Chin. Geogra. Sci. 2015 Vol. 25 No. 6 pp. 657–671
doi: 10.1007/s11769-015-0739-0

Springer Science Press
www.springerlink.com/content/1002-0063

Impacts of Total Energy Consumption Control and Energy Quota Allocation on China′s Regional Economy Based on A 30-region Computable General Equilibrium Analysis

LI Na[1, 2], SHI Minjun[1, 2], SHANG Zhiyuan[1, 2], YUAN Yongna[1]

(1. *University of Chinese Academy of Sciences*, *Beijing* 100049, *China*; 2. *Research Center on Fictitious Economy & Data Science*, *Chinese Academy of Sciences*, *Beijing* 100190, *China*)

Abstract: This paper examined the impacts of the total energy consumption control policy and energy quota allocation plans on China′s regional economy. This research analyzed the influences of different energy quota allocation plans with various weights of equity and efficiency, using a dynamic computable general equilibrium (CGE) model for 30 province-level administrative regions. The results show that the efficiency-first allocation plan costs the least but widens regional income gap, whereas the outcomes of equity-first allocation plan and intensity target-based allocation plan are similar and are both opposite to the efficiency-first allocation plan′ outcome. The plan featuring a balance between efficiency and equity is more feasible, which can bring regional economic losses evenly and prevent massive interregional migration of energy-related industries. Furthermore, the effects of possible induced energy technology improvements in different energy quota allocation plans were studied. Induced energy technology improvements can add more feasibility to all allocation plans under the total energy consumption control policy. In the long term, if the policy of the total energy consumption control continues and more market-based tools are implemented to allocate energy quotas, the positive consequences of induced energy technology improvements will become much more obvious.

Keywords: total energy consumption control; energy quota allocation; computable general equilibrium (CGE) model; induced energy technology improvements

Citation: Li Na, Shi Minjun, Shang Zhiyuan, Yuan Yongna, 2015. Impacts of total energy consumption control and energy quota allocation on China′s regional economy based on a 30-region computable general equilibrium analysis. *Chinese Geographical Science*, 25(6): 657–671. doi: 10.1007/s11769-015-0739-0

1 Introduction

China′s economic development is facing not only the constraints from domestic resources and the environment, but also the pressure in the form of global greenhouse gas emission mitigation (He *et al*., 2012; Zhao *et al*., 2014). In the 12th Five-Year Plan, the Chinese Central Government established goals to reduce energy intensity and CO_2 intensity by 16% and 17% respectively, and increase the non-fossil energy ratio to 11.4% by 2015 (The State Council, 2011a). However, these targets seem a stretch as the local governments always have ambitions for fast economic growth. If all regions maintain the current energy consumption patterns and achieve the GDP growth goals set in their own 12th Five-Year Plans (http://www.gov.cn/zwgk/2012-05/10/content_2104148.htm. 2012-05-102012), the total energy consumption will exceed 5×10^9 t of standard coal equivalent (tce) in 2015. This will make a huge challenge for China′s energy supply and energy conservation goals. To curb the fast growing energy consumption, the Central Government put forward a total energy consumption control

---

Received date: 2014-05-06; accepted date: 2014-09-05
Foundation item: Under the auspices of National Natural Science Foundation of China (No. 41101556, 71173212, 71203215)
Corresponding author: SHI Minjun. E-mail: mjshi1964@gmail.com

policy in early 2013 (The State Council, 2013). In this policy, the national energy consumption is set to be within 4×10^9 tce by 2015. This total energy quota will be allocated to regions, and each region′s energy consumption must not exceed the quotas as allocated (quotas can not be traded across regions). This policy is expected to create a revised pressure mechanism to push for transformations in the current unsustainable economic development pattern.

The key question of the total energy consumption control policy is how to allocate the energy quotas to regions. Different allocation plans may impose different economic impacts on regions, which in turn affect the feasibility of the policy itself. Efficiency and equity are two basic principles of environmental resource allocation. Efficiency-first allocation plans usually pursue a minimization of policy′s economic cost through, e.g., auctions or intensity-based allocation (Edwards and Hutton, 2001; Cramton and Kerr, 2002; Den Elzen *et al*., 2005; Wang *et al*., 2011). Equity-first allocation plans focus on the balance of interests among stakeholders through, e.g., schemes that are based on historical emissions, GDP, population or equal emission reduction rate (Grubb, 1989; Bohm and Larsen, 1994; Janssen and Rotmans, 1995; Baumert *et al*., 1999; Wang *et al*., 2010). Some scholars suggested that allocation plans should combine the two principles. They believed such plans feature the spirit of ′common but differentiated responsibilities′. China′s regional economic development is significantly unbalanced, and regional energy efficiencies vary dramatically. In a country like China, to control total energy consumption, an energy quota allocation plan with relatively low economic cost and small economic losses variation among regions may be more satisfactory. However, the design of such an allocation plan is no easy task. That is why a specific energy consumption quota allocation plan has still not been introduced by the central government. Therefore, efficiency and equity should both be considered in the design of an energy quota allocation plan.

There is limited literature focused on China′s energy consumption quota allocation plan under the total energy consumption control policy. Within related research, Bai (2011) made calculations of energy consumption quota allocation based on provincial energy intensity targets in the 12th Five-Year Plan and discovered that the provinces with larger energy exports and the western underdeveloped provinces would receive smaller quotas and face too much energy conservation pressure. Sun *et al*. (2012) allocated the energy quotas based on the principle of efficiency and concluded that regions with higher energy efficiency would have larger quotas. Unfortunately, these studies discussed little on the allocation principles or indicators, and made no comparison among possible allocation plans. Most importantly, the impacts of these allocation plans on the regional economy have never been examined. The feasibility of these allocation plans, therefore, remains to be discussed.

In the study of quota allocation, there are lots of researches on carbon emissions trading system (ETS). Most of them are studied at the national level (Burniaux *et al*., 1992; Chen and Wu, 1998; Bollen *et al*., 1999; Li and Yuan, 2014). As for a few researches at the regional level, some scholars studied the initial allocation of China′s regional carbon emissions permits. Based on the principle of equity, Li and He (2011) studied carbon permit allocation plans in relation to historical emissions and population and the impacts on the regional economy. They concluded that both plans were going to burden western resource-intensive regions with much more economic costs, ensuing larger regional economic disparity. Yuan *et al*. (2012) studied the impacts of two ETS permit allocation plans based separately on intensity and absolute quantity on the regional economy. Their results showed that an intensity-based plan was better because it would have less negative impacts on regions′ GDP and would create less regional economic imbalance than the absolute quantity-based plan. These above-proposed allocation plans were more inclined to equity in the initial allocation phase because efficiency factor could be readily introduced by incorporating carbon permit trading under a Cap-and-Trade mechanism. However, under the total energy consumption control policy discussed here, in which quotas can not be traded, it may be highly inefficient if the allocation plan puts equity on top. Therefore, in this research, efficiency and equity are considered simultaneously in the energy quota allocations.

Besides setting constraints on energy supply, the total energy consumption control policy can induce energy technology improvements with its revised pressure mechanism. Existing researches have proved that environmental policy instruments were able to not only facilitate industrial restructuring but also induce technological innovation and improvement (Jung *et al*., 1996). Some empirical studies on energy technology innovations have observed that energy efficiency improvements and the number of energy technology-related patents surged with the increase in energy prices or energy-saving costs (Landjouw and Mody, 1996; Newell *et al*., 1999; Popp, 2002). Such induced energy technology improvements under the total energy consumption control policy can change regional energy consumption and thus further influence the regional economy. However, few scholars have considered induced technology improvements in their studies of the impacts of quota allocation on the regional economy.

This paper aimed to examine the impacts of different energy quota allocation plans on China's regional economy under the total energy consumption control policy using a dynamic multi-regional computable general equilibrium model (CGE) model. This research, compared with existing literature, contributed in the following aspects: first, by performing a quantitative simulation of the economic impacts of the total energy consumption control policy in China, a better understanding of the results of economic development were obtained after this policy's implementation; second, by analyzing and comparing the impacts of several energy quota allocation plans with various weights of equity and efficiency on multiple aspects of the regional economy, including regional economic growth, the regional income of residents, regional industrial structures and the regional migration of energy-related industries, a more balanced and feasible energy quota allocation plan was suggested; third, by taking into consideration the possible induced energy technology improvements in different energy quota allocation plans, the influences of these plans on regional economic development were re-examined to give a more comprehensive evaluation of the feasibility of the total energy consumption control policy.

