electric Power and Heat Power, Petroleum Refining, Coking, and Nuclear Fuel Processing, Textile Industry, Wholesale, Retail Trade and Hotel, Restaurants, Mining and Dressing of Metal Ores, Transport, Storage and Post, Papermaking, Printing&Manufacture of Cultural, Educational and Sports Articles, Manufacture of Chemical Products.

Grouping by direct emission intensity, low carbon intensity group with carbon intensity less than 0.37 t/10^4Yuan, middle carbon intensity group with carbon intensity great than 0.37 t/10^4Yuan and less than 3.7t/10^4Yuan, high carbon intensity group with carbon intensity great than3.7 t/10^4Yuan,the top ten departments belong to the middle carbon intensity group.

Grouping by total emission density, low carbon density group with carbon density less than0.74 t/10^4yuan, middle carbon density group with carbon intensity great than0.74 t/10^4yuan and less than 7.4 t/10^4yuan, high carbon density group with carbon density great than 7.4 t/10^4yuan,the top nine departments belong to the middle carbon density group. These departments in middle carbon intensity and density group should be the key departments for treatment, and actually they were the targets of treatment during the 12th five year period in Guangdong province.

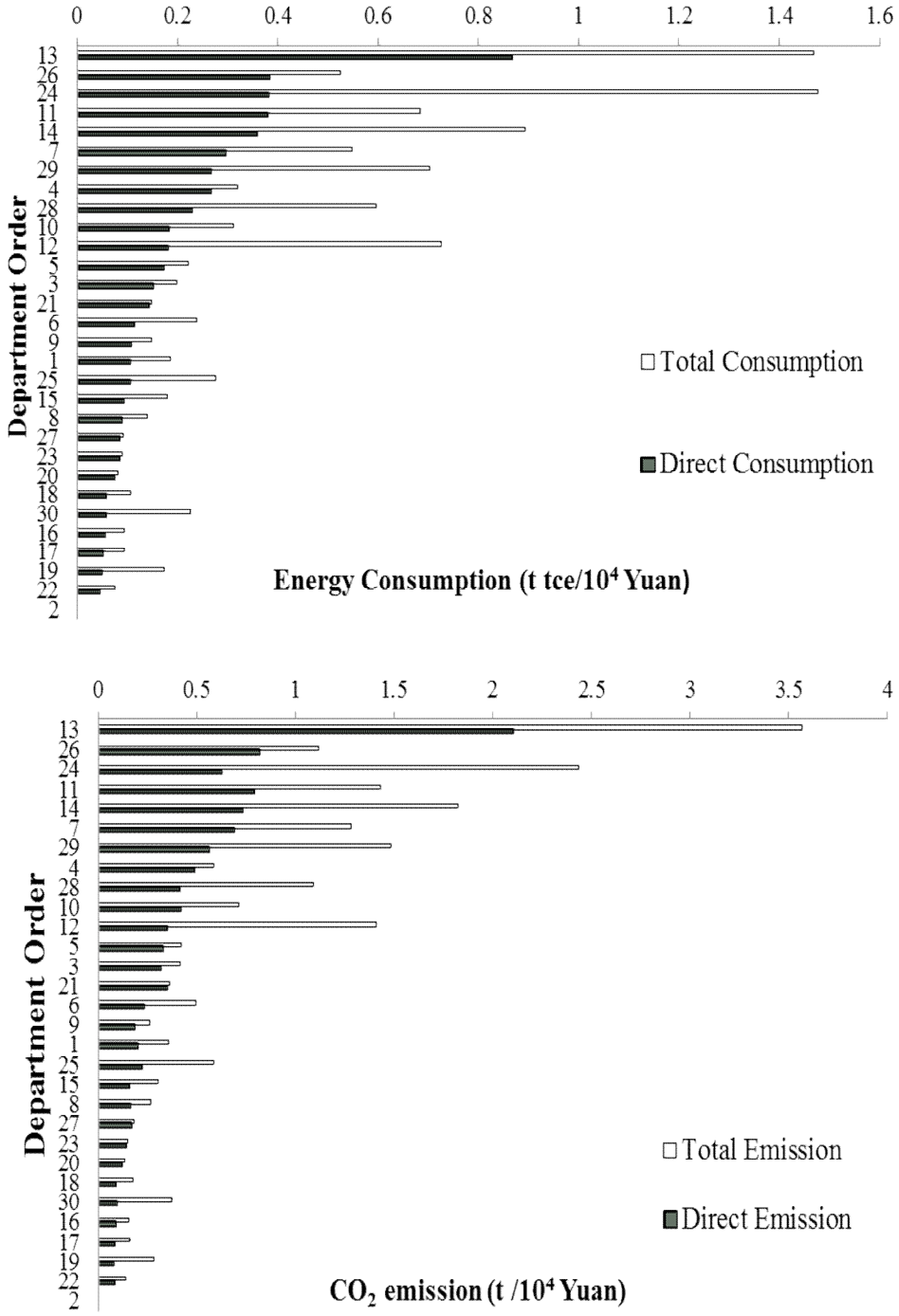

Fig.1 Energy and carbon intensity of each department

Feasibility analysis of the energy saving and carbon emission reduction goal in 2015

