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Regional efforts to mitigate climate change in China: A multi-criteria assessment approach

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Regional efforts to mitigate climate change in China: A multi-criteria assessment approach

Abstract: The task of mitigating climate change is usually allocated through administrative regions. In order to put pressure on regions that perform poorly in mitigating climate change and highlight regions with best-practice climate policies, this study explored a method to assess regional efforts on climate change mitigation at the sub-national level. A climate change mitigation index (CCMI) was developed with 15 objective indicators, which were divided into four categories, namely, emissions, efficiency, non-fossil energy, and climate policy. The indicators' current level and recent development were measured for the first three categories. The index was applied to assess China's provincial performance in climate protection based on the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) method. Empirical results show that the middle Yangtze River area and southern coastal area perform better than other areas in mitigating climate change. The average performance of the northwest area in China is the worst. In addition, climate change mitigation performance has a negative linear correlation with energy self-sufficiency ratio but does not have a significant linear correlation with social development level. Therefore, regional resource endowments should be paid much more attention in terms of mitigating climate change, because regions with good resource endowments in China tend to perform poorly.

Keywords: mitigation efforts, climate policy, carbon efficiency, energy efficiency, non-fossil energy, TOPSIS

1. Introduction

Climate change poses a significant potential risk for human society and the natural system (Wei et al. 2014). To prevent the dangerous anthropogenic interference with the climate system, climate change mitigation has become one of the most important tasks for all countries (Scrieciu et al. 2013). As the leading energy consumer and the largest carbon-emitting country in the world, China's carbon dioxide (CO_2) emissions from fuel combustion accounted for 25.9% of global emissions in 2012 (IEA 2014). China has occupied more than one half of the global increased CO_2 emissions between 1990 and 2012 (Fig. 1) (Feng et al. 2013; IEA 2014). Therefore, China's performance in carbon reduction is critical to the effects of global actions in mitigating climate change.

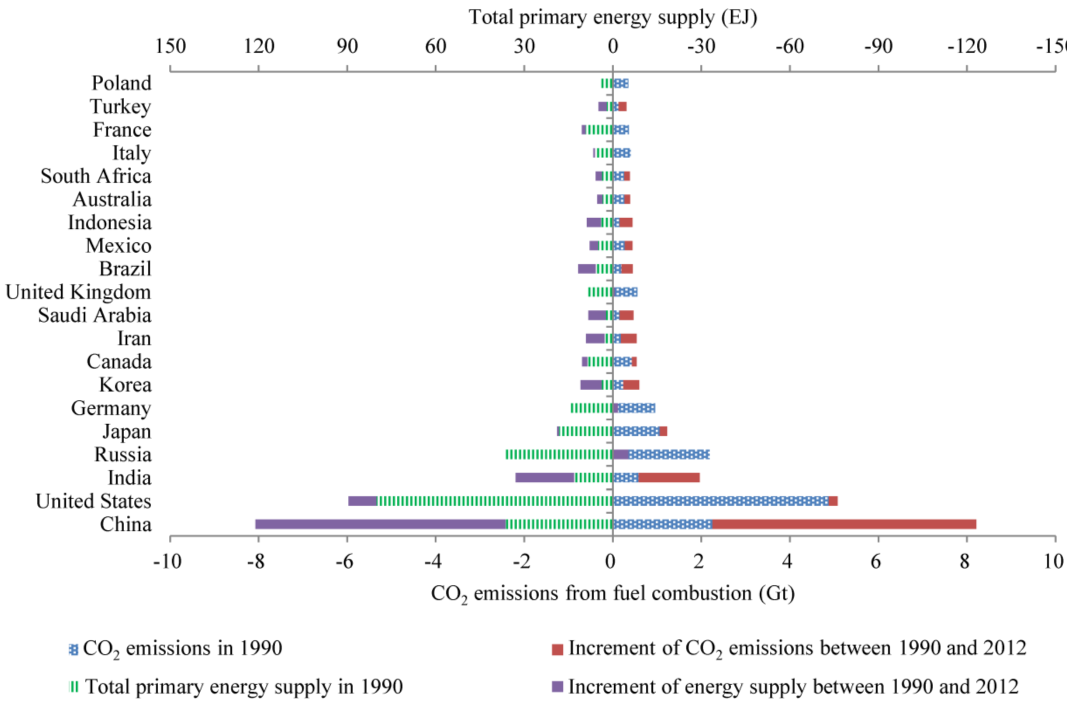

Fig. 1. CO_2 emissions and total primary energy in 2012 consist of levels in 2009 and the increments. EJ refers to 10^{18} joules, and Gt refers to 10^9 tonnes. Data sources: IEA (2014)

Faced with international pressure to reduce its CO_2 emissions as well as limited domestic fossil energy supply and a high level of air pollution, China has set a target to cut carbon intensity [i.e., CO_2 emissions per unit of gross domestic product (GDP)] by 40% to 45% during the period of 2006–2020 (Liu et al. 2013). In the "U.S.–China Joint Announcement on Climate Change" released on November 12, 2014, China announced that it aims to achieve the peaking of CO_2 emissions around 2030 and increase the share of non-fossil fuels in primary energy consumption to approximately 20% by 2030 (The White House 2014).

To achieve the climate-related targets, the task of reducing carbon emissions is usually allocated through sectors or administrative regions. The Chinese political system requires the country's energy conservation and emission reduction targets to be allocated not through sectors but through administrative regions. The government's Twelfth Five-year Plan (2011–2015) calls for a 16% reduction in energy intensity and a 17% reduction in carbon intensity (State Council 2011b). Each province has been allocated mandatory targets. The target of reducing energy intensity is set to 18% in five regions, 17% in four regions, 16% in twelve regions, 15% in six regions, and 10% in three regions (State Council 2011a). Therefore, examining the provincial performance in climate protection in China is significant (Liu et al. 2012).

Many researchers and institutions have attempted to assess regional efforts on climate change mitigation at the national level. To the best of our knowledge, only a few studies have addressed this issue at the sub-national level. Therefore, this study explored a method to assess regional efforts to mitigate climate change at the sub-national level. A climate change mitigation index (CCMI) was developed based on the climate change performance index proposed by Germanwatch (Burck et al. 2014b). The goal of CCMI is to put pressure on regions that perform poorly in mitigating climate change and to highlight regions with best-practice climate policies. The index was utilized to assess China's provincial efforts to mitigate climate change based on the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) method.

2. Literature review

National efforts on climate change mitigation have been assessed by many researchers and reports. The fifth assessment report of the Intergovernmental Panel on Climate Change (IPCC) (2014) assessed performance of climate policies and measures in developed and developing countries taking into account development level and capacity. These polices are divided into economic instruments, regulatory approaches, information programmes, government provision of public goods and voluntary agreements. Van Sluisveld et al. (2013) used a multi-model comparison to analyze post-2020 mitigation efforts of five major economies, including the United States (US), the European Union (EU), Japan, China and India, in the context of the 2°C target. The results showed that India and the US emphasize on prolonging fossil fuel consumption with carbon storage technologies, whereas China and the EU prefer a rigorously shift to carbon-neutral technologies with renewables. Calvin et al. (2012) assessed national climate policy goals in the Copenhagen Accord using 23 energy and integrated assessment models. They found that the targets outlined by the US, the EU, Japan, and Korea require significant policy action, whereas India's goals are met without any climate policy. Konidari and Mavrakis (2007) used the multi-attribute theory and simple multi-attribute ranking technique to assess the aggregate performances of climate change mitigation policy instruments in eight countries.