2 Model and Data

2.1 Dynamic multi-regional computable general equilibrium model

A dynamic multi-regional CGE model was built based on the structure developed by Li *et al*. (2009; 2010) to describe the evolution of China's economy. This CGE framework modeled the developments of 30 province-level administrative regions (Hong Kong, Macao, Taiwan and Tibet were not included due to data unavailability) (Table 1) and specified regional economic diversities and interregional economic linkages. In this model, all relevant economic agents' (producers, consumers, government, importers, exporters, *etc*.) optimal behaviors were specified at the provincial level. The parameters in equations describing these behaviors were set based on each region's own characteristics, which reflected regional economic differences. In production module, capital, labor and energy were treated as production factors in sectors' production functions①. The output was delineated in a multi-level nested constant elasticity of substitution (CES) function. First, different fossil fuels were composited together through the CES function. Second, fossil fuels and electricity were put together to form composite energy bundles. Third, energy bundles and capital were composited together to form a capital-energy mix, and then labor was added to form a capital-energy-labor mix. The production factor and intermediate inputs were mutually non-substitutable. The intermediate commodities within the intermediate inputs bundles were non-substitutable one another either. These non-substitutable relationships were described by a Leontief function. The elasticity of substitution in CES functions originated from the work of Li *et al*. (2010) and Wu and Xuan (2002). Electric power generation was divided into two types: thermal power and renewable power. These two types of power were perfectly substitutable. For the detailed structure of electricity production, please refer to Fig. 1. In other modules, residents' consumption of different commodities of each region was decided by an extended linear expenditure system (ELES) function. Local government's consumption was considered to be endogenous and decided by a Cobb-Douglas function. The government's tax rate was exogenous. The demand of commodities for industrial investments was expressed in a Leontief function. Stock investments were constant. The import, export and foreign savings to China's GDP ratio

---

① Energy in the energy conversion industries was treated as intermediate inputs. In the production process for the processing of petroleum and coking industry, oil and coal are converted into gasoline and coke, respectively. Thus, oil and coal are intermediate inputs rather than production factors for the industrial output (Leontief function). This is also true for the coal, oil and natural gas in thermal power generation.

were set to be endogenous, and the foreign exchange rate was exogenous.

This model also specified economic linkages across regions, including interregional commodity trading, interregional investment and labor allocation mechanisms. In commodity trading across regions, goods from different regions were presumed to be imperfectly substitutable, and a CES function was adopted to describe this characteristic. Investments in different regions were endogenous and determined by investment returns and capital price, delineated by a logistic function. Labor forces in different regions were endogenous. On the condition of a constant domestic labor population, they were decided by the national average salary and a regional salary distortion factor.

The model was recursively dynamic and the simulation period was from 2007 to 2015. Capital accumulation, labor increases and technology improvements drove the economy to grow and made the industrial structure change. Capital accumulations in different regions were endogenous in the model. Regions' labor growth rates from 2007 to 2010 were from historical records, whereas the numbers from 2011 to 2015 were set based on historical growth trends. Technology improvements were mainly reflected by total factor productivity (TFP) growth and autonomous energy efficiency improvements (AEEI). Each region' TFP from 2007 to 2015 was calibrated according to regional GDP data. Regions' GDP used for calibration from 2007 to 2010 were historical records, whereas the numbers from

Table 1 Regions and their codes in this paper

Code	Region	Code	Region	Code	Region
BJ	Beijing	ZJ	Zhejiang	HI	Hainan
TJ	Tianjin	AH	Anhui	CQ	Chongqing
HE	Hebei	FJ	Fujian	SC	Sichuan
SX	Shanxi	JX	Jiangxi	GZ	Guizhou
IM	Inner Mongolia	SD	Shandong	YN	Yunnan
LN	Liaoning	HA	Henan	SN	Shaanxi
JL	Jilin	HB	Hubei	GS	Gansu
HLJ	Heilongjiang	HN	Hunan	QH	Qinghai
SH	Shanghai	GD	Guangdong	NX	Ningxia
JS	Jiangsu	GX	Guangxi	XJ	Xinjiang

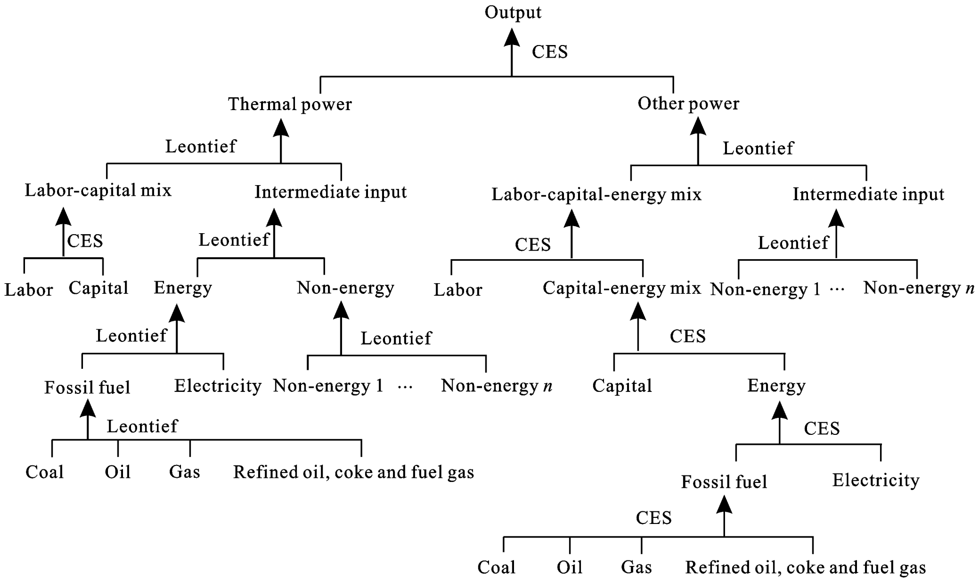

Fig. 1 Production structure of electricity sector

2011 to 2015 were set based on the economic growth goals in local governments′ 12th Five-year plans. AEEI in different sectors were set according to the work of Shi and Zhou (2010). By doing so, the economic growth and economic structures simulated can be basically in line with China′s actual situation. The General Algebraic Modeling System (GAMS), a high-level modeling system for mathematical programming and optimization, is used to solve the model.

2.2 Data

Most of the data employed for the base year in this model came from interregional input-output table of 55 sectors of China′s 30 regions in 2007, which was built by the Research Center on Fictitious Economy and Data Science of Chinese Academy of Sciences (Shi and Zhang, 2012). To highlight the impacts of the total energy consumption control policy on different kinds of sectors, the 55 sectors were merged into nine sectors. Energy-related sectors that may be most affected by the policy were picked out. They were merged into an energy mining & extraction sector and five high-energy-consuming sectors (EME and HEC) according to the classification of National Economic Industries (GB/T4754-2011). The remaining sectors less likely influenced were merged into service, agriculture and other industrial sector (Table 2). Because thermal power and renewable power in the input-output table were not separated, the electric sector needs to be split according to these two power ratios in different regions in *China Energy Statistical Year Book* (NBSC, 2008). The energy and carbon emission data were calculated from the Energy Balance Sheet in *China Energy Statistical Year Book* (NBSC, 2008). Regions′ labor growth rates and regions′ GDP from 2007 to 2010 were from the records of *China Statistical Year Book* (NBSC, 2011).

