**Reducing Greenhouse Gas Emissions via Industry Shifts and Regional Shares: An Interregional Dorfman-Samuelson-Solow Leontief System of China**

**Xue Fu1\*,Michael Lahr,2 Zhang Yaxiong,3and Bo Meng4**

1. Nanchang University, Xuefu Road 999, Nanchang, Jiangxi, 330031, China, fuxue@amss.ac.cn
2. EJB School of Planning & Public Policy, Rutgers University, Civic Square Building, 33 Livingston Avenue, New Brunswick, NJ, 08901 USA
3. State Information Center, Xicheng District 58 Sanlihe Road, Beijing, China, 100045
4. Institute of Development Economies-JETRO, 3-2-2 Wakaba, Mihama-ku, Chiba-shi, Chiba, 261-8545, Japan

**Abstract**

China promise to reduce nation’s carbon dioxide emissions in 2020 by at least 40% of its 2005 levels. This paper proposes that interregional industrial shifts might enable China to meet this goal. A Dorfman-Samuelson-Solow model is presented by using an environmental multiregional input-output table of China in a linear programming format and at given national carbon targets, with aim of maximizing national GDP, under constrains for both demand-supply balance and energy-use change within practical limits. In each province, excluding the energy preserved in the secondary energy, final consumption of 39 manufacturing accounted by bottom-up and up-down methods, final consumption of other sectors, energy transition and loss are calculated by 20 energy type into carbon emissions. The model suggest that moving the energy and heavy industries out of China’s North Coast would help considerably, GDP losses from which could be counteracted by raising the output of high-tech industries in the South Coast and of selected services across most of China’s regions, moreover, adjusting the energy mix toward cleaner resources would alleviate some pressure to reduce carbon emissions of heavy industry throughout China and of the energy industry in the Central.

*Keywords*: multiregional input-output analysis, carbon emissions, industry structural change

1. **Introduction**

Under international pressure, China promised years ago to reduce the nation’s carbon dioxide emissions per GDP (carbon intensity) by at least 40% of its 2005 levels before the year 2020. It also hopes to generate 15% of its primary energy from nonfossil sources in that year. In its 12th five-year plan, the horizon of which ends in 2015, China seeks to reduce the carbon intensity of China’s economy by 17% from 2010 levels, with regional targets ranging from a 10% reduction in China’s less developed West to a 19% reduction in East Coast provinces.

A strategy to reduce regional carbon emissions logically should be based on a trajectory of regional development and with changes in economic structure. Due to energy security issues among others, the composition of energy resources is unlikely to change in the near future; industrial shifts, energy conservation, and investment in energy-efficient technologies are keys to reducing carbon emissions. In addition, unlike most developed countries, China has a large share of state-owned enterprises in both energy and heavy industries. Besides market-oriented policies such as taxation, emissions trade system, and environmental regulations, changes in industrial structure can reduce carbon dioxide emissions. Indeed, the Third Plenary Session of the 18th Central Committee affirmed the importance of restructuring, relocation, and retooling of production capacity across a broad range of industries for reducing pollution and energy consumption, as opposed for just enhancing economic growth.

In light of the above, this paper produces a practical guide for how industry shifts in regional production can enable China to meet simultaneously both emissions reduction and economic growth targets. GDP growth is maintained in the simulations by raising production shares in services and high technology sectors in affluent regions. Restructuring is being enabled by further development of electronic commerce, courier services, and public infrastructure—particularly high-speed intercity railways and local rail transit.

Various regional strategies can possibly be applied to reduce carbon emissions, especially given regional differences in economic structure, energy efficiency, and life qualities. Figure 1 shows that in 2008 the shares of value added and final demand are greater, but the shares of energy consumption and carbon emissions are lower, in the affluent North Municipalities, the East Coast, and South Coast regions, and oppositely in the less developed Northeast, North Coast, Central, Northwest, and Southwest regions. Therefore, the less-developed, resource-rich West, which relies on heavy industry, is more able to reduce the carbon intensity of its production than can the East Coast provinces, which concentrates in producer services and the production of goods with high technical content. In this vein, across-the-board cuts in energy-intensity reductions, as suggested by the 12th five-year plan, are potentially at odds with the capacity to effect regional industrial change.

 China’s diverse but integrated production and consumption across regions determine that energy use and carbon emissions embodied in interregional trade also are critical elements of national industry-based strategy. China’s less-developed regions discharge carbon emissions to enable consumption in and exports by developed regions (Meng et al., 2013; Zhang and Lahr, 2014a). Thus, setting regionwise industry adjustments or emission targets is more appropriate than equivalents effected nationwide to minimize exacerbation of any existing interregional welfare imbalances. This is enabled here by using an energy-carbon-economy interregional input-output table (ECEIRIO table) in a linear programming framework. The resulting model displays China’s economy as an integrated system in which regional economies and their resource endowments are interconnected via production and consumption behaviors. Plus it adds a special focus on energy use and carbon emissions embodied in interregional trade. This exercise has real potential policy implications because China’s economy remains centrally monitored and controlled to some degree. Thus, the political will in China to implement the changes could cause them to be achieved. A similar exercise for an economy that more fully embraces laissez-faire capitalism would be strictly an act of academic inquiry.

<Insert Figure 1>

More recent research, which also uses input-output tables or models, identifies drivers of carbon emissions and analyze effects of China’s economic behavior on carbon emissions (Guan et al. 2008, 2009; Weber et al.2008; Feng et al.2009, 2012, 2013; Peters et al.2010; Minx et al. 2011; Qi et al. 2013; Zhang et al. 2014). Modeling industry structural change constrained by input-output technology (Dorfman et al., 1958) has been less common. That is, until Xia (2010) and Wang et al. (2011) examined China’s ability to meet its 11th five-year energy-savings targets, These authors ignored interregional differentials, however. While interesting, we contend that greater spatial detail is critical because China continues to foster interior economic development while simultaneously expressing extreme concern about pollution levels in its densely populated East Coast.

Both Xia and Wang et al. emphasize structural change as a means of reducing national energy consumption, but they largely disregard national welfare concerns. Policies modifying energy consumption behavior clearly can alter carbon emissions production as well as other airborne pollutants, so such a focus is certainly important. Reducing energy is a means of attaining energy security, but at best it is an indirect way to examine scenarios with an environmental focus. Our application of the Dorfman-Samuelson-Solow model in China is novel in its interregional in nature and in that it optimizes GDP constrained by industry-based carbon emissions targets. It therefore relies on China current energy consumption behavior.

Several studies on energy use and carbon emissions focus on China at a regional level.[[1]](#footnote-2) Some examine past restructuring of China’s industrial regime to attain emissions targets. In most, multiregional input-output (MRIO) tables are sources both of regional economic information and interregional insight.[[2]](#footnote-3) Liang et al. (2007), for example, detect significant interregional spillovers effects among China’s regions with regard to energy-use and find that energy end-use efficiency generates substantial intra-regional energy savings. Minx et al. (2011) note that emissions growth is largely explained by structural change towards pollution-intensive sectors of China’s economy and that the structural change through 2007 was instigated by capital investment. Feng et al. (2012) add the perspective that China’s most polluting sectors and companies are largely state-owned enterprises and urbanization contributes substantially to China’s CO2 emissions. They also find that China’s coast has favored international exports at the expense of emission-intensive production (e.g., metal products and textiles), which has moved to the nation’s interior. Feng et al. (2013, abstract) find that “up to 80 percent of the emissions related to goods consumed in the highly developed coastal provinces are imported from less developed provinces in central and western China where many low–value-added but high–carbon-intensive goods are produced.” Zhang and Lahr (2014a, 2014b) find energy consumption in export industries and households (and the urbanization of them) have enhanced China’s overall energy intensity and energy consumption levels and has induced CO2 emissions. Meng et al.(2013) measure interregional spillovers of CO2 emissions to reveal that emissions levels are related to regional industries’ intensity of involvement in domestic and global supply chains. Still, while much is known about how China’s economy has lead it to its current extreme CO2 emissions conditions, it is not perfectly clear how China’s might extricate itself from its current precarious position.