Some institutions assessed national efforts on climate change mitigation by developing index system. Germanwatch developed the Climate Change Performance Index to estimate and compare the climate protection performance of 58 countries whose CO_2 releases accounted for more than 90% of global emissions. The index combines thirteen objective indicators and two subjective indicators assessed by more than 200 experts from different countries (Burck et al. 2014b). PricewaterhouseCoopers (PwC) established the Low Carbon Economy Index to examine the rate of decarbonization in the Group of Twenty (G20) economies. The report showed that based on the carbon budget in the fifth assessment report of the IPCC, the global economy needs to reduce carbon intensity by 6.0% yearly until 2100 (PwC 2013). The American Security Project established the Climate Change and Global Security Defense Index to detail how governments around the world plan for and anticipate the strategic threats imposed by climate change. The results showed that more than 70% of the nations in the world view climate change as a serious national security issue (Holland and Vagg 2013). Dual Citizen (2012) introduced the Global Green Economy Index to rank 27 countries based on their efforts to incorporate environmentally sustainable practices, such as reliance on renewable energy, into their economies. Simultaneously, the index aims to capture how these efforts are regarded internationally.

To the best of our knowledge, only a few studies have estimated regional efforts to mitigate climate change at the sub-national level. Some researchers analyzed China's regional efforts from the perspective of energy and environmental efficiency using Data Envelopment Analysis (DEA) (Zhou et al. 2008; Sueyoshi and Goto 2012; Zhou et al. 2010). Wang et al. (2013) utilized DEA model to evaluate China's regional energy and environmental efficiency. The empirical results illustrated that the eastern area of China has the highest energy and environmental efficiency, whereas the efficiency of the western area is the worst. Generally, the energy and environmental efficiency of China increased slightly from 2000 to 2008. Guo et al. (2011) used DEA to evaluate the carbon emission performance of 29 Chinese provincial administrative regions. They found that most of regions have an irrational energy structure and exhibit an overdependence on coal consumption.

Some other studies tried to assess China's regional performance on climate change mitigation from the perspective of low-carbon or green development by developing index system. Price et al. (2013) developed a low-carbon indicator system at provincial and city levels; the system consists of indicators employed by energy end-use sectors. The indicator system was applied to evaluate the low-carbon performance of 30 provinces, autonomous regions, and cities in China in 2008. Pan et al. (2013) developed a low-carbon development index to examine the comprehensive levels of low-carbon development in China's 100 cities.

3. Methodology

3.1 Research framework

Fig. 2 shows the framework of this research. First of all, CCMI was developed with objective indicators. Second, it was utilized to assess China's provincial efforts to mitigate climate change based on the TOPSIS method. Third, China's provincial performance was assessed in four fields, namely, emissions, efficiency, non-fossil energy, and climate policy. Fourth, the comprehensive performance of mitigating climate change was estimated. Lastly, several suggestions for mitigation on both national and regional levels were provided.

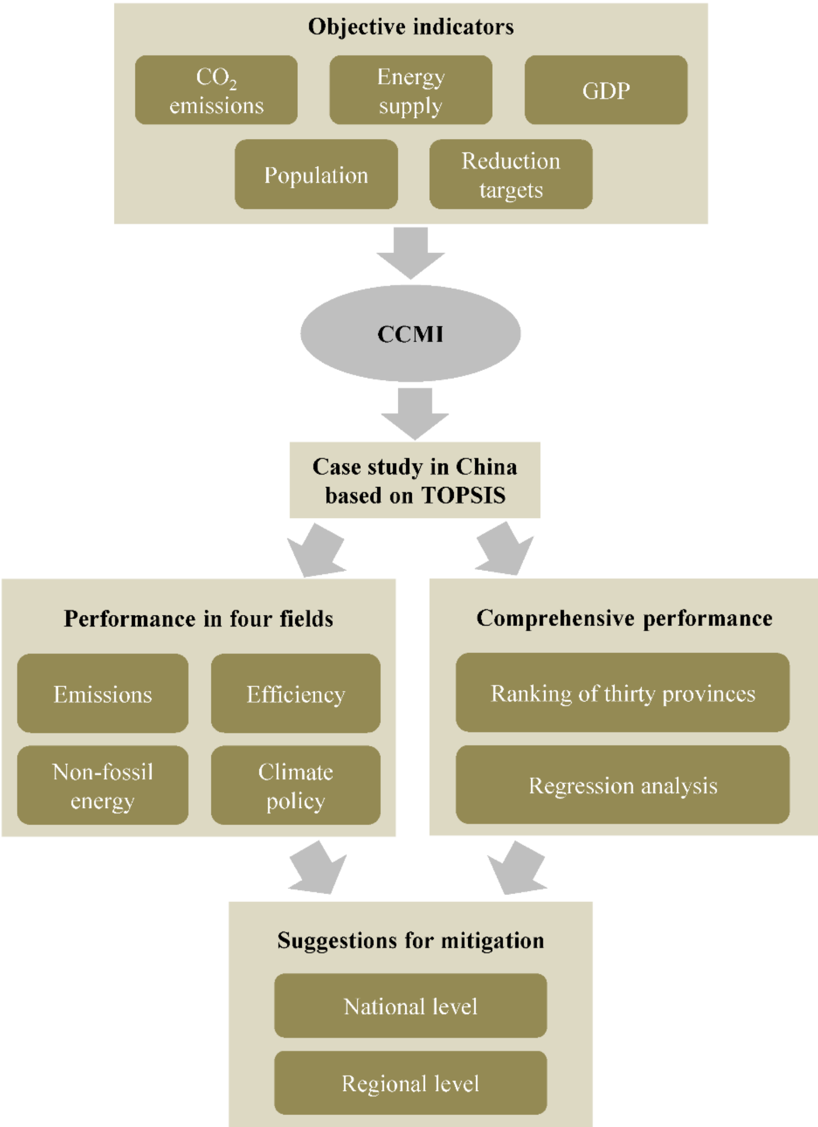

Fig. 2. China's regional efforts to mitigate climate change are assessed using the CCMI.

3.2 Components and weights of CCMI

CCMI was assessed by 15 objective indicators integrated into a single composite indicator. The indicators were divided into four categories: emissions, efficiency, non-fossil energy, and climate policy. The indicators' current level and recent development were measured for the first three categories. Fig. 3 shows all indicators and their corresponding weights in the overall score.