3 Scenario Design

There were nine scenarios in this study (Table 3). The base scenario (S_0) was a simulation of economic development from 2007–2015 without the total energy consumption control policy. The remaining eight were scenarios under the total energy consumption control policy. S_{ef}, S_{eq}, S_{b} and S_{i} were those with no consideration for induced energy technology improvements. S_{ef} and S_{eq} stood for an efficiency-first scenario and an equity-first scenario respectively, whereas S_{b} represented an efficiency-and-equity-balanced scenario. These three scenarios were different from one another in that efficient allocation method and equal allocation method carried different weights in the process of quota allocation. In the efficiency-first scenario, the weight of efficient allocation method was 80% while the weight of equal allocation method was 20%. By contrast, in the equity-first scenario, equal allocation method carried 80% weight while efficient allocation method carried 20% weight. In the efficiency-and-equity-balanced scenario, the efficient allocation method and equal allocation method were equally weighted. The efficient allocation method (not considering equity at all) in this paper involved minimizing the energy-saving costs (like an auction), which led to the same energy-saving costs in all regions. Then the quotas allocated to each region were obtained through the simulation of the 30-region CGE model. The equal allocation method (not considering efficiency at all) was a revised allocation of Regional Greenhouse Gas Initiative (RGGI, 2007): 60% of

Table 2 Sector divisions in this paper

Sector type	Sector	
Energy mining& extraction and high-energy-consuming industry (EME & HEC)	1	Mining and dressing of coal, extracting of petroleum and natural gas
	2	Processing of petroleum and coking
	3	Manufacturing of raw chemical materials and chemical products
	4	Manufacturing of non-metallic mineral products
	5	Smelting, pressing of metals
	6	Producing and supplying of electric power, heat power and gas
Service industry	7	Services
Other industry	8	Agriculture
	9	Other industrial sectors

total quotas were allocated based on regions′ historical energy consumption, 20% were allocated based on regions′ population and the rest 20% were allocated based on regions′ GDP per capita. Furthermore, there was an intensity target-based scenario (S_i) in this research. This scenario assumed that each region would achieve its own energy intensity reduction target in the 12th Five-Year Plans (The State Council, 2011b). Then the energy consumption of each region can be deduced. The allocation plan was performed based on the individual ratios of regional energy consumption to all regions′ energy consumption. S_{ef+T}, S_{eq+T}, S_{b+T} and S_{i+T} were scenarios that induced energy technology improvements were considered. The AEEI values in these scenarios are larger than in S_{ef}, S_{eq}, S_b and S_i. However, it is very difficult to quantify induced energy technology improvements, and such induced effects vary in different policy and market environments. Thus, in this research, a national average rate of induced energy technology improvement of 15% was set by referring to the technological improvement increase rate under the scenario of quick transformation in the development pattern for China in the work of Li and He (2010). Regional induced energy technology improvement rates were set based on the extent of each region′s energy consumption reduction, assuming induced energy technology improvements would be faster in regions with tighter energy consumption constraints. The induced technological improvement rate in region i under the scenarios of induced energy technology improvements (A_i) was calculated as follows:

$$A_i = B_i / B_{\text{ave}} \times A_{\text{ave}} \tag{1}$$

where B_i and B_{ave} respectively represent the energy consumption reduction rate in region i and the national average energy consumption reduction rate under the scenarios of no induced energy technology improvements (i = 1, …, n, stand for different regions); A_{ave} represents the national average induced technological improvement rate of 15%.

The sum of regions′ energy consumption is not equal to the total national energy consumption in the *China Energy Statistical Year Book* because there are statistical discrepancies in different conversion coefficients. In 2010, the sum of regions′ energy consumption was 3.895×10^9 tce, which was 1.2 times of the total national energy consumption of 3.249×10^9 tce. In 2011, this ratio grew from 1.2 to 1.21. Following this trend, in 2015, the ratio may reach 1.25. Because the simulation was at the regional level, the total energy consumption control target should be adjusted to an aggregated control target of regions′ energy consumption. Thus, the total national energy consumption control target of 4×10^9 tce was transformed to a target of 5×10^9 tce for all regions in 2015, which was taken as the total amount for energy quota distribution in the simulation.

4 Results

4.1 Energy-saving effects of total energy consumption control

The simulation results show that the total energy con-

Table 3 Scenario design

Scenario	Total amount of quotas (10^9 tce)	Weight of method			Rate of induced energy technology improvement
		Efficient allocation method (%)	Equal allocation method (%)	Intensity target-based allocation method (%)	
S_0	–	–	–	–	–
S_{ef}	5	80	20	–	–
S_{eq}	5	20	80	–	–
S_b	5	50	50	–	–
S_i	5	–	–	100	–
S_{ef+T}	5	80	20	–	Calculated using Equation (1)
S_{eq+T}	5	20	80	–	
S_{b+T}	5	50	50	–	
S_{i+T}	5	–	–	100	

Notes: S_0 stands for the base scenario; S_{ef}, S_{eq}, S_b and S_i represent the efficiency-first, the equity-first, the efficiency-and-equity-balanced and the intensity target-based scenarios respectively, without considering induced energy technology improvements; S_{ef+T}, S_{eq+T}, S_{b+T} and S_{i+T} are their counterpart scenarios in which induced energy technology improvements are considered sumption control policy leads to a good effect on energy savings and carbon emission reduction. In 2015, the sum of regions' energy consumption is 6.7 × 10^8 tce less than that in S_0, and the sum of regions' CO_2 emission is approximately 1.2 × 10^9–1.4 × 10^9 t less than that in S_0 (Table 4). The national energy-saving targets set in 12th Five-Year Plan can be achieved. In all of the eight scenarios with the total energy consumption policy, the energy intensity and carbon intensity can decrease by at least 19% and 22% respectively during 2010–2015, and the non-fossil energy proportion can exceed 11.6% in 2015, all of which are beyond the targets. The total energy consumption control proves to be tighter than the targets of 16% reduction in energy intensity or 17% reduction in carbon intensity. By contrast, in S_0, all the targets fail to be realized. Viewing the energy-saving effects from the regional level (Fig. 2), in the intensity target-based scenario (S_i), all regions can achieve the energy intensity reduction targets, and the energy-saving rates among regions show little difference. In the rest scenarios, regional energy-saving rates are rather different, but most regions reach their energy intensity reduction targets excluding some regions with relatively high energy efficiency and slow decreases in energy intensity (such as Beijing, Shanghai, Zhejiang, Shandong, and Guangdong).

4.2 Impacts of different allocation plans on regional economy (without considering induced energy technology improvements)

Among the four scenarios, the national GDP loss rate in the efficiency-first scenario (S_ef) is the smallest (0.59%) compared with S_0 in 2015, whereas in the intensity target-based scenario (S_i) it is the largest (1.03%) (Fig. 3). The national GDP loss rate in the equity-first scenario (S_eq) (0.95%) is larger than in the efficiency-and-equity-

Table 4 Reduced rates of energy intensity and CO_2 intensity, and non-fossil energy proportion of 2015 in different scenarios

Scenario	Energy consumption (10^9 tce)	CO_2 emission (10^9 t)	Reduced energy intensity rate compared to 2010 (%)	Reduced CO_2 intensity rate compared to 2010 (%)	Non-fossil energy proportion (%)
S_0	5.67	11.11	9.65	13.30	11.05
S_ef	5.00	9.90	19.86	22.29	11.64
S_eq	5.00	9.85	19.57	22.42	11.66
S_b	5.00	9.86	19.77	22.51	11.66
S_i	5.00	9.78	19.50	22.89	11.63
$S_\text{ef+T}$	5.00	9.84	20.03	22.91	11.63
$S_\text{eq+T}$	5.00	9.78	19.74	23.10	11.64
$S_\text{b+T}$	5.00	9.80	19.93	23.15	11.65
$S_\text{i+T}$	5.00	9.71	19.69	23.60	11.61

Note: each scenario is the same meaning as shown in Table 3

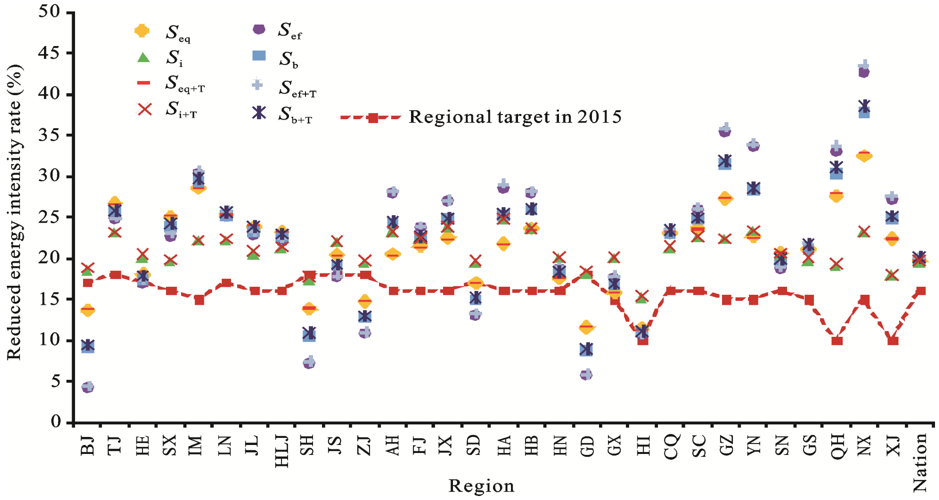

Fig. 2 Reduced energy intensity rate by region during 2010–2015. Full name of each region's codes are shown in Table 1