The novelty of the paper is embodied in the regional breakout of national carbon goals without losing sight of similar goals for national welfare. China economy is already slowing down and is expected to grow at less than 70 percent of rates that persisted during the most recent decade. Moreover, obligations to reduce carbon emissions typically constrain economic growth. In essence, we seek to discover how China’s government can best navigate its economy through the decelerating effects of international carbon emissions obligations, instead of highlighting the obvious conflict between economic development and environment protection. That is, while maximizing China’s national welfare, we assure it meets carbon emissions targets, while retaining current industry-based production and consumption relationships. In this vein, it yields substantially different insight from the intuition supported by algebraic estimates of national carbon emissions per unit GDP in Pan and Zhuang (2010).

Prior related studies (Xia, 2010; Wang et al., 2011) probe for the best national industrial structural adjustment that minimizes energy consumption, while ignoring interregional welfare concerns. A regional treatment is critical since China is presently more concerned with emissions releases in some regions than it is in others. We set binding regional carbon intensity targets by decomposing the national carbon index into regions’ individual industry carbon indices. Further the ultimate objective of the mathematical program is to maximize national GDP constrained by these industry carbon indices. The *Blue Book of Low Carbon Development* (2012) indicates a binding 20% energy-saving target in the 11th five-year plan. Local targets are determined through negotiations between each local government and the central government. Rather than applying a political bargaining game, we use a comprehensive economy-environment system.

Lately China has been emphasizing renewable energy options. Indeed, in 2012 China spent $65 billion US (the U.S. spent $36 billion that same year) while also expanding its coal production and consumption, commissioning 40 Gwh of coal-fired electricity generation plants, requiring on the order of 0.86 billion tons of more coal production by 2015 (EIA, 2013). According to Arnold Cohen (2014) of Breakthrough Institute, China added 1 Gwh of solar energy in 2013with another 27 Gwh of coal-fired electric power; this over 600 percent of its investment in new wind energy. So we also examine the sensitivity of the economy to changes in energy mix, which could diminish the pressure to alter industry structure in order to attain carbon reduction targets.

China’s current strategy to reduce the effect of carbon emissions is to move energy-intense industry away from its populations centers and into its interior. The serious air-pollution situation in the affluent Northern municipalities has them spending comparatively large sums on energy conservation and emissions reduction programs. A total of nearly 3,400 billion￥ (620 billion ￥ in the most recent year alone) has been spent nationwide to meet national environmental aspects of *Twelfth Five-Year Plan*. Beyond this total, Beijing alone has received additional 760 billion ￥in 2014.Central financing provided 10 billion ￥in special funds to mitigate air pollution in Beijing, Tianjing, Hebei and surrounding areas, the Yangtze River Delta, and the Pearl River Delta.

We investigate the indirect effect that self-contained conservation programs wind up having on carbon emissions discharged in China’s Central and Western regions. That is, in a final accounting, while conditions in more affluent regions would appear to improve, less developed regions of the interior would now suffer both income wise and environmentally since now they would support final demands generated in the nation’s more affluent and more heavily populated regions. Instead, it seems more rational that the more affluent regions should shoulder more responsibility for updating their industrial base, as opposed to sloughing polluting industries to the interior. Both their advantage in both occupational wealth in high technology and capital resources suggest this strategy. Moreover similar social politics have been suggested on a worldwide scale, i.e., greater responsibility for carbon emissions should be undertaken by the developed countries due to their greater propensity to generate final demand (Ferng, 2003; Shui and Harriss, 2006; Li and Hewitt, 2008, Wang and Watson, 2007; Smith et al., 2007). In any case, we consider both production and final demand factors across the various regions of China when assigning local industry carbon-reduction responsibility.

This paper investigates the extent of regional industrial structural adjustment and the change of CO2 assignments by industry and region required to meet national CO2 target while continuing to maximize GDP under conventional technological and carbon constraints. Our work is distinct from that of Xia(2010) and Wang et al.(2011) in that we reduce carbon emissions instead of altering energy-savings directly. Moreover, we assure carbon emissions are met at a regional level, not at national one. We effect this set of goals and constrains in a linear program that uses a multiregional input-output table that focuses on the carbon emissions embodied in the energy-used to produce goods involved in interregional trade, and considering changes in energy mix after accounting carbon emissions by energy type.

**2. Methods and Data**

**2.1. Principle**

We use a multiregional input-output table with the eight regions that are aggregates of China’s 31 provinces. The Central and North Coast regions 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.

Intuitively, a solid adjustment strategy for reducing carbon emissions can be founded on the principles of raising the share of GDP produced by low carbon emissions industries and of decreasing the share of GDP generated by industries that emit high levels of carbon. Moreover, from a technological perspective, this strategy is easier to effect through industries in which value added comprises a large share of the value of total output.

Presently, Agriculture and Services both have the largest GDP shares and lowest carbon emissions shares. For example, Other services produces 22.4%-47.4% of each region’s GDP and releases between 1.1%-7.6% of each region’s carbon emissions. Energy-producing industries—like Production and supply of electricity, steam, gas and water—release the greatest shares of regional carbon emissions (from 36.6% to 54.8%) but yield fairly low shares of GDP for each region (from 3% to 5%). For example, although it produces just 54.8% of all carbon emissions in the Northwest, the energy industry produces just 5% of the region’s GDP. Heavy industries also release fairly large shares of each region’s carbon emissions but contribute comparatively little to overall regional GDP. In the North Coast, Smelting and pressing of metals & metal products releases 29.1% of all carbon emissions but yields just 6.7% of the region’s GDP. In the South Coast, Nonmetal mineral products releases 21.2% of the region’s emissions but contributes only 2.5% of the region’s GDP.

<Insert Figure 2>

<Insert Table 1>

To achieve the national target of reducing carbon emissions, industry structure must change and carbon emissions must be reduced differentially across the various regions of China, at least if the GDP of China is not to suffer much (see Figure 3). In the East region, for example, the adjustment strategy would yield two effects. Energy inputs would have to change to reduce carbon emissions; but an alternative strategy would be to substitute domestic intermediate industry inputs with imports. Technological updating and transformation of heavy industry in the Northwest and Central regions, perhaps through both domestic and foreign direct investment, would improve energy efficiency and *ipso facto* decrease CO2 emissions.

Although the China’s national plan calls for a rise in GDP and for carbon intensity to fall, the East Coast’s targets ought to be different in character from the nation’s. That is, to protect the health of the large share of the nation’s population that lives there, the region should be even more aggressive than the nation in reducing the output of industries that are carbon intensive (heavy industries) and in enhancing the output in industries that emit very little carbon (high technology industries. The direct and indirect carbon emissions declines caused by reducing the output of heavy industry would, of course, more than offset the direct and indirect carbon emissions required by proposed output rises in high value-added, low carbon-emitting sectors. The precise adjustment of industry structure and reduction of carbon emissions required of the East Coast is a function of the region’s industry mix (and, hence, energy usage and GDP yield), as well as of the mix of intermediate inputs in the other regions (its interregional supply chain) upon which its industries’ outputs rely.

