Potential impacts of industrial structure on energy consumption and CO_2 emission: A case study of Beijing

Zhi-Fu Mi [a,b], Su-Yan Pan [a,b], Hao Yu [a,b], Yi-Ming Wei [a,b,*]

[a] Center for Energy and Environmental Policy Research, Beijing Institute of Technology, Beijing, 100081, China;

[b] School of Management and Economics, Beijing Institute of Technology, Beijing, 100081, China;

Corresponding author:

Yi-Ming Wei, PhD., Professor
Director, Center for Energy and Environmental Policy Research
Dean, School of Management and Economics
Beijing Institute of Technology
5 South Zhongguancun Street, Haidian District
Beijing 100081 China
Tel./ Fax: +86-10-68918651
Email: ymwei@263.net
Web site: www.ceep.net.cn

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Abstract：An optimization model is developed based on the Input-Output model to assess the potential impacts of industrial structure on the energy consumption and CO_2 emission. The method is applied to a case study of industrial structure adjustment in Beijing, China. Results demonstrate that industrial structure adjustment has great potential of energy conservation and carbon reduction. When the average annual growth rate of GDP is 8.29% from 2010 to 2020, industrial structure adjustment can save energy by 39.42% (50.06 million tons of standard coal equivalent), and reduce CO2 emission by 46.06% (96.31 million tons) in Beijing in 2020. Second, Beijing had better strive to develop several low energy intensive and low carbon intensive sectors, such as information transmission, computer service and software, and finance. Third, energy intensity is possible to decrease without negatively affecting economic growth by reasonable industrial structure adjustment. Four, compared to "intensity targets", "total amount targets" are more effective on the energy conservation and carbon reduction, but have much greater negative effects on economic growth. Therefore, it needs to be balanced between "total amount targets" and "intensity targets".

Keywords: industrial structure, energy consumption, CO_2 emission, input-output, optimization model

1. Introduction

With the rapid development of the world economy, energy supply and environmental problems become increasingly severe (Cong, 2013; IPCC, 2013; Nanduri and Saavedra-Antol ńez, 2013; Quadrelli and Peterson, 2007). In the past several decades, China economy enjoyed a rapid development. The average growth rate of China's gross domestic product (GDP) was over 10% from 1990 to 2011 (NBS, 2012). However, energy shortage and climate change issues have greatly influenced China's economy(Wei et al., 2013a, b). In order to reduce energy consumption and mitigate climate change, Chinese government has set the target to cut energy consumption per unit of GDP by 16% and cut carbon dioxide (CO_2) emission per unit of GDP by 17% during the period of 2011 to 2015 (State Council, 2011b).

Industrial structure is one of main factors which determine the energy consumption and CO_2 emission (Adom et al., 2012; Wei et al., 2009). Uchiyama (2002) investigated the past and future trends of energy demand and supply in Japan. The results showed that recent growth of the energy demand in Japan was getting stable because of industrial structure from materials and heavy industries to service industries. Liou (2010) revealed that Taiwan's industrial structure which had a great bias towards manufacture industry was one of the main reasons for the relatively high energy consumption and greenhouse gas emission. He considered that Taiwan's industrial structure should be adjusted urgently. Moreover, researchers usually take industrial structural effect into consideration, when identifying the factors which influence the level of energy consumption and CO_2 emission (Kim and Worrell, 2002; Liaskas et al., 2000).

In fact, industrial structure in China needs to be improved in order to save energy and reduce CO_2 emission (Jin, 2012; Zhao and Niu, 2013). Compared to the developed countries whose tertiary industries are highly developed, China's economy is more dependent on secondary industries which are energy intensive and carbon intensive. In 2010, the proportion of tertiary industry in China was 43.19% which was less than that of most developed countries (Fig. 1). Liao et al. (2007) decomposed China's energy intensity changes between 1997 and 2002 into sectoral structural effects and efficiency effects. The results showed that in this period, efficiency effects possibly contributed to a majority of the decline of energy intensity, while the contribution from structural effects was less. In future, structural effects in energy conservation should be enhanced.