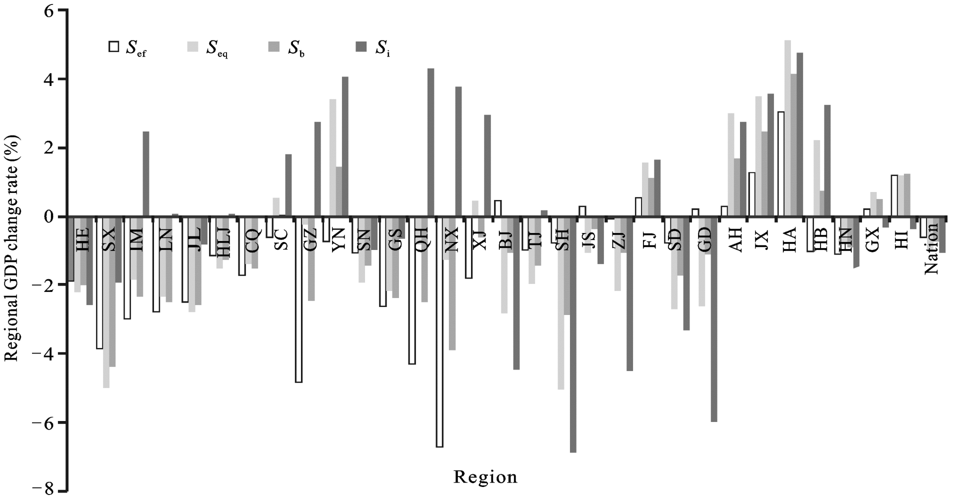

Fig. 3 Regional GDP changes in 2015 without considering induced energy technology improvements. Full name of each region′s codes are shown in Table 1

balanced scenario (S_b) (0.71%).

In order to further analyze the results conveniently, 30 provinces were grouped into five regions in this paper: Hebei, Shanxi and Inner Mongolia belong to the northern region (Northern China); Liaoning, Jilin and Heilongjiang belong to the northeastern region; Chongqing, Sichuan, Guizhou, Yunnan, Shaanxi, Gansu, Qinghai, Ningxia and Xinjiang belong to the western region; Beijing, Tianjin, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong and Guangdong belong to the eastern region; and Anhui, Jiangxi, Guangxi, Henan, Hubei, Hunan, and Hainan belong to the middle region.

At the regional level, the simulation results suggest that the higher the energy-saving rate and the greater the marginal energy-saving cost, the greater economic loss is, as shown by Fig. 4 and Fig. 5. In the efficiency-first scenario (S_{ef}), most the western regions′ economy suffer losses, which is especially salient for Guizhou, Gansu, Qinghai, Ningxia, Xinjiang, Chongqing, *etc*. All the northern regions (Shanxi, Inner Mongolia, Hebei) and northeastern regions (Liaoning, Jilin, Heilongjiang) also face a certain economic loss. The energy efficiency in these seriously affected regions is relatively low and there are more energy-intensive industries in most of these regions. In this scenario, regions with less energy efficiency and more energy consumption are allocated with smaller energy quotas, so these regions have to reduce their energy consumption more. In other words, the energy-saving rate should be higher (Fig. 6). In S_{ef}, as the marginal energy-saving costs are about the same among regions, the regions with higher energy-saving rates should face greater economic losses. By contrast, more economic growths emerge in the eastern regions such as Beijing, Jiangsu and Guangdong and the middle regions such as Anhui, Jiangxi, Guangxi, Hainan and Henan. The reasons are that there are fewer energy-intensive industries and lower energy-saving rates in these regions and these regions are more attractive to production factors under the total energy consumption control policy.

In the equity-first scenario (S_{eq}), all the northern regions and northeastern regions face significant negative impacts on economic growth. In particular, the GDP loss for Shanxi is even larger than that in S_{ef}. The eastern regions such as Shanghai, Zhejiang, Jiangsu, Shandong and Guangdong also suffer relatively greater economic losses. The western regions are subject to losses as well, but the losses are much less than that in S_{ef}. Such results can be explained from the aspects of regional energy-saving rates and marginal energy-saving costs too. Beijing, Shanghai, Zhejiang, Shandong and Guangdong bear very high energy-saving rates, and other places in the northern and northeastern regions also bear relatively high energy-saving rates. The marginal energy-saving costs in these regions are certainly higher with mounting energy-saving pressures. Therefore, there are greater GDP losses in these regions. By contrast, in the western regions, the energy-saving rates and marginal energy-saving costs are lower than that in S_{ef}, so the economic losses are less (Fig. 6).

As for the efficiency-and-equity-balanced scenario (S_b), the energy-saving rates and marginal energy-

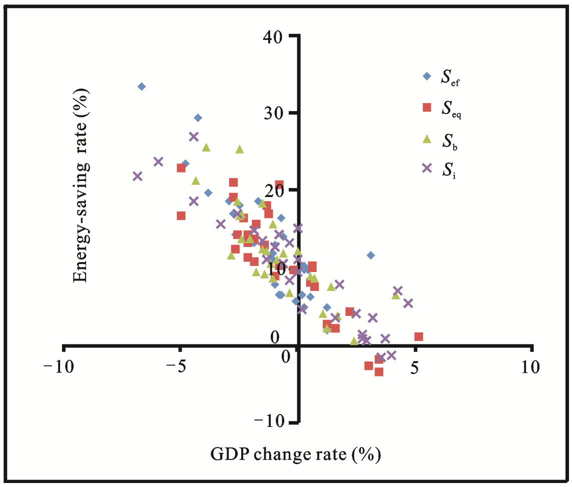

Fig. 4 Relationship between regional GDP change rate and energy-saving rate

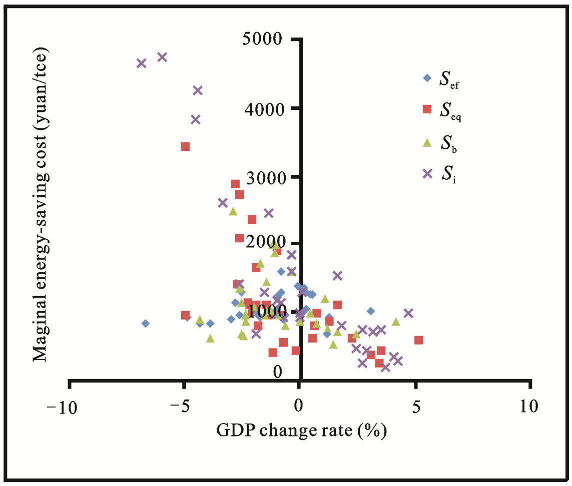

Fig. 5 Relationship between regional GDP change rate and marginal energy-saving cost

saving costs in different regions are between those of the S_{ef} and S_{eq} scenarios. So, regions' economic losses are between in S_{ef} and S_{eq} scenarios and more evenly distributed among the northern, northeastern, eastern and western regions. In the intensity target-based scenario (S_i), the western regions show positive economic growths, whereas the eastern regions such as Beijing, Shanghai, Zhejiang, Shandong and Guangdong are subject to substantial economic losses, up to 3%–7%. The reasons are that there are very high energy-saving rates and marginal energy-saving costs in the eastern regions, whereas the situation in the western regions is just the opposite. All these cause a flow of production factors from the eastern regions to the western regions and boost the economic growth in the western regions.

The impact of the total energy consumption control policy on residents' real income is greater than that on GDP. In S_{ef}, S_{eq}, S_b and S_i scenarios, the losses in residents' real income are 5.86%, 7.24%, 6.54% and 8.64% respectively compared with S_0 in 2015. From a regional perspective, the influences on residents' real income follow a similar pattern in terms of the spatial distribution as the influences on GDP loss (Fig. 7). It can be observed from the above analysis that the efficiency-first allocation plan has less negative impacts on the eastern developed regions than under-developed resource-rich regions, whereas the effects of equity-first and intensity target-based allocation plans are the opposite. To examine quantitatively the regional economic disparities, regional income *Gini* coefficients in different scenarios are also calculated and compared. It turns out that efficiency-first allocation plan widen regional income gap by 1.02%. The equity-first, intensity target-based and efficiency-and-equity-balanced allocation plans narrow the gap by 2.01%, 2.02% and 0.5% respectively.

