**Restructuring Regional Economic Structure to Reduce Greenhouse Gas Emissions using an Interregional Input-Output Model[[1]](#endnote-1)**

**Xue Fu1, Zhang Yaxiong2, Klaus Hubacek3, Kuishuang Feng4, Bo Meng5 Michael Lahr6**

1. Associate Professor, Nanchang University, Nanchang, China, 330029, tel: 021 64323747 / fax: 021 64322100, fuxue@amss.ac.cn.
2. National Information Center, Beijing.
3. Professor, Department of Geographical Sciences, University of Maryland, College Park, USA.
4. Research assistant professor, Department of Geographical Sciences, University of Maryland, College Park, USA.
5. Research fellow, Institute of Development Economies-JETRO.
6. Associate research professor, EJB School of Planning & Public Policy, Rutgers University, New Brunswick, USA

**Abstract**

China promises to decrease carbon intensity by 40% -45% of its 2005 level by 2020. We use an Energy-Carbon-Economy Interregional Input-Output (ECEIRIO) table to examine industry adjustment to this goal. Under constraints of regional carbon emissions by industry with the aim of maximizing GDP, we find that it is necessary to decrease energy (i.e. production of thermal power, heat, and gas) and heavy industry in the Northeast and North Coast regions, while increasing the output share of high-tech in the South Coast region and selected services in most regions except Southwest. A slower growing economy puts ever more pressure on carbon emissions reduction and requires more industry adjustments, especially in the Central. The energy mix improvement can lessen the Central pressure of carbon reduction in heavy industry and energy industry.

Key word: input-output analysis, carbon emissions, industry structure

1. **Introduction**

As the high speed of economic development and population rose over the last few decades in China, its energy production and consumption increased substantially. According to the US Energy Information Administration (EIA),[1] China emitted 8.715 billion metric tons of carbon dioxide in 2011, accounting for 26.7% of the world’s total emissions and surpassing the US as the world's largest emitter (EIA, 2012). Under international pressure, China established a long-term target for 2020 to reduce carbon dioxide emissions per GDP (carbon intensity) by 40%-45% of the 2005 level. China is also committed to generate 15% of its primary energy from non-fossil sources by 2020. At midterm, the 12th five-year plan seeks to reduce the carbon intensity of China’s economy by 17% from 2010 levels by 2015, with regional efforts ranging from a 10% reduction of carbon intensity in China’s less developed West to a 19% reduction in the East Coast provinces. The strategy to reduce regional carbon emissions should be made logically based on the trajectory of regional development and economy structure. Since the structure of energy resources is unlikely to change in the near future, industrial shifts, energy conservation, and investment in energy-efficient technology are key to reducing carbon emissions.

Figure 1 shows the trend in carbon intensity using market exchange rates (sources from EIA) from 1995 to 2009 for the six largest emitters in the world. Next to Russia, China’s carbon intensity was the second highest in the world before 2004. It has been the highest sincethen. China reduced emissions radically from 3.053 metric tons of CO2 per US $1,000 (in 2005 constant prices) in 1995 to 1.935 metric tons per US $1,000 in 2001. But it slipped back to 2.219 metric tons per US$1,000 in 2009.

<Insert Figure 1>

Through its central planning, China is capable of adjusting its industrial structure to reduce carbon dioxide emissions. Still, different strategies can be applied to reduce carbon emissions is due to regional differences in economic structure, energy efficiency, and life qualities. Figure 2 shows the share of value added, final demand, energy consumption and carbon emission across China’s eight regions, covering 31 provinces (see Table 1).[[2]](#endnote-2) The shares of value added and final demand are greater but the shares of energy consumption and carbon emission are lower in the affluent North Municipalities (Beijing and Tianjiang), the East Coast, and South Coast regions.[[3]](#endnote-3) The shares of value added and final demand are lower while the shares of energy consumption and carbon emissions are greater in the less developed Northeast, North Coast, Central, Northwest, and Southwest regions. Therefore, there is more room for China to reduce carbon intensity of production in its less developed West than there is for it to reduce industry emissions in its East Coast provinces. ,This is because the less-developed regions rely on heavy industry as they are generally resource-rich, while the East Coast regions rely on the production of goods with high technical content and a service economy.

 China’s economy is integrated: Its production and consumption at the regional level are diverse and interrelated. Thus energy use and carbon emissions embodied in interregional trade must be considered within any industry-based strategy. From an interregional perspective, China’s undeveloped regions apparently discharge carbon emissions to enable consumption or exports of developed regions (Meng et al., 2013).[2] Thus, some care must be taken when setting industry adjustments or emissions targets, since they must vary from region to region to minimize exacerbation of any interregional welfare imbalances. We will enable such an examination by using an energy-carbon-economy interregional input-output model (ECEIRIO model), which displays the Chinese economy as an integrated system in which regional economies and their resource endowments are interconnected via production and consumption, with a special focus on energy use and embodied carbon emission in interregional trade.

<Insert Figure 2>

<Insert Table 1>

Much recent research has used input-output models to analyze drivers of carbon emissions and the effects of China’s economy on carbon emissions (Peters, et al., 2010, Weber, et al., 2008, Guan, et al., 2009, Feng, et al. 2009, Minx, et al., 2011).[3-7] Modeling industry structural adjustment requires constraining adjustment by input-output technology (Dorfman et al. 1958). [8] Linear programming has been combined with input-output table for decision making purposes by several prior researchers (e.g., Lopez-Morales and Duchin, 2011).[9] In particular, Xia (2010) [10] and Wang et al. (2011) [11] have designed an energy economy that combines an input-output table at national level with linear programming aiming at energy consumption on the condition of production and energy constraints to study China’s industrial restructuring potential for the 11th plan’ energy saving target.

Some studies on energy use and carbon emissions focus at the regional level merely reflecting independent regions’ industrial complexity.[12] A multiregional input-output (MRIO) model, however, provides both the regional information and the interregional information. The Chinese MRIO table tables are provided from 1987 to 2007 (Ichinura and Wang, 2003, Zhang and Qi, 2012, Meng and Qu, 2007). [13-15] Han et al. (2004) investigate change features of Chinese energy intensity and economic structure. Zhang and Lahr (2013) make a multi-regional structural decomposition on China’s energy consumption change from 1987 to 2007.[16] Feng et al. (2013) examine the source of consumption-based carbon emissions using interregional input-output model.[17] Meng et al. (2013) measured the interregional spillover of CO2 emissions (2013).[2] Of course, MRIO models for areas outside of China have been use to examine carbon emissions as well. Lenzen et al. (2010) studied the UK’s carbon footprint by MRIO model,[18] Wiedmann et al. (2010, 2011, 2013) established the data of MRIO model and got institutional requirements, compared the energy footprints embodied in trade, and made environment extensions and policy-relevant application. [19-21]

The aim of this paper first establish China’s Energy-Carbon-Economy Interregional Input-Output optimal model to investigate the extent of interregional industrial structural adjustment that would be required to meet national CO2 target while continuing to maximize GDP. Unlike the previous national energy-concentrated optimal IO model, it focus on the energy-used carbon emission embodied in interregional trade. An input-output table yields an optimal industry structure that maximizes GDP under technological and carbon emissions constraints.

**2. Environment and economy input–output model**

**2.1. Adjusting industrial structure to reduce carbon emissions across region**

China’s 31 provinces can be classified into eight regions. Among the eight regions, the Central region and the North Coast region produce the largest shares of total carbon emissions, 22.3% and 18.6% respectively. The Northern Municipalities and South Coast produce the lowest shares ─3.0% and 8.8%, respectively.

The output shares of 17 industries and their carbon dioxide emissions for each region are shown as figure 3 (the 17 industries are listed in table 2). The energy and heavy industries produce the largest shares of emissions. Not surprisingly, the largest shares of carbon emissions for all regions were generated in the Production and Supply of Electricity, Steam, Gas and Water. Its share was especially high in the Northwest region (54.8%), East Coast region (46.1%), and Northeast region (43.9%). The second largest shares of carbon emissions tended to be those for Smelting and Stamping of Metals & Metal Products: for example, 29.1% in North Coast region, 20.1% in Northern Municipalities, and 19% in the central region. In the South Coast and Southwest, Nonmetal Mineral Products had the second largest shares at 21.2% and 18.7%, respectively. For several regions, Real Estate Finance and Other Services had the largest value added share, 20.4% in Northeast, 18.1% in Southwest, and 11.2% in Northwest. But the value added share of Electric & Telecommunications Equipment was the largest (13.0%) in the South Coast and the second largest (8.0%) in the Northeast. The largest shares of carbon emissions tended to be for Smelting and Stamping of Metals & Metal Products, 8.6% in the North Coast; in the East Coast and Central region, it had the second largest share at 6.4% and 7.4%, respectively. The output share of construction was the second largest in Northwest (8.3%) and Southwest regions (11.8%).