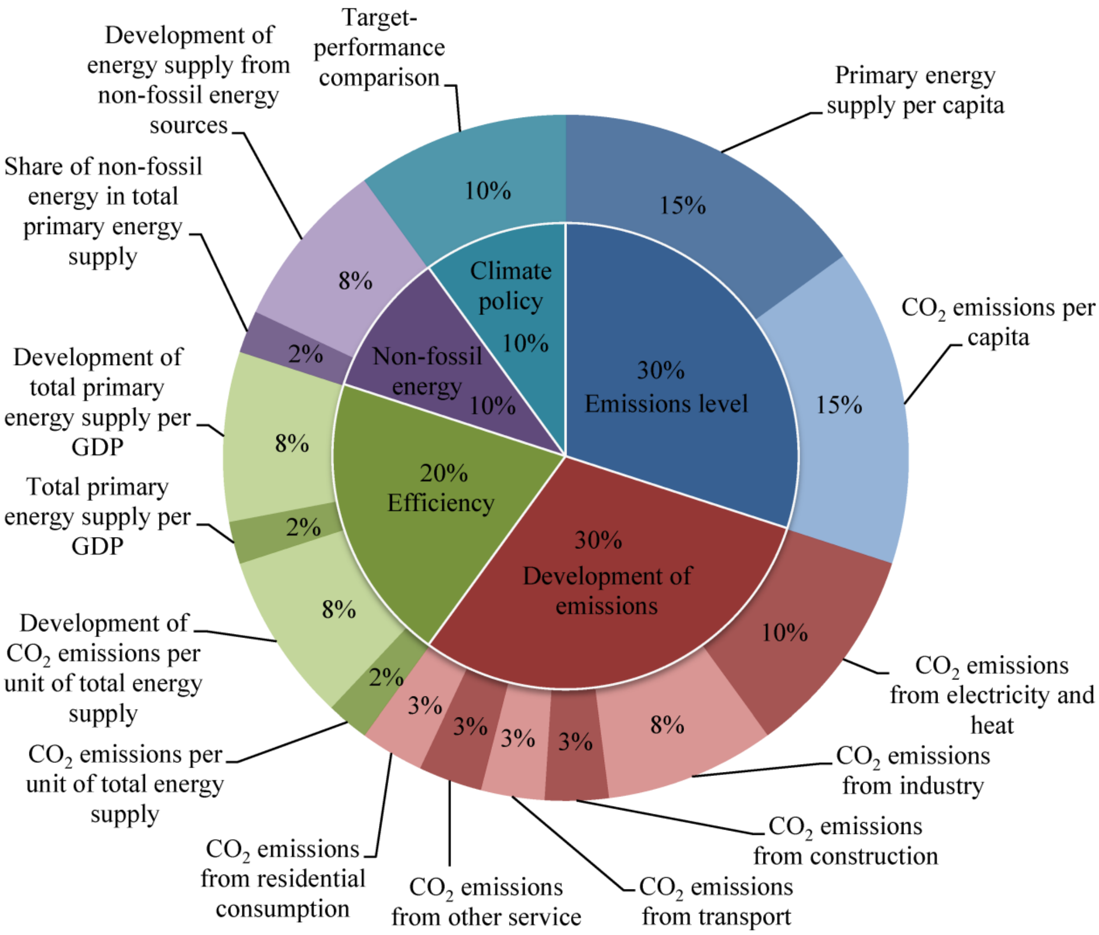

Fig. 3. CCMI is composed of 15 objective indicators.

3.2.1 Emissions

CO_2 emitted from fossil energy is the main cause of human-induced climate change (Sueyoshi and Goto 2012). They are usually regarded as the most important indicator in measuring the effects of climate policies. Therefore, emissions contribute the largest share (60%) in the overall score of a region; the half of this figure is for current emission level, and the other half is for the recent development of emissions.

Two separate indicators, namely, CO_2 emissions per capita and primary energy supply per capita, were utilized to measure the level of current emissions. Egalitarianism is implemented in the index system. In other words, people have equal rights to use atmospheric resources (Baer et al. 2000; Oberheitmann 2010). Hence, the per-capita value rather than total quantity was used.

This study only focused on CO_2 emissions from fossil fuel combustion. The emissions from anthropogenic land use change were not included because of data unavailability (Chen and He 2014; Yu et al. 2014). The CO_2 emissions were calculated by using the algorithm in the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 2006; Tang and Nan 2013).

$$T_j = \sum_{i=1}^{m} \left[(A_{ij} - S_{ij}) e_i c_i O_i \cdot 44/12 \right], \tag{1}$$

where T_j is the total CO_2 emissions of region *j*, A_{ij} is the total consumption of fuel *i* in region *j*, S_{ij} is the non-energy use consumption of fuel *i* in region *j*, e_i is the factor for the conversion of fuel *i* into energy units on a net calorific value basis, c_i is the carbon content of fuel *i*, O_i is the fraction of oxidized carbon of fuel *i*, $44/12$ is the molecular weight ratio of CO_2 to C, *m* is the number of fuel types ($m = 27$), and $i = 1, 2, ..., m$; $j = 1, 2, ..., 30$. The sectors which consume energy are divided into two transformation sectors (thermal power and heating supply) and seven final consumption sectors (agriculture, forestry, animal husbandry, fishery and water conservancy; industry; construction; transport, storage and post; wholesale, retail trade and hotel, restaurants; other services; and residential consumption). Fuels which are used as feedstock, reductant or non-energy products do not lead to fuel combustion emissions, so those are excluded from the total energy consumption. There are twenty-seven fuel types, including raw coal, cleaned coal, other washed coal, briquettes, gangue, coke, coke oven gas, blast furnace gas, converter gas, other gas, other coking products, crude oil, gasoline, kerosene, diesel oil, fuel oil, naphtha, lubricants, paraffin waxes, white spirit, bitumen asphalt, petroleum coke, liquefied petroleum gas, refinery gas, other petroleum products, natural gas, and liquefied natural gas.

Primary energy supply per capita is the other emission level indicator, although the CO_2 emission figure is calculated from energy consumption. Under the assumption that energy will never be abundant, this indicator is an important complement to per-capita emissions (Burck et al. 2014a).

The recent development of emissions accounts for 30% of a region's overall score. To rate the overall performance in protecting climate and analyze the strengths and shortcomings in detail, the changes in CO_2 emissions were measured from the electricity and heat production, industry, construction, transport, other service, and residential sectors. According to the categorization in China's statistical data (NBS 2013a), the energy sector contains thermal power and heating supply, and the transport sector includes transport, storage, and post. The weighting of each sector was set according to its proportion in national emissions.

The development of emissions in the agriculture sector was excluded for two main reasons. First, the carbon emissions of the agricultural sector are much lower than those of other sectors. In 2012, the agriculture sector in China emitted 141.07 million tons of CO_2, which only accounted for 1.4% of the national emission figure. Furthermore, agriculture, which provides food, is the fundamental industry of human society. With the growth of the population, it is reasonable to achieve a not very high increase in agricultural emissions.

The recent development of each indicator can be obtained by

$$\alpha_{jk,t} = \left(L_{jk,t} - L_{jk,t-1}\right) / L_{jk,t-1} , \tag{2}$$

where $\alpha_{jk,t}$ is the development of indicator k in region j at year t, $L_{jk,t}$ is the level of indicator k in region j at year t, and $L_{jk,t-1}$ is the level of indicator k in region j at year t-1.

3.2.2 Efficiency

One of the most effective methods to control CO_2 emissions is to improve the energy and carbon efficiency (Streimikiene et al. 2012; Scrieciu et al. 2014), especially for China whose energy consumption is increasing rapidly. Two indicators were considered: CO_2 emissions per unit of total energy supply (10%) and total primary energy supply per GDP (10%). Both the current level (2%) and development (8%) were evaluated for the two indicators. The current development of the efficiency indicators was also calculated with Equation (2).

The first indicator in the measurement of carbon efficiency, the CO_2 emissions per unit of total energy supply, mainly reflects the structure and efficiency of the generation system and the selected fuel mix. The second indicator, total primary energy supply per GDP, is the measurement of energy efficiency; it focuses on the structure of the general economic system and its efficiency (Burck et al. 2014a).

3.2.3 Non-fossil energy

The substitution of fossil fuel by renewable energy is another effective means to reduce carbon emissions (Streimikiene and Balezentis 2013; IPCC 2011). Therefore, the indicator of non-fossil energy contributes 10% to a region's overall score. The largest part of this indicator (80%) is dependent on the development of energy supply from non-fossil energy sources. Considering that several regions have already obtained a high proportion of non-fossil energy in the total energy supply and therefore have less potential to further increase their share of non-fossil energy, the rest (20%) is based on the share of non-fossil energy in the total primary energy supply.

The non-fossil energy of each region contains two parts. The first part is nuclear power and renewable energy (e.g., hydro power, wind power, and solar energy). The second part is imported heat and electricity from other regions or countries. For instance, region 2 imports heat (b_1) and electricity (b_2) from region 1 (see Fig. 4). The total primary energy supply of the two regions is p_1 and p_2, respectively, and the supply of nuclear power and renewable energy is r_1 and r_2, respectively. The two regions' share of non-fossil energy in the total primary energy supply can be obtained by

$$\beta_1 = \left(r_1 - b_1 - b_2\right) / P_1 , \quad (3)$$

$$\beta_2 = \left(r_2 + b_1 + b_2\right) / P_2 , \quad (4)$$

where β_1 and β_2 are the share of non-fossil energy of regions 1 and 2, respectively. In this manner, the imported heat and electricity are contained in non-fossil energy while the indigenous production of heat and electricity are excluded. Moreover, a certain region's share of non-fossil energy may be negative if its net exports of heat and electricity are larger than the supply of nuclear power and renewable energy (e.g.,

$b_1 + b_2 > r_1$).