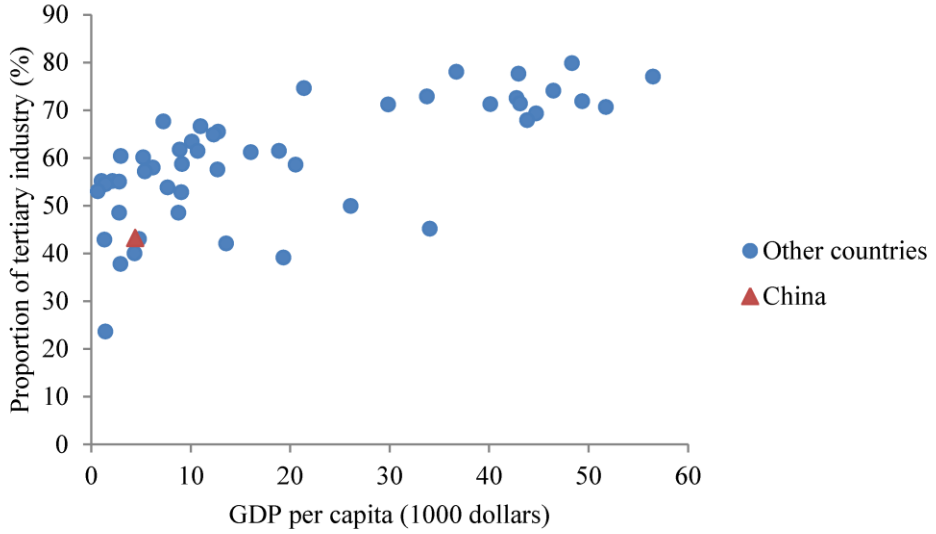

Fig. 1. The proportions of tertiary industry in different countries in 2010.

(Data sources: World bank database)

Industrial structure adjustment is an optimization problem where the proportions of various types of industry are adjusted to satisfy one or more goals. Over the past decades, many optimization methods were used to adjust industrial structure. Bisdorff and Laurent (1995) utilized constraint logic programming (CLP) method to solve the constrained decision problems in the industrial production scheduling. This model aimed to solve a mixed linear multicriteria selection problem and a linear integer multicriteria location problem. Wei et al. (2004) developed a nonlinear goal programming model to research the coordinated development of population, resources, environment, and economy. Kravanja and Zula (2010) applied the mixed-integer non-linear programming (MINLP) approach to present the simultaneous cost, topology and standard cross-section optimization of single-storey industrial steel building structures. Zhou (2012) developed an inexact fuzzy multi-objective programming model (IFMOP) for dealing with industrial structure optimization problems under uncertainty, and used this model to optimize the industrial structure of South Four Lake watershed in Shandong province, China. Cong and Shen (2014) developed a renewable power optimization model (RPOM) to assess the optimal development paths of renewable in a cost-effective way. The results showed that the rise of on-grid ratio of renewable power will first promoted the development of wind power and then solar power and biomass power.

In this study, an optimization model is developed based on the Input-Output model to assess the potential impacts of industrial structure on the energy consumption and CO_2 emission. The method is applied to a case study of industrial structure adjustment in Beijing, China. The rest of the paper is organized as follows. Section 2 introduces the methodology. Section 3 shows the investigation and data. Section 4 presents the results, while Section 5 provides some concluding remarks.

2. Methodology

2.1 Research framework

An optimization model is developed based on the Input-Output model in this paper. The adjusted industrial structures of Beijing in 2020 are obtained by the model. The initial industrial structure in 2010 is chosen as baseline as usual (BAU). The potential impacts of industrial structure are assessed by the comparisons between the adjusted structures and initial structure. Fig. 2 demonstrates the research framework.

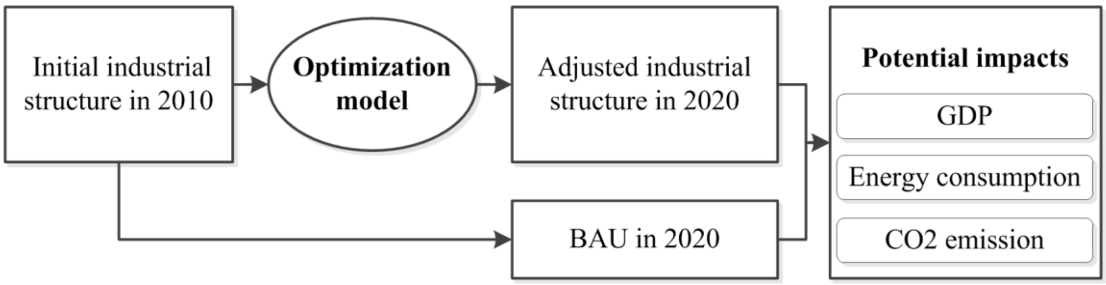

Fig. 2. The research framework.