<Insert Figure 3>

<Insert Table 2>

To achieve the national target of reducing carbon emissions, industry structure must change and carbon emissions reduced to different degrees among the different regions, at least if the GDP of China is not to suffer much (See Figure 3). The eight regions each requires nine types of energy and non-energy inputs from its own and other regions, and their production must meet the intermediate and final demand of their own as well as for other regions. For the East Coast region, for example, the adjustment strategy yields two effects. Energy inputs must change to reduce carbon emissions; but an alternative is to substitute domestic industry intermediate inputs with imports to decrease a given industry’s carbon emissions. Heavy industry must be updated and transformed in the Northwest and Central regions, perhaps through foreign direct investment. These actions would improve energy efficiency of technology and, hence, decreasing carbon dioxide emissions.

Although national plans call for total GDP to rise and for carbon intensity to fall in China, the East Coast targets ought necessarily to be different in nature from nation’s. That is, the region should reduce production in industries that emit carbon heavily (heavy industries) and increases in the production of industry that emit little carbon (high technology industries) at rates different from the nation or from every other region. In the East Coast, the direct and indirect carbon emissions caused by production declines in heavy industry more than offsets the direct and indirect carbon emissions caused by proposed production rises in high value added and low carbon-emitting sectors. It would reduce the production in industries with low total demand coefficients for carbon emission, and increase the output of industries with either high total demand coefficients for carbon emission, with high rates of value added, or with both . The adjustment of industry structure and reduction of carbon emissions required of the East Coast region is determined by its own industry mix, energy usage, and GDP yield, as well as by that of other regions upon which it relies through interregional input-output relationships (its supply chain) with other regions.

<Insert Figure 4>

**2.2. Methodology**

The purpose of this study is to discover the potential effect of a change in regional industry structure required to meet national carbon emissions targets. Industry structural adjustments cause a shift in the industry mix shares of the national economy. This, in turn, results in a change in the amount of carbon dioxide produced. A suitable research method is to connect the various inputs, including energy, to the industry production among different regions in the national economy. The production of each industry corresponds to an amount of carbon dioxide released which is related to each industry’s mix of fossil fuel to meet that production. Henceforth, we call “carbon coefficients” the ratio of carbon dioxide emissions to gross industry output. In general, our model should shift production from industries with large carbon coefficients emissions to industries with small carbon coefficients. Thereby, emissions of the country would be reduced.

This research presents a model that optimizes GDP while reducing carbon emissions. That is, it essentially determines the potential capabilities of regions to meet emissions target through production shifts alone. Negative figures identify decreases in GDP shares, and positive figures refer to increases. If an industry’s GDP share can expand, then the given industry has capacity to improve the industry condition so its contribution rise. The potential capability for adjustment of industrial structure in region r is shown as

 (1)

 refers to the ratio of GDP of industry  to the total GDP of in region r,  and are the value added coefficient and the industry output in region r.  and  are respectively the optimal industry structure of industry  and the initial industry structure of industry  in region. The reduction percentage of carbon emissions of each industry in region *r* is

 (2)

and is the amount of carbon emitted in this region before and after optimization.

**2. 3.1 Optimal input-output model**

Carbon emissions are produced when energy resources are consumed. This study strictly focuses on emissions from fossil fuel sources.

The optimization model is enabled as follows

 

Where,  is annual GDP growth, and  is annual rate of carbon emissions.  denotes the direct requirements matrix of the interregional input-output tables,  is the output vector, is the national final demand vector ,  is the vector of industry price index by region that accounts for assumed future price changes. Here,  is the exports vector by region,  is the vector of carbon coefficients by industry in region s,  is national household carbon emissions vector by region,  is the initial total carbon emissions vector by region, is vector of value added coefficient in region s, where subscript and superscript  are lower and upper bounds, respectively. Also  is the initial endowment of GDP. If is the industry price index by region at the target year (2008), then is nominal GDP. While is the industry GDP at constant prices (base year 2007 in this study). All value variables in the constraint equations are also in terms of constant prices. The objective function (3.1) maximizes GDP, namely, the total production less that for intermediate use across all regions; It is subject to five constraints: (3.2) demand balance conditions, which through production technology essentially determines the amount of energy consumed and carbon emitted both directly and indirectly (Lenzen et al., 2010); net real emission reduction targets (3.3) a limit on total carbon emissions; targets (3.4) a GDP minimum, and (3.5) the upper and lower bounds on production and exports. Since carbon intensity reduction is regarded as mandated final target, (3.3) and (3.4) work against each other and are set according to the scenarios presented in Table 3 (see 2.3.2). The model essentially requires only the carbon emissions constraint (3.3) since GDP is maximized automatically, make (3.4) redundant. Rose et al.(1996) set the 75% lower and 125% upper bound of China’s household and institute consumption which are their rough approximation of basic human need.[22] Considering investment increase huge in China, after examining history data of each industry growth by regions in regional IO tables, no sectors have the estimates of output and export that differ by more than 35% and less than 5%.In this competitive IRIO table, imports are reflected by row ratio than by column, so exports, unlike net exports in classic IO table, are considered in the demand balance conditions.

The model calculates China’s optimal industry mix. It is initiated with the base year’s structure. In the case of scenario 2 (see Table 3), the model finds how industry structure might be arranged at the least to realize a 6.35% reduction in carbon emission intensity by the next period. This is equivalent to a 1.14% increase in the amount of carbon emitted when GDP rises by 8%. Here,, ,  are from China’s base-year ECEIRIO table (see Table 4). Carbon emissions are based on final consumption of energy. Endogenous variables are regional production by industry, exports  by industry. Exogenous variables are final demand (including the household consumption and capital formation), the upper bound for total carbon emissions , carbon emissions of households , the lower bound for aggregate GDP , the upper bound for regional production , and the upper bound for exports . All variables are from historic data for the year following China’s 2007 national accounts. The model results in a corner solution. Since household consumption and capital formation are given, the solution maximizes exports. It reflects China’s policy reality of maximizing GDP based on an export-oriented strategy. This is in contrast to developed nations in which household consumption tends to be maximized. China’s welfare is reflected, to avoid the corner solution, in maximizing domestic final demand (including households and government consumption and investment), which are endogenous given in the model (ten Raa et al., 2005) [23].

**2.3.2 Constraint of amount of carbon emission**

Table 3 shows the three scenarios for reduction carbon-intensity: high, middle and low. Each is examined using three different growth rates resulting in nine different perspectives on carbon emissions change. Carbon intensity (), a widely used metric that normalizes carbon releases by economic growth, is the amount of carbon dioxide () per unit of GDP,. China’s goal for the reduction of carbon intensity over 15 years is represented by the following:[[4]](#endnote-4)



Thus, annual carbon-intensity reduction from 2005 to 2020 ranges from -6.76% to -5.93%.[[5]](#endnote-5) We use the mean annualized value of the carbon emissions change target for more detailed analyses. Using three GDP growth rate levels, namely rapid (9%), moderate (8%) and slow (7.5%) from the World Bank forecast[26], we accordingly estimate the changes in carbon emissions required to reduce the intensity of carbon emissions.

<Insert Table 3>

**3 Data**

**3.1 The energy-carbon-economy input-output table**

We designed and compiled an energy-carbon-economy interregional input-output (ECEIRIO) table. It presents the supply of various industries and the demand of these same industries and households. It also embodies carbon dioxide emitted during production and consumption. This table shows the usage of energy by type in each industry by region as well as the embodied carbon emissions. This enables computation of the intensity of carbon emissions by industry. Input by energy type is accounted by both the value and standard physical quantity units, i.e. ton coal equivalent.For instance, one metric ton coal is deemed to be equivalent to 0.7143 Metric ton standard coal, one ton crude oil equivalent to 1.4286 Metric ton standard coal (see *China’s Energy Statistical Yearbook*). The standard coal conversion coefficient transforms the energy consumed by energy resource into the quantity of carbon emissions, for example, one ton standard coal of raw coal emitting 0.7559 ton carbon, while one ton standard coal of crude oil emitting 0.5825 ton carbon (see IPCC). Thus, the table connects the value of the economic system to the quantity of consumed energy of type and embodied carbon emissions. We can calculate the direct and indirect usage of energy, and direct and indirect emitted carbon dioxide for the output of each.

In the ECEIRIO table shown in Table 2, industries are classified into energy and non-energy industries. The energy industry consists of the primary energy industry and the secondary energy industry. The former includes (1) coal extraction, (2) oil extraction, and (3) natural gas producing and extraction (4) hydro power and nuclear power. Primary energy sources are extracted directly from nature without transformation and procession. Secondary energy production includes (5) thermal power, (6) petroleum processing, (7) coking, (8) steam and heat water distribution, and (9) gas distribution. Secondary energy sources have been produced from the transformation of a primary energy source. The energy industry can be classified into the fossil energy and the non-fossil energy sources as well as the renewable and non-renewable energy sources. The industry in (4) uses non-fossil energy and renewable energy; the other industries use fossil energy and non-renewable energy. The energy type, affiliated industry and the carbon coefficient of the energy type are listed in Table A.1. To avoid double computation, China’s National Statistics Bureau merely accounts for primary energy sources’ consumption by industry in its *Energy Statistic Yearbook*; meanwhile, secondary energy sources are converted back to primary energy sources consumption. To distinguish their different consumption structure, it necessary makes classification of primary and secondary energy industry in ECEIRIO table.