<Insert Figure 3>

**2.2. Methods**

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 of the national economy.[[3]](#endnote-2) This, in turn, results in a change in the amount of carbon dioxide produced.[[4]](#endnote-3) 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. The optimization model is enabled as follows



whereand  are annual GDP growth and annual rate of carbon emissions, respectively;denotes the direct requirements matrix of the interregional input-output table; 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; ,, andare the vectors of exports, carbon coefficients, and value added coefficients by industry in region *s*;and are national household carbon emissions, initial total carbon emissions, and the initial endowment of GDP; and the subscript and superscript  are lower and upper bounds, respectively. If we letbe the vector of industry price indices by region for 2008, then is nominal GDP in that year. Note that all value variables are in terms of real 2007 prices, so that  is real industry GDP in base year (2007) prices. The objective function (3.1) maximizes GDP, namely, the total production less intermediate uses 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.[[5]](#endnote-4) The model essentially requires only the carbon emissions constraint (3.3) since GDP is maximized automatically, which makes (3.4) redundant.

Rose et al.(1996) set lower and upper bounds on personal consumption at 75% and 125%, respectively, as a rough approximation of possible variations in basic human need. Considering that investment increases in China have been extraordinarily high, it was somewhat of a surprise when an examination of recent historic data by industry revealed no sector had output or exports that rose by more than35%or less than 5% on an annual basis. Such an export bound places China somewhere in between a “small country” (its export quantities do not affect world prices) and a “large country” (its export levels affect world prices). In China’s MRIO table, imports are only reported in accounts rowwise, so that exports are part of the demand balance conditions.

As stated earlier, our model calculates China’s optimal industry mix for the next period. It is initiated with the base year’s structure. In the case of scenario 1, the model finds how industry structure might be minimally re-arranged to realize a 5.93% reduction in carbon emission intensity by the next period. This is equivalent to a 2.53% increase in the amount of carbon emitted when GDP rises by 9%.[[6]](#endnote-5)Here,, ,  are from China’s base-year ECEIRIO table (see Table 2). Carbon emissions are based on final consumption of energy. Endogenous variables are regional production by industry, exportsby 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.[[7]](#endnote-6)

**3 Data**

The energy-carbon-economy interregional input-output (ECEIRIO) accounts in Table 2 shows energy use by type of resource for each industry in each region (accounted by both the value and standard physical quantity units) as well as the embodied carbon emissions (transformed from energy consumed by energy resource using standard coal’s CO2 conversion coefficient). The energy type, affiliated industry and the CO2 conversion coefficient of the energy type are listed in Table 3. The value part of ECEIRIO accounts is the classic interregional input-output table. The introduction of the hybrid I-O table enables accounting of the regional energy and carbon emissions in physical terms. This enables computation of the intensity of carbon emissions by industry. Thus, the table connects the value of the economic system to the quantity of consumed energy by type, which in turn relates directly to carbon emissions. We can calculate the direct and indirect usage of energy, and direct and indirect emitted carbon dioxide for the output of each.

<Insert Table 2>

<Insert Table 3>

The ECEIRIO table involves two accounts—energy usage and consumption by energy type (Miller and Blair2009; Xia 2010). The use of energy *k* is the total amount of consumed energy of type *k* for the all industries production and households. Energy use covers the energy preserved in secondary energy production (), e.g., electricity, which is excluded from “total energy consumption” in *China’s Energy Statistical Yearbook* to avoid double computation. That is, total energy consumption converts all consumed energy resources into primary energy sources (e.g., electricity is converted into coal, oil, biomass, and other resources). The total consumption of energy() is divided into final consumption of energy(), the energy loss of processing and transaction (), and the energy loss of allocation, .The final energy consumption refers to energy of all 20 types, purchased from other energy industries that are consumed directly in the industry for its production. In *China’s Energy Statistical Yearbook*, the final energy consumption by industrial sector  is available at national level, and the final energy consumption of 20 types by agriculture, manufacturing, construction, transportation, other services, and household in r province  is provided from both national and 30 provincial energy balance tables. The energy loss during processing and transmission of secondary energy sources is difference between the sector’s energy inputs and the energy it delivers to its demanders; both are obtained from “input and output transformation” in the national and provincial energy balance table. In addition, energy from the primary energy sources and that transmitted via the secondary energy sector are both included as energy usage in the ECEIRIO table,. Beside   at national level, all types'    are available from provincial energy balance tables in China’s Energy Yearbook. As in material flow tables, the energy use reflects the production and usage of ***all*** energy types, but it also displays duplicative accounts induced via production of secondary energy resources like electricity and steam heat.

The energy consumption of an industry[[8]](#endnote-7) includes energy purchased by the industry for its final use in production as well as indirect energy consumption. The latteris the secondary energy self-supply of this industry as \ inputs for its final use in production. For example, the energy consumption in the chemical industry includes fuel oil (fuel stocks, excluding feed stocks) and coking coal used to produce chemicals (), as well as any fossil fuel used to produce electrical and thermal power that is used for its production (). Here, the part  is regarded as the *k*th energy consumption of the *j*th (Chemical) industry from mix industry principle (shown in term of *the fuel consumption and its main variety by sector*), reflecting in energy balance table as a part of the energy transaction and loss transformed from the *k*th primary energy source and preserved in the *g*th secondary energy source (), namely,. From energy balance table, the part  is allocated to the parts of the *k*th energy usage of the *g*th energy industry, thus, in ECERIO table, according to pure industry principle, . It means that the sum of all types’ “energy consumption by industry” repeats computation of energy preserved in the secondary energy source (). T*he fuel consumption* by mix industry is summed as the same amount of the total energy usage and its part exceeding final energy consumption is energy transaction and loss (). Comparing the fuel consumption and final energy consumption by manufacturing, the excessdistributed in a few manufacturing industries, such as Mining and Dressing, Chemical Industry, Smelting and Pressing of Metals & Metal Products, etc..[[9]](#endnote-8) The distribution at the national level is obtained by.[[10]](#endnote-9)

 and  of 20 energy types by 39 manufacturing are only available from Shanghai, Jiangxi, and seldom provincial statistical departments (r=1,..,s).[[11]](#endnote-10) Fuel consumption by all energy types for large-scale manufacturing in each province in the *2008 China’s Economy Survey* is compared to ,the main fuel consumption by detailed manufacturing as reported in various provincial statistical yearbook for consumption of all energy-resource types in manufacturing. The energy consumption by industries are the sum of energy consumption of all types by industry subtracted by the preserved energy from input to output , and the energy consumption by type is the sum of energy consumption of all industries by type. The final energy consumption by industry are the sum of final energy consumption of all types by industry and the final energy consumption by type is the sum of the final energy consumption of all industry by type . All of them are available in various Provincial Statistical Yearbook and China's Energy Statistical Year book.