2.2 Objectives of the optimization model

The objectives are of great importance in optimization models. As for industrial structure planning, multiple objectives need to be taken into consideration including economic objectives, energy objectives, and carbon emission objectives. In this model, maximization of GDP is chosen as economic objective, minimization of energy intensity (energy consumption per unit GDP) and minimization of energy consumption are chosen as energy objectives, and minimization of carbon intensity (CO_2 emission per unit GDP) and minimization of CO_2 emission are chosen as carbon emission objectives.

Objective 1: Maximization of GDP

$$\text{Max } G = \sum_{i=1}^{n} v_i \quad (1)$$

Objective 2: Minimization of energy intensity

$$\text{Min } \mathrm{E}/G \quad (2)$$

Objective 3: Minimization of energy consumption

$$\text{Min } E = \sum_{i=1}^{n} b_i v_i \quad (3)$$

Objective 4: Minimization of carbon intensity

$$\text{Min } C/G \quad (4)$$

Objective 5: Minimization of CO_2 emission

$$\text{Min } C = \sum_{i=1}^{n} d_i v_i \quad (5)$$

where G is the GDP in the target year; v_i is the added value of sector i in the target year; n is the number of sectors; E is the total energy consumption in the target year; b_i is the sectoral energy intensity (energy consumption per unit added value) of sector i; C is the total CO_2 emission in the target year; and d_i is the sectoral carbon intensity (CO_2 emission per unit added value) of sector i.

2.3 Constraints of the optimization model

2.3.1 Constraints of basic linear equations of Input-Output model

The Input-Output (I-O) model is an analytical framework developed by Wassily Leontief in the late 1930s (Leontief, 1936). The main purpose of the I-O model is to establish a tessellated I-O table and a system of linear equations. An I-O table shows monetary interactions or exchanges between the economic sectors and therefore their interdependence. The rows of an I-O table describe the distribution of a sector's output throughout the economy, while the columns describe the inputs required by a particular sector to produce its output (Miller and Blair, 1985). The basic linear equations of this system are

$$\left(I - A\right) X = Y \quad (6)$$

$$(I - A_c) X = V \quad (7)$$

where (suppose there are n sectors in the economy) X is the total output vector in the target year with n dimensions whose element x_j is the output of sector j; Y is the final demand vector in the target year with n dimensions whose element y_j is the final demand of sector j (final demand consists of consumption, capital formation, and net export); V is the added value vector in the target year with n dimensions whose element v_j is the added value of sector j; I is the $n \times n$ dimension identity matrix; A is the direct requirement matrix with $n \times n$ dimensions whose element a_{ij} denotes the direct requirement of sector i for per unit output of sector j; a_{ij} is obtained through

$$a_{ij} = \frac{x_{ij}}{x_j} \quad (i, j = 1, 2, ..., n) \tag{8}$$

where x_{ij} is the monetary value from sector i to sector j; and A_c is obtained through

$$A_c = \begin{pmatrix} \sum_{i=1}^{n} a_{i1} & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & \sum_{i=1}^{n} a_{in} \end{pmatrix} \tag{9}$$

2.3.2 Economic development constraints

Energy saving and emission reduction both possibly have negative impacts on economic development. In order to guarantee stable social and economic development, it is constrained that the average annual growth rate of GDP is greater than λ.

$$G = \sum_{i=1}^{n} v_i \tag{10}$$

$$G \geq (1 + \lambda)^t G_0 \tag{11}$$

where G is the GDP in the target year; G_0 is the GDP in the basic year; t is the number of years between the base year and the target year; λ is an exogenous parameter.

2.3.3 Energy consumption constraints

The development of economy is supported by energy resources, especially fossil energy. For most areas, however, energy supply is limited. In order to control the energy consumption, it is constrained that the average annual growth rate of total energy consumption is less than μ_1, and the energy intensity is reduced by over μ_2 from the basic year to the target year.

$$E = \sum_{i=1}^{n} b_i v_i \tag{12}$$

$$E \leq (1 + \mu_1)^t E_0 \tag{13}$$

$$E/G \leq (1 - \mu_2) E_0 / G_0 \tag{14}$$

where E is the total energy consumption in the target year; E_0 is the total energy consumption in the basic year; b_i is the sectoral energy intensity of sector i; μ_1 and μ_2 are exogenous parameters.