<Insert Table 4>

The ECEIRIO table is a hybrid table that combines monetary and physical values. The input of the energy industry is reflected in both monetary and physical units. Carbon emissions are presented in physical units only. The rows of the ECEIRIO table reflect the use of products. Since the value part of ECEIRIO table is the classic interregional input-output table, the introduction of the hybrid IO table concentrates on accounting of the regional energy and carbon emissions in physical value.

The carbon emissions account involves two aspects. The first is to classify energy usage and corresponding carbon emissions. An industry’s carbon emissions are the sum of the products of energy used by resource type multiplied and the energy-carbon conversion coefficient for that industry. .[[6]](#endnote-6) Energy usage in the ECEIRIO table corresponds to the total consumption of energy in *China’s Energy Statistical Yearbook*, which converts all used energy sources into primary energy sources. Instead, the ECEIRIO table accounts the consumption by energy types. The total consumption of energy by an industry is the total amount of energy that is used by that industry.  It includes energy purchased by this industry for its final use in production as well as indirect energy consumption. The latter is the secondary energy self-supply of this industry as \ inputs for its final use in production. For example, the total consumption of energy in the chemical industry includes fuel oil (fuel stocks, excluding feedstocks) and coking coal used to produce chemicals, as well as any fossil fuel used to produce electrical and thermal power which is used for its production. Put in another way, the total consumption of energy () is divided into final consumption of energy （）, processing and transaction of energy（）, and the loss of energy , . The transaction of energy is the input part of energy preserved in the secondary energy, namely so-called “input and output transformation processing” in the energy balance table. For example, the energy preserved in thermal power is transformed from the input of energy, such as raw coal, oil, coking, etc., excluding the part burned and lost in electricity production due to process inefficiencies. The loss of energy is the actual loss during processing or transmission of energy into the secondary energy product. The use of secondary energy source and loss of energy do not direct emit carbon emission, while emit carbon emission during the production by means of fossil fuel combustion. The energy transaction and loss, energy used by agriculture, manufacture, construction, transportation, other services, and household in each province was obtained from the province energy balance tables in *China’s Energy Statistical Yearbook*. The final consumption of energy by detailed manufacturing sector in each province was obtained from the *2008 China’s Economy Survey*. In the ECEIRIO table, we account for the usage by energy type and embodied carbon emissions that originated from the final consumption of energy, energy processing and transformation (Miller and Blair, 2009; Xia, 2010). [23,9] It is a more accurate and complete depiction of carbon emissions. However, the energy transformed in thermal heat is transmitted from the producing region to the demanding region. This avoids double-counting and enables ready accounting of carbon emissions originating from energy final consumption at the regional level. Thus the consumption of all energy types by industries in ECEIRIO can be indirectly deduced from “final consumption” of all energy types by industry and energy “Input & Output of Transformation” in China’s energy balance table, both of which are accounted in *China’s Energy Statistical Yearbook*.

The final consumption of energy in the ECEIRIO table is not composed of the energy converted in the secondary energy source by transformation of energy. It refers to energy of all types, purchased from other industries that are consumed directly in the industry for its production. It can be obtained by deducing the transformation and the loss of secondary energy from energy usage in the province’s energy balance tables. All of these energy data are transformed to standard quantities (coal equivalents) from physical quantities of thermal units. The final consumption of energy includes the portion of energy used as raw material, not as burning fossil energy, which should be deduced from the energy used for carbon emissions in this industry. There are 19 types of energy, including Raw Coal , Cleaned Coal, Other Washed Coal , Crude Oil , Natural Gas , Hydro & Nuclear Power, Thermal Power , Gasoline, Kerosene , Diesel Oil, Fuel Oil , Other Petroleum Product , Coke, Other Coking Products , Heat, Coke Oven Gas , Other Gas , LPG , Refinery Gas, belonging to nine energy industries, Mining and Washing of Coal , Extraction of Petroleum , Extraction of Natural Gas, Hydro & Nuclear Power, Production and Distribution of Thermal Power, Processing of Petroleum, Processing of Nuclear Fuel , Coking, Production and Distribution of Heat Power, Production and Distribution of Gas. (See Table A1.)

The second is the carbon conversion coefficients difference across energy types. For primary energy, the carbon conversion coefficients refer to the standards from US Oak Ridge National Laboratory (http://www.ornl.gov/), *2006 IPCC Guidelines on National Greenhouse Gas Inventories (http://unfccc.int/)*[25] and the standards of the Development Research Center of the State Council of China (DRCSCC, our reference standard). Secondary energy sources, such as electricity and thermal heat, are used for processing and transformation of the primary energy source, so it is a composed using coefficients from the primary energy sources, which are calculated by using the transformation of thermal power and heat as reflected in the Energy Balance Table in *China’s Energy Statistical Yearbook.* This is a more accurate method than using fixed coefficients according to the assumed input source. From the Energy Balance Table, the primary energy input to thermal power is multiplied by its carbon emission coefficient; its sum is divided by the output of thermal power (or heat). The resulting value more precisely represents the carbon emission coefficient of thermal power (or heat), taking thermal power for example, .[[7]](#endnote-7)

**3.2 Change of industries structure and energy input structure**

 By comparing the carbon emissions share with the GDP share of each industry in figure 5, the reduction of carbon emissions can be realized through an increase in the GDP of low carbon emissions industries, and a decline in the GDP of high carbon emissions heavy and energy industries. The GDP share of low carbon emissions industries should rise and shares of high emitting industries should decrease differentially. Among the 17 industries, agriculture and services have the large GDP shares and lowest carbon emissions shares. In other services, the GDP share is 8.3%-20.4% and carbon emissions shares are 1.1%-7.6%. Energy industries, like Production and Supply of Electricity, Steam, Gas and Water have the highest carbon emissions shares, from 36.6% to 54.8%, but lower GDP shares from 2.2% to 3.7% (for example, a 54.8% carbon emissions share and a 3.7% GDP share in the Northwest). Heavy industries have comparatively large carbon emissions shares but lower GDP shares. In the North Coast, Smelting and Pressing of Metals & Metal Products have higher carbon emissions shares, i.e. 29.1%, but low GDP shares, i.e. 8.6%. In the South Coast region, Nonmetal Mineral Products have high carbon emissions share, i.e. 21.2% and low output share, i.e. 1.8%.

<Insert Figure 5>

1. **Structural adjustment for carbon reduction**

This model is applied to China’s 2007 ECEIRIO table to identify the structural adjustment required to reduce carbon emissions. Industry adjustment potential and carbon reduction are obtained based on three scenarios of carbon intensity reduction, each of them is evaluated using three economic growth rates, making nine carbon scenarios in total. Carbon intensity varies by fossil fuel used. Three more scenarios consider changes in the structure of energy resources.

**4.1 Potential of industrial structure adjustment and the change of carbon emission**

The optimal adjustment of industry structure and optimal industry structure are shown in table 5. After adjustment, the most undeveloped regions share of carbon emissions would decline, e.g. at the greatest rates in the Northeast (1.2%) and Northwest (1.0%) and at the modest rates in the Central region (0.7%) and North Coast(0.2%); and other rich regions would experience low growth in share of carbon emission─, 0.6% in the South Coast, and 0.4% in the North Municipalities and the East Cost. The Southwest region would have the largest rise in carbon emissions share (0.8%).

Our model estimates under given technology that China would increase its total carbon emissions by 2.53% in 2008 compared to 2007 levels. This amounts to a 5.93% decline in carbon emissions per unit of GDP since GDP rises 9% annually. Such a scenario affects carbon emissions in heavy-industry-intensive regions: -9.7% and -7.1% declines would be expected in the Northeast and Northwest region, respectively. Regions with modern services and high technology industries would experience a significant rise in carbon emissions, for example, rises of 16.8% in the North Municipalities, of 11.6% in the East Coast region, of 10.1% in the Southwest, and of 9.9% in the South Coast. Under balanced growth, industry output rises at similar rates for most low carbon-intensive industries in most regions. So carbon emissions of these regional industries grow at similar rates given carbon intensity fixed as that in 2007. For most industries in all regions, carbon emissions increase by 60.5%. To the contrary, decreases in output of industries with higher carbon intensity differ across regions, so carbon-emissions declines vary by industry across regions. The exceptions are the Production and Supply of Electricity, Steam, Gas and Water and the Nonmetal Mineral Products, Smelting and Pressing of Metals & Metal Products industries. The carbon emissions of Nonmetal Mineral Products decreased by 37.2% in the North Coast region, by 36.6% in the South Coast region, by 9.9% in Central region, and by 8.8% in the Northeast region and North Municipalities. Carbon emissions of Smelting and Pressing of Metals & Metal Products decreased by 40.4% in the Northeast and by 14.6% in the North Coast.