The missing data of are complete by bottom-up approach. Some are directly obtain from  of 20 types' energy consumption of 39 manufacturing provided by provincial statistical department. Some are indirectly modified according to ,, and  of 39 large-scale manufacturing, which are inconsistently provided by provincial statistical yearbooks for main energy types, and 2008 China’s Economy Survey (Energy Volume) for all 22 energy types (plus blast-furnace gas, briquettes)[[12]](#endnote-11). After subtracting  of 9 available main types'[[13]](#endnote-12) energy consumption of 39 large-scale manufacturing provided by (Jiangxi) Statistical Yearbook from the corresponding figure in  provided by (Jiangxi) Statistical Department, the small-scare manufacturing'  are given, taking a small share of the corresponding type' energy consumption, for example, 2.7% of raw coal's consumption[[14]](#endnote-13), and scattering merely among seldom manufacturing.[[15]](#endnote-14) From , (,), for the main energy consumption of the most manufacturing, i.e. 54.3 and 84. thousands tons the raw coal consumption by MFM and MNF in Jiangxi Statistical Department and by large-scale MFM and MNF in Jiangxi Statistical Yearbook,  equal to , (,), of 39 large-scale manufacturing from province statistical yearbook or 2008 China’s Economy Survey in the other provinces, while the energy consumption of the rest energy types by the other manufacturing,(,) is obtained by a modified biproportional scaling method (Stone 1960). The original element (, ) if, and  if .  repeatedly multiply on the left with raw controlling vector  and on the right with the column controlling vector until the deviation less than infinite small (i.e. 0.15). So the elements of , (, ) at the last iteration form the missing data, and they plus and , () together form ().

 of 20 types' energy consumption of 39 manufacturing are directly provided by some provincial statistical department, where the energy transmission and loss by industry mix is distributed by the share,[[16]](#endnote-15) while they are indirectly obtained according to and , deduced  , and their difference with  distributed among industries , which are assumed constant across China's geography and obtained by. Knowing denominator,  can be inferred from the provincial distribution ratio with given , (r=s+1,...,S) and modified by a biproportional scaling method. The original element ,, if , ,, and  if,.  repeatedly multiply on the left with raw controlling vector  and on the right with the column controlling vector until the deviation less than infinite small (i.e. 0.15). So the element of , () at the last iteration,  , and ,  together form ,. The final consumption for detailed manufacturing  is added to the energy transaction by pure industry to yield energy use by pure manufacturing.

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The energy consumption in the ECEIRIO table avoids the double accounting of energy produced by secondary energy sectors, during accounting of which, bottom-up approach is combined with up-down approach. It is the total *actual* amounts of raw energy resource consumed of type *k* . After excluding the *k*th primary energy resource preserved in the *g*th secondary energy sourcefrom the energy use , according to the share of energy input for the production of the secondary energy , we estimate the *k*th energy resource consumption by pure industry. The *k*th energy input from for the *g*th energy processing and transaction, the energy loss, energy consumed by the agriculture, manufacturing, construction, transportation service, other services, and household sectors in each province was obtained from provincial energy balance tables in the *China’s Energy Statistical Yearbook*. Accounting of industrial energy consumption by type avoids double-counting and also enables a more accurate and complete depiction of industrial carbon emissions originating from energy consumption at the regional level. The energy resources preserved in and transformed to thermal heat are transmitted from the producing region to the demanding region and forms the energy consumption of demanding regions.

An industry’s carbon emissions are the sum of the energy consumption by resource type multiplied by the energy-carbon conversion coefficient for that industry. .[[17]](#endnote-16) Here, the portion of energy source used as raw processing material and not as burning fossil energy should be deduced from the energy consumption for carbon emissions in this industry. The carbon conversion coefficients differ across energy types (see Table 3).[[18]](#endnote-17)

1. **Industry structural change for carbon reduction**

**4.1Potential of industrial structure change and carbon emission reduction**

Instead of obtaining an overall national energy-saving for all industries (Xia, 2010, Wang et al, 2011), we find that China’s regions necessarily differ in their targets for reducing carbon intensity when compared to the national average. The model reveals a key way to reduce carbon emissions is to increase the share of GDP and carbon emissions in affluent regions and to decrease the share of GDP and carbon emissions in less-developed regions.[[19]](#endnote-18)This is quite different from present practice by China’s government, which transfers industry from China’s affluent North Municipalities and eastern region toward the interior (Liu et al. 2011). Despite this, GDP and final demand shares in China’s affluent North Municipalities, East Coast, and South Coast regions rise but the shares of energy consumed and CO2 emitted both lower. Through a reconfiguration of inter industry structure, the share of GDP rises by 0.4% in East Coast and 0.1% North Municipalities and it declines by 0.4% in North Coast, while shares of carbon emissions rise for the developed East Coast by 1.4% and South Coast by 0.6%, decrease for less developed Northeast by 1.2% and Northwest by 1%.

In such a scenario, carbon emissions decline in heavy-industry-intensive regions, by 9.7% and 7.1% in the Northeast and Northwest region, respectively, rise significantly in regions with modern services and high technology industries, by 16.8% in the North Municipalities, by 11.6% in the East Coast region. The output of most low carbon-intensive industries in all regions increase at the same rate due to fixed 2007 technology and a balance growth assumption, so these industries’ carbon emissions increase by 60.5%. In essence the model directs China’s regions toward a convergence in industrial structural, a phenomena found also by many economists (Young and Alwyn, 2000; Yeneder 2003; Guglerand Pfaffermayr, 2004; Palan and Schmiedeberg, 2010, Druckerand Feser 2012). Industry convergence across regions is caused by market and government failure, supply and demand factors, etc.. Local benefit drive fierce interregional competition and lack of social welfare system prevent energy, raw material, technology, human capital from mobilizing across regions. Lack of government performance supervision, opaque fiscal budget results in the redundant construction. Industrial bandwagon diverging from regional factor endowment structure weaken industry division and value chain’s regional extension. The convergence server due to the globalization of economy and the integration of regional economy, low supply technical level, and lack of contractual relation. Decreases in output and carbon emissions differ across regions, among higher carbon intensity industries, for example in Nonmetal Mineral Products by 37.2% in the North Coast region, by 36.6% in the South Coast region, and in Smelting and Pressing of Metals & Metal Products by 40.4% in the Northeast and by 14.6% in the North Coast. Thus the key to reducing carbon emissions is reducing carbon emissions emanating from a few key heavy manufacturing industries and the energy industry. This is especially the case in North Coast. Instead of key industry,, China could attain potential energy-savings of 0.01-0.29 tce per ten thousand ￥ for all industries (Xia, 2010).

The industry shift naturally varied from one region to the next, causing carbon emissions decline in most undeveloped regions. The largest declines appear in the energy-intensive Northeast and Northwest region by 9.7% and 7.1%, respectively, and then by 6% in the Central region that transmit energy to the East Coat and South Coast. This is quite different from modest declining shares of manufacturing, on the order of 0.1%-0.5%,suggested by Xia (2010) and Wang et al. (2011) *for industries with high carbon coefficients—energy and heavy industries. In particular, GDP shares decline* most steeply in the Production and Supply of Electricity, Stream, Gas and Water (most in less-developed regions, by 3.2% in the Northwest,3.0% in the Southwest, 2.4% in the Central region) but more moderately in Smelting and Pressing of Metal & Metal Products (by 2.9% in the North Coast and by 2.8% in the Northeast, and in Nonmetal Mineral Products, by 2.3% in the North Coast and by 1.5% in the South Coast region).

We also obtained substantially different nationwide outcomes on an increasing share of services, smaller than the rising of other services by 3.5% in Xia (2010) and Wang et al.(2011). *The declines of output of energy and heavy industry were offset by output share rises in smaller carbon emission coefficients services and high technology industries* of most regions, in Real Estate Finance and other services by 1.0%-1.6% (by just 0.6% in the East Coast), in the Transportation & Trade and Catering Services by 0.8% in most developed North Coast and Central region, and by 0.7% in Northwest region, in Electric &Telecommunications Equipment by 0.3%in the developed South Coast, by 0.2% in the East Coast and North Coast. According to the “12th five-year comprehensive economic design of saving energy and reducing emissions,” Central and West regions should receive a substantial rise in traditional industry, in spite of in admissibility of carbon-intense industries using outdated technologies here. Outdated production capacity can be readily eliminated by adjusting the central government’s budget for the unemployed workforce to include retraining of workers, by importing new technology, and by updating the set of products produced on existing production lines. It also is important to attempt to minimize the export of products that require high amounts of energy resources—those that produce substantial carbon emissions. Without specifying these priorities in the model, it yields outcomes that work in the same direction as the intentions in China’s 12th five-year plan. Carbon emissions are predicted to rise by 16.8% in the Northern Municipalities and by 11.6% in the East Coast. The environment pollution in Beijing and Tianjing are nearly resolved by reducing emissions in the Northeast, Northwest, and Central regions via comprehensive management. Our findings support the policy of granting funds for undeveloped west and north regions instead of concentrating them in the North Municipalities.

