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# Potential impacts of industrial structure on energy consumption and $CO_2$ emission: a case study of Beijing

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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 $CO_2$ 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".

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## 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-Antolínez, 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 2011–2015 (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 by change 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

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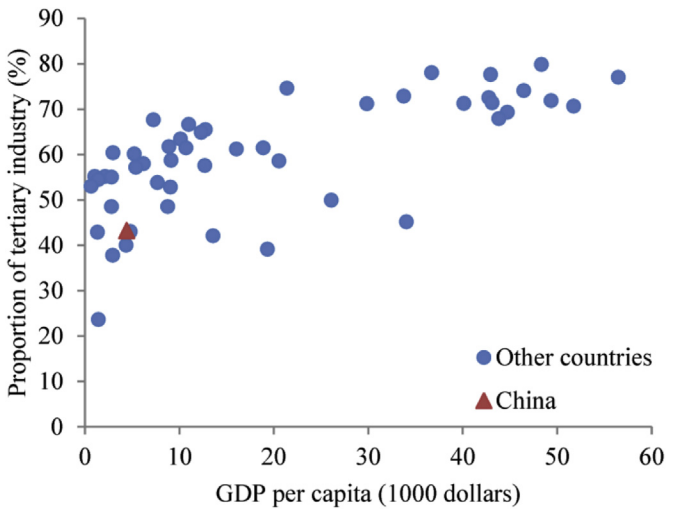



**Fig. 1.** The proportions of tertiary industry in different countries in 2010. (Data sources: World bank database).

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.

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 et al. (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.

### 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

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

**Objective 2**: Minimization of energy intensity

$$\text{Min } E/G \tag{2}$$

**Objective 3**: Minimization of energy consumption

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

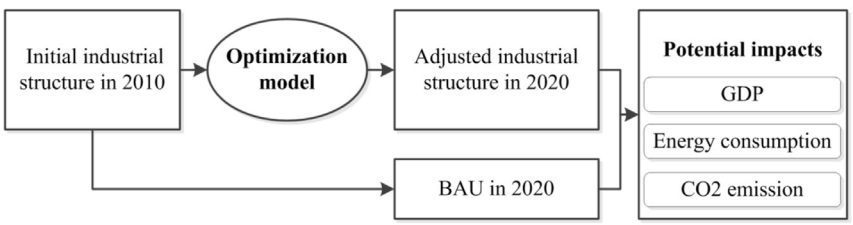



**Fig. 2.** The research framework.

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**Objective 4**: Minimization of carbon intensity

$$\text{Min } C/G \tag{4}$$

**Objective 5**: Minimization of $CO_2$ emission

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

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

$$(I - A)X = Y \tag{6}$$

$$(I - A_c)X = V \tag{7}$$

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

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

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 $\lambda$.

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

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

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; $\lambda$ 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 $\mu_1$, and the energy intensity is reduced by over $\mu_2$ 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 $i$; $\mu_1$ and $\mu_2$ 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 GDP by 17% in the period of 2011–2015. Therefore, it is constrained that the average annual growth rate of total $CO_2$ emission is less than $\varphi_1$, and the carbon intensity is reduced by over $\varphi_2$ from the basic year to the target year.

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

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

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

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 $i$; $\varphi_1$ and $\varphi_2$ 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 $\eta$ from the basic year to the target year.

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

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

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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 $i$; $\eta$ 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.

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

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

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 $i$; $\alpha_i$ and $\beta_i$ are exogenous parameters.

#### 2.3.7. Consumption and investment constraints

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

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

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.

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

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

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

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.

Eqs. (26) and (27) give 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 $\delta_i$.

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

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

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

where $\gamma_1$, $\gamma_2$, and $\delta_i$ 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 was 16.04% from 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 reached to 69.95 million tons of standard coal equivalent

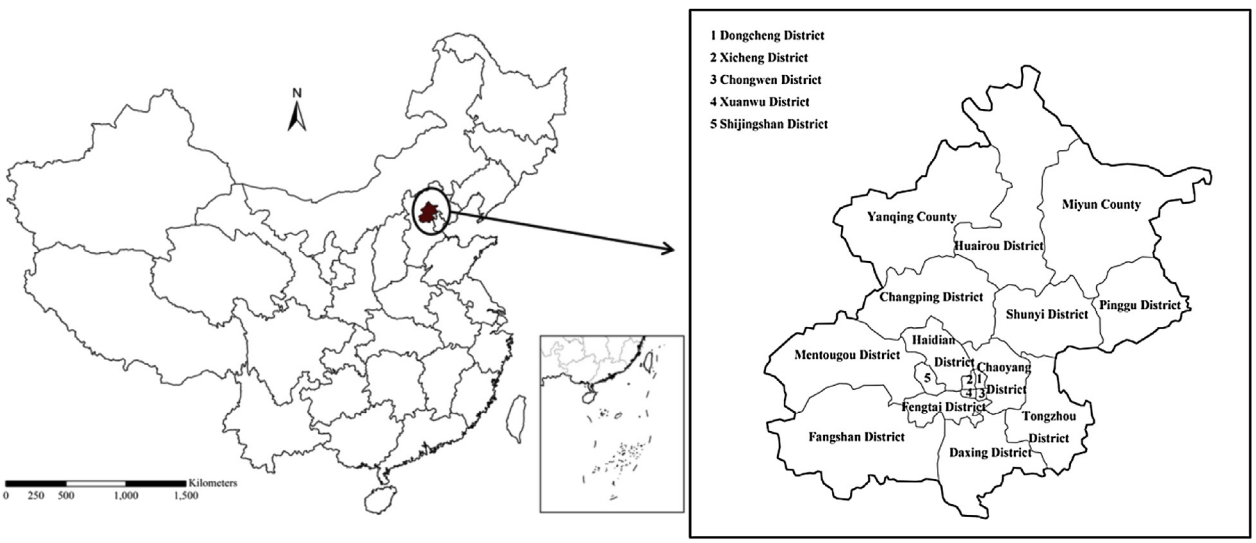



**Fig. 3.** Location of Beijing. It is a schematic map and does NOT implicate the definite boundaries.

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(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 2011–2015 (State Council, 2011a).

