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Scenario analysis of energy-based low-carbon development in China

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ABSTRACT

China’s increasing energy consumption and coal-dominant energy structure have contributed not only to severe environmental pollution, but also to global climate change. This article begins with a brief review of China’s primary energy use and associated environmental problems and health risks. To analyze the potential of China’s transition to low-carbon development, three scenarios are constructed to simulate energy demand and CO2 emission trends in China up to 2050 by using the Long-range Energy Alternatives Planning System (LEAP) model. Simulation results show that with the assumption of an average annual Gross Domestic Product (GDP) growth rate of 6.45%, total primary energy demand is expected to increase by 63.4%, 48.8% and 12.2% under the Business as Usual (BaU), Carbon Reduction (CR) and Integrated Low Carbon Economy (ILCE) scenarios in 2050 from the 2009 levels. Total energy-related CO2 emissions will increase from 6.7 billion tons in 2009 to 9.5, 11, 11.6 and 11.2 billion tons; 8.2, 9.2, 9.6 and 9 billion tons; 7.1, 7.4, 7.2 and 6.4 billion tons in 2020, 2030, 2040 and 2050 under the BaU, CR and ILCE scenarios, respectively. Total CO2 emission will drop by 19.6% and 42.9% under the CR and ILCE scenarios in 2050, compared with the BaU scenario. To realize a substantial cut in energy consumption and carbon emissions, China needs to make a long-term low-carbon development strategy targeting further improvement of energy efficiency, optimization of energy structure, deployment of clean coal technology and use of market-based economic instruments like energy/carbon taxation.

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Introduction

China has abundant energy resources in terms of total reserves. According to British Petroleum (BP, 2012), by the end of 2011, proven coal, oil and natural gas reserves in China accounted for 13.3%, 0.9% and 1.5% of the world total, respectively. The rapid economic growth in China over the past decades has been accompanied by a significant increase in energy consumption. China is now the largest energy producer and consumer in the world. The share of China’s primary energy consumption in the world total rose from 4.8% in 1965 to 21.3% in 2011 (BP, 2011, 2012). Resource endowment of “rich in coal and poor in oil and natural gas” has made China’s energy consumption structure heavily dependent on coal, accounting for around 70% of the energy share. China consumed almost half of the world coal in 2011 (BP, 2012).

Burning coal produces more pollution than other energy sources. Burning one ton of raw coal emits 2.77 tons of CO2, which are 0.62 and 1.13 tons higher than burning 1 ton of crude oil and natural gas, respectively. Chen and Xu (2010) estimate that coal combustion is responsible for 90% of SO2, 70% of CO2, 67% of...
NOx, and 70% of dust emissions in China. China’s increasing energy consumption and the over-dependence on coal comes at the cost of the environment and human health. China is now the world largest SO2, CO2 and NOx emitter (China Council for International Cooperation on Environment and Development, 2007; BP, 2012; Vennemo et al., 2012). The annual mean value of PM_{10} in 114 key environmental protection cities is more than two times of the European Union’s (EU) standards and more than four times of the World Health Organization (WHO) standards (WHO, 2006; Ministry of Environmental Protection, 2012; European Commission, 2012). According to the China Council for International Cooperation on Environment and Development (CCICED, 2007), economic losses caused by air pollution account for 3% to 7% of China’s GDP and by 2020, the losses from diseases caused by burning coal could take up 13% of GDP if the current trends are not changed.

China is facing dual challenges of solving its worsening domestic environmental problems without impeding economic development and the ever increasing international pressures to curb CO2 emissions. With the further development of industrialization and urbanization, energy consumption and energy related CO2 emissions are expected to continue to increase in the foreseeable future. Decoupling carbon and pollution emissions from economic development and moving to a low-carbon development path are a must for China to ease domestic pollution problems, tackle global climate change and achieve its long-term development goal.