Sensitivity coefficient of control measures

By means of equation (14), (15) and statistics (energy statistics, economic statistics) in 2012, sensitivity coefficients of energy consumption and carbon emission have been measured in four aspects of energy structure, industry structure, economic development and energy consumption level, and the results are as follows in table 4. According to that chart, fluctuation conditions of energy consumption and carbon emission brought out by the energy restructuring, change of industry structure, economic development and the consumption level can be calculated and summarized, as well as comprehensive influence of various factors.

Table 4 Sensitivity coefficient of each factor

Factor (i)	(Energy consumption)	(CO_2 Emission)	Remark
Energy structure			
Coal	0.1721	0.2449	
Petroleum Products	0.2585	0.2809	
Natural gas	0.0241	0.0201	
Electricity, Heat and others	0.5453	0.4543	
Industrial structure			Proportion of added value
Primary industry	0.0163	0.0159	0.05
Secondary industry	0.6464	0.6604	0.50
Tertiary industry	0.2002	0.1952	0.45
Key department			Ranking by sensitivity (top 10)
Nonmetal Mineral Products	0.1159	0.1424	
Production and Supply of Electric Power and Heat Power	0.0781	0.0651	
Manufacture of Chemical Products	0.0723	0.0711	
Smelting and Pressing of Metals	0.0662	0.0684	
Petroleum Refining, Coking, and Nuclear Fuel Processing	0.0486	0.0514	
Transport, Storage and Post	0.0469	0.0432	
Papermaking, Printing& Manufacture of Cultural, Educational and Sports Articles	0.0451	0.0522	
Manufacture of Communication Equipment, Computers and Other Electronic Equipment	0.0400	0.0334	
Textile Industry	0.0253	0.0300	
Construction	0.0246	0.0250	
Energy consumption			Ranking by energy intensity (Top 10)
Nonmetal Mineral Products	0.1159	0.1424	3.51
Smelting and Pressing of Metals	0.0662	0.0684	2.10
Petroleum Refining, Coking, and Nuclear Fuel Processing	0.0486	0.0514	1.80
Production and Supply of Electric Power and Heat Power	0.0781	0.0651	1.45
Production and Supply of Water	0.0047	0.0051	1.32
Textile Industry	0.0253	0.0300	1.25
Papermaking, Printing& Manufacture of Cultural, Educational and Sports Articles	0.0451	0.0522	0.92
Manufacture of Chemical Products	0.0723	0.0711	0.78
Mining and Dressing of Metal Ores	0.0028	0.0026	0.78
Handicraft and Other Manufactures	0.0016	0.0020	0.62

“12th Five-Year Plan” target reachability analysis

During the 12th Five-Year Plan period, the scheme of energy restructuring is to reduce coal and petroleum both by 3%, and to increase natural gas by 6%; the percentage of primary industry decreases by 1%, the secondary industry by 2%, the tertiary industry by 3%; the economic growing speed is expected to be 8% to 10%, and by conservative estimate, the bottom line is 8%; according to our energy saving goal (saving 30Mt), top ten energy consumption departments assumingly are to be reduced by 15%.

The calculation procedures and results can be found in table 5. As can be seen in table 5, the economic growth will cause an increase of 46.9% in energy saving and carbon emission, energy restructuring can reduce the energy saving and carbon emission respectively by 1.15% and 1.45%, industry restructuring can reduce respectively by 0.72% and 0.75%, higher energy use efficiency can reduce respectively by 6.91% and 7.35%. Integrating the four aspects, the energy consumption and carbon emission can ultimately increase by 38.1% and 37.3%. Energy consumption per unit added value and carbon emission account for 81.3% and 79.6% of those in 2010, i.e. a decrease of 18.7% and 20.4% compared to 2010, amounting to 18% and 19.5% of the prescribed goal in energy saving and carbon emission.