To improve GDP and reduce embodied carbon, China should replace traditional industry by high technology in undeveloped regions; integrate the information and industrialization; support technology updates and the relocation of industry that emit high concentrations of carbon; improve the processing trade in developed regions from just being goods made in China to products designed, created, and used in China; enhance the Innovative industrial agglomeration of the whole country, and encourage industrial diversify and product diversification across the different regions. *Asian Development Outlook 2014* confirms that structural adjustments are more important than the nation’s 7.5% growth goal. The interregional industry shift enables China restricting carbon intensity more in its less developed West and lesson its East Coast provinces and imply China emphases more on the development of the high-technology industries in East Coast and lesson production of heavy industries in its northern resource-rich provinces.

<Insert Table 4>

**4 .2 Optimal industrial structure under the low carbon constraint**

The scenario with the low carbon intensity target (6.76%) at the highest growth rate (9%) and at the low economic growth rate (7.5%) shows (see Table 5) that the shares of carbon emissions rose in almost all regions. The share grew most in the East Coast, by 0.15% from the highest carbon-intensity target to the lowest, and then by 0.23% from the highest growth rate to the lowest rate. Only the Central region decreased its share of emission production, by 0.64%from the highest carbon intensity to the lowest, and then by 14% from the highest growth rate to the lowest.

Achievement of emissions reduction goals requires deeper cuts in carbon-intense industries—particularly in traditional manufacturing regions—and somewhat steeper GDP share rises in both low-carbon, high-tech industries in export-oriented regions and in services across the board. 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 very deeply, although especially so in the Central region. Moreover, the carbon emissions and GDP shares must decline more under slower growth scenarios than when carbon targets are intensified. At the high rates of economic growth, carbon emissions in Nonmetal Mineral Products of the Central region decreased by 13.5% in the most carbon-intense scenario under a low growth rate, about 3.6 percentage points more than in the “base” scenario, i.e., about 1.4 percentage points originates from tighter carbon intensity and 2.2 percentage points from the slower growth rate. The potential adjustment of industrial structure to a lower carbon-release scenario yields changes that are similar in direction to the base scenario, although with smaller declines in heavy industry shares. In the Central China, for example, the share of Smelting and Pressing of Metal & Metal Products decreased most—by 3.5%. This is almost double that in the base scenario with about 0.6 percentage points originating from the tighter carbon intensity and a percentage point from the slower growth rate.

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 in 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. The model suggests the value-added share of Services in North Municipalities should rise to 62.9%, which is much higher than the 47%—the current (2015)national average share of GDP in Services. The region with the next largest shares of GDP in Service is the South Coast (43.2%). The share of newer industries in regional GDP, Transportation Equipment and Electric & Telecommunications Equipment in South Coast, East Coast, and North Municipalities are, respectively, 11.8%, 10.6% and 8.4%. These shares are greater than the proposed 2015 national requirement of 8%. In reality, affluent regions’ government investments in public infrastructure—e.g., high-speed railways and subways—along with the combination of the rapid emergence of electronic commerce and courier services, provide a plausible foundation for the restructuring required.

Differing from the somewhat similar nationwide studies, ours also investigates alternative, slower growth rates and the possibility of changing the energy mix substantially. China’s less-developed regions emit substantial amounts of carbon to support exports or production used by other regions. With this in mind, 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 reflects this. So a key policy solution is to improve technology transfer and cooperation between China’s affluent regions and its more backward regions, as well as to encourage environment-friendly foreign direct investment in its less-developed regions.

China will face ever more development pressure in the future. Some GDP-laden industry structure will be sacrificed if its economy slows as expected by the World Bank (ww.worldbank.org). Heavy industry is a likely candidate to be sacrificed. For example, if national GDP growth should slow to 7.5%, we find the production of Smelting and Pressing of Metal & Metal Products would have to decrease by about 3.5%─twice the rate of decline under a national growth rate of 9%.

<Insert Table 5>

* 1. **Optimal industrial structure with variable energy mix**

To compare the above cases with invariable energy mix, another scenario is considered for industry structure adjustment using the same carbon reduction target in case of changes in the structure of energy resources, such as to improve non-fossil fuel share in primary energy mix and to enhance energy conservation efforts. In the consumption of primary energy, 15% is expected to be from non-fossil resources in 2020, while 7.5% is to be from Hydro & Nuclear Power an annual rise between now and then of 4.9 percentage points to 471 billion kWh of capacity if no other renewable energy resources are applied, this is 4.7 percentage points more than embodied in the 2007 MRIO accounts for primary resources for electricity.[[20]](#endnote-19) The proposed change has two effects: (1) a substitution effect—the substitution of 1% conventional steam-plant power production by Hydro & Nuclear Power results in reduction by 0.47 percentage points in fossil fuel consumption and by 0.16 percentage points in carbon emissions—and (2) an efficiency effect—a 0.9 percentage point decrease in conventional steam-plant power production results in reduction by 0.15 percentage points in energy consumption and by 0.49 percentage points in carbon emissions.[[21]](#endnote-20) Comprehensively, the carbon emissions intensity decreases overall by 1%. Assuming all regions are consistent, industry structure is restricted by the national carbon reduction target and carbon emissions change through their change in energy mix. C*omparing it to the scenario* ***without*** *changes in the energy resource mix, the potential adjustment of industrial structure* ***with*** *energy resource mix change yields the same direction of change, but with a smaller range of increase and decrease*. See Table 6. The difference from the fixed energy mix scenario is greatest for high or low carbon-intense industries in the Central region, where GDP and carbon emissions shares differ by 0.1% and 1.1%, respectively. By industry, carbon emissions are 5.0 percentage points lower in Nonmetal Mineral Products, approximately half of the carbon difference found for the case of fixed energy mix. They lower by 36.6% in the Production and Supply of Electricity, Steam, Gas and Water, which is 6.6 percentage point slower than in the fixed energy mix scenario. To the contrary, the GDP share of Real estate finance rises by 1.5 percentage points, and that for Others services rises by 0.6 percentage points above its GDP share under the fixed energy mix scenario.

<Insert Table 6>

1. **Conclusion**

One important way that China could meet its carbon-intensity goals for 2020 is to alter its industry structure. The “12th five-year comprehensive economic design of saving energy and reducing emissions” issued by the State Council of the People confirms that the goal of energy-saving and emissions abatement will have to be realized through industry shifts, the elimination or technological revamping of the outdated facilities, changes in the mix of energy resources used, and by expanding production in services and high-tech industries. China hopes to meet this aim while also providing an ever-improving quality of life.

Prior work (Xia, 2010, Wang et al., 2011) has examined the advantage of structural change in meeting carbon goals using a national energy-concentrated optimal I-O model. Instead, we developed an energy-carbon-economy *interregional* input-output table (ECEIRIO model) that provides more insight into China’s large, spatially integrated economy. We therefore are able to focus on the energy-based carbon emissions embodied in *interregional* trade. We also consider possible changes in energy resource mix.

In our modeling effort, each regional economy has a unique set of resource and industry endowments. Each also is connected to other regions by industry production and consumption through interregional trade including energy use. The goods and services traded in turn embody carbon emissions, which we assign to the consuming region. We apply a linear programming approach to examine how to reduce carbon intensity via differential adjustments to industry structure across China’s interrelated regions. We limit all industry adjustments by setting realistic lower and upper bounds on changes in personal consumption, industry GDP, and exports.