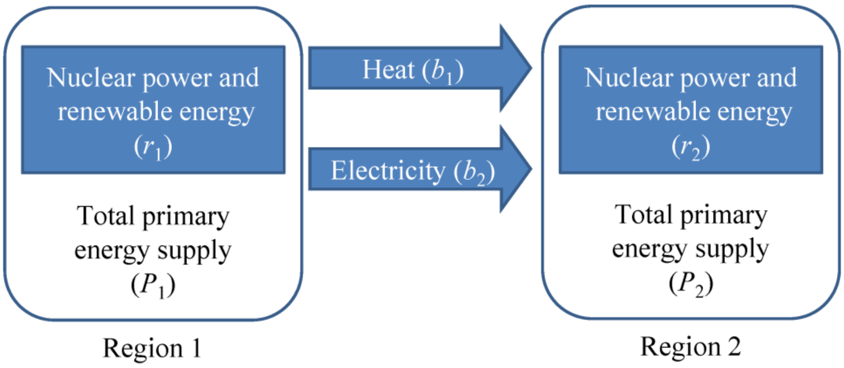

Fig. 4. The non-fossil energy contains imported heat and electricity from other regions.

3.2.4 Climate policy

Climate policy occupies 10% of the overall score of a region. This indicator was evaluated by comparing the target and actual performance. To reduce energy consumption and mitigate climate change, the Chinese government has set the target to reduce energy consumption per unit of GDP by 16% and cut CO_2 emissions per unit of GDP by 17% during the period of 2011–2015 (State Council 2011b). Each region has been allocated mandatory targets. The target of reducing energy intensity is set to 18% in five regions, 17% in four regions, 16% in twelve regions, 15% in six regions, and 10% in three regions (State Council 2011a). In this study, the reduction targets are distributed equally in five years to measure the performance in each year. The indicator of target–actual performance comparison is evaluated by

$$\gamma_j = \left(G_j - \overline{G_j}\right) / \overline{G_j} \,, \tag{5}$$

where γ_j is the target performance comparison score of region j, $\overline{G_j}$ is the target of reducing the energy intensity of region j, and G_j is the actual performance of reducing energy intensity.

The comparison indicator of target and actual performance cannot completely reflect the effects of a region's climate policies. Long-term climate policies would generate effects in future years and even decades (Scrieciu and Chalabi 2014). Therefore, a certain year's target performance comparison can only show the effects of short-term policies in that year and partial policies in the past years.

3.3 Combination of indicators based on TOPSIS

The final score of CCMI was combined by the 15 weighted indicators using the TOPSIS method. The TOPSIS, first developed by Hwang and Yoon (1981), is a widely used multi-criteria evaluation technique. It is based on the concept that the positive ideal alternative has the best level for all attributes while the negative ideal is the one with all worst attribute values. According to the method, the optimal alternative should simultaneously have the shortest distance from the positive-ideal solution and the farthest distance from the negative-ideal solution (Ertuğrul and Karakaşoğlu 2009).

All indicators were divided into benefit- and cost-type indicators. The larger the value of a benefit-type indicator is, the better its performance is. The opposite condition applies to the cost-type indicators. For example, the share of non-fossil energy in the total primary energy supply is a benefit-type indicator, whereas CO_2 emission per capita is a cost-type indicator. The benefit-type indicators are normalized by

$$Y_{jk} = 100\left(\frac{X_{jk} - X_k^{\min}}{X_k^{\max} - X_k^{\min}}\right), \tag{6}$$

where Y_{jk} is the normalized indicator k in region j, X_{jk} is the actual value of indicator k in region j, $X_k^{\min} = \min_j X_{jk}$, and $X_k^{\max} = \max_j X_{jk}$. Accordingly, the cost-type indicators are normalized by

$$Y_{jk} = 100\left(\frac{X_k^{\max} - X_{jk}}{X_k^{\max} - X_k^{\min}}\right). \tag{7}$$

In this manner, all normalized indicators are benefit-type indicators, with 100 points as the highest score and zero as the lowest score. The region that performs best in one indicator receives full points in that indicator; the region that performs worst in one indicator receives a score of zero. A score of 100 can be achieved, but this would only mean the best relative performance and not necessarily the optimal effort for climate change mitigation (Burck et al. 2014a). In addition, a score of zero does not mean that the region does nothing to mitigate climate change.

The distance between the region *j* and the worst performance can be obtained by

$$d_j^- = \sqrt{\sum_{k=1}^{n} \omega_k^2 \left(Y_{jk} - Y_k^{\min}\right)^2}\ , \tag{8}$$

and the distance between the region *j* and the best performance can be obtained by

$$d_j^+ = \sqrt{\sum_{k=1}^{n} \omega_k^2 \left(Y_k^{\max} - Y_{jk}\right)^2}\ , \tag{9}$$

where d_j^- is the distance between the region *j* and the worst performance, d_j^+ is the distance between the region *j* and the best performance, Y_{jk} is the normalized indicator *k* in region *j*, ω_k is the weighting of indicator *k*, $Y_k^{\min} = \min_j Y_{jk}$, $Y_k^{\max} = \max_j Y_{jk}$, and *n* is the number of indicators (currently $n = 15$).

The overall score of CCMI can be determined by

$$I_j = d_j^- \Big/ \left(d_j^- + d_j^+\right), \tag{10}$$

where I_j is the overall score of region *j*.

3.4 Regression analysis of CCMI's correlation to resource endowments and social development levels

Resource endowments and social development levels have considerable influence on a region's carbon emissions (Mi et al. 2014). Their relationships with CCMI were estimated by linear regression models. The energy self-sufficiency ratio was used as the proxy for resource endowments, and GDP per capita and urbanization rate were selected as the indicators for social development levels. Therefore, the three linear regression functions are

$$I_j = \lambda_f + \mu_f h_{fj} + \varepsilon_j \qquad (f = 1,2,3)\ , \tag{11}$$

where I_j is the overall score of region *j*, λ_f and μ_f are regression coefficients, h_{1j}, h_{2j}, and h_{3j} are energy self-sufficiency ratio, GDP per capita, and urbanization rate, respectively, in region *j*, and ε_j is an error term.

4. Data sources

In this paper, we measured China's efforts to mitigate climate change by using regional data, including GDP, population, energy supply and consumption, and CO_2 emissions. The data on GDP and population were obtained from the *China Statistical Yearbook 2013* (NBS 2013b), and the data on energy were from the *China Energy Statistical Yearbook 2012* (NBS 2012) and *China Energy Statistical Yearbook 2013* (NBS 2013a). The CO_2 emissions of each sector were calculated from energy consumption by using the algorithm in the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 2006). Table 1 provides a summary of the statistics of each region.

Table 1. Key data for each province in China in 2012 are used in the assessment.