*There are declines in output shares of energy and heavy industries with high carbon emission coefficients.* The output shares of Production and Supply of Electricity, Stream, Gas and Water declines steeply. It decrease most in less-developed regions, by 3.23% in the Northwest, 2.97% in the Southwest, 2.41% in the Central region , and 1.98% in Northeast. The output shares of selected heavy industry decline as well. For example, output of Smelting and Pressing of Metal & Metal Products declines by 2.77% in the Northeast and by 2.85% in the North Coast, while that of Nonmetal Mineral Products declines by 2.30% in the North Coast and by 1.49% in the South Coast region. *The declines were offset by output share rises in the other industries, especially services and high technology industries with smaller carbon emission coefficients*. For most regions, the output shares of Real Estate Finance and other services increased most. Although it increases by just 0.6% in the East Coast, it did so by 0.98% - 1.61% in other regions. The output shares of the Transportation & Trade and Catering Services increases the second most in most developed regions of the north and east: for example, by 0.78% in North Coast, by 0.75% in Central region, and 0.71 in Northwest region. In the most developed regions, output shares rose in the third most for Electric & Telecommunications Equipment. For instance, its shares increased by 0.34% in the South Coast, by 0.16% (third highest) in the East Coast region, and by 0.17% (second most) in the North Coast.

<Insert Table 5>

**4 .2 Industrial structure adjustment on the low carbon constraint**

The results of the scenario with the lowest carbon intensity target (6.76%) at the highest growth rate (9%) and at the lowest economic growth rate are respectively shown in table 6. Compared to the previous carbon emissions scenario, the shares of carbon emissions rose in almost all regions, but it did so most in the East Coast region by 0.15% when carbon intensity target changes from the highest to the lowest, and then by 0.23% when the growth rate change from the highest to the lowest rate. The exception is the Central region’s share of carbon emissions decreases by 0.64% when the carbon intensity change from the highest to the lowest, and rises by 14% when the growth rate change from the highest to the lowest.

The changes in carbon emissions and output shares by industry generally follow the pattern exhibited in the previous scenario. Most services and high technology industries and other industry increase their carbon emissions. Only carbon emissions from Production and Supply of Electricity, Stream, Gas and Water, Nonmetal Mineral Products, and Smelting and Pressing of Metal & Metal Products decrease. The output shares also decrease in these industries. Industries with carbon emissions reduction decreased more deeply, especially in the Central region. Moreover, the carbon emissions and output shares decline more apparently in the case of slowing growth than the case of tightening carbon intensity target. At the highest rate, the carbon emissions in Nonmetal Mineral Products of this region decreased by 13.5% in the scenario of the tightest carbon intensity at the lowest growth rate, about 3.6 percentage points more than in the previous scenario, i.e., about 1.4 percentage point originating from tightening carbon intensity, 2.2 percentage point from slowing growth rate. The potential adjustment of industrial structure to a lower carbon release scenario has changes that are similar in direction to the previous scenario, although with smaller declines in heavy industry shares. Although in the Central China, the share of Smelting and Pressing of Metal & Metal Products decreased most, by 3.5%, almost double that in the previous scenario, about 0.6 percentage point originating from tightening carbon intensity, 1 percentage point from slowing growth rate.

<Insert Table 6>

**4 .3 Industrial structure adjustment with variable energy mix**

The ratio of non-fossil energy to the consumption of first primer energy increase 15% from 2005 to 2020, (equivalent to annual increase by 5.4%. The potential adjustment of industrial structure with the energy structure change is shown in Table 7. *The potential adjustment of industrial structure has the same direction of change, but a small range of increase and decrease comparing the situation without energy change*. It is apparent in the Central, and in the industries with high or low carbon intensity. The Central regional share s of value added and carbon emissions are respectively 0.3% and 1.7% more than these shares of in the case of invariable energy mix. As for the detailed industry, the carbon emissions decrease by 5.0% in Nonmetal Mineral Products, approximate half of the carbon decline in case of invariable energy mix, and by 36.6% in the Production and Supply of Electricity, Stream, Gas and Water, 6.6% less than that of no energy mix change. To the contrary, the share of value added increase by 1.5% in Real estate finance and Others services, 0.6% more than the share in the case of invariable energy mix.**5. Conclusion**China targets its carbon intensity to decline by 40% -45% of its 2005 level by 2020. One important way to meet such a shift carbon emission reduction goal is by altering the nation’s industry structure. Of course, China should reach this aim with an eye toward maximizing its national welfare. We developed an energy-carbon-economy interregional input-output model (ECEIRIO model) that reflects Chinese economy as an integrated system. Different with previous national energy-concentrated optimal IO model (Xia, 2010, Wang et al., 2011), it focus on the energy-used carbon emission embodied in interregional trade. In it, each regional economy has its own resource endowment is connected to other regions by industry production and consumption, including interregional trade through which it is functionally connected to energy used and embodied as carbon emissions. We applied a linear programming approach to examine how to reduce carbon intensity via adjustments to industry structure across China’s interrelated regions. Overall reduction targets are realized by adjusting reducing carbon emissions differentially across regions and their industries.

Different industry strategies are required by region to reduce carbon emissions due to thedifferent industry input requirements, energy efficiencies, and life qualities across regions. The shares of output and final demand are greater but the shares of energy consumption and carbon emissions are lower in China’s affluent North Municipalities (Beijing and Tianjiang), East Coast, and South Coast regions.[[8]](#endnote-8) The share of GDP and final demand declines while shares of energy consumption and carbon emissions rise for the less-developed Northeast, North Coast, Central, Northwest, and Southwest regions. This enables China to be less restrictive with respect to carbon intensity in its less developed West and more restrictive on its East Coast provinces. The implication is that China should emphasize even more the development the high-technology industries in East Coast and to de-emphasize production of heavy industries in its northern resource-rich provinces.

 The optimization exercise suggests increasing shares of GDP of high technology industry and services that release low densities of carbon emissions, and reducing GDP shares of heavy and energy industries with large carbon emission coefficients. Declines related to the energy industry (i.e. Production of thermal power, heat, and gas) are partly satisfied by equivalent imports or renewable energy resources but largely though energy conservation and efficiency gains. As the Northwest and Northeast regions concentrate energy-intensive industries and the affluent Southeast and East Coast region emphasize capital-intensive and high technology industry, industry diversity in carbon intensity requires differential industry adjustments by region. Our findings suggest declines in high carbon-intensity industries, particularly in traditional manufacturing regions, (i.e. Smelting and Pressing of Metal & Metal Products by 40.4% in the Northeast and Nonmetal Mineral Products by 37.2% in the North Coast ) and rises in output shares of low-carbon, high-tech industries in export-oriented regions (i.e. Electric & Telecommunications Equipment by 7.87% in the South Coast) and of services across the broad (i.e., Real estate finance and other service by 5.01%-6.8% , except in the Southwest).

China’s regions differ in their targets for reducing carbon intensity when compared to the national average. As a result, the industry adjustment strategy must naturally vary from one region to the next. Adjustments suggested by the exercise cause carbon emissions to decline in most undeveloped regions. Emissions in the energy-intensive Northeast and Northwest region declined most–by 16.7% and 7.1%, respectively. Regions that transmit energy to the East Coast and South Coast were predicted to reduce their emissions via the model by 0.7% in the Central region and by 0.2% in the North Coast. Carbon emissions were predicted to rise in developed regions by 16.8% in the Northern Municipalities and by 11.8% in the East Coast. The environment and air pollution in Beijing and Tianjing are be resolved by reducing the emissions in the nearly Northeast, Northwest, and Central regions via economic ties.

Undeveloped regions discharge a substantial amount of carbon emissions on behalf of other regions’ consumption or exports. Households in the affluent Southeast and East Coast regions consume more than do manufacturers in the north, west and central regions. Like western countries, the Southeast and East Coast, which produce few carbon emissions themselves, consume products that embody a substantial amount of carbon emissions. China’s interregional and international trade reflect this. So a key is to improve the technology transfer and cooperation between China’s affluent regions with backward regions, as well as to encourage foreign direct investment in its less-developed regions.

China will clearly face ever more development pressure in future. Some GDP-laden industry structure will be sacrificed if the economy slows as suggested by the World Bank. Heavy industry is a likely candidate to be sacrificed. For example, if GDP growth slows to 7.5%, we find the production of Smelting and Pressing of Metal & Metal Products will have to decrease by about 5.3%─twice the rate of decline under a growth rate of 9% .