1. Energy consumption and CO2 emissions in China

China has made remarkable achievements since launching the economic reform and open-up policy in the late 1970s, with an average annual GDP growth rate of almost 10% over the past three decades. Total energy consumption has also increased sharply along with the rapid economic development. According to the National Bureau of Statistics of China (NBSC, 2012), total primary energy consumption rose from 586 million tons of coal equivalent (tce) in 1980 to 3.48 billion tce in 2011. One of the unique features of China’s energy structure is the dominance of coal. The coal-based energy structure makes China very different from other countries. Coal accounted for 68.4% of the total energy consumption in 2011, compared with 22.1% in the USA, 17% in EU, 21.2% in Japan and 5.2% in Brazil and the world average of 30.3% (NBSC, 2012; BP, 2012).

The increasing energy consumption and coal-dominant energy structure have made China’s CO2 emissions grow very fast over the past 45 years. CO2 emissions from fossil fuel combustion have increased from 0.48 billion tons in 1965 to 8.7 billion tons in 2011, accounting for 25% of the world total (BP, 2012). With further population growth and economic development, it is anticipated that China’s increasing energy consumption will continue to drive up its energy-related CO2 emissions.

2. Environmental consequences and health impact associated with energy use in China

China’s increasing energy consumption and excessive use of coal have resulted in severe environmental pollution, ecological deterioration, profound human health impacts and huge economic losses.

Urban air quality degradation caused by burning coal and automobile exhaust has been identified as one of the most pressing environmental problems in China. Ministry of Environmental Protection’s (MEP) statistics (2012) show that in 2011, only 3.1% of 325 cities monitored reached grade I national ambient air quality standards, accounting for only 0.9% of the 114 key environmental protection cities.

China’s SO2 emissions account for 25% of the world total, being almost as high as the EU and the US combined, and China is the 3rd largest acid rain area in the world after North America and Europe (CCICED, 2007; Lu et al., 2010; Vennemo et al., 2012). Acid rain, which is mainly the result of SO2 and NOx emissions from thermal power plants and mobile sources, was recognized as a potential environmental problem in China in the late 1970s and early 1980s (Zhao and Sun, 1986; Menz and Seip, 2004; Larssen et al., 2006). Many studies have found correlations between SO2 concentration and damage to crops, forests and severe corrosion of metals (Cao, 1988, 1989; The World Bank, 1997; Larssen et al., 1999; Feng et al., 2002; Chinese Academy of Engineering, MEP, 2011). The study of Feng et al. (2002) showed that the area of crops damaged by acid rain was 12.9 million hm², with the economic loss of 4.26 billion yuan per year from 1991 to 2000 in 10 Chinese provinces. Forest decline due to the direct effects of acid rain was observed in areas with high concentrations of SO2, including Emei Mountain of Sichuan Province, Nanshan Mountain of Chongqing, the suburban area of Liuzhou, Guangxi Province and Wan county of Sichuan Province in the early 1980s (Chinese Academy of Engineering, MEP, 2011). Larssen et al. (1999) point out that the corrosion rates of metals in Shanghai and Chongqing were 1.5 to 4.5 times faster than the Japanese average due to high SO2 emissions.

Human health is closely linked to environmental conditions. Air quality has significant impacts on the potential exposure of people to health risks. Many epidemiologic studies have confirmed the associations between ambient air quality and human health (WHO, 2002, 2008, 2012). Environmental degradation caused by coal combustion has contributed to the declining health in China. A recent study by Cheng et al. (2013) shows that the total number of premature deaths attributable to PM_{10} pollution increased from 418,000 in 2001 to 514,000 in 2011.

Since the 1980s, many Chinese and western researchers have conducted research on the economic losses caused by air pollution in China. Air pollution has become a huge burden on China’s economy, and costs the Chinese economy from 1% to 7% of GDP each year according to different studies (Xu, 1988; Guo and Zhang, 1990; Smil, 1996; Xia, 1998; the World Bank, 1997, 2007). Matus et al. (2012) estimate that the economic cost of health damage due to air pollution alone accounted for 5% of total GDP in 2005 in China.