Model results suggest that moving the energy and heavy industries out of China’s North Coast would help immensely. To counteract those GDP losses, China could raise the output of high-tech industries in the South Coast and of selected services (i.e., Real estate finance and Other services) across most of China’s regions. The goal of State Council of the People that the shares of national total GDP in Services and new technology industries should be above 47% and 8% by 2015 are met in affluent regions. If China’s GDP growth rate slows, however, it will be tougher to reduce carbon emissions. This is because deeper industry adjustments will be needed across the board, particularly in energy-resource-rich Central China. Adjusting the energy mix toward cleaner resources, such as wind and solar resources, would alleviate some of the pressure to reduce carbon emissions of heavy industry throughout China and of the energy industry in the Central China, in particular. The model results reemphasize even more development of the high-technology industries and modern services in East Coast and de-emphasize heavy industries in China’s northern resource-rich provinces.

Moreover, if China enhances its annual share of non-fossil energy resource use by the 5.4 percentage points, the pressure to adjust its industrial structure would decline somewhat compared to a fixed energy mix case. In particular, Central China would have more room to emit carbon, especially in high carbon-intensive heavy and energy industry, although it would gain lower shares of GDP growth from the low carbon-intensive industries. The “comprehensive 12th five year economic design of saving energy and reducing emissions” suggests developing nuclear energy generation to ensure the energy security, exploring hydroelectric power generation to meet ecological concerns, expanding natural gas usage, and pushing other renewable energy (wind, solar, biomass, geothermal energy, etc.) so that the share of non-fossil energy resources rises to 11.4% in 2015. The Central and West have the greatest capacity to develop renewable energy.

In general, accelerating changes in China’s industry mix can effectively at reduce CO2 emissions. But other keys measures can be applied to reduce carbon emissions in China. We show that enabling greater energy conservation and changing the energy resource mix can help. We also suggest that inducing “dirty” firms to update via “green” technology, and advancing efficient and clean usage of coal in energy sectors would help as well. In addition, as Zhang and Lahr (2014b) suggest a focus on household consumption of energy, such as improving their environment-friendly lifestyle is also paramount as China is shifting from the word factory to the world consumption market.

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**Figure 1:** Shares of output, final demand, energy consumption and carbon emissions[[22]](#endnote-21)

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**Figure 2:** Share of output and share of CO2 by industry across region

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**Figure 3**: Principle of interregional industry shift to reduce CO2[[23]](#endnote-22)

**Table 1:** The classification of industries and sectors[[24]](#endnote-23)

|  |  |
| --- | --- |
|  Industry and sector |  Industry and sector |
| 1. Farming, Forestry, Husbandry, Fishery | 9.Smelting and Pressing of Metals & Metal Products  |
|  AGR: Agriculture |  SFM: Smelting and Pressing of Ferrous Metals |
| 2. Mining and Dressing \* |  SNM: Smelting and Pressing of Non-ferrous Metals |
|  MWC: Mining and Washing of Coal\* |  MMP: Manufacture of Metal Products |
|  EOP: Extraction of Petroleum\* | 10.Ordinary Machinery & Equipment for Special Purposes  |
|  ENG: Extraction of Natural Gas\* |  MPM: Manufacture of General Purpose Machinery |
|  MFM: Mining and Processing of Ferrous Metal Ores |  MSM: Manufacture of Special Purpose Machinery |
|  MNF: Mining and Processing of Non-Ferrous Metal Ores | 11.Transportation Equipment |
|  MNO: Mining and Processing of Nonmetal Ores and Mining of Other Ores |  MTE: Manufacture of Transport Equipment |
| 3. Food Processing & Tobacco Processing  | 12.Electric &Telecommunications Equipment |
|  MOF: Manufacture of Foods |  MEE: Manufacture of Electrical Machinery and Equipment |
|  MOB: Manufacture of Beverages |  MCE: Manufacture of Communication Equipment, Computers and Other Electronic Equipment |
|  MTO: Manufacture of Tobacco |  MIC: Manufacture of Measuring Instruments and Machinery for Cultural Activity and Office Work |
| 4.Textile Industry & Garments and Other Fiber Products | 13.Other Manufacturing Industry  |
|  MTE: Manufacture of Textile |  OMF: Other Manufacturing |
|  MTW: Manufacture of Textile Wearing Apparel, Footware, and Caps | 14.Production and Supply of Electricity, Steam, Gas and Water\* |
|  MLF: Manufacture of Leather, Fur, Feather and Related Products |  PHN: Production and Distribution of Hydro Power and Nuclear Power\* |
| 5.Timber Processing, Fiber Products & Furniture Manufacturing  |  PTP: Production and Distribution of Thermal Power\* |
|  PTW: Processing of Timber, Manufacture of Wood, Bamboo, Rattan, Palm, and Straw Products and Manufacture of Furniture |  PHP: Production and Distribution of Heat Power\* |
| 6. Printing and Cultural and Sports Articles  |  PDG: Production and Distribution of Gas\* |
|  PPP: Manufacture of Paper and Paper Products |  PDW: Production and Distribution of Water |
|  PRR: Printing, Reproduction of Recording Media | 15.Construction  |
|  ACE: Manufacture of Articles For Culture, Education and Sport Activity | COS: Construction |
| 7.Chemical Industry \* | 16.Transportation & Trade and Catering Services |
|  PPN: Processing of Petroleum and Nuclear Power\* |  TSP: Transportation, storage, Storage and Post |
|  COK: Coking\* | 17.Real estate finance and Others services |
|  MCM: Manufacture of Raw Chemical Materials and Chemical Products |  WRT: Wholesale and Retail trades |
|  MOM: Manufacture of Medicines |  RFO: Real estate finance and other service |
|  MCF: Manufacture of Chemical Fibers | 18.Urban |
|  MOR: Manufacture of Rubber |  UHH: Urban households |
|  MOP: Manufacture of Plastics | 19.Rural |
| 8.Nonmetal Mineral Products  |  RHH: Rural households |
|  MNM: Manufacture of Non-metallic Mineral Products | 20.Total |

**Table2:** Interregional Energy-Carbon-Economy Input-output Table with Asset[[25]](#endnote-24)

|  |  |  |  |
| --- | --- | --- | --- |
| 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 |  |  |  |  |  |  |  |  |  |  |
| Non-Energy Industry |  |  |  |  |  |  |  |  |  |  |
| … | 　 | 　 |  |  |  |  |  |  |  |  |  |
| Region m | Energy Industry |  |  |  |  |  |  |  |  |  |  |
| Non-Energy Industry |  |  |  |  |  |  |  |  |  |  |
| Energy usage |  |  |  |  |  |  |  |  |  |  |
| Energy consumption |  |  |  |  |  |  |  |  |  |  |
| Total energy consumption |  |  |  |  |  |  |  |  |  |  |
| Carbon emission |  |  |  |  |  |  |  |  |  |  |
| Total carbon emission |  |  |  |  |  |  |  |  |  |  |
| import |  |  |  |  |  |  |  |  |  |  |
| Primary Input |  |  |  |  |  |  |
| Asset | Nature resourceFixed capitalHuman capital |  |  |  |  |  |  |
| Total input |  |  |  |  |  |  |