*However, if China increase the annual ratio of non-fossil energy to the primary energy by the 5.4%, The adjustment pressure of industrial structure will become smaller, in the same direction of change, but a small range of increase and decrease comparing the situation of invariable energy change*. The Central will have more carbon emissions space, especially in heavy industry and energy industry with high carbon intensity, and less value added share increase in the industries with low carbon intensity.

China can accelerate change in its industry mix and update technology of older firms like the steel and chemical industries. Another way to reduce carbon emissions includes controlling total energy consumption, changing the energy resource mix, and advancing efficient and clean usage of coal. A focus on household consumption of energy is paramount as Chinese consumers improve the quality of their lives.

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**Figure 1:** Carbon intensity using market exchange rates (EIA)[[9]](#endnote-9)



**Figure 2:** Shares of output, final demand, energy consumption and carbon emissions



**Figure 3**: Industry structure and industry share of emission in 8 regions

**Figure 4**: Adjustment of Industry structure across eight regions to reduce CO2[[10]](#endnote-10)

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**Figure 5:** Share of output and share of CO2 by industry across region

**Table 1:** Classification of regions and provinces

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| *region* | *province* | *region* | *province* | *region* | *province* |
| 1. Northeast region
 | Heilongjiang | 1. South

Coast region | Fujian | 7. Northwest region | Inner Mongolia |
| Jilin | Guangdong | Shannxi |
| Liaoning | Hainan | Ningxia |
| 1. North Municipalities
 | Beijing | 6. Central region | Shanxi | Gansu |
| Tianjin | Henan | Qinghai |
| 1. North Coast region
 | Hebei | Anhui | Xinjiang |
| Shandong | Hubei | 1. Southwest region
 | Sichuan |
| 1. East Coast region
 | Jiangsu | Hunan | Chongqing |
| Shanghai | jiangxi | Guangxi |
| Zhejiang |  | Yunnan |
|  |  | Guizhou |
|  |  | Xizhang |

**Table 2:** The classification of industries and sectors

|  |  |
| --- | --- |
|  *Industry and sector* |  *Industry and sector* |
| 1. Farming, Forestry, Husbandry, Fishery | 11.Transportation Equipment |
| 2. Mining and Dressing  | 12.Electric & Telecommunications Equipment |
| 3. Food Processing & Tobacco Processing  | 13.Other Manufacturing Industry  |
| 4.Textile Industry & Garments and Other Fiber Products | 14.Production and Supply of Electricity, Steam, Gas and Water |
| 5.Timber Processing, Fiber Products & Furniture Manufacturing  | 15.Construction  |
| 6. Printing and Cultural and Sports Articles  | 16.Transportation & Trade and Catering Services |
| 7.Chemical Industry  | 17. Real estate finance and Others services  |
| 8.Nonmetal Mineral Products  | 18.Urban |
| 9.Smelting and Pressing of Metals & Metal Products  | 19.Rural |
| 10.Ordinary Machinery & Equipment for Special Purposes  | 20.Total |

Energy industry: (2), (7), (14); Non energy industry: (1), (3), (4), (5), (6), (8), (9), (10),(11), (12), (13), (15),(16),(17).

**Table 3:** Index of intensity of carbon emissions and the carbon emissions per year (%)[[11]](#endnote-11)

|  |  |  |
| --- | --- | --- |
| Scenario 1 | Scenario 2 | Scenario 3 |
|  |  |  |  |  |  |  |  |  |
|  -5.93 | 9 | 2.53 | -6.35 | 9 | 2.08 | -6.76 | 9 | 1.63 |
| 8 | 1.60 | 8 | 1.14 | 8 | 0.70 |
| 7.5 | 1.12 | 7.5 | 0.67 | 7.5 | 0.23 |

**Table 4:** Interregional Energy-Carbon-Economy Input-output Table with Asset

|  |  |  |  |
| --- | --- | --- | --- |
| Input/Asset Output | Intermediate Demand | Final Demand | Total output |
| Region 1 | … | Region m | Final consumption | Capital formation | Export | Inventor |
| Energy Industry | Non-Energy Industry | … | Energy Industry | Non-Energy Industry |
| Intermediate input | Region 1 | Energy Industry |  |  |  |  |  |  |  |  |  |  |
| Energy usage |  |  |  |  |  |  |  |  |  |  |
| Carbon emission |  |  |  |  |  |  |  |  |  |  |
| Non-Energy Industry |  |  |  |  |  |  |  |  |  |  |
| … | 　 | 　 |  |  |  |  |  |  |  |  |  |
| Region m | Energy Industry |  |  |  |  |  |  |  |  |  |  |
| Energy usage |  |  |  |  |  |  |  |  |  |  |
| Carbon emission |  |  |  |  |  |  |  |  |  |  |
| Non-Energy Industry |  |  |  |  |  |  |  |  |  |  |
| Energy usage |  |  |  |  |  |  |  |  |  |  |
| Total energy consumption |  |  |  |  |  |  |  |  |  |  |
| Carbon emission |  |  |  |  |  |  |  |  |  |  |
| Total carbon emission |  |  |  |  |  |  |  |  |  |  |
| import |  |  |  |  |  |  |  |  |  |  |
| Primary Input |  |  |  |  |  |  |
| Asset | Nature resourceFixed capitalHuman capital |  |  |  |  |  |  |
| Total input |  |  |  |  |  |  |