	GDP (2005 Billion CNY)		Population (M)		Primary energy supply (Mtce)		CO_2 emissions ($MtCO_2$)		Targets (%)
	Level	Share	Level	Share	Level	Share	Level	Share	
Beijing	1392	3.08%	21	1.54%	60	1.40%	103	1.02%	17
Tianjin	1092	2.41%	14	1.05%	77	1.80%	181	1.80%	18
Hebei	2123	4.69%	73	5.42%	289	6.76%	790	7.86%	17
Shanxi	896	1.98%	36	2.69%	201	4.71%	494	4.91%	16
Inner Mongolia	1119	2.47%	25	1.85%	274	6.42%	699	6.95%	15
Liaoning	1902	4.20%	44	3.26%	238	5.58%	519	5.16%	17
Jilin	924	2.04%	28	2.04%	105	2.47%	250	2.49%	16
Heilongjiang	1200	2.65%	38	2.85%	132	3.10%	282	2.80%	16
Shanghai	1828	4.04%	24	1.77%	105	2.46%	211	2.09%	18
Jiangsu	4284	9.47%	79	5.89%	280	6.57%	671	6.67%	18
Zhejiang	2769	6.12%	55	4.07%	165	3.87%	394	3.91%	18
Anhui	1275	2.82%	60	4.45%	129	3.03%	315	3.13%	16
Fujian	1567	3.46%	37	2.79%	104	2.43%	235	2.34%	16
Jiangxi	940	2.08%	45	3.35%	67	1.56%	156	1.55%	16
Shandong	4134	9.14%	97	7.20%	371	8.69%	926	9.20%	17
Henan	2392	5.29%	94	6.99%	197	4.62%	544	5.41%	16
Hubei	1600	3.54%	58	4.30%	161	3.78%	403	4.00%	16
Hunan	1594	3.52%	66	4.94%	135	3.16%	300	2.98%	16
Guangdong	4821	10.66%	106	7.88%	258	6.03%	546	5.43%	18
Guangxi	955	2.11%	47	3.48%	86	2.01%	199	1.98%	15
Hainan	210	0.46%	9	0.66%	19	0.45%	34	0.34%	10
Chongqing	920	2.03%	29	2.19%	77	1.81%	169	1.68%	16
Sichuan	1818	4.02%	81	6.01%	160	3.75%	331	3.29%	16
Guizhou	474	1.05%	35	2.59%	99	2.31%	233	2.32%	15
Yunnan	776	1.71%	47	3.46%	99	2.32%	213	2.12%	15

Shaanxi	1011	2.23%	38	2.79%	119	2.78%	250	2.49%	16
Gansu	416	0.92%	26	1.92%	66	1.54%	161	1.60%	15
Qinghai	128	0.28%	6	0.43%	26	0.61%	44	0.44%	10
Ningxia	139	0.31%	6	0.48%	56	1.32%	140	1.39%	15
Xinjiang	540	1.19%	22	1.66%	113	2.64%	269	2.67%	10
National Total	45242	100%	1345	100%	4268	100%	10062	100%	16

Note: CNY refers to Chinese Yuan, M refers to million, Mtce refers to million tonnes of standard coal equivalent, and $MtCO_2$ refers to million tonnes of CO_2. Targets are energy intensity reduction targets from 2011 to 2015. The national total data do not contain those of Tibet, Hong Kong, Macao, and Taiwan.

5. Result analysis and discussions

5.1 Eight economy-geography areas in Mainland China

The efforts of 30 provinces to mitigate climate change in China were examined. Tibet, Hong Kong, Macao, and Taiwan were excluded because of the absence of relevant energy and emissions data. According to the economic development and geographical feature, Mainland China can be divided into eight economy-geography areas (Wang and Wei 2014): northeast, northern coastal, eastern coastal, southern coastal, middle Yellow River, middle Yangtze River, southwest, and northwest areas (see Fig. 5).

The northeast area consists of three industry-based provinces: Liaoning, Jilin, and Heilongjiang. The natural conditions and resource endowment structures of provinces in this area are almost similar. They face several common problems, such as resource exhaustion and updating of the industrial structure.

The northern coastal area includes two municipalities (China's national capital Beijing and Tianjin) and two provinces (Hebei and Shandong). This area is characterized by an advantageous geographical location and convenient transportation. Educational, scientific, technological, and cultural undertakings are well developed in this area.

Including one municipality (Shanghai) and two provinces (Jiangsu and Zhejiang), the eastern coastal area is the wealthiest area in China. Considering its earlier modernization, this area maintains tighter economic relations with foreign countries than other Chinese regions. It also has a large human capital.

Three provinces (Fujian, Guangdong, and Hainan) are located in the southern coastal area. The degree of opening up in this area is the highest in China, and the area has rich overseas social resources. The economic aggregate of this area is also highly ranked in China, and its industrial sector has developed completely.

The middle Yellow River area consists of three provinces (Shaanxi, Shanxi, and Henan) and one autonomous region (Inner Mongolia). This area is abundant in natural resources, especially coal. Thus, this area exports a large amount of electricity to neighboring regions each year. Given that it is located inland, the degree of opening up to the outside world in this area is insufficient. In addition, the area is overly dependent on resource-intensive industries.

The middle Yangtze River area (including Hubei, Hunan, Jiangxi, and Anhui) has the best natural conditions for agricultural industries and sustains the highest population density in China. Similar to the middle Yellow River area, this area also suffers from insufficient opening up to the outside world and faces the pressure of industrial transformation.

The southwest area, which includes Yunnan, Guizhou, Sichuan, Chongqing, and Guangxi, is located in a mountainous area. This area is inhabited by ethnic minorities, and its poverty level is higher than that of eastern and central areas of China. However, this area is rich in renewable energy resources, such as hydropower and biomass energy, and is in an advanced level of foreign trade with Southeast Asian countries.

The northwest area comprises two provinces (Gansu and Qinghai) and three autonomous regions (Ningxia, Tibet, and Xinjiang). With very poor natural conditions, this area covers a vast territory with a sparse population and a small market. It has become China’s largest energy production base for oil and natural gas. This area also links energy-rich countries in Central Asia to China for further energy cooperation.

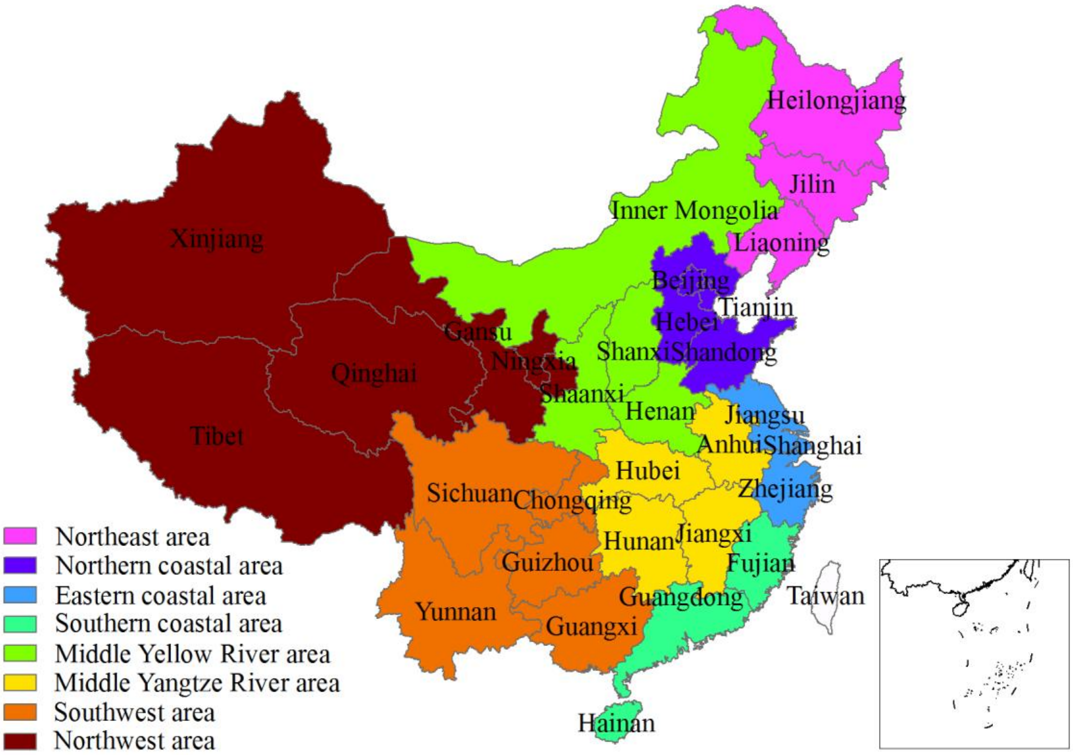

Fig. 5. Mainland China is divided into eight economy-geography areas (the map is schematic and does not indicate the definite boundaries).