2.3.4 CO_2 emission constraints

CO_2 emission from energy consumption is one of the main reasons for global warming. Most countries have taken measures to reduce CO_2 emission or control the growth rate of CO_2 emission. For instance, Chinese government has set the target to cut CO_2 emission per unit of GDP by 17% in the period of 2011 to 2015. Therefore, it is constrained that the average annual growth rate of total CO_2 emission is less than φ_1, and the carbon intensity is reduced by over φ_2 from the basic year to the target year.

$$C = \sum_{i=1}^{n} d_i v_i \tag{15}$$

$$C \le (1+\varphi_1)^t C_0 \tag{16}$$

$$C/G \le (1-\varphi_2) C_0/G_0 \tag{17}$$

where C is the total CO_2 emission in the target year; C_0 is the total CO_2 emission in the basic year; d_i is the sectoral carbon intensity of sector i; φ_1 and φ_2 are exogenous parameters.

2.3.5 Employment constraints

Employment is one of the most important issues in macroeconomic planning. Beijing has set the target that the urban unemployment rate is less than 3.5% in 2015. In order to control the unemployment rate, it is constrained that the average annual growth rate of employment opportunities is more than η from the basic year to the target year.

$$P = \sum_{i=1}^{n} q_i v_i \tag{18}$$

$$P \ge (1+\eta)^t P_0 \tag{19}$$

where P is the total employment opportunities in the target year; P_0 is the total employment opportunities in the basic year; q_i is the employment opportunities per unit added value for sector i; η is an exogenous parameter.

2.3.6 Industry diversity constraints

In an area, we cannot only develop a/few economic sector(s). Diverse industries should be developed so as to satisfy local social request. In addition, the industrial structure cannot be adjusted freely within a period of time. Therefore, the lower limit and upper limit of the proportions of sectoral added value are constrained in the model.

$$v_i/G \ge (1+\alpha_i) v_{0i}/G_0 \quad (i = 1, 2, ..., n) \tag{20}$$

$$v_i/G \le (1+\beta_i) v_{0i}/G_0 \quad (i = 1, 2, ..., n) \tag{21}$$

where v_i is the added value in the target year of sector i; v_{0i} is the added value in the basic year of sector i; α_i and β_i are exogenous parameters.

2.3.7 Consumption and investment constraints

Final demand consists of consumption, capital formation, and net export,

$$y_i = r_i + f_i + h_i \quad (i = 1, 2, ..., n) \tag{22}$$

where y_i, r_i, f_i, and h_i are the final demand, consumption, capital formation, and net export in the target year of sector *i*, respectively.

For every sector, the proportions of consumption, capital formation, and net export are assumed to be constant.

$$r_i / y_i = r_{0i} / y_{0i} \quad (i = 1, 2, ..., n) \tag{23}$$

$$f_i / y_i = f_{0i} / y_{0i} \quad (i = 1, 2, ..., n) \tag{24}$$

$$h_i / y_i = h_{0i} / y_{0i} \quad (i = 1, 2, ..., n) \tag{25}$$

where y_{0i}, r_{0i}, f_{0i}, and h_{0i} are the final demand, consumption, capital formation, and net export in the basic year of sector *i*, respectively.

Eq. (26) and (27) gives the lower limit and upper limit of consumption rate. In order to satisfy the household and government consumption request, the adjusted industrial structure should provide basic consumption. Therefore, it is constrained that the ratio of consumption of sector *i* between the target year and the basic year is greater than δ_i.

$$\sum_{i=1}^{n} r_i \Big/ G \geq \gamma_1 \tag{26}$$

$$\sum_{i=1}^{n} r_i \Big/ G \leq \gamma_2 \tag{27}$$

$$r_i / r_{0i} \geq \delta_i \quad (i = 1, 2, ..., n) \tag{28}$$

where γ_1, γ_2, and δ_i are exogenous parameters.

2.3.8 Nonnegative constraints

In the economy, the total output and added value should be positive.

$$X \geq 0 \tag{29}$$

$$V \geq 0 \tag{30}$$

3. Case study

3.1 The study area

Beijing, the capital of China, is the political and cultural center (Fig. 3)Beijing has adjusted its industrial structure greatly in the past several decades. In 1978, Beijing depended on the secondary industry which occupied 71.1% of GDP. Then, Beijing made great efforts to develop the tertiary industry. As a result, Beijing's tertiary industry accounted for 76.1% of GDP in 2011, which was much greater than the proportion of secondary industry (23.1%).