Table 3: The energy industry classification, energy types and CO2 conversion coeffiecient[[26]](#endnote-25)

|  |  |  |
| --- | --- | --- |
| Industry classification | Energy type | CO2conversion coefficient(104 t) |
| ECEIRIO table | input-output table | DRCSCC | IPCC |
| 1. MWC: 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. EOP: Extraction of Petroleum | Extraction of Petroleum and Natural Gas | Crude Oil | 0.5825 | 0.5857 |
| 3. ENG: Extraction of Natural Gas | Extraction of Petroleum and Natural Gas | Nature Gas | 0.4435 | 0.4483 |
| 4. PHN: 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. PTP: Production and Distribution of Thermal Power | Production and Distribution of Electric Power and Heat Power | Thermal Power | 2.1114\* |  |
| 6. PPN: 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. COK：Coking | Coking | Coke,  | 0.7476 | 0.855 |
| Other Coking Products | 0.7476 | 0.6449 |
| 8.PHP: Production and Distribution of Heat Power | Production and Distribution of Electric Power and Heat Power | Heat | 0.9966\* |  |
| 9.PDG: 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 |

**Table 4:** Potential adjustment of industrial structure and reduction of carbon emissions (%)[[27]](#endnote-26)

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | *Northeast region* | *NorthMunicipalities* | *North Coastregion* | *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 5:** Potential adjustment of industrial structure and reduction of carbon emissions in low level (%)[[28]](#endnote-27)

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | *Northeast region* | *NorthMunicipalities* | *North Coastregion* | *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 6:** Potential adjustment of industrial structure and reduction of carbon emissions (%)[[29]](#endnote-28)

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | *Northeast region* | *NorthMunicipalities* | *North Coastregion* | *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 | 8.1 | 0.2 | 60.5 | 15.7 | 0.6 | 60.5 | 13.4 | 0.5 | 60.5 | 19.6 | 0.7 | 60.5 |
| 2 | 11.4 | 0.3 | 60.5 | 4.0 | 0.1 | 60.5 | 8.2 | 0.5 | 60.5 | 0.5 | 0.0 | 60.5 | 1.8 | 0.0 | 60.5 | 5.7 | 0.2 | 60.5 | 16.9 | 0.6 | 60.5 | 3.4 | 0.1 | 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 | 2.5 | 0.1 | 60.5 | 5.1 | 0.2 | 60.5 | 3.8 | 0.1 | 60.5 | 7.1 | 0.3 | 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 | 5.5 | 0.1 | 60.5 | 2.5 | 0.1 | 60.5 | 1.0 | 0.0 | 60.5 | 1.0 | 0.0 | 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 | 1.1 | 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 | 8.4 | 0.2 | 60.5 | 4.5 | 0.1 | 60.5 | 7.7 | 0.5 | 60.5 | 7.5 | 0.2 | 60.5 | 5.9 | 0.1 | 60.5 | 5.9 | 0.2 | 60.5 | 4.6 | 0.2 | 60.5 | 4.4 | 0.2 | 60.5 |
| 8 | 1.0 | -0.7 | -4.0 | 0.6 | 0.1 | 60.5 | 1.7 | -2.3 | -35.9 | 1.1 | -0.5 | 7.2 | 1.0 | -1.5 | -36.3 | 2.0 | -1.3 | -4.9 | 1.2 | -0.6 | 3.3 | 1.1 | -0.5 | 6.0 |
| 9 | 4.7 | 0.1 | 56.0 | 4.2 | 0.1 | 60.5 | 4.0 | -2.7 | -9.7 | 6.4 | 0.1 | 60.5 | 3.9 | 0.1 | 60.5 | 7.2 | 0.3 | 10.6 | 7.4 | 0.3 | 60.5 | 6.1 | 0.2 | 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 | 2.3 | 0.1 | 60.5 | 3.1 | 0.1 | 60.5 | 1.3 | 0.1 | 60.5 | 2.2 | 0.1 | 60.5 |
| 11 | 5.2 | 0.1 | 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 | 1.0 | 0.0 | 60.5 | 2.7 | 0.1 | 60.5 |
| 12 | 1.5 | 0.0 | 60.5 | 5.9 | 0.1 | 60.5 | 2.4 | 0.2 | 60.5 | 7.6 | 0.2 | 60.5 | 9.7 | 0.2 | 60.5 | 2.1 | 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 | 2.0 | 0.1 | 60.5 | 0.4 | 0.0 | 60.5 | 1.3 | 0.1 | 60.5 |
| 14 | 1.1 | -2.0 | -46.5 | 1.0 | -1.9 | -46.5 | 1.9 | -1.1 | -5.4 | 1.2 | -1.5 | -29.5 | 3.5 | -0.7 | 30.8 | 1.6 | -2.3 | -36.6 | 2.0 | -3.0 | -39.4 | 1.6 | -3.0 | -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 | 4.2 | 0.1 | 60.5 | 6.5 | 0.2 | 60.5 | 7.4 | 0.3 | 60.5 | 7.0 | 0.3 | 60.5 |
| 16 | 13.4 | 0.4 | 60.5 | 14.5 | 0.3 | 60.5 | 11.5 | 0.8 | 60.5 | 12.5 | 0.3 | 60.5 | 12.4 | 0.3 | 60.5 | 12.0 | 0.4 | 60.5 | 13.0 | 0.5 | 60.5 | 12.1 | 0.4 | 60.5 |
| 17 | 23.0 | 0.7 | 60.5 | 48.3 | 1.0 | 60.5 | 23.6 | 1.5 | 60.5 | 29.0 | 0.6 | 60.5 | 30.2 | 0.7 | 60.5 | 24.3 | 0.9 | 60.5 | 25.1 | 0.9 | 60.5 | 27.2 | 1.0 | 60.5 |
| Total |  |  | -9.7 |  |  | 20.5 |  |  | 1.5 |  |  | 11.6 |  |  | 9.9 |  |  | -6.0 |  |  | -7.1 |  |  | 10.1 |
|  | **8.7** |  |  | **5.3** |  |  | **13.9** |  |  | **20.9** |  |  | **14.9** |  |  | **19.0** |  |  | **7.2** |  |  | **10.1** |  |  |
|  |  |  | 10.3 |  |  | 2.9 |  |  | 18.6 |  |  | 15.2 |  |  | 8.8 |  |  | 22.3 |  |  | 11.2 |  |  | 10.6 |
|  |  |  | 10.1 |  |  | 3.2 |  |  | 17.5 |  |  | 15.4 |  |  | 10.2 |  |  | 22.7 |  |  | 10.3 |  |  | 10.6 |

1. MRIO models have examined UK’s carbon footprint (Lenzen et al.,2010), investigated institutional requirements, and energy footprints embodied in trade, made environmental extensions, and developed policy recommendations (Wiedmann et al., 2010, 2011, 2013). [↑](#footnote-ref-2)
2. Chinese MRIO tables are presently available for 1987, 1992, 1997, 2002, and 2007 (Ichinura and Wang 2003; Meng and Qu 2007; Zhang and Qi 2012). [↑](#footnote-ref-3)
3. The potential capability for adjustment of industrial structure in region r is shown aswhere which refers to the ratio of GDP of industry *j* in region r to the total regional GDP of, and are the value added coefficient and the industry output in region r. and  are respectively the optimal industry structure and initial industry structure of industry *j* in region. 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 expand its reproduction scale and improve its productivity so its contribution should rise. [↑](#endnote-ref-2)
4. The reduction percentage of carbon emissions of each industry in region r is