**Table 5:** Potential adjustment of industrial structure and reduction of carbon emissions (%)[[12]](#endnote-12)

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | *Northeast region* | *North Municipalities* | *North Coast region* | *East coast region* | *South coast region* | *Central region* | *Northwest region* | *Southwest region* |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 1 | 13.3 | 0.7 | 60.5 | 1.6 | 0.0 | 60.5 | 12.0 | 0.8 | 60.5 | 5.5 | 0.1 | 60.5 | 8.2 | 0.3 | 60.5 | 16.1 | 1.0 | 60.5 | 13.6 | 0.7 | 60.5 | 19.6 | 0.7 | 60.5 |
| 2 | 11.8 | 0.7 | 60.5 | 4.0 | 0.1 | 60.5 | 8.2 | 0.6 | 60.5 | 0.5 | 0.0 | 60.5 | 1.9 | 0.1 | 60.5 | 5.8 | 0.4 | 60.5 | 17.2 | 0.9 | 60.5 | 3.4 | 0.1 | 60.5 |
| 3 | 3.4 | 0.2 | 60.5 | 1.4 | 0.0 | 60.5 | 5.3 | 0.4 | 60.5 | 2.5 | 0.1 | 60.5 | 2.6 | 0.1 | 60.5 | 5.3 | 0.3 | 60.5 | 3.8 | 0.2 | 60.5 | 7.1 | 0.3 | 60.5 |
| 4 | 1.2 | 0.1 | 60.5 | 0.7 | 0.0 | 60.5 | 4.1 | 0.3 | 60.5 | 6.3 | 0.1 | 60.5 | 5.6 | 0.2 | 60.5 | 2.5 | 0.2 | 60.5 | 1.0 | 0.1 | 60.5 | 1.0 | 0.0 | 60.5 |
| 5 | 1.0 | 0.1 | 60.5 | 0.2 | 0.0 | 60.5 | 1.8 | 0.1 | 60.5 | 0.9 | 0.0 | 60.5 | 1.2 | 0.0 | 60.5 | 1.3 | 0.1 | 60.5 | 0.3 | 0.0 | 60.5 | 0.5 | 0.0 | 60.5 |
| 6 | 0.5 | 0.0 | 60.5 | 0.6 | 0.0 | 60.5 | 1.6 | 0.1 | 60.5 | 1.6 | 0.0 | 60.5 | 2.5 | 0.1 | 60.5 | 1.4 | 0.1 | 60.5 | 0.5 | 0.0 | 60.5 | 0.9 | 0.0 | 60.5 |
| 7 | 8.7 | 0.5 | 60.5 | 4.5 | 0.1 | 60.5 | 7.7 | 0.5 | 60.5 | 7.5 | 0.2 | 60.5 | 6.0 | 0.2 | 60.5 | 6.0 | 0.4 | 60.5 | 4.7 | 0.3 | 60.5 | 4.4 | 0.2 | 60.5 |
| 8 | 1.0 | -0.7 | -8.0 | 0.4 | -0.3 | -8.0 | 1.7 | -2.3 | -37.2 | 1.1 | -0.5 | 7.2 | 1.0 | -1.5 | -36.6 | 2.0 | -1.3 | -9.9 | 1.1 | -0.6 | 0.9 | 1.1 | -0.5 | 5.9 |
| 9 | 1.8 | -2.8 | -40.4 | 4.2 | 0.1 | 60.5 | 3.8 | -2.9 | -14.6 | 6.4 | 0.1 | 60.5 | 4.0 | 0.1 | 60.5 | 5.1 | -1.9 | 10.6 | 6.0 | -1.1 | 28.9 | 6.1 | 0.2 | 60.5 |
| 10 | 3.8 | 0.2 | 60.5 | 3.0 | 0.1 | 60.5 | 4.7 | 0.3 | 60.5 | 5.5 | 0.1 | 60.5 | 2.4 | 0.1 | 60.5 | 3.2 | 0.2 | 60.5 | 1.3 | 0.1 | 60.5 | 2.2 | 0.1 | 60.5 |
| 11 | 5.4 | 0.3 | 60.5 | 2.5 | 0.1 | 60.5 | 2.5 | 0.2 | 60.5 | 3.0 | 0.1 | 60.5 | 2.0 | 0.1 | 60.5 | 1.6 | 0.1 | 60.5 | 1.1 | 0.1 | 60.5 | 2.7 | 0.1 | 60.5 |
| 12 | 1.5 | 0.1 | 60.5 | 5.9 | 0.1 | 60.5 | 2.5 | 0.2 | 60.5 | 7.6 | 0.2 | 60.5 | 9.8 | 0.3 | 60.5 | 2.2 | 0.1 | 60.5 | 0.9 | 0.0 | 60.5 | 1.8 | 0.1 | 60.5 |
| 13 | 2.0 | 0.1 | 60.5 | 2.1 | 0.0 | 60.5 | 1.7 | 0.1 | 60.5 | 4.0 | 0.1 | 60.5 | 3.1 | 0.1 | 60.5 | 2.1 | 0.1 | 60.5 | 0.4 | 0.0 | 60.5 | 1.3 | 0.0 | 60.5 |
| 14 | 1.1 | -2.0 | -46.5 | 1.0 | -1.9 | -46.5 | 1.9 | -1.1 | -6.4 | 1.2 | -1.5 | -29.5 | 2.4 | -1.8 | -11.9 | 1.5 | -2.4 | -43.0 | 1.8 | -3.2 | -46.5 | 1.6 | -3.0 | -46.5 |
| 15 | 5.9 | 0.3 | 60.5 | 5.1 | 0.1 | 60.5 | 5.3 | 0.4 | 60.5 | 5.0 | 0.1 | 60.5 | 4.3 | 0.1 | 60.5 | 6.7 | 0.4 | 60.5 | 7.5 | 0.4 | 60.5 | 7.0 | 0.3 | 60.5 |
| 16 | 13.9 | 0.8 | 60.5 | 14.5 | 0.3 | 60.5 | 11.5 | 0.8 | 60.5 | 12.5 | 0.3 | 60.5 | 12.6 | 0.4 | 60.5 | 12.3 | 0.8 | 60.5 | 13.2 | 0.7 | 60.5 | 12.1 | 0.4 | 60.5 |
| 17 | 23.8 | 1.3 | 60.5 | 48.4 | 1.1 | 60.5 | 23.7 | 1.6 | 60.5 | 29.0 | 0.6 | 60.5 | 30.6 | 1.1 | 60.5 | 24.9 | 1.5 | 60.5 | 25.5 | 1.4 | 60.5 | 27.2 | 1.0 | 60.5 |
| Total |  |  | -9.7 |  |  | 16.8 |  |  | 1.5 |  |  | 11.6 |  |  | 9.9 |  |  | -6.0 |  |  | -7.1 |  |  | 10.1 |
|  | **8.5** |  |  | **5.4** |  |  | **14.0** |  |  | **21.2** |  |  | **14.9** |  |  | **18.8** |  |  | **7.1** |  |  | **10.2** |  |  |
|  |  |  | 10.3 |  |  | 2.9 |  |  | 18.6 |  |  | 15.2 |  |  | 8.8 |  |  | 22.3 |  |  | 11.2 |  |  | 10.6 |
|  |  |  | 9.1 |  |  | 3.3 |  |  | 18.4 |  |  | 16.6 |  |  | 9.4 |  |  | 21.6 |  |  | 10.2 |  |  | 11.4 |