In recent years, Beijing's economy developed rapidly, and the average annual growth rate of GDP is 16.04% in the period of 2000 to 2011.Accordingly, Beijing's energy consumption increased at a rate of 4.88% during this period. In 2011, the total energy consumption of Beijing has reached to 69.95 million tons of standard coal equivalent (Mtce). In order to reduce energy consumption and mitigate climate change, Beijing government has set the target to cut energy consumption per unit of GDP by 17% during the period of 2011 to 2015 (State Council, 2011a).

Fig. 3. Location of Beijing.

(Note: It is a schematic map and does NOT implicate the definite boundaries.)

3.2 Data sources

In this case, we use the data of Beijing in 2010 to assess the potential impacts of industrial structure on energy consumption and CO_2 emission in 2020. The data of I-O table are derived from *Beijing Input-Output Table 2010* (Beijing Municipal Bureau of Statistics, 2011a), and other data are derived from *Beijing Statistical Yearbook 2011* (Beijing Municipal Bureau of Statistics, 2011b). The economic activity of Beijing is divided into 42 sectors in the Input-Output table. The codes and names of sectors are listed in Table 1.

Table 1 Sector full names and their codes

Code	Full name of sector	Code	Full name of sector
S1	Farming, Forestry, Animal Husbandry and Fishery	S22	Scrap and Waste
S2	Mining and Washing of Coal	S23	Production and Supply of Electric Power and Heat Power
S3	Extraction of Petroleum and Natural Gas	S24	Production and Distribution of Gas
S4	Mining of Metal Ores	S25	Production and Distribution of Water
S5	Mining and Processing of Nonmetal Ores	S26	Construction
S6	Manufacture of Foods and Tobacco	S27	Transportation and Storage
S7	Manufacture of Textile	S28	Posts and Telecommunications

S8	Manufacture of Textile Wearing Apparel, Footwear, Caps, Leather, Fur, Feather (Down) and Its products	S29	Information Transmission, Computer Service and Software
S9	Processing of Timbers and Manufacture of Furniture	S30	Wholesale Trade and Retail Trade
S10	Papermaking, Printing and Manufacture of Articles for Culture, Education and Sports Activities	S31	Hotel and Restaurants
S11	Processing of Petroleum, Coking, Processing of Nuclear Fuel	S32	Finance
S12	Chemical Industry	S33	Real Estate Trade
S13	Manufacture of Nonmetallic Mineral Products	S34	Tenancy and Commercial Service
S14	Smelting and Rolling of Metals	S35	Research and Development Service
S15	Manufacture of Metal Products	S36	Compositive Technical Service
S16	Manufacture of General Purpose and Special Purpose Machinery	S37	Water, Environment and Municipal Engineering Conservancy
S17	Manufacture of Transport Equipment	S38	Resident Services and Other Services
S18	Manufacture of Electrical Machinery and Equipment	S39	Education
S19	Manufacture of Communication Equipment, Computer and Other Electronic Equipment	S40	Health Care, Social Security and Social Welfare
S20	Manufacture of Measuring Instrument and Machinery for Cultural Activity and Office Work	S41	Culture, Art, Sports and Recreation
S21	Manufacture of Artwork, Other Manufacture	S42	Public Manage and Social Organization

3.3 Exogenous parameters in the model

When setting the exogenous parameters, we reference government plans including *comprehensive work plan for energy conservation and emission reduction during the Twelfth Five-Year Plan period* (State Council, 2011a) and *the Twelfth Five-Year Plan for the national economic and social development of Beijing* (Beijing Municipal Commission of Developement and Reform, 2011). Table 2 shows the settings of all exogenous parameters in the model.

Table 2 The settings of exogenous parameters in the model

Parameter	Meaning of parameter	Setting	Assumption and explanation
λ	The lower limit of the average annual growth rate of GDP	0.07	The average annual growth rate of GDP is over 8% from 2011 to 2015 (government plans). The average annual growth rate of GDP is over 6% from 2016 to 2020 (growth rate slows down).