5.2 Overall scores of CCMI

The scores of CCMI are shown in Figs. 6 and 7. The performance of provinces is divided into five categories: the first (ranking the 1st to 6th), second (ranking the 7th to 12th), third (ranking the 13th to 18th), fourth (ranking the 19th to 24th), and fifth (ranking the 25th to 30th) categories.

Only three provinces have scores that are higher than 75. These three are Jiangxi (77.86), Hunan (76.14), and Fujian (76.11). Jiangxi occupies the first place in CCMI because it performs well in all four fields, especially for the indicator of emissions. In 2012, its primary energy supply per capita and CO_2 emissions per capita were 1.48 tonnes of standard coal equivalent and 3.47 tonnes, respectively, which were both lowest in China. As a result, it achieves 100 points in these two indicators. In addition, its CO_2 emissions from electricity and heat production declined by 12.58% from 2011 to 2012, which causes it to obtain a very high score (97.58) in that indicator.

The two lowest scores are gained by Inner Mongolia (36.82) and Xinjiang (42.13). Two main factors account for Inner Mongolia's poor performance. First, as one of the largest energy industry regions in China, it is overly dependent on fossil energy. The energy consumption and CO_2 emissions are both rather high because of the high density of heavy industries in this region. In 2012, its primary energy supply per capita and CO_2 emissions per capita were 11.01 tonnes of standard coal equivalent and 28.08 tonnes, respectively, which were both highest in China. Hence, it achieves a score of zero in these two indicators. Second, Inner Mongolia also provides a large amount of electricity to neighboring provinces. The net electricity export was 132.75 billion kilowatt hour (kW·h) in 2012, which resulted in a negative share of non-fossil energy in the total primary energy supply (−4.54%) according to Equation (3). Hence, this region only achieves a score of 0.20 in that indicator.

Xinjiang is in the northeast area of China. Its performance in the efficiency section is the poorest in China. Both its carbon efficiency (CO_2 emissions per unit of total energy supply) and energy efficiency (total primary energy supply per GDP) declined from 2011 to 2012 while most provinces improved their efficiency. The CO_2 emissions per unit of total energy supply increased by 1.44%, and total primary energy supply per GDP increased by 9.05%, which were the highest among all provinces. According to the plan of the Chinese central government, Xinjiang needs to cut its energy intensity by 10% from 2011 to 2015 (see Table 1). Hence, this region needs to reduce its energy intensity by 2.09% each year on the average. A huge gap exists between the target and actual performance. Therefore, Xinjiang achieves a score of zero in the indicators of development of total primary energy supply per GDP and target–actual performance comparison.

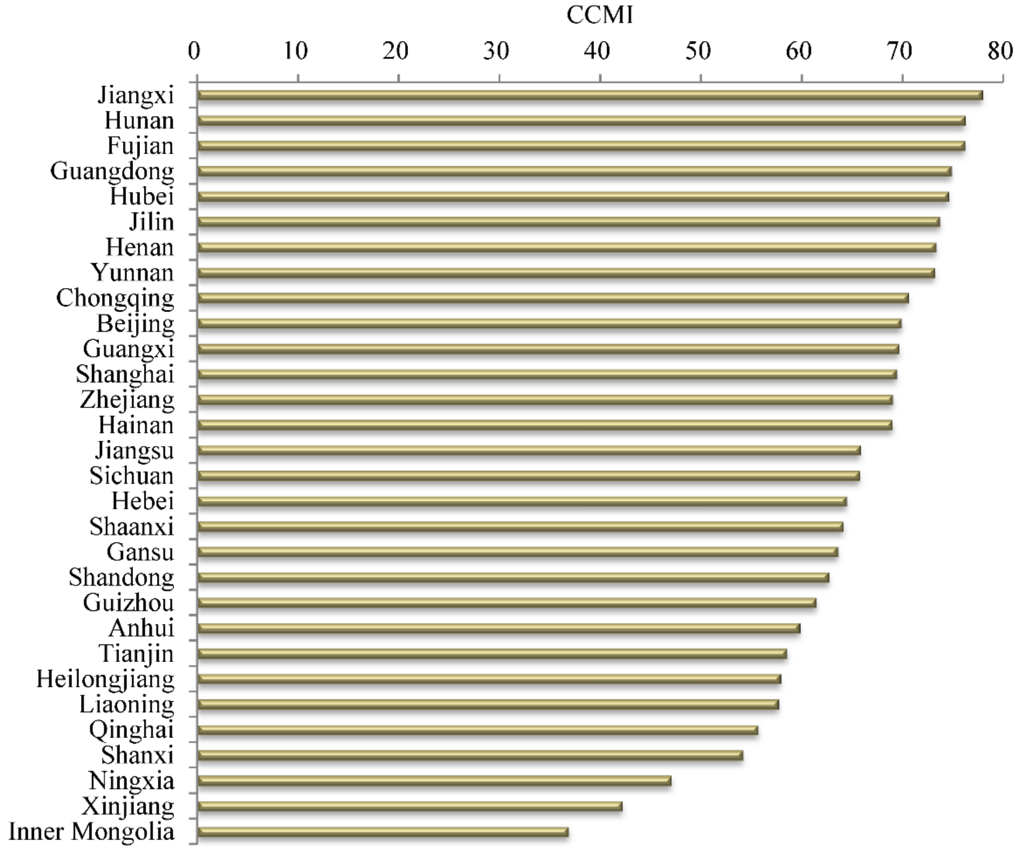

Fig. 6. Overall scores of 30 provinces in China are obtained using CCMI.

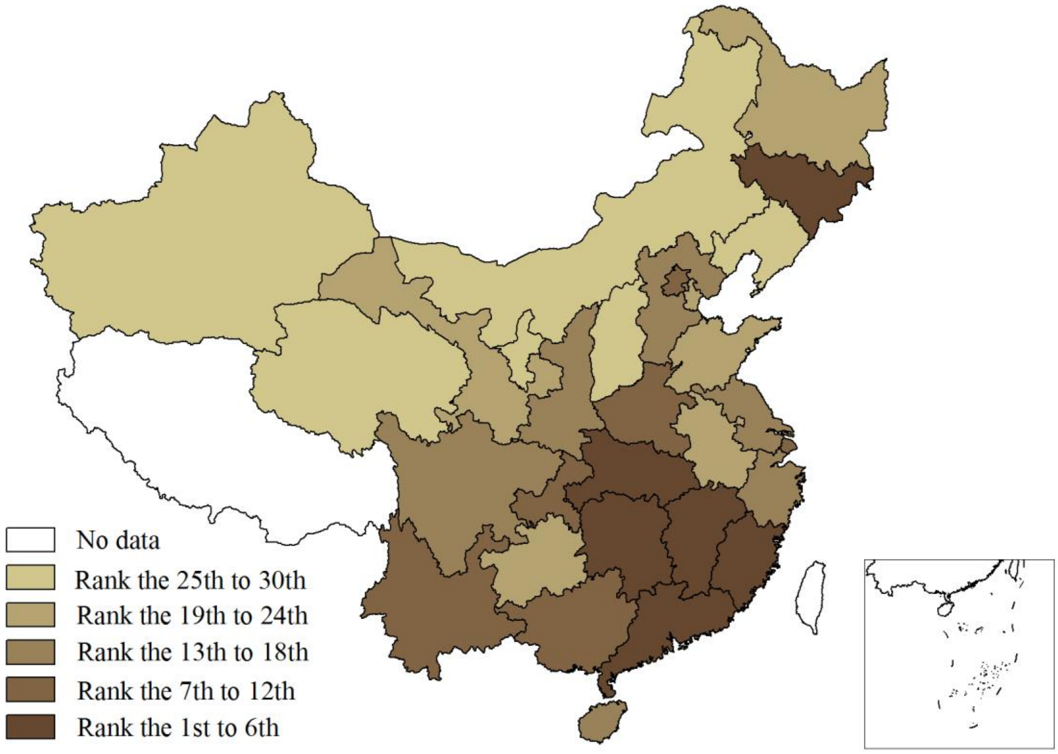

Fig. 7. Regional performance of climate change mitigation in China is assessed using CCMI (the map is schematic and does not indicate the definite boundaries).