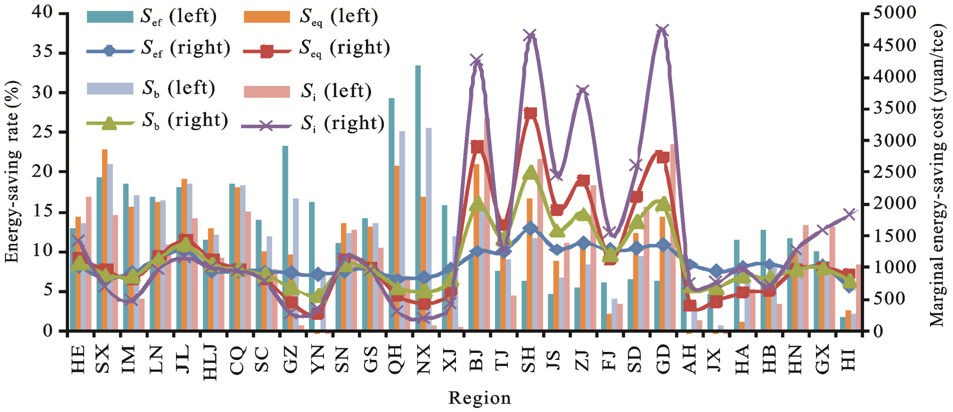

Fig. 6 Energy-saving rates and marginal energy-saving costs in 2015 without considering induced energy technology improvements. Full name of each region's codes are shown in Table 1

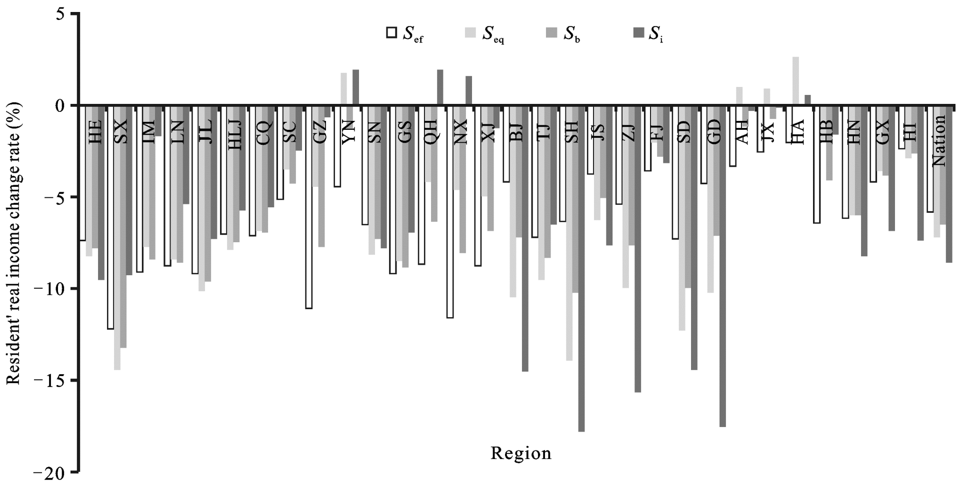

Fig. 7 Residents′ real income changes in 2015 without considering induced energy technology improvements. Full name of each region's codes are shown in Table 1

In addition, the total energy consumption control policy boosts green economic transformation by increasing industries′ production costs and promoting energy substitution. As a result, there are significant decreases in the outputs of EME & HEC industries. Other industries also suffer negative but smaller impacts than EME & HEC industries. On the contrary, there is a growth in service industry's output (Table 5). At the regional level, the impacts on different industries vary in different scenarios. In S_{ef}, there is a big decline in energy-related sectors′ outputs of regions heavily relied on energy-intensive industries. In S_{eq}, all industries suffer noticeable losses in the eastern regions such as Beijing, Tianjin, Shanghai, Shandong and Guangdong. By contrast, there is a raise in the output of EME & HEC industries in Anhui, Jiangxi, Hainan, Henan, Hubei, Yunnan, *etc*. It means that there is much more interregional migration of energy-related industries from regions with tighter energy constraints to looser ones in this case. This phenomenon probably undermines the whole country′s energy-saving effort and is unfavorable. In S_{b}, the losses in EME & HEC industries in each region are more moderate than those in S_{ef} and S_{eq}, and the extent of interregional industry migration is acceptable. In S_{i}, the industrial structure transformation shares similar characteristics with that in S_{f}. But it has less impacts on the western regions and more serious impacts on the eastern regions (Table 5).

4.3 Impacts of different allocation plans on regional economy (considering induced energy technology improvement)

Induced energy technology improvements triggered by the total energy consumption control policy increase energy efficiency and reduce marginal energy-saving costs, which alleviate the negative economic losses. The simulation results show that induced energy technology improvements decrease the marginal energy-saving costs by 2%, or 20 yuan/tce as a whole, in 2015. Meanwhile, the losses in national GDP in $S_{\mathrm{ef+T}}$, $S_{\mathrm{eq+T}}$, $S_{\mathrm{b+T}}$ and $S_{\mathrm{i+T}}$ are 0.40%, 0.73%, 0.50% and 0.8%, respectively, which are less than those without considering induced energy technology improvements by 0.19%, 0.21%, 0.20% and 0.23% respectively. In addition, the different regions′ energy-saving costs vary in different scenarios. But in general, regions with tighter energy constraints and higher marginal energy-saving costs decrease more in marginal energy-saving costs when induced energy technology improvements are considered (Fig. 8). However, regions with higher marginal energy-saving costs are still the higher ones. Consequently, induced energy technology improvements only offset a limited amount of regional GDP losses (Fig. 9).

Besides, residents′ real income also changes when induced energy technology improvements are considered. However, the extent of this change is even smaller than that of regional GDP. In $S_{\mathrm{ef+T}}$, $S_{\mathrm{eq+T}}$, $S_{\mathrm{b+T}}$ and $S_{\mathrm{i+T}}$, the whole residents′ real income take a loss of 5.77%, 7.16%, 6.45% and 8.59% respectively in 2015, which is a reduction of 0.09%, 0.08%, 0.08% and 0.06% respectively, compared with S_{ef}, S_{eq}, S_{b} and S_{i}. Furthermore, the influences on residents′ real income in different regions exhibit a similar spatial pattern as the influences on GDP loss. From the aspects of GDP and residents′

Table 5 Sectoral output changes in different regions in 2015 without considering induced energy technology improvements (%)