μ_1	The upper limit of the average annual growth rate of total energy consumption	0.03	The average annual growth rate of total energy consumption is less than 3% (according to historical data, the average annual growth rate was 3.8% from 2006 to 2010).
μ_2	The energy intensity reduction target	0.29	The energy intensity is reduced by over 17% from 2011 to 2015 (government plans). The energy intensity is reduced by over 15% from 2016 to 2020 (government plans).
φ_1	The upper limit of the average annual growth rate of CO_2 emission	0.025	According to the upper limit of the average annual growth rate of total energy consumption (μ_1).
φ_2	The carbon intensity reduction target	0.35	According to the energy intensity reduction target (μ_2).
η	The lower limit of the average annual growth rate of employment opportunities	0.06	The average annual growth rate of employment opportunities is larger than 6% (according to historical data, the average annual growth rate was 5.7% from 2001 to 2010).
α_i	The lower limit of the adjustment of the proportion of sector *i*'s added value	-0.5	From 2001 to 2010, most of the change rates of sector's proportions were greater than -50%.
β_i	The upper limit of the adjustment of the proportion of sector *i*'s added value	1.5	From 2001 to 2010, most of the change rates of sector's proportions were less than 150%.
γ_1	The lower limit of the consumption rate	0.6	In 2015, the consumption rate is greater than 60% (government plans).
γ_2	The upper limit of consumption rate	0.85	In 2011, the consumption rate was 83.4%.
δ_i	The lower limit of the ratio of consumption of sector *i* between the target year and the basic year	1	For every sector, the consumption in 2020 is greater than that in 2010.

4. Result analysis and discussions

Based on the optimization model, the adjusted structures of Beijing with the five objectives in 2020 are obtained. In addition, the initial industrial structure in 2010 is chosen as baseline as usual (BAU). In BAU scenario, it is supposed that the GDP is the same as Objective 1 (maximization of GDP). Fig. 4 shows the results of adjusted structures and initial structure in 2020 in Beijing.

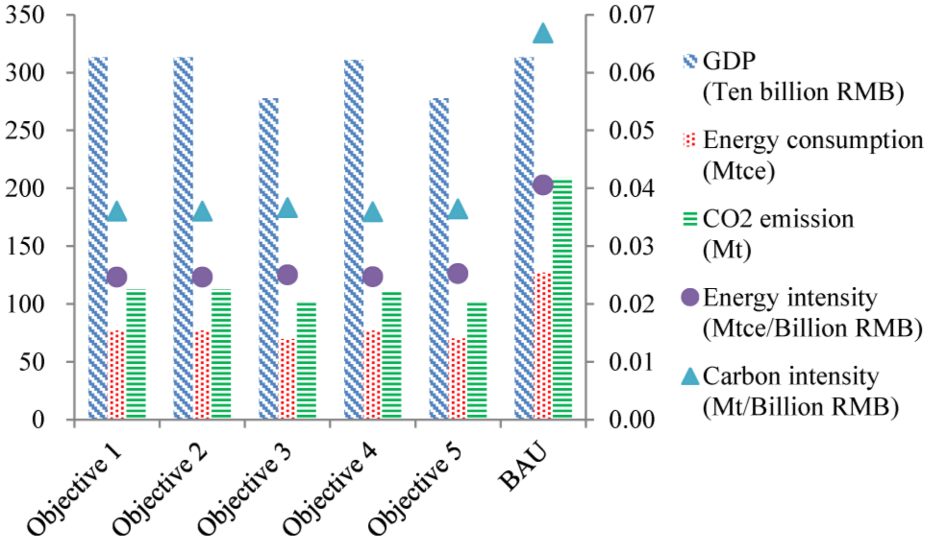

Fig. 4. Comparisons of adjusted structures and initial structure in 2020 in Beijing.

(Note: GDP, Energy consumption, and CO_2 emission are measured by left coordinate axis. Energy intensity and carbon intensity are measured by right coordinate axis.)

4.1 Industrial structure adjustment saves energy and reduce CO_2 emission remarkably

The energy intensity and carbon intensity in Beijing both decline considerably through industrial structure adjustment. Compared to initial industrial structure (BAU), the energy intensity and carbon intensity of adjusted structures (Objective 1-5) are much smaller. In objective 1, the GDP of Beijing rises from 1,411 billion RMB in 2010 to 3,131 billion RMB in 2020 with an average annual growth rate of 8.29%. The energy consumption and CO_2 emission are 112.79 Mtce and 76.93 Mt, respectively. With initial industrial structure, however, Beijing will consume 209.11 Mtce and produce 126.99 Mt CO_2 emission to get the same GDP (3,131 billion RMB). Therefore, industrial structure adjustment can save energy by 39.42% (50.06 Mtce), and reduce CO_2 emission by 46.06% (96.31 Mt).