**Table 6:** Potential adjustment of industrial structure and reduction of carbon emissions in low level (%)

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | ***Northeast region*** | ***North Municipalities*** | ***North Coast region*** | ***East coast region*** | ***South coast region*** | ***Central region*** | ***Northwest region*** | ***Southwest region*** |
|  | **1.63** | **0.23** | **1.63** | **0.23** | **1.63** | **0.23** | **1.63** |  | **0.23** |  | **1.63** |  | **0.23** |  | **1.63** |  | **0.23** |  | **1.63** |  | **0.23** |  | **2.53** |  | **0.23** |  |
| **GDP**  | **9** |  | **7.5** |  | **9** |  | **7.5** |  | **9** |  | **7.5** |  | **9** |  | **7.5** |  | **9** |  | **7.5** |  | **9** |  | **7.5** |  | **9** |  | **7.5** |  | **9** |  | **7.5** |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| **1** | **0.8** | **60.5** | **0.8** | **60.5** | **0.0** | **60.5** | **0.0** | **60.5** | **0.8** | **60.5** | **0.8** | **60.5** | **0.1** | **60.5** | **0.1** | **60.5** | **0.3** | **60.5** | **0.3** | **60.5** | **1.1** | **60.5** | **1.3** | **60.5** | **0.7** | **60.5** | **0.8** | **60.5** | **0.7** | **60.5** | **0.7** | **60.5** |
| **2** | **0.7** | **60.5** | **0.7** | **60.5** | **0.1** | **60.5** | **0.1** | **60.5** | **0.6** | **60.5** | **0.6** | **60.5** | **0.0** | **60.5** | **0.0** | **60.5** | **0.1** | **60.5** | **0.1** | **60.5** | **0.4** | **60.5** | **0.5** | **60.5** | **0.9** | **60.5** | **1.0** | **60.5** | **0.1** | **60.5** | **0.1** | **60.5** |
| **3** | **0.2** | **60.5** | **0.2** | **60.5** | **0.0** | **60.5** | **0.0** | **60.5** | **0.4** | **60.5** | **0.4** | **60.5** | **0.1** | **60.5** | **0.1** | **60.5** | **0.1** | **60.5** | **0.1** | **60.5** | **0.4** | **60.5** | **0.4** | **60.5** | **0.2** | **60.5** | **0.2** | **60.5** | **0.3** | **60.5** | **0.3** | **60.5** |
| **4** | **0.1** | **60.5** | **0.1** | **60.5** | **0.0** | **60.5** | **0.0** | **60.5** | **0.3** | **60.5** | **0.3** | **60.5** | **0.1** | **60.5** | **0.1** | **60.5** | **0.2** | **60.5** | **0.2** | **60.5** | **0.2** | **60.5** | **0.2** | **60.5** | **0.1** | **60.5** | **0.1** | **60.5** | **0.0** | **60.5** | **0.0** | **60.5** |
| **5** | **0.1** | **60.5** | **0.1** | **60.5** | **0.0** | **60.5** | **0.0** | **60.5** | **0.1** | **60.5** | **0.1** | **60.5** | **0.0** | **60.5** | **0.0** | **60.5** | **0.0** | **60.5** | **0.0** | **60.5** | **0.1** | **60.5** | **0.1** | **60.5** | **0.0** | **60.5** | **0.0** | **60.5** | **0.0** | **60.5** | **0.0** | **60.5** |
| **6** | **0.0** | **60.5** | **0.0** | **60.5** | **0.0** | **60.5** | **0.0** | **60.5** | **0.1** | **60.5** | **0.1** | **60.5** | **0.0** | **60.5** | **0.0** | **60.5** | **0.1** | **60.5** | **0.1** | **60.5** | **0.1** | **60.5** | **0.1** | **60.5** | **0.0** | **60.5** | **0.0** | **60.5** | **0.0** | **60.5** | **0.0** | **60.5** |
| **7** | **0.5** | **60.5** | **0.5** | **60.5** | **0.1** | **60.5** | **0.1** | **60.5** | **0.5** | **60.5** | **0.5** | **60.5** | **0.2** | **60.5** | **0.2** | **60.5** | **0.2** | **60.5** | **0.2** | **60.5** | **0.4** | **60.5** | **0.5** | **60.5** | **0.3** | **60.5** | **0.3** | **60.5** | **0.2** | **60.5** | **0.2** | **60.5** |
| **8** | **-0.7** | **-8.1** | **-0.7** | **-8.1** | **-0.3** | **-8.0** | **-0.3** | **-8.0** | **-2.3** | **-37.3** | **-2.3** | **-37.2** | **-0.5** | **7.2** | **-0.5** | **7.1** | **-1.5** | **-36.7** | **-1.5** | **-36.8** | **-1.3** | **-11.3** | **-1.4** | **-13.5** | **-0.6** | **0.9** | **-0.6** | **0.3** | **-0.5** | **5.9** | **-0.5** | **5.9** |
| **9** | **-2.8** | **-40.5** | **-2.8** | **-40.4** | **0.1** | **60.5** | **0.1** | **60.5** | **-2.9** | **-15.4** | **-3.0** | **-14.6** | **0.1** | **60.5** | **0.1** | **60.5** | **0.1** | **60.5** | **0.1** | **60.5** | **-2.5** | **-4.1** | **-3.5** | **-26.2** | **-1.1** | **29.3** | **-1.5** | **20.1** | **0.2** | **60.5** | **0.2** | **60.5** |
| **10** | **0.2** | **60.5** | **0.2** | **60.5** | **0.1** | **60.5** | **0.1** | **60.5** | **0.3** | **60.5** | **0.3** | **60.5** | **0.1** | **60.5** | **0.1** | **60.5** | **0.1** | **60.5** | **0.1** | **60.5** | **0.2** | **60.5** | **0.3** | **60.5** | **0.1** | **60.5** | **0.1** | **60.5** | **0.1** | **60.5** | **0.1** | **60.5** |
| **11** | **0.3** | **60.5** | **0.3** | **60.5** | **0.1** | **60.5** | **0.1** | **60.5** | **0.2** | **60.5** | **0.2** | **60.5** | **0.1** | **60.5** | **0.1** | **60.5** | **0.1** | **60.5** | **0.1** | **60.5** | **0.1** | **60.5** | **0.1** | **60.5** | **0.1** | **60.5** | **0.1** | **60.5** | **0.1** | **60.5** | **0.1** | **60.5** |
| **12** | **0.1** | **60.5** | **0.1** | **60.5** | **0.1** | **60.5** | **0.1** | **60.5** | **0.2** | **60.5** | **0.2** | **60.5** | **0.2** | **60.5** | **0.2** | **60.5** | **0.3** | **60.5** | **0.3** | **60.5** | **0.2** | **60.5** | **0.2** | **60.5** | **0.1** | **60.5** | **0.1** | **60.5** | **0.1** | **60.5** | **0.1** | **60.5** |
| **13** | **0.1** | **60.5** | **0.1** | **60.5** | **0.1** | **60.5** | **0.1** | **60.5** | **0.1** | **60.5** | **0.1** | **60.5** | **0.1** | **60.5** | **0.1** | **60.5** | **0.1** | **60.5** | **0.1** | **60.5** | **0.1** | **60.5** | **0.2** | **60.5** | **0.0** | **60.5** | **0.0** | **60.5** | **0.1** | **60.5** | **0.1** | **60.5** |
| **14** | **-2.0** | **-46.5** | **-2.0** | **-46.5** | **-1.9** | **-46.5** | **-1.9** | **-46.5** | **-1.1** | **-6.5** | **-1.1** | **-6.4** | **-1.5** | **-29.5** | **-1.5** | **-29.6** | **-1.8** | **-12.0** | **-1.8** | **-12.0** | **-2.4** | **-44.9** | **-2.5** | **-46.5** | **-3.2** | **-46.5** | **-3.2** | **-46.5** | **-3.0** | **-46.5** | **-3.0** | **-46.5** |
| **15** | **0.3** | **60.5** | **0.3** | **60.5** | **0.1** | **60.5** | **0.1** | **60.5** | **0.4** | **60.5** | **0.4** | **60.5** | **0.1** | **60.5** | **0.1** | **60.5** | **0.1** | **60.5** | **0.1** | **60.5** | **0.5** | **60.5** | **0.5** | **60.5** | **0.4** | **60.5** | **0.4** | **60.5** | **0.3** | **60.5** | **0.3** | **60.5** |
| **16** | **0.8** | **60.5** | **0.8** | **60.5** | **0.3** | **60.5** | **0.3** | **60.5** | **0.8** | **60.5** | **0.8** | **60.5** | **0.3** | **60.5** | **0.3** | **60.5** | **0.4** | **60.5** | **0.4** | **60.5** | **0.8** | **60.5** | **1.0** | **60.5** | **0.7** | **60.5** | **0.8** | **60.5** | **0.4** | **60.5** | **0.4** | **60.5** |
| **17** | **1.3** | **60.5** | **1.3** | **60.5** | **1.1** | **60.5** | **1.1** | **60.5** | **1.6** | **60.5** | **1.6** | **60.5** | **0.6** | **60.5** | **0.6** | **60.5** | **1.1** | **60.5** | **1.1** | **60.5** | **1.7** | **60.5** | **2.0** | **60.5** | **1.4** | **60.5** | **1.5** | **60.5** | **1.0** | **60.5** | **1.0** | **60.5** |
|  | **8.5** | **8.5** | **5.4** | **5.4** | **14.0** | **14.0** | **21.2** | **21.2** | **14.9** | **14.9** | **18.7** | **18.7** | **7.1** | **7.1** | **10.3** | **10.3** |
|  | **-9.8** | **-9.8** | **16.8** | **16.8** | **1.2** | **0.7** | **11.6** | **11.5** | **9.9** | **9.9** | **-4.4** | **-9.6** | **-7.1** | **-7.1** | **10.1** | **10.1** |
|  | **9.2** | **9.3** | **3.3** | **3.4** | **18.6** | **18.7** | **16.7** | **16.9** | **9.5** | **9.6** | **21.0** | **20.1** | **10.3** | **10.3** | **11.5** | **11.7** |