By further analysis of the three energy saving and carbon emission measures, energy restructuring devotes 13.1% and 15.2% respectively to energy saving and carbon emission, industry restructuring devotes 8.20% and 7.85%, increased energy use efficiency devotes 78.7%and 76.9%.

The proportion of increasing energy use efficiency(reduce energy consumption) sets as 15%, and only for high energy consumption enterprises, still under the intensity of the planned energy consumption of 3000 10^4t, which indicates that this measure has the potential of energy saving and carbon reduction. Table 4 shows that industry restructuring has great energy saving and carbon reduction potential, and the energy consumption and carbon intensity sensitivity coefficients of tertiary industry respectively amount to 0.20, and 0.195, while the secondary industry amounts to 0.646,0.660. According to sensitivity coefficient, the sum of top ten sensitivity coefficients in industrial sectors reaches to 0.563, and according to energy consumption intensity the sum reaches to 0.461. If the industrial restructuring can be enhanced further, the development of low energy consumption industrial sectors can be promoted, and its ratio can be boosted, the conflict between economic development and energy saving and carbon reduction can be effectively relieved.

Table 5 Contribution of factors to energy consumption and CO_2 emission

Factor(i)	Changing rate	Energy consumption changing rate	CO_2 emission changing rate
Energy structure			
Coal	-3%	-0.52%	-0.73%
Petroleum Products	-3%	-0.78%	-0.84%
Natural gas	+6%	+0.14%	+0.12%
Electricity, Heat and others	--	--	--
Industrial structure			
Primary industry	-1%	-0.02%	-0.02%
Secondary industry	-2%	-1.30%	-1.31%
Tertiary industry	+3%	+0.60%	+0.58%
Economic growth	GDP annual growth 8%		
Primary industry		+0.76%	+0.75%
Secondary industry		+30.30%	+30.95%
Tertiary industry		+9.38%	+9.15%
Household		6.43%	6.04%
Energy intensity	Key department decreased by 15%		
Nonmetal Mineral Products		-1.74%	-2.14%
Smelting and Pressing of Metals		-0.99%	-1.03%
Petroleum Refining, Coking, and Nuclear Fuel Processing		-0.73%	-0.77%
Production and Supply of Electric Power and Heat Power		-1.17%	-0.98%
Production and Supply of Water		-0.07%	-0.08%
Textile Industry		-0.38%	-0.45%
Papermaking, Printing& Manufacture of Cultural, Educational and Sports Articles		-0.68%	-0.78%
Manufacture of Chemical Products		-1.08%	-1.07%
Mining and Dressing of Metal Ores		-0.04%	-0.04%
Handicraft and Other Manufactures		-0.02%	-0.03%
Sum up		38.1%	37.3%
Energy intensity and CO_2 emission reduction in 2015		18.7%	20.4%

Conclusions and suggestion

1. In 2012, energy consumption per unit GDP of Guangdong Province amounted to 0.534 t tce/10^4yuan (value of that year), and carbon emission of ten thousand yuan GDP 1.056t,reflecting a respective decrease of 10.4% and 12.6% compared to the year of 2010[12]. Energy consumption

departments ranking top are, Nonmetal Mineral Products, Production and Supply of Water, Production and Supply of Electric Power and Heat Power, Petroleum Refining, Coking, and Nuclear Fuel Processing, Textile Industry, Wholesale, Retail Trade and Hotel, Restaurants, Mining and Dressing of Metal Ores, Transport, Storage and Post, Papermaking, Printing& Manufacture of Cultural, Educational and Sports Articles, Manufacture of Chemical Products, they all belong to middle carbon intensity and density group.

2. During the 12th Five-Year Plan period the energy saving and carbon emission reduction can reach the expected goal. At the economy growth rate of presumed 8%, energy consumption and carbon emission will increase by 46.9%, but by means of energy restructuring, industry restructuring and increased energy use efficiency, energy consumption can be reduced by 8.78%, and carbon emission by 9.56%, resulting in a final increase of 38.1% and 37.3%. Energy consumption and carbon emission per unit added value respectively point to 81.3% and 79.6% of the year 2010, showing a decrease of 18.7% and 20.4% compared to the year 2010 and accomplishing 18% and 19.5% of the energy saving and carbon emission reduction plan.

3. Great potential lies in raising the energy use efficiency so that it is necessary to advocate energy saving and efficiency enhancing in key sectors as industry, construction and transportation, to actively promote building energy saving reconstruction and to boost energy use efficiency in various links of energy production, transportation and end of using. In the meanwhile, great efforts should be devoted to promote the production service and low energy consumption industry to reach the win-win situation of economic development and energy saving and carbon emission reduction.

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