4.2 Sectors which are low energy intensive and low carbon intensive develop fast

Fig. 5 shows the sectoral added value in 2010 and 2020, sectoral energy intensity, and sectoral carbon intensity in Beijing. It can be seen that added value of all sectors increases. On the one hand, sectors which are low energy intensive and low carbon intensive develop fast. S32 (Finance) is the fastest developing sector with an average annual growth rate of 18.69%. The added value of S32 is 1,033 billion RMB which accounts for 33.01% of GDP in 2020. In fact, the S32's energy intensity (0.0023 Mtce/Billion RMB) and carbon intensity (0.0007 Mt/Billion RMB) are much lower compared to other sectors in Beijing. S29 (Information Transmission, Computer Service and Software) and S20 (Manufacture of Measuring Instrument and Machinery for Cultural Activity and Office Work) also develop fast with average annual growth rates of 16.23% and 15.39%, respectively. On the other hand, sectors which are high energy intensive and high carbon intensive develop slow. S22 (Scrap and Waste) is the slowest developing sector with an average annual growth rate of 1.04%. The added value of S22 occupies 0.0067% of GDP which is the smallest proportion. In fact, S22's energy intensity (0.1971 Mtce/Billion RMB) and carbon intensity (0.2049 Mtce/Billion RMB) are much higher than those of other sectors in Beijing. S7 (Manufacture of Textile) and S24 (Production and Distribution of Gas) also develop slow.

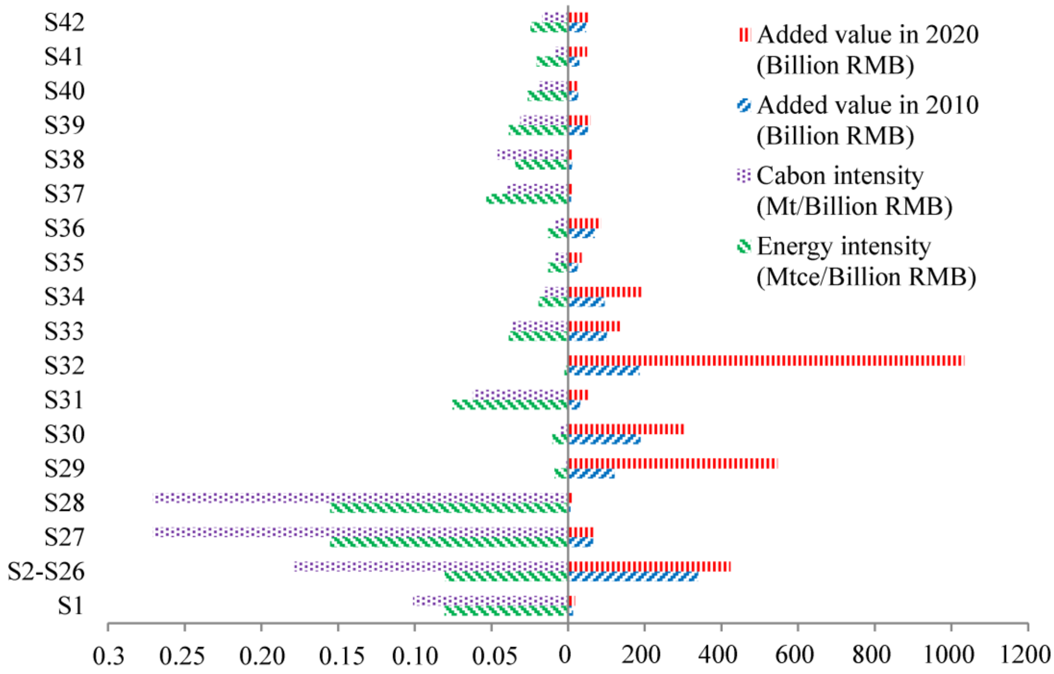

Fig. 5. Added value in 2010 and 2020, energy intensity, and carbon intensity.

The proportion of tertiary industry increases, while the proportion of secondary industry decreases. To be specific, proportion of tertiary industry goes up from 75.11% in 2010 to 85.90% in 2020 with a growth rate of 14.37% (Fig. 6). On the contrary, the proportion of secondary industry declines from 24.01% to 13.53% during the same period. This change is beneficial for energy conservation and emission reduction, because the average energy intensity and carbon intensity of tertiary industry are both less than those of secondary industry in Beijing.