**Table 7:** Potential adjustment of industrial structure and reduction of carbon emissions (%)[[13]](#endnote-13)

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | *Northeast region* | *North Municipalities* | *North Coast region* | *East coast region* | *South coast region* | *Central region* | *Northwest region* | *Southwest region* |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 1 | 12.9 | 0.4 | 60.5 | 1.6 | 0.0 | 60.5 | 12.0 | 0.8 | 60.5 | 5.5 | 0.1 | 60.5 | 8.2 | 0.3 | 60.5 | 15.7 | 0.6 | 60.5 | 13.7 | 0.7 | 60.5 | 19.6 | 0.70% | 60.5 |
| 2 | 11.5 | 0.3 | 60.5 | 4.0 | 0.1 | 60.5 | 8.2 | 0.5 | 60.5 | 0.5 | 0.0 | 60.5 | 1.9 | 0.1 | 60.5 | 5.7 | 0.2 | 60.5 | 17.2 | 0.9 | 60.5 | 3.4 | 0.12% | 60.5 |
| 3 | 3.3 | 0.1 | 60.5 | 1.4 | 0.0 | 60.5 | 5.3 | 0.4 | 60.5 | 2.5 | 0.1 | 60.5 | 2.6 | 0.1 | 60.5 | 5.1 | 0.2 | 60.5 | 3.8 | 0.2 | 60.5 | 7.1 | 0.25% | 60.5 |
| 4 | 1.2 | 0.0 | 60.5 | 0.7 | 0.0 | 60.5 | 4.1 | 0.3 | 60.5 | 6.3 | 0.1 | 60.5 | 5.6 | 0.2 | 60.5 | 2.5 | 0.1 | 60.5 | 1.0 | 0.1 | 60.5 | 1.0 | 0.03% | 60.5 |
| 5 | 0.9 | 0.0 | 60.5 | 0.2 | 0.0 | 60.5 | 1.8 | 0.1 | 60.5 | 0.9 | 0.0 | 60.5 | 1.2 | 0.0 | 60.5 | 1.3 | 0.1 | 60.5 | 0.3 | 0.0 | 60.5 | 0.5 | 0.02% | 60.5 |
| 6 | 0.5 | 0.0 | 60.5 | 0.6 | 0.0 | 60.5 | 1.6 | 0.1 | 60.5 | 1.6 | 0.0 | 60.5 | 2.5 | 0.1 | 60.5 | 1.4 | 0.1 | 60.5 | 0.5 | 0.0 | 60.5 | 0.9 | 0.03% | 60.5 |
| 7 | 8.4 | 0.2 | 60.5 | 4.5 | 0.1 | 60.5 | 7.7 | 0.5 | 60.5 | 7.5 | 0.2 | 60.5 | 6.0 | 0.2 | 60.5 | 5.9 | 0.2 | 60.5 | 4.7 | 0.3 | 60.5 | 4.4 | 0.16% | 60.5 |
| 8 | 1.0 | -0.7 | -4.4 | 0.4 | -0.3 | -7.7 | 1.7 | -2.3 | -36.7 | 1.1 | -0.5 | 7.2 | 1.0 | -1.5 | -36.4 | 2.0 | -1.3 | -5.0 | 1.2 | -0.6 | 1.0 | 1.1 | -0.51% | 6.0 |
| 9 | 4.6 | 0.0 | 56.0 | 4.2 | 0.1 | 60.5 | 4.0 | -2.7 | -10.0 | 6.4 | 0.1 | 60.5 | 4.0 | 0.1 | 60.5 | 7.2 | 0.3 | 10.6 | 6.0 | -1.2 | 27.2 | 6.1 | 0.22% | 60.5 |
| 10 | 3.7 | 0.1 | 60.5 | 3.0 | 0.1 | 60.5 | 4.6 | 0.3 | 60.5 | 5.5 | 0.1 | 60.5 | 2.4 | 0.1 | 60.5 | 3.1 | 0.1 | 60.5 | 1.3 | 0.1 | 60.5 | 2.2 | 0.08% | 60.5 |
| 11 | 5.2 | 0.2 | 60.5 | 2.5 | 0.1 | 60.5 | 2.5 | 0.2 | 60.5 | 3.0 | 0.1 | 60.5 | 2.0 | 0.1 | 60.5 | 1.5 | 0.1 | 60.5 | 1.1 | 0.1 | 60.5 | 2.7 | 0.10% | 60.5 |
| 12 | 1.5 | 0.0 | 60.5 | 5.9 | 0.1 | 60.5 | 2.5 | 0.2 | 60.5 | 7.6 | 0.2 | 60.5 | 9.8 | 0.3 | 60.5 | 2.1 | 0.1 | 60.5 | 0.9 | 0.1 | 60.5 | 1.8 | 0.06% | 60.5 |
| 13 | 2.0 | 0.1 | 60.5 | 2.1 | 0.1 | 60.5 | 1.7 | 0.1 | 60.5 | 4.0 | 0.1 | 60.5 | 3.1 | 0.1 | 60.5 | 2.0 | 0.1 | 60.5 | 0.4 | 0.0 | 60.5 | 1.3 | 0.05% | 60.5 |
| 14 | 1.1 | -2.0 | -46.5 | 1.0 | -1.9 | -46.5 | 1.9 | -1.1 | -5.5 | 1.2 | -1.5 | -29.5 | 2.4 | -1.8 | -11.9 | 1.6 | -2.3 | -36.6 | 1.8 | -3.2 | -46.5 | 1.6 | -2.97% | -46.5 |
| 15 | 5.7 | 0.2 | 60.5 | 5.1 | 0.1 | 60.5 | 5.3 | 0.4 | 60.5 | 5.0 | 0.1 | 60.5 | 4.3 | 0.2 | 60.5 | 6.5 | 0.2 | 60.5 | 7.5 | 0.4 | 60.5 | 7.0 | 0.25% | 60.5 |
| 16 | 13.5 | 0.4 | 60.5 | 14.5 | 0.3 | 60.5 | 11.5 | 0.8 | 60.5 | 12.5 | 0.3 | 60.5 | 12.6 | 0.4 | 60.5 | 12.0 | 0.4 | 60.5 | 13.2 | 0.7 | 60.5 | 12.1 | 0.43% | 60.5 |
| 17 | 23.1 | 0.7 | 60.5 | 48.4 | 1.1 | 60.5 | 23.6 | 1.6 | 60.5 | 29.0 | 0.6 | 60.5 | 30.6 | 1.1 | 60.5 | 24.3 | 0.9 | 60.5 | 25.6 | 1.4 | 60.5 | 27.2 | 0.98% | 60.5 |
| Total |  |  | -9.7 |  |  | 16.8 |  |  | 1.5 |  |  | 11.6 |  |  | 9.9 |  |  | -6.0 |  |  | -7.1 |  |  | 10.1 |
|  | **8.7** |  |  | **5.3** |  |  | **13.9** |  |  | **21.0** |  |  | **14.8** |  |  | **19.1** |  |  | **7.1** |  |  | **10.2** |  |  |
|  |  |  | 10.3 |  |  | 2.9 |  |  | 18.6 |  |  | 15.2 |  |  | 8.8 |  |  | 22.3 |  |  | 11.2 |  |  | 10.6 |
|  |  |  | 10.3 |  |  | 3.1 |  |  | 17.9 |  |  | 15.8 |  |  | 9.0 |  |  | 23.3 |  |  | 9.7 |  |  | 10.9 |

**Appendix I**

Table A.1: The classification of industry and energy types and their carbon emission

|  |  |  |
| --- | --- | --- |
| Industry classification | Energy type | carbon emission coefficient(104 t) |
| ECEIO table | input-output table | DRCSCC | IPCC |
| 1.Mining and Washing of Coal | Mining and Washing of Coal | Raw Coal  | 0.7476 | 0.7559 |
| Cleaned Coal  | 0.7476 | 0.7559 |
| Other Washed Coal  | 0.7476 | 0.7559 |
| 2.Extraction of Petroleum | Extraction of Petroleum and Natural Gas | Crude Oil  | 0.5825 | 0.5857 |
| 3.Extraction of Natural Gas | Extraction of Petroleum and Natural Gas | Nature Gas  | 0.4435 | 0.4483 |
| 4.Production and Distribution of Hydro Power and Nuclear Power | Production and Distribution of Electric Power and Heat Power | Hydro Power and Nuclear Power  | 0 | 0 |
| 5.Production and Distribution of Thermal Power  | Production and Distribution of Electric Power and Heat Power | Thermal Power  | 2.1114\* |  |
| 6.Processing of Petroleum, Processing of Nuclear Fuel | Processing of Petroleum, Processing of Nuclear Fuel | GaslineKerosene | 0.58250.5825 | 0.55380.5714 |
|  |  | Diesel Oil  | 0.5825 | 0.5921 |
| Fuel Oil, | 0.5825 | 0.6185 |
| other Petroleum Product | 0.5825 | 0.5857 |
| 7.Coking | Coking | Coke,  | 0.7476 | 0.855 |
| Other Coking Products | 0.7476 | 0.6449 |
| 8.Production and Distribution of Heat Power | Production and Distribution of Electric Power and Heat Power | Heat | 0.9966\* |  |
| 9.Production and Distribution of Gas | Processing of Petroleum, Processing of Nuclear Fuel, Coking, Production and Distribution of Gas | Coke Oven Gas | 0.7476 | 0.3548 |
| Other Gas | 0.7476 | 0.3548 |
| LPG | 0.5825 | 0.5042 |
| Refinery Gas | 0.5825 | 0.4602 |

1. Supporting foundation: “Dynamic Programming on Industry Structure of Low carbon Economy based on Multiregional Input-Output Model”, National Social Science Foundation, 2010, 7, No.10CJL033, (hosting); “Research on the strategy of low carbon development during China’s urbanization”, Key grant of project of National Social Science Foundation, 2010, 7, No. 10zd&032, (participating).” [↑](#endnote-ref-1)
2. Except Xizang, the 30 provinces (including autonomous regions, and municipality) compile their input-output table synchronously with Chinese National Statistical Bureau. [↑](#endnote-ref-2)
3. The North Municipalities, East Coast, and South coast regions are comparatively well developed. The Northeast, North Coast, Central, Northwest and Southwest regions are less developed. [↑](#endnote-ref-3)
4. China targets decreasing carbon intensity (carbon dioxide emissions per GDP) in 2020 to 40%-45% of the 2005 levels. Non-fossil fuels is slated to 15% around proportion in primary energy consumption by 2020. [↑](#endnote-ref-4)
5. The lower bound and upper bound are expressed as  and . [↑](#endnote-ref-5)
6. Here,  is the origin of carbon dioxide from the usage of energy of type  in industry ;  is the usage of energy of type  in industry ； refers to the CO2 emissions coefficient of type； The carbon emissions conversion coefficient is 《2006 IPCC Guidelines on National Greenhouse Gas Inventories》. CO2 emissions coefficient () = carbon embodied × net thermal value × oxidation rate. Carbon emission conversion coefficients by energy type are listed in table A.1. The carbon emissions coefficient of thermal power or heat is carbon emissions of all input of energy of all types for one unit of the output of product of thermal power or heat according to the energy balance table of each year. [↑](#endnote-ref-6)
7. is the input of energy of type k to thermal power in the process and transaction, is the output of thermal power. [↑](#endnote-ref-7)
8. The North Municipalities, East Coast, and South coast regions are comparatively well developed. The Northeast, North Coast, Central, Northwest and Southwest regions are less developed. [↑](#endnote-ref-8)
9. Source: US EIA statistics. [↑](#endnote-ref-9)
10. The CO2 intensity and value added rate are obtained from the 2007 ECEIRIO table with 17 industries. [↑](#endnote-ref-10)
11. Change rate of carbon intensity in region s,  Growth rate of GDP,  Change rate of carbon amount [↑](#endnote-ref-11)
12. The carbon emission increases by =1.4 million ton carbon dioxide (carbon emission intensity decrease 6.35% per year). is the ratio of industry to total output.  means the change in the amount of carbon emission. Positive (+) means increase, and minus (-) means decrease. Computation from optimal input-output model based on 2007 ECEIRIO table. [↑](#endnote-ref-12)
13. The carbon emission increases by =1.4 million ton carbon dioxide (carbon emission intensity decrease 6.35% per year). is the ratio of industry to total output.  means the change in the amount of carbon emission. Positive (+) means increase, and minus (-) means decrease. Computation from optimal input-output model based on 2007 ECEIRIO table. [↑](#endnote-ref-13)