Regions	S_{ef}			S_{eq}			S_b			S_i		
	EME & HEC	Service	Others	EME & HEC	Service	Others	EME & HEC	Service	Others	EME & HEC	Service	Others
HE	–10.1	0.5	–2.1	–11.4	0.7	–2.5	–10.7	0.7	–2.3	–13.8	1.1	–2.7
SX	–9.8	0.8	–4.4	–12.3	0.8	–5.2	–11.0	0.8	–4.8	–7.7	3.4	–2.0
IM	–12.5	0.0	–0.9	–10.5	1.6	–0.3	–11.4	0.8	–0.6	–2.3	6.2	2.5
LN	–10.3	–0.6	–2.2	–9.3	0.0	–2.1	–9.7	–0.3	–2.1	–4.8	2.1	–0.2
JL	–13.7	–1.1	–0.9	–15.0	–1.1	–1.2	–14.2	–1.1	–1.0	–10.4	1.1	–0.1
HLJ	–7.0	0.6	–1.9	–8.1	0.8	–2.6	–7.5	0.7	–2.2	–5.9	2.9	–0.8
CQ	–10.0	0.9	–2.3	–10.0	1.5	–2.0	–9.9	1.2	–2.2	–7.8	2.7	–0.7
SC	–9.3	0.7	–0.9	–6.4	1.9	0.0	–7.7	1.4	–0.4	–4.3	3.2	1.1
GZ	–18.1	–1.1	–3.5	–7.2	2.5	–0.3	–12.6	0.8	–1.9	–0.6	5.1	2.0
YN	–10.4	1.6	–0.5	3.0	4.6	2.3	–3.6	3.2	0.9	2.6	5.4	3.1
SN	–5.7	1.8	–0.7	–7.8	1.5	–1.1	–6.7	1.7	–0.9	–7.1	3.1	–0.4
GS	–3.0	0.6	–7.0	–2.3	1.2	–6.7	–2.6	0.9	–6.8	–0.2	2.5	–5.0
QH	–24.4	0.7	–2.3	–17.2	4.0	0.4	–20.8	2.4	–0.9	–5.7	8.5	4.6
NX	–24.6	–1.7	–2.7	–11.1	2.0	0.4	–17.9	0.2	–1.1	1.2	5.4	3.6
XJ	–9.8	–1.2	–4.0	–5.3	2.4	–1.5	–7.6	0.6	–2.7	–1.0	6.1	1.5
BJ	–8.6	1.6	–1.8	–20.0	–0.8	–6.4	–14.3	0.5	–3.9	–25.8	–1.9	–8.7
TJ	–3.3	–0.2	–2.1	–6.0	–0.8	–3.0	–4.5	–0.5	–2.5	–1.6	1.3	–0.9
SH	–3.8	–0.3	–1.8	–14.5	–4.0	–5.3	–9.2	–2.2	–3.6	–19.8	–5.6	–6.7
JS	–3.4	2.0	–0.3	–8.1	1.7	–1.3	–5.7	1.8	–0.8	–10.7	2.0	–1.4
ZJ	–1.7	1.4	–2.2	–6.4	0.3	–5.0	–4.0	0.9	–3.6	–11.8	–1.0	–8.2
FJ	–2.7	1.7	0.1	–0.3	2.6	1.1	–1.4	2.2	0.6	–1.5	2.9	1.3
SD	–5.8	0.4	–0.9	–11.4	–1.5	–2.2	–8.6	–0.6	–1.5	–14.2	–1.8	–2.7
GD	–1.1	0.9	–1.2	–7.1	–0.8	–5.2	–4.0	0.1	–3.1	–13.9	–2.9	–9.9
AH	–7.6	2.0	0.4	3.2	4.4	1.9	–2.2	3.3	1.2	–0.6	4.7	2.0
JX	–2.1	2.5	0.6	3.9	4.8	2.4	1.0	3.7	1.5	2.3	5.2	2.6
HA	3.2	1.1	0.2	7.0	4.9	2.2	5.6	2.3	1.0	6.3	4.2	1.7
HB	–7.2	1.6	–3.1	1.2	4.3	0.4	–2.7	3.1	–1.2	2.7	5.6	1.3
HN	–8.2	1.0	–2.2	–7.4	1.5	–2.0	–7.6	1.3	–2.1	–10.5	1.5	–2.7
GX	–4.9	2.0	–0.6	–4.0	2.9	–0.4	–4.4	2.5	–0.4	–8.1	2.4	–1.2
HI	2.0	0.5	0.3	1.9	0.3	0.1	2.1	0.4	0.2	–0.8	–2.2	–1.8
Nation	–4.6	0.9	–2.6	–5.9	0.8	–3.7	–5.3	0.9	–3.1	–6.9	1.0	–4.4

Note: full name of each region′s codes are shown in Table 1

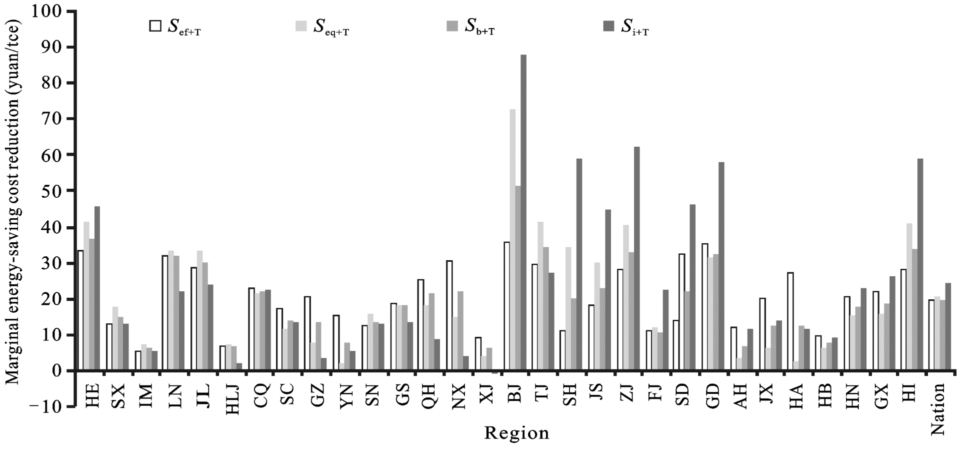

Fig. 8 Marginal energy-saving cost reduction in 2015 considering induced energy technology improvements compared with the cases not considering induced energy technology improvements. Full name of each region′s codes are shown in Table 1

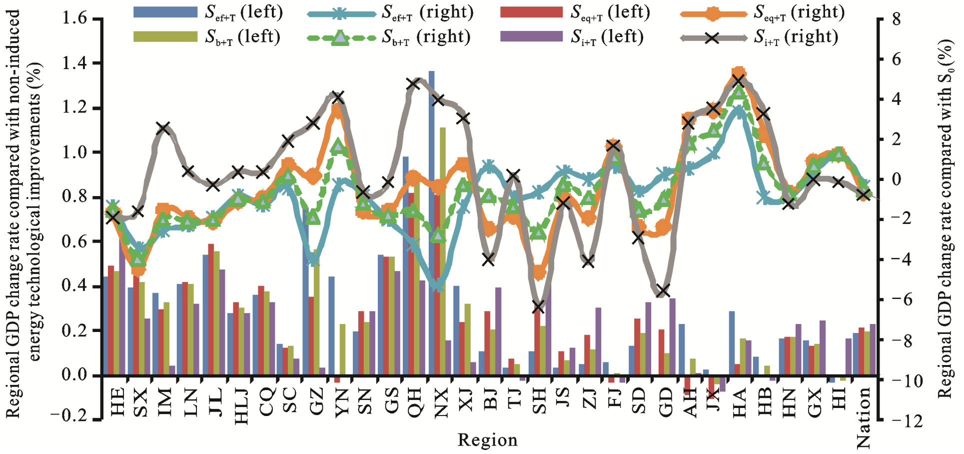

Fig. 9 Regional GDP changes in 2015 considering induced energy technology improvements. Full name of each region's codes are shown in Table 1

income, induced energy technology improvements can not fundamentally change allocation plans′ impacts on the spatial economic structure. However, it can reduce the GDP losses and real income losses in regions more affected and help alleviate regional economic disparity. In S_{ef+T}, S_{eq+T}, S_{b+T} and S_{i+T}, induced energy technology improvements decrease the regional income *Gini* coefficient by 0.05%, 0.05%, 0.01% and 0.05% compared with S_{ef}, S_{eq}, S_b and S_i respectively.

Induced energy technology improvements modify the industrial structure to some extent (Table 6). At the national level, energy efficiency does increase in every industry. Compared with scenarios without considering induced energy technology improvements, the outputs of EME & HEC industries and other industries increase approximately 0.1%, while the service industry suffers an output reduction of 0.1%–0.2%. Some more obvious changes can be found in a certain specific regional industries. Generally speaking, the regional industries which are heavily influenced by the total energy consumption control policy suffer a greater decrease in output loss (or increase in output growth) when induced energy technology improvements are considered. For example, there is a great alleviation in the output loss of the EME & HEC industries of Guizhou in S_{ef+T}. Interregional migration of energy-related industries also decrease compared with that in the scenarios of no induced energy technology improvements. In particular, the most significant decrease in the interregional migration of energy-related industries happens in S_{eq+T}. This phenomenon adds to the effectiveness of the total energy consumption control policy.

5 Discussion and Conclusions

This paper examined the impacts of the total energy consumption control policy and energy quota allocation plans on China′s regional economy by using a dynamic multi-regional CGE model for China. Not only the pros and cons of energy quota allocation plans with different weights of equity and efficiency, but also the influences of possible induced energy technology improvements in different energy quota allocation plans were studied.