### 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.

### 3.3. Exogenous parameters in the model

When setting the exogenous parameters, we reference government plans including *the 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.

## 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.

### 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 1411 billion RMB in 2010 to 3131 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 (3131 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 1033 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

**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 |

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**Table 2**
The settings of exogenous parameters in the model.

| Parameter | Meaning of parameter | Setting | Assumption and explanation |
|---|---|---|---|
| $\lambda$ | 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). |
| $\mu_1$ | 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). |
| $\mu_2$ | 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). |
| $\varphi 1$ | 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 ($\mu_1$). |
| $\varphi 2$ | The carbon intensity reduction target | 0.35 | According to the energy intensity reduction target ($\mu_2$). |
| $\eta$ | 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). |
| $\alpha i$ | 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%. |
| $\beta i$ | 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%. |
| $\gamma 1$ | The lower limit of the consumption rate | 0.6 | In 2015, the consumption rate is greater than 60% (government plans). |
| $\gamma 2$ | The upper limit of consumption rate | 0.85 | In 2011, the consumption rate was 83.4%. |
| $\delta i$ | 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. |

(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.

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.

### 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).

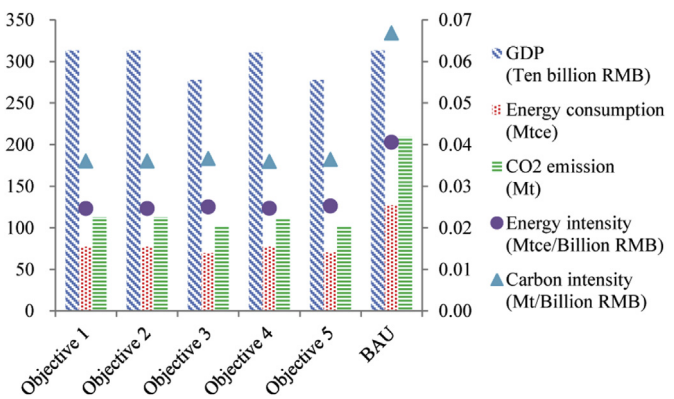



**Fig. 4.** Comparisons of adjusted structures and initial structure in 2020 in Beijing. (Note: GDP, Energy consumption, and $CO_2$ emission are measured by left coordinate axis. Energy intensity and carbon intensity are measured by right coordinate axis.)

### 4.4. 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 2776 billion RMB in 2020, while GDP of intensity targets (objective 2 and objective 4) is 3130 and 3109 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

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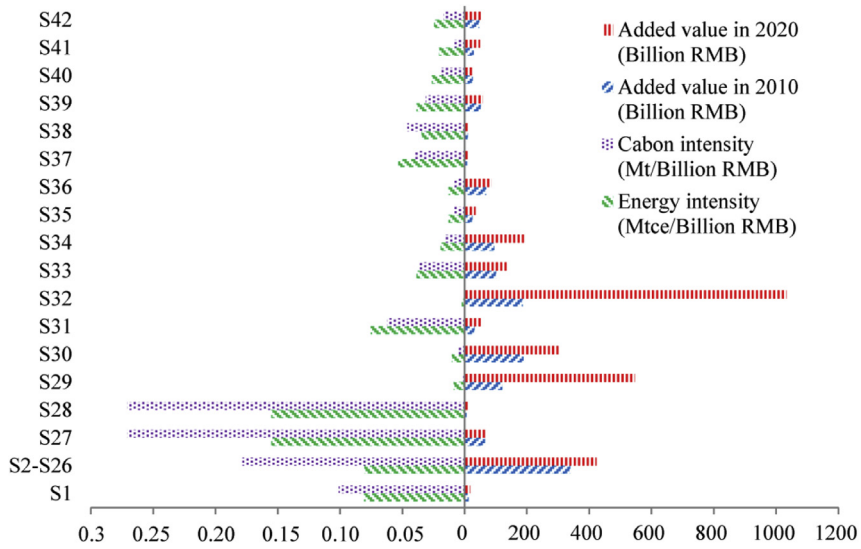



**Fig. 5.** Added value in 2010 and 2020, energy intensity, and carbon intensity.

$CO_2$ 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.

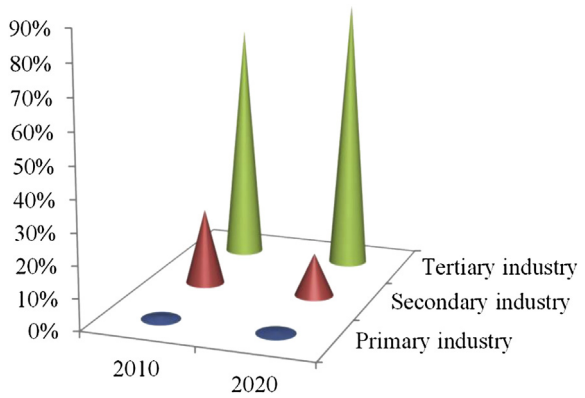



**Fig. 6.** The proportions of primary industry, secondary industry, and tertiary industry.

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