and is the amount of carbon emitted in this region before and after optimization. [↑](#endnote-ref-3)
5. Since carbon intensity reduction is regarded as mandated final target, (3.3) and (3.4) work against each other. [↑](#endnote-ref-4)
6. Two scenarios show two levels carbon-intensity reduction with two different growth rates resulting in four different perspectives on carbon emissions change. From China’s goal for the reduction of carbon intensity over 15 years as , annual carbon-intensity reduction from 2005 to 2020 ranges from -6.76% () to -5.93% (). Carbon intensity(), a widely used metric that normalizes carbon releases by economic growth, is the amount of carbon dioxide () per unit ofGDP,. Using two GDP growth rate levels (), namely rapid (9%) and slow (7.5%) from the World Bank forecast, we accordingly estimate the changes in carbon emissions () by 2.53% and 1.12% required to reduce the intensity of carbon emissions by 5.93%(scenario 1 with the upper bound), and the changes in carbon emissions () by 1.16% and 0.23% required to reduce the intensity of carbon emissions by 6.76%(scenario 2 with the lower bound),Corresponding the first scenario, the third scenario with energy mix change reflects the ratio of non-fossil energy to primary energy reaches to 15% in 2020. [↑](#endnote-ref-5)
7. 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 a scale of overall domestic final demand (including households and government consumption and investment), which are alike a column vector of outputs to be endogenous given and unlike endogenous exports in the model(ten Raa and Pan, 2005). [↑](#endnote-ref-6)
8. This refers to the fuel consumption and its main variety by sector in *China’s Energy Statistical Yearbook*. Here, the energy industry is defined as mixture. All energy consumption in an establishment is attributed to a single energy industry—the one primarily used by the establishment. It therefore differs in definition to the “pure” industry classification in the ECEIRIO table, which is mostly based on the production technology used by an industry. [↑](#endnote-ref-7)
9. distributed mainly into energy industries (PTP, MWC, PNP and COK), and a few into heavy industry (MCM, MCF, MOF, PPP, MIC). The main energy distribute more industries, such as raw coal on MWC, EOP MTE, PPP, PPN, COK, MCM, MCF, SFM, SNM, MIC, PTP, PHP, PDG, than the subordinate energy, such as coking. on MWC, MCM, SFM, SNM, PDG. [↑](#endnote-ref-8)
10. The regional energy transmission and loss is distributed by the share  by mixture industry. [↑](#endnote-ref-9)
11. The raw coal, crude oil and electricity consumption  are provided for 37 detailed manufacturing from Zhejiang Statistical Department and for the rough-classified manufacturing from Jiangsu, and Anhui, Henan, Statistical Department. [↑](#endnote-ref-10)
12. The former are more reliable than the latter. [↑](#endnote-ref-11)
13. In Jiangxi Statistical Yearbook, main types' energy includes raw coal, cleaned coal, wash coal, other washed coal, coke, crude oil, gasoline, kerosene, diesel oil, fuel oil, etc.. [↑](#endnote-ref-12)
14. The raw coal's consumption of the entire manufacturing (46.67 million tons) exceeds the raw coal's consumption of the large-scale manufacturing by 1.24 million tons. [↑](#endnote-ref-13)
15. Among raw coal consumption of all manufacturing. small-scale MIC taking 28.77% of this manufacturing raw coal consumption, small-scale MCM taking 13.91% , MWC taking 9.42% , and MTE taking 7.58%. The raw coal consumption of other most manufacturing are exact the same with the raw coal consumption of large-scale manufacturing. [↑](#endnote-ref-14)
16. are distributed mainly into energy industries (PTP, 66.2%, MWC, 27.0%, PNP and COK, 1.8%), and a few into heavy industry (MCM,1.6%, MCF, 1%, MOF, 0.7%, PPP, 1.5%, MIC, 0.1%) in Jiangxi. The provincial distribution of main energy concentrate less industries than national distribution. [↑](#endnote-ref-15)
17. Here,  is the origin of carbon dioxide from the consumption of energy of type *k* in industry ; is the consumption of energy of type *k* in industry *j*； refers to the CO2 emissions conversion coefficient of type*k*CO2 emissions conversion coefficient *d*=carbon embodied ×net thermal value×oxidation rate. [↑](#endnote-ref-16)
18. For primary energy, the carbon conversion coefficients refer to the standards from the US Oak Ridge National Laboratory (http://www.ornl.gov/),*2006 IPCC Guidelines on National Greenhouse Gas Inventories (http://unfccc.int/)*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,.. is the input of energy of type k to thermal power in the process and transaction, is the thermal power production. [↑](#endnote-ref-17)
19. This model is applied to China’s 2007 ECEIRIO table to identify the structural adjustment required to reduce carbon emissions. From table 4, the optimal industry structure and its change are shown in a scenario that under the given technology, China would increase its total carbon emissions by 2.53% in 2008 compared to 2007 levels, amounting to a 5.93% declinein carbon emissions per unit of GDP as GDP rises 9% annually. [↑](#endnote-ref-18)
20. Hydro & Nuclear Power takes 7.3% of Indigenous production in 2005 with 2.16 billion ton coal equivalent, and its change rises to 7.66%, 165.6 million ton coal equivalent (471 billion kW.h), 20.9 billion more than original level. The increased electricity is equivalent to 2.6 million calorific value, 4.7% of electricity in Hydro & Nuclear Power, (1% of electricity in Thermal Power, and 0.2% of energy consumption). The ratio of Hydro & Nuclear Power rose to 7.6% in 2007. [↑](#endnote-ref-19)
21. According to 2005 standard, The 2509 thousand ton calorific value of Hydro & Nuclear Power is required to replace the Thermal Power, taking 0.47% of the total energy consumption, and resulting in a 0.16% reduction of carbon emissions. According to the ECEIO table, the reduced input and transaction of energy due to reduction of Thermal Power can be inferred, approximatea 0.15% reduction in energy consumption and a 0.49% decline in carbon emissions. [↑](#endnote-ref-20)
22. Except Xizang, the 30 provinces (including autonomous regions, and municipality) compile their input-output table synchronously with Chinese National Statistical Bureau, and are categorized into eight regions in interregional input-output table. Northeast region (Heilongjiang, Jilin, Liaoning), North Municipalities(Beijing, Tianjin), North Coast region (Hebei, Shandong), East Coast region (Jiangsu, Shanghai, Zhejiang), SouthCoast region(Fujian, Guangdong, Hainan), Central region (Shanxi, Henan, Anhui, Hubei, Hunan, Jiangxi), Northwest region(Inner Mongolia, Shannxi, Gansu, Qinghai, Xinjiang), Southwest region (Sichuan, Chongqing, Guangxi, Yunnan, Guizhou). [↑](#endnote-ref-21)
23. The CO2 intensity and value added rate are obtained from the 2007ECEIRIO table with 17 industries. [↑](#endnote-ref-22)
24. Industry with \* denote energy industry. Other industry is non-energy industry. Industry 2 includes MWC, EOP, ENG; industry 14 includes PHN, PTP, PHP, PDG; industry 7 includes PPN, COK. 44 industries are integrated into 17 industries in ECEIRIO table. [↑](#endnote-ref-23)
25. 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*). [↑](#endnote-ref-24)
26. In the ECEIRIO table, 9 energy industries corresponding 19 energy sources are classified into primary energy industry (MWC, EOP, ENG,PDG), which extract primary energy sources directly from nature without transformation and procession, and secondary energy industry(PHN, PTP, PHP, PDG, PPN), which produce secondary energy sources from the transformation of a primary energy source.Among19 energy sources accounted by ECEIRIO table, Hydro Power and Nuclear Power produced by PDG belongs to the fossil energy and the renewable, and the others are non-fossil energy sources and nonrenewable energy sources. . .The standard coal’s CO2conversion coefficient transforms the energy consumed by energy resource into the quantity of carbon emissions. [↑](#endnote-ref-25)
27. 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. Here, carbon intensity declines annually by 5.61% ()) [↑](#endnote-ref-26)
28. and carbon intensity decline annually by6.76% (). [↑](#endnote-ref-27)
29. The energy mix change: the ratio of non-fossil energy to the consumption of first primer energy increase annually by 5.4%. Here, carbon intensity decline annually by 5.61% ().). [↑](#endnote-ref-28)