Global concern about climate change is also closely linked to the increasing CO2 emissions in the atmosphere, which will most likely lead to global climate change, resulting in rising of sea levels, increasing risks of species extinction, more extreme climate events, damage to crops, and threats to human settlements and health.

The Information Office of the State Council of China (2008) reports China’s average surface air temperature increased 1.1°C from 1908 to 2007, which was 0.36° higher than the global average rise. The Ministry of Science and Technology et al. (MOST, 2011)
report an average annual sea level rise of 2.6 mm over the past three decades. China has also suffered an increasing frequency and intensity of weather-related disasters and extreme climate events since the 20th century, causing enormous economic loss every year. Since the founding of China in 1949, the disaster-related death toll has been more than 500,000 with a direct economic loss of 30% of the average fiscal revenue, which is tens of times that of the US and Japan (CCICED, 2007). MOST (2011) report that 40% of the Chinese population, 35% of the farmland and 60% of the industrial and agricultural production will be subject to long-term flooding in China.

3. Scenario analysis of low-carbon development in China

In order to tackle climate change and reduce environmental pollution caused by burning of fossil fuels, developed countries like the UK, Sweden, Japan, and Korea are exploring a new development path featured by low-carbon, known as the low-carbon economy or low-carbon development. The goal of having the total economic volume quadruple by 2020 and achieve a full stage of modernization in 2050 in China will have to be supported by certain economic growth rates and lead to continued increase in energy consumption, which will exert huge pressures on China’s environment, and even the global environment and sustainable development. To address these issues, three scenarios are developed in this article to explore different options for China’s low-carbon future by using the LEAP model, with 2009 as the base year and 2020, 2030, 2040 and 2050 as the target years.

The LEAP model is a modeling tool for long-term energy policy analysis and climate change mitigation assessment developed at the Stockholm Environment Institute. It can help develop scenarios for future energy demand, carbon mitigation assessment and low-carbon development strategies at different scales (HEAPs, 2012). The key advantages of the LEAP model are its flexible modeling structure, low initial data requirements, and simple but comprehensive accounting framework (HEAPs, 2012). The LEAP model has been used in more than 190 countries worldwide. In China, researchers have adopted the LEAP model to simulate future energy demand, carbon emissions, and low-carbon development level on a national scale (Zhou et al., 2003; Wang et al., 2011; Zhao et al., 2011; Shan et al., 2012) and at the local level (Lin et al., 2010; Huang et al., 2011; Zhang et al., 2011). It has also been used for scenario analysis of carbon reduction potentials in high-energy-consuming industrial sectors (Wang et al., 2007; Cai et al., 2008). However, the time frame of most of these studies extends up to 2020 and 2030 and there have been very few studies using the LEAP model to analyze China’s long-term energy demand and carbon emission trends up to 2050.

3.1. Model structure

Taking into account the availability of data and based on the categorization of energy end-use and energy conversion sectors in the China Energy Statistical Yearbook, the general model structure is shown in Fig. 1 (Zhou et al., 2009). In different sectors, the main driving factors affecting carbon emissions from energy consumption/conversion are different. Based on their characteristics and the availability of data, a simplified sectoral energy demand and carbon emission model is developed as shown in Fig. 2 (Guo et al., 2011).

At present, there are no officially published CO₂ emission factors for each fuel type in China. This study uses the effective carbon emission factors recommended in the 2006 IPCC Guideline for National Greenhouse Gas Inventories (IPCC, 2006), based on which effective CO₂ emission factors are calculated using the net calorific value of 29307 kJ/kgce given in the National General Principles for Calculation of Comprehensive Energy Consumption (GB2589-2008).

3.2. Scenario design and assumptions

Taking into consideration the socio-economic development and corresponding energy demand, changes in the primary energy mix, penetration of new technologies, adjustment of industrial structure and improvement of energy efficiency, the following three scenarios are developed to analyze China’s energy demand and CO₂ emissions up to 2050.