Under the influences of the total energy consumption control policy, different allocation plans are all effective in energy savings, but their economic influences vary among different regions in China. The efficiency-first allocation plan is the plan with the lowest energy-saving costs. However, it imposes heavier burdens on the economic growth, residents′ income and energy-related industries′ outputs in underdeveloped resource-rich regions than in the eastern developed regions. All these exacerbate the regional economic disparity, which are probably unacceptable. By contrast, the equity-first allocation plan has an exact opposite result, which is favorable for narrowing the regional income gap. However, the equity-first allocation plan incurs a heavy economic cost, with national GDP loss of nearly 1%, which is 60% higher than the efficiency-first allocation plan. Besides, in the equity-first allocation plan, there is evident interregional migration of energy-related industries from the regions with tighter energy consumption constraints to the regions with looser constraints, which may damage the initiative of energy savings to some extent. The intensity target-based allocation plan is easier

Table 6 Sectoral output changes in different regions in 2015 considering induced energy technology improvement (%)

Region	$S_{\text{ef+T}}$			$S_{\text{eq+T}}$			$S_{\text{b+T}}$			$S_{\text{i+T}}$		
	EME & HEC	Service	Others	EME & HEC	Service	Others	EME & HEC	Service	Others	EME & HEC	Service	Others
HE	–9.8	1.1	–1.9	–11.1	1.3	–2.2	–10.4	1.2	–2.0	–13.4	1.8	–2.5
SX	–9.5	1.0	–4.0	–11.9	1.0	–4.8	–10.7	1.0	–4.4	–7.6	3.6	–1.6
IM	–12.1	0.3	–0.7	–10.3	1.8	–0.1	–11.2	1.1	–0.3	–2.4	6.2	2.6
LN	–9.8	–0.5	–2.0	–8.9	0.2	–1.9	–9.3	–0.1	–1.9	–4.5	2.3	0.0
JL	–13.1	–0.5	–0.7	–14.4	–0.3	–0.9	–13.7	–0.4	–0.8	–9.9	1.7	0.1
HLJ	–7.0	1.0	–1.7	–8.0	1.2	–2.3	–7.4	1.1	–2.0	–5.8	3.2	–0.6
CQ	–9.6	1.2	–2.1	–9.6	1.8	–1.7	–9.5	1.5	–1.9	–7.5	3.0	–0.4
SC	–9.2	0.9	–0.8	–6.3	2.1	0.1	–7.6	1.5	–0.3	–4.4	3.3	1.2
GZ	–17.3	–0.7	–3.1	–6.9	2.8	–0.1	–12.1	1.1	–1.6	–0.7	5.2	2.1
YN	–10.0	2.0	–0.3	2.7	4.6	2.4	–3.5	3.4	1.1	2.3	5.5	3.2
SN	–5.6	2.0	–0.4	–7.6	1.8	–0.9	–6.5	1.9	–0.6	–6.9	3.3	–0.1
GS	–2.3	0.9	–6.9	–1.6	1.6	–6.6	–1.9	1.3	–6.7	0.3	2.8	–4.9
QH	–23.7	1.8	–1.8	–16.6	4.9	0.8	–20.2	3.5	–0.4	–5.4	9.0	4.8
NX	–23.4	–0.8	–1.9	–10.4	2.5	0.9	–17.0	0.9	–0.4	1.2	5.6	3.8
XJ	–9.6	–0.7	–3.8	–5.2	2.6	–1.3	–7.4	1.0	–2.5	–1.1	6.2	1.6
BJ	–8.6	1.7	–1.7	–19.8	–0.6	–6.4	–14.2	0.6	–3.9	–25.4	–1.7	–8.7
TJ	–3.5	–0.1	–1.9	–6.3	–0.7	–2.9	–4.8	–0.4	–2.4	–1.9	1.3	–0.8
SH	–3.7	–0.3	–1.7	–14.1	–3.9	–5.2	–8.9	–2.0	–3.4	–19.3	–5.4	–6.5
JS	–3.4	2.0	–0.3	–8.0	1.8	–1.3	–5.7	1.9	–0.8	–10.6	2.1	–1.3
ZJ	–1.8	1.5	–2.2	–6.3	0.4	–4.9	–4.0	1.0	–3.5	–11.6	–0.8	–8.1
FJ	–2.7	1.8	0.1	–0.6	2.6	1.1	–1.6	2.3	0.6	–1.8	3.0	1.2
SD	–5.7	0.5	–0.8	–11.2	–1.3	–2.0	–8.5	–0.4	–1.4	–13.9	–1.5	–2.5
GD	–1.2	0.8	–1.2	–6.8	–0.7	–5.1	–3.9	0.1	–3.1	–13.4	–2.8	–9.8
AH	–7.4	2.3	0.5	2.8	4.4	1.9	–2.2	3.4	1.3	–0.8	4.8	2.1
JX	–2.2	2.6	0.6	3.6	4.7	2.4	0.8	3.7	1.6	2.0	5.2	2.6
HA	3.6	1.4	0.4	7.0	5.2	2.4	5.6	2.8	1.2	6.3	4.7	1.9
HB	–7.3	1.7	–3.1	1.0	4.4	0.4	–2.8	3.2	–1.2	2.4	5.6	1.3
HN	–8.0	1.2	–2.1	–7.3	1.7	–1.9	–7.5	1.5	–2.0	–10.3	1.7	–2.6
GX	–4.8	2.2	–0.5	–3.9	3.0	–0.3	–4.2	2.6	–0.4	–7.8	2.6	–1.1
HI	1.6	0.6	0.3	1.5	0.5	0.2	1.7	0.6	0.3	–1.2	–1.7	–1.6
Nation	–4.5	1.1	–2.5	–5.8	1.0	–3.5	–5.2	1.0	–3.0	–6.8	1.2	–4.3

Note: full name of each region′s codes are shown in Table 1

for all regions to reach the energy-saving target in the 12th Five-Year Plan, but it imposes heavy economic costs on the eastern developed regions. For example, the economic losses for the eastern developed regions reach 3%–7%. The efficiency-and-equity-balanced allocation plan has a relatively even burden in terms of economic cost on all regions, and it can alleviate the regional economic disparity and induce less migration of energy-related industries. Therefore, among all the allocation plans, the efficiency-equity-balanced allocation plan is the most feasible plan for the total energy consumption control policy.

When the induced energy technology improvements are considered in the total energy consumption control policy implementation, the above simulation results get some changes. Because the induced energy technology improvements are faster in regions with tighter energy consumption constraints, more alleviation of economic losses can be found in regions that suffer heavy impacts. Therefore, in the efficiency-first allocation plan, induced energy technology improvements help to reduce regional economic disparity. In the equity-first, the equity-and-efficiency-balanced and intensity target-based allocation plans, they help to reduce the energy-saving costs and mitigate the interregional migration of energy-related industries. In summary, induced energy technology improvements add more feasibility to all of the above plans. However, induced energy technology improvements can not fundamentally change the impacts of allocation plans on the spatial economic structure because if there is no major technological breakthrough, the rate of induced energy technology improvements would be relatively small in general (as in this paper, set at 15%). Thus, the government can give more incentive and support to energy-related sectors for technological research and innovation while implementing the total energy consumption control policy, which will enhance the effect and performance of induced energy technology improvements and increase the effectiveness of the total energy consumption control policy.

The situation has not been optimistic since the implementation of the total energy consumption control policy. The total national energy consumption in 2013 is 3.76×10^9 tce, which is 3.9% more than that in 2012. If the target of total national energy consumption control of 4×10^9 tce in 2015 is to be achieved, the average annual growth rate of energy consumption should be maintained at no more than 3.1% from 2014 to 2015, which is a huge challenge. The later the implementation of an allocation plan and the less rigid the control, the more difficult it will be to realize the goal. Therefore, a feasible allocation plan (as suggested in this paper) should be carried out as soon as possible. Furthermore, the allocation plan should be rigidly managed, and any violation should be punished, or else this policy will not be as effective as expected.

Within a short period following the implementation of the total energy consumption control policy, the effects of induced energy technology improvements may be limited. Not only do energy technological investment and innovation require some time, but there is also always a lag between the energy technology adoption phase and the effects of energy technology improvements beginning to show and fully develop. Over a longer span of time, however, the positive consequences of induced energy technology improvements may become much more obvious. In addition, as the policy of total energy consumption control continues and energy quota constraints strengthen, the price of energy will increase further. To control production costs, more and more enterprises will actively involve themselves in energy-saving activities by increasing the investment in and innovation of energy technologies, which may finally make the positive effects of energy-saving efforts even larger. Some researchers had a similar point of view (Kerr and Newell, 2003). Therefore, as the effect of induced energy technology improvements increases over time, its influence on the spatial economic structure may evolve. In addition, some other researchers held that the policy effects of market-based tools on technology innovation and technology diffusion were larger than those of administrative tools, and the effect of auction quotas was larger than that of free quota allocation (Jaffe *et al*., 2002; Requate, 2005). Therefore, the current form of the total energy control policy can be modified to be more market based, and a part of energy quotas could be allocated through auction, which would induce larger energy technology improvements to facilitate transformations in the current economic development pattern.