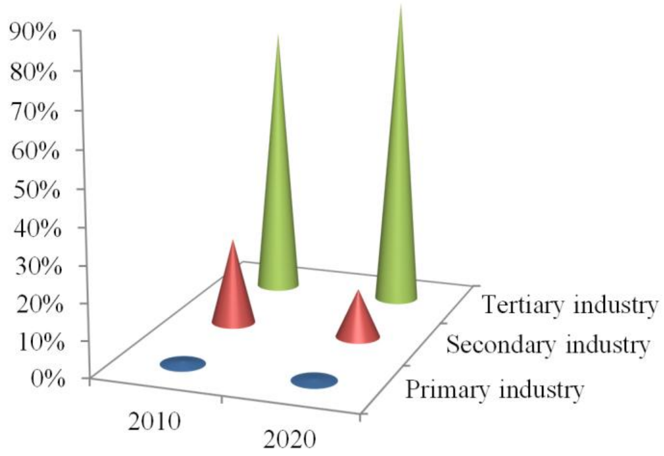

Fig. 6. The proportions of primary industry, secondary industry, and tertiary industry.

4.3 Energy intensity is possible to decrease without negatively affecting economic growth

According to Fig. 4, the results of objective 1 (maximization of GDP) and objective 2 (minimization of energy intensity) are the same. In other words, energy intensity reaches the minimum when GDP reaches the maximum. On the one hand, energy intensity is possible to decrease without negatively affecting economic growth by reasonable industrial structure adjustment. On the other hand, the rapid growth of economy may be beneficial to reduce energy intensity. From 2010 to 2020, energy intensity declines by 37.87% when the average annual growth rate of GDP is 7% (objective 5), energy intensity declines by 39.10% when the average annual growth rate of GDP is 8.22% (objective 4), and energy intensity declines by 39.35% when the average annual growth rate of GDP is 8.29% (objective 1).

4.4 Total amount targets are more effective on the energy conservation and carbon reduction than intensity targets

There are two kinds of targets for energy conservation and carbon reduction including total amount targets and intensity targets. Total amount targets mean to control energy consumption and CO_2 emission, while intensity targets mean to control energy intensity and carbon intensity. In the model, objective 3 (minimization of energy consumption) and objective 5 (minimization of CO_2 emission) are total amount targets, while objective 2 (minimization of energy intensity) and objective 4 (minimization of carbon intensity) are intensity targets.

Total amount targets are more effective on the energy conservation and carbon reduction than intensity targets. First, energy consumption of intensity target (objective 2) increases by 34.29%, while energy consumption of total amount target (objective 3) only increases by 21.38%. Second, CO_2 emission of intensity target (objective 4) increases by 18.58%, while CO_2 emission of total amount target (objective 5) only increases by 7.30%.

However, total amount targets have greater negative effects on economic growth than intensity targets. Beijing's GDP of total amount targets (objective 3 and objective 5) is 2,776 billion RMB in 2020, while GDP of intensity targets (objective 2 and objective 4) is 3,130 and 3,109 billion RMB, respectively. In addition, carbon emission trading (CET) market is an effective way to realize total amount targets. It works by first giving participants a limit on emission permits, and then allowing them to buy or sell permits in the market (Pizer, 2002). The CET market increases enterprise's production cost. For instance, if China implements CET to reduce CO_2 emissions, the average electricity price may be increased by 12% (Cong and Wei, 2010).

5. Conclusions

An optimization model is developed based on the Input-Output model to assess the potential impacts of industrial structure on the energy consumption and CO_2 emission. The method is applied to a case study of industrial structure adjustment in Beijing, China. According to the results, several conclusions can be gained.

(1) Industrial structure adjustment has great potential of energy conservation and carbon reduction. When the average annual growth rate of GDP is 8.29% from 2010 to 2020, industrial structure adjustment can save energy by 39.42% (50.06 Mtce), and reduce CO_2 emission by 46.06% (96.31 Mt) in Beijing in 2020. As a result, the energy intensity and carbon intensity decline considerably through industrial structure adjustment.

(2) Raising the proportion of sectors which are low energy intensive and low carbon intensive is an effective method to save energy and reduce carbon emission. To be specific, Beijing had better strive to develop several low energy intensive and low carbon intensive sectors including S32 (Finance), S29 (Information Transmission, Computer Service and Software), and S20 (Manufacture of Measuring Instrument and Machinery for Cultural Activity and Office Work). On the contrary, the development of several high energy intensive and high carbon intensive sectors had better be strictly controlled including S22 (Scrap and Waste), S7 (Manufacture of Textile) and S24 (Production and Distribution of Gas).

(3) Energy intensity is possible to decrease without negatively affecting economic growth by reasonable industrial structure adjustment. Moreover, the rapid growth of economy may be beneficial to reduce energy intensity.

(4) Compared to intensity targets, total amount targets are more effective on the energy conservation and carbon reduction, but have much greater negative effects on economic growth. Therefore, it needs to be balanced between total amount targets and intensity targets.

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