The middle Yangtze River area and southern coastal area perform better than other areas in China in terms of mitigating climate change (Fig. 8). The average overall scores of the middle Yangtze River area (72.06) and southern coastal area (73.27) are higher than those of other areas. As shown in Fig. 6, the five highest scores all come from the two areas.

By contrast, the average performance of the northwest area is the worst in China. All provinces in this area belong to the fourth or fifth category (overall scores rank among 19th to 30th) in CCMI. It has the lowest scores in emissions, efficiency, and climate policy. The northwest area is the least developed in China, and its per capita income is much lower than that in the eastern and central parts of China. Therefore, development remains a significant task to improve the quality of life in this area.

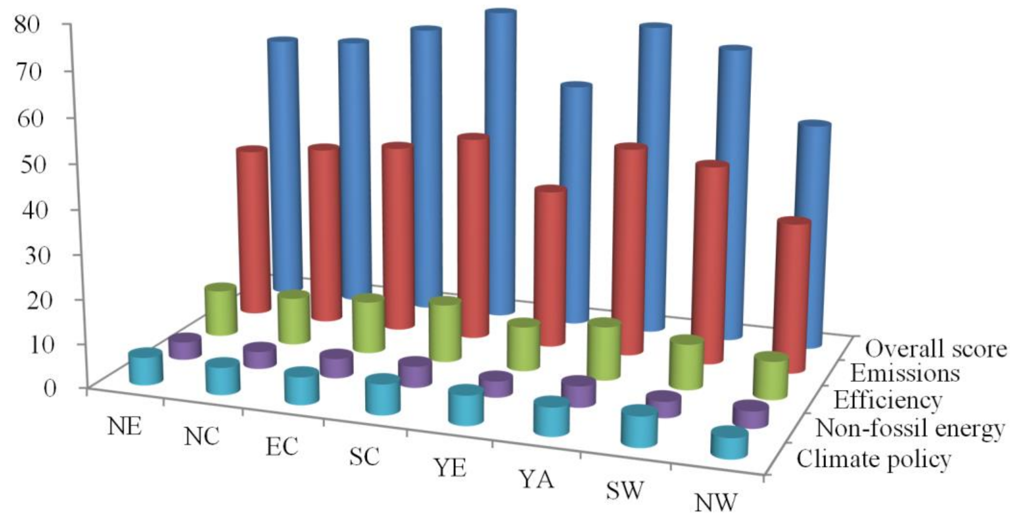

Fig. 8. Average scores of each area in China are calculated from the provincial scores. NE, NC, EC, SC, YE, YA, SW, and NW refer to the northeast, northern coastal, eastern coastal, southern coastal, middle Yellow River, middle Yangtze River, southwest, and northwest areas, respectively.

5.3 Performance in the four fields

Fig. 9 shows regional performance in the four fields of CCMI: emissions, efficiency, non-fossil energy, and climate policy. Fig. 10 compares CO_2 emissions in six sectors in 2011 and 2012 of China's 30 provinces.

The middle Yangtze River area performs best in the field of emissions. The two highest scores are achieved by Jiangxi (51.54) and Hunan (51.04), which lays the foundation for their good performance in the overall scores. Other provinces in the middle Yangtze River area also have good performance in this field. The provinces that perform worst are generally located in the middle Yellow River area and northwest area. Three provinces have scores that are below 30; these three are Xinjiang (28.61), Ningxia (28.20), and Inner Mongolia (20.79).

The indicator of efficiency accounts for 20% in CCMI. Hubei, Yunnan, and Fujian have the highest scores in this field, whereas Sichuan, Heilongjiang, and Xinjiang have the worst. Hubei has high scores in the development of efficiency because of a significant improvement in energy efficiency and carbon efficiency. To be specific, its CO_2 emissions per unit of total energy supply and total primary energy supply per GDP declined by 6.34% and 6.73%, respectively. Conversely, the two indicators in Xinjiang increased by 1.44% and 9.05%, respectively.

Jilin has a score of 8.55 (the highest score) in the indicator of non-fossil energy. The proportion of non-fossil energy in total energy supply increased from 1.32% in 2011 to 2.94% in 2012 in Jilin. The growth rate was 122.44%, which gives Jilin 100 points in the development of energy supply from non-fossil energy sources. On the contrary, Heilongjiang decreased its non-fossil energy proportion from 1.78% to 0.61% during the same period. As a result, it only has a score of 0.47 in this field. Jilin and Heilongjiang are both located in the northeast area. The two provinces have almost similar natural conditions and resource endowments and face several common problems, such as resource exhaustion and updating of the industrial structure. Therefore, Heilongjiang can refer to Jilin as a model.

For the indicator of climate policy, Henan performs best with full marks. The energy intensity in Henan declined by 18.17% from 2011 to 2012, which was the highest in China. Ningxia also performs well in this field, although it exhibits poor performance in the other three fields. The energy intensity in Ningxia decreased by 12.12% during the same period. As the China's national capital, Beijing performs poorly in this field. From 2011 to 2012, Beijing reduced its energy intensity by only 3.73%, which was slightly higher than its mandatory target (3.66%).

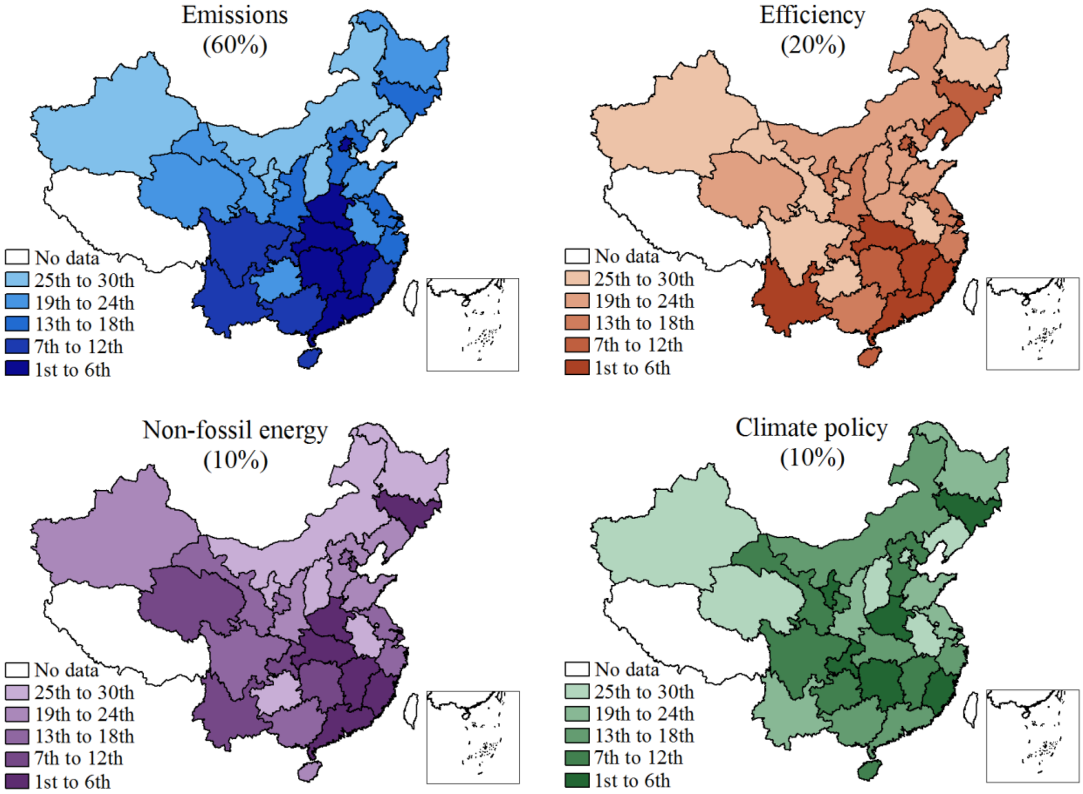

Fig. 9. China's regional climate change mitigation performance is demonstrated in the four fields (the map is schematic and does not indicate the definite boundaries). The figures in parentheses refer to their corresponding weights in the overall score.