References

Bai Wanping, 2011. A study of the control of energy consumption, energy intensity and energy consumption structure for China in its 12th Five-Year period. *Macroeconomics*, (9): 93–98. (in Chinese)

Baumert K A, Bhandari R, Kete N, 1999. *What Might a Developing Country Climate Commitment Look Like?* Washington: WRI, 1–20.

Bohm P, Larsen B, 1994. Fairness in a tradable-permit treaty for carbon emissions reductions in Europe and the Former Soviet Union. *Environmental and Resources Economics*, 4(3): 219–239. doi: 10.1007/BF00692325

Bollen J, Gielen A and Timmer H, 1999. Clubs, ceilings and CDM: Macroeconomics of compliance with the Kyoto Protocol. *The Energy Journal*, *Special Issue*: *The Costs of the Kyoto Protocol*: *A Multi-Model Evaluation*, 20: 177–206. doi: 10.5547/ISSN0195-6574-EJ-Vol20-NoSI-8

Burniaux J M, Nicolett G, and Oliveira-Martins J, 1992. Green: A global model for quantifying the cost of policies to curb CO_2 Emissions. *Economic Studies*, *Special Issue*: *Costs of Reducing CO_2 Emissions*, 19: 49–90.

Chen Wenying, Wu Zongxin, 1998. Carbon emission permit allocation and trading. *Journal of Tsinghua University*: *Sci & Tech*, 38(12): 15–18. (in Chinese)

Cramton P, Kerr S, 2002. Tradeable carbon permit auctions: How and why to auction not grandfather. *Energy Policy*, 30(4):

333–345. doi: 10.1016/S0301-4215(01)00100-8

Den Elzen M, Lucas P, Vuuren D, 2005. Abatement costs of post-Kyoto climate regimes. *Energy Policy*, 33(16): 2138–2151. doi: 10.1016/j.enpol.2004.04.012

Edwards T H, Hutton J P, 2001. Allocation of carbon permits within a country: A general equilibrium analysis of the United Kingdom. *Energy Economics*, 23(4): 371–386. doi: 10.1016/S0140-9883(00)00077-3

Grubb M, 1989. *The Greenhouse Effect: Negotiating Targets*. London: Royal Institute of International Affairs, 7–34.

He Jiankun, Yu Zhiwei, Zhang Da, 2012. China's strategy for energy development and climate change mitigation. *Energy Policy*, 51: 7–13. doi: 10.1016/j.enpol.2012.03.084

Jaffe A B, Newell R G, Stavins R N, 2002. Environmental policy and technological change. *Environmental and Resource Economics*, 22(1–2): 41–70.

Janssen M, Rotmans J, 1995. Allocation of fossil CO_2 emission rights quantifying cultural perspectives. *Ecological Economics*, 13(1): 65–79. doi: 10.1016/0921-8009(94)00058-4

Jung C H, Krutilla K, Boyd R, 1996. Incentives for advanced pollution abatement technology at the industry level: An evaluation of policy alternatives. *Economics and Management*, 30(1): 95–111. doi: 10.1006/jeem.1996.0007

Kerr S, Newell R G, 2003. Policy-induced technology adoption: Evidence from the U.S. Lead Phasedown. *The Journal of Industrial Economics*, 51(3): 317–343. doi: 10.1111/1467-6451.00203

Landjouw J O, Mody A, 1996. Innovation and international diffusion of environmentally responsive technology. *Research Policy*, 25 (4): 549–571. doi: 10.1016/0048-7333(95)00853-5

Li Guoping, Yuan Yuan, 2014. Impact of regional development on carbon emission: empirical evidence across countries. *Chinese Geographical Science*, 24(5): 499–510. doi: 10.1007/s11769-014-0710-5

Li Na, Shi Minjun, Wang Fei, 2009. Roles of regional differences and linkages on Chinese regional policy effect: Based on an eight-region CGE model for China. *Systems Engineering-Theory & Practice*, (10): 35–44. (in Chinese)

Li Na, Shi Minjun, Yuan Yongna, 2010. Impacts of carbon tax policy on regional development in China: A dynamic simulation based on China multi-regional CGE model. *Acta Geographica Sinica*, 65(12): 1572–1584. (in Chinese)

Li Shantong, He Jianwu, 2010. *Computable General Equilibrium Model for China and Its Application*. Beijing: Economic Science Press. (in Chinese)

Li S, He J, 2011. Impact of China's domestic carbon emission trading scheme. *The 19th International Input Output Conference*, June, Alexandria Virginia, USA.

NBSC (National Bureau of Statistics of China), 2008. *China Energy Statistical Year Book 2008*. Beijing: China Statistics Press. (in Chinese)

NBSC (National Bureau of Statistics of China), 2011. *China Statistical Year Book 2011*. Beijing: China Statistics Press. (in Chinese)

Newell R G, Jaffe A B, Stavins R N, 1999. The induced innovation hypothesis and energy-saving technological change. *The Quarterly Journal of Economics*, 114(3): 941–975. doi: 10.1162/003355399556188

Popp D, 2002. Induced innovation and energy price. *American Economic Review*, 92(1): 339–349. doi: 10.3386/w8284

Requate T, 2005. Dynamic incentives by environmental policy instruments: A survey. *Ecological Economics*, 54(2): 175–195. doi: 10.1016/j.ecolecon.2004.12.028

RGGI (Regional Greenhouse Gas Initiative), 2007. *Overview of RGGI CO_2 Budget Trading Program*. Available at: http://rggi.org/docs/program_summary_10_07.pdf. 2007-10-10.

Shi Minjun, Zhou Shenglv, 2010. The impact of low carbon technology development on China's CO_2 emission reduction. *Management Review*, 22(6): 48–53. (in Chinese)

Shi Minjun, Zhang Zhuoying, 2012. *The Construction of China Interregional Input Output Model 2007*. Beijing: Research Centre on Fictitious Economy & Data Science, Chinese Academy of Sciences. (in Chinese)

Sun Zuoren, Zhou Dequn, Zhou Peng *et al*., 2012. Quota allocation of China's energy conservation based on environmental ZSG-DEA. *Systems Engineering*, 30(1): 84–90. (in Chinese)

The State Council (The State Council of the People's Republic of China), 2011a. *The Twelfth Five-year Plan for National Economic and Social Development of the People*'s *Republic of China*. Available at: http://www.gov.cn/2011lh/content_1825838_2.htm. 2011-12-20. (in Chinese)

The State Council (The State Council of the People's Republic of China), 2011b. *Regional Energy Saving Targets of the Twelfth Five-year Plan Period*. Available at: http://www.gov.cn/zwgk/2011-09/07/content_1941731.htm. 2011-09-07. (in Chinese)

The State Council (The State Council of the People's Republic of China), 2013. *The Twelfth Five-year Plan of Energy Development* (*2011–2015*). Available at: http://www.gov.cn/zwgk/2013-01/23/content_2318554.htm. 2013-01-23. (in Chinese)

Wang J, Cai B, Cao D *et al*., 2011. Scenario study on regional allocation of CO_2 emissions allowance in China. *Acta Scientiae Circumstantiae*, 31(4): 680–685. (in Chinese)

Wang Zheng, Wu Jing, Zhu Yongbin *et al*., 2010. *The Research of Economics for Climate Protection*. Beijing: Science Press, 134–147. (in Chinese)

Wu Yajun, Xuan Xiaowei, 2002. *The Theory of Environmental Tax and Its Application in China*. Beijing: Economic Science Press. (in Chinese)

Yuan Yongna, Shi Minjun, Li Na *et al*., 2012. Intensity allocation criteria of carbon emission permits and China's regional development: Based on a 30-province/autonomous region computable equilibrium model analysis. *Advances in Climate Change Research*, 8(1): 60–67. (in Chinese)

Zhao Rongqin Huang Xianjin, Liu Ying *et al*., 2014. Carbon emission of regional land use and its decomposition analysis: case study of Nanjing City, China. *Chinese Geographical Science*, 24(2): 198–212. doi: 10.1007/s11769-014-0714-1