1. Business as Usual (BaU): Economic development is the primary focus of China supported by high resource-consuming and polluting secondary industry as it is today. However, environmental protection and promotion of ecological civilization will also be on the government priority agenda. Measures will be taken to achieve the objective of building a resource-conserving and environmentally-friendly society, including adjustment of economic structure, phase-out of outdated production capacity, increasing the share of renewable energy and reduction of energy and carbon intensity.

2. Carbon Reduction (CR): Apart from the above measures, China will implement a series of stringent energy policies to adjust energy structure, reduce energy consumption and carbon intensity, and vigorously promote renewable energy and clean energy. Low-carbon technologies are at the demonstration scale and applied to a limited degree.

3. Integrated Low Carbon Economy (ILCE): China will explore the maximum energy related CO₂ emission reduction potentials, and will take comprehensive economic and energy policies and technological measures to move towards a low-carbon economy, including adjustment of economic and energy structures, large increase in renewable energy share, increasing investment and widespread deployment of advanced low-carbon technologies. Carbon capture and storage (CCS), ultra-supercritical generation technology, Integrated Gasification Combined Cycle (IGCC), and Natural Gas Combined Cycle (NGCC) will be applied on a large scale.

Macro-socioeconomic parameters (GDP growth rate, population dynamics, industrial structure and urbanization rate) are set based on the review and summary of previous studies (Jiang et al., 2009a,b; CCICED, 2010; Renmin University and of China, UNDP, 2010), as shown in Table 1. The average annual GDP growth rate is set at 6.45%, population will peak at 1.54 billion in 2040 and the urbanization rate will reach 70% in 2050. Secondary industry is expected to drop from 46.3% in 2009 to 37.73% in 2050, while tertiary industry will increase from 43% in 2009 to 56.2% in 2050.
CO₂ emissions from energy use are largely dependent on energy structure. Natural gas and renewable energy burns cleaner than coal and emits less pollutants and carbon. It is estimated that China will replace coal by natural gas and renewable energy step by step in the future. Based on the work by Guo et al. (2011), the assumptions of energy consumption structure of end-use sectors are shown in Table 2. It is assumed that the share of coal will decline dramatically under the CR and ILCE scenarios from 2009 to 2050, while the share of natural gas and renewable energy will be greatly increased.

3.3. Analysis of primary energy demand and energy-related carbon emissions under different scenarios

3.3.1. Total primary energy demand
Along with the continued rapid economic development and population growth, China’s total primary energy demand is expected to keep increasing under all three scenarios until 2050, as shown in Fig. 3. Under the BaU and CR scenarios, total energy demand will reach its peak around 2040, while under the ILCE scenario, it will peak at 2030. Under the BaU scenario, total energy demand will grow from 4.1 billion tce (ton of standard coal equivalent) in 2009 to 5.9 billion tce in 2020, 6.9 billion tce in 2030, 7.2 billion tce in 2040 and 6.7 billion tce in 2050, with an overall increase of 63.4% from 2009 to 2050. Under the CR and ILCE scenarios, total primary energy demand will reach 5.6 and 5.0 billion tce in 2020, 6.4 and 5.2 billion tce in 2030, 6.6 and 5.1 billion tce in 2040, and 6.1 and 4.6 billion tce in 2050, with an overall increase of 48.8% and 12.2%, respectively. Compared with the BaU scenario, total primary energy demand will be lower by 0.6 and 2.1 billion tce under the CR and ILCE scenarios in 2050, down by 9.4% and 32.3%, respectively.

3.3.2. Primary energy demand by fuel
Coal demand will decline under all scenarios as a result of the increasing efforts by China in addressing energy-related environmental problems and global climate change, while the
demand for cleaner fuels (oil, natural gas and renewable energy) will increase sharply by 2050. Total coal demand will increase to 3.5, 3.6 and 3.3 billion tce in 2020, 2030 and 2040, and drop slightly in 2050 under the BaU scenario. Under the CR and ILCE scenarios, coal demand will reduce significantly, from the baseline level in 2009 to 2.4 and 2.3 billion tce in 2020; 2.1 and 1.1 billion tce in 2040; and 1.6 and 0.7 billion tce in 2050 (Fig. 4). Compared with the BaU scenario, coal demand will reduce by 42.2% and 74.7% in 2050 under the CR and ILCE scenarios. Oil, natural gas and renewable energy demand will increase by 2.8, 2.7 and 70.3 times; 1.8, 3.2 and 157.3 times; 1.6, 2.8 and 164.3 times of the 2009 levels in 2050 under the BaU, CR and ILCE scenarios, respectively.