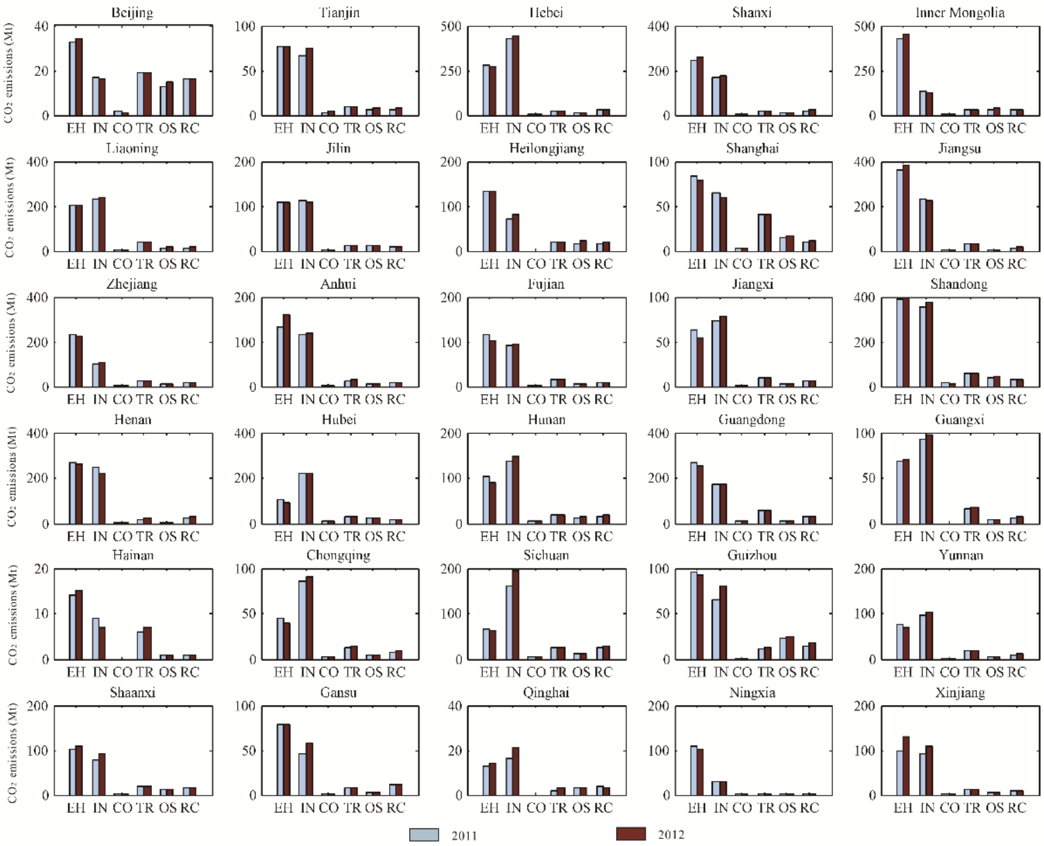

Fig. 10. Most CO_2 emissions are emitted from the electricity and heat production, and industry in China. EH, IN, CO, TR, OS, and RC refer to the electricity and heat production, industry, construction, transport, other service, and residential consumption, respectively.

5.4 Regional performance's correlation to resource endowments and social development levels

Resource endowments and social development levels have a significant influence on a region's carbon emissions. Their relationships with CCMI were estimated by three linear regression models. The results of the regression models are shown in Table 2.

Table 2 shows that a negative linear correlation exists between CCMI and energy self-sufficiency ratio. In other words, regions with good resource endowments tend to perform poorly in climate change mitigation. There are two main reasons. First, regions with a high energy self-sufficiency ratio are likely to be dependent on fossil fuel and develop energy-intensive industries. Second, provinces with a low energy-sufficiency ratio purchase plenty of electricity and heat from other provinces in China. The carbon emissions emitted in the generation of these electricity and heat are accounted to the producer.

In addition, no significant linear correlation exists between CCMI and social development levels. The coefficients of GDP per capita and urbanization rate are both not significant in the regression models. Therefore, provinces at different stages of development all have the capability to perform well in mitigating climate change.

Table 2. Linear regression models are used to estimate regional performance's correlation to resource endowments and social development levels.

	Model 1	Model 2	Model 3
Constant	69.750***	63.971***	61.854***
	(2.028)	(4.236)	(8.074)
Energy self-sufficiency ratio	-0.065***		
	(0.016)		
GDP per capita		0.014	
		(0.111)	
Urbanization rate			0.048
			(0.144)
R^2	0.595	0.024	0.062

6. Conclusions and policy implications

CCMI was developed from comprehensive viewpoints of emissions, efficiency, non-fossil energy, and climate policy. The index was utilized to assess the efforts of 30 provinces to mitigate climate change in China based on the TOPSIS method. The classic regression methods were also employed to discuss the correlation of overall performance to resource endowments and social development levels. According to the economic development and geographical feature, Mainland China was divided into eight economy-geography areas. Several conclusions were obtained.

(1) The middle Yangtze River area and southern coastal area perform better than other areas in mitigating climate change. The average overall scores of the middle Yangtze River area and southern coastal area are higher than those of other areas, and the five highest scores all come from the two areas.

(2) The average performance of the northwest area is the worst. All provinces in the northwest area

belong to the fourth or fifth category (overall scores rank among 19th to 30th). This area has the lowest scores in emissions, efficiency, and climate policy.

(3) The best performance in the indicator of emissions, efficiency, non-fossil energy, and climate policy is exhibited by Jiangxi, Hubei, Jilin, and Henan, respectively.

(4) Climate change mitigation performance has a negative linear correlation with energy self-sufficiency ratio but does not have a significant linear correlation with social development levels. Regions with good resource endowments tend to perform poorly in climate change mitigation. The coefficients of GDP per capita and urbanization rate are both not significant in the regression models. Therefore, provinces at different stages of development all have the capability to perform well in mitigating climate change.

Our findings offer some implications for climate change mitigation policies. First, regions could learn from neighboring regions to improve their performance in climate change mitigation. For instance, Heilongjiang can refer to Jilin as a model. The two provinces are both located in the northeast area with almost similar natural conditions and resource endowments, and face several common problems like resource exhaustion and updating of the industrial structure. However, Jilin performs much better than Heilongjiang. Second, resource endowments should be paid much more attention. Regions with good resource endowments tend to perform poorly in climate change mitigation, because they are likely to be dependent on fossil fuel and develop energy-intensive industries. Third, the recent development of carbon emission should be more important than the current emission level in assessing regional efforts to mitigate climate change. The changes in a region's emission can reflect its efforts more compared to its current level.

However, our method has several limitations. First, several important factors were not considered because of data unavailability. For instance, the CO_2 emission from land use change and the effects of forest carbon sink were not assessed. Second, the weights of the indicators are controversial. This paper provides a method to assess regional efforts to mitigate climate change at the sub-national level. The weights can be adjusted for different countries.

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