3.3.3. Energy intensity
With the increasing improvement of energy efficiency and the adjustment of the energy structure, energy intensity is expected to continue to decrease under the three scenarios. As shown in Fig. 5, under the BaU scenario, energy intensity will drop by 37.8%, 60.8%, 74.8% and 84.6% in 2020, 2030, 2040 and 2050, respectively. Under the CR and ILCE scenarios, energy intensity will decline by 40.6% and 47.6% in 2020; 63.6% and 70.6% in 2030; 76.9% and 82.5% in 2040; and 86% and 89.5% in 2050, respectively. Compared with the BaU scenario, energy intensity in 2050 will be lower by 9.1% and 31.8% under the CR and ILCE scenarios.

3.3.4. Per capita energy demand
China’s per capita energy demand will keep growing from 2009 to 2045 under the BaU and CR scenarios and then start to drop slightly (Fig. 6). Under the ILCE scenario, per capita energy demand will peak around 2025. Per capita energy demand will increase by 46.4% and 32.7% in 2050 under the BaU and CR scenarios. Compared with the BaU scenario, per capita energy demand will reduce by 9.4% and 32.4% under the CR and ILCE scenarios in 2050.

3.3.5. Total CO₂ emissions from energy consumption
As shown in Fig. 7, under the BaU scenario, total CO₂ emissions will grow from the baseline value of 6.7 billion tons to 9.5 in 2020, 11 in 2030, 11.6 in 2040 and 11.2 billion tons in 2050, with an average annual growth rate of 1.26%. CO₂ emissions will peak around 2043. Under the CR scenario, total CO₂ emissions in 2020, 2030, 2040 and 2050 will reach 8.2, 9.2, 9.6 and 9 billion tons, with an average annual growth rate of 0.72%. CO₂ emissions will reach the highest level around 2040. Under the ILCE scenario, total CO₂ emissions will reach the peak of 7.4 billion tons around 2030, and then decline to 7.2 and 6.4 billion tons in 2040 and 2050, respectively.

Compared with the BaU scenario, total CO₂ emissions under the CR and ILCE scenarios will be lower by 13.7% and 25.3% in 2020, 16.4% and 32.7% in 2030, 17.2% and 37.9% in 2040, and 19.6% and 42.9% in 2050 under the CR and ILCE scenarios, respectively.

---

### Table 1 – Assumptions of socio-economic parameters.
**2009 data source: NBSC, 2012.**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>2009</th>
<th>2020</th>
<th>2030</th>
<th>2040</th>
<th>2050</th>
<th>2009–2050 average</th>
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</thead>
<tbody>
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<td>GDP growth rate (%)</td>
<td>8.7</td>
<td>7.95</td>
<td>6.4</td>
<td>5</td>
<td>4.2</td>
<td>6.45</td>
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<tr>
<td>Total population (million)</td>
<td>1330</td>
<td>1450</td>
<td>1520</td>
<td>1540</td>
<td>1500</td>
<td></td>
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<tr>
<td>Urban population (%)</td>
<td>49.7</td>
<td>56</td>
<td>62</td>
<td>66</td>
<td>70</td>
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<tr>
<td>Rural population (%)</td>
<td>50.3</td>
<td>44</td>
<td>38</td>
<td>34</td>
<td>30</td>
<td></td>
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<tr>
<td><strong>Industrial structure</strong></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Agriculture</td>
<td>10.3</td>
<td>9.97</td>
<td>6.97</td>
<td>6.07</td>
<td>6.07</td>
<td></td>
</tr>
<tr>
<td>Industry</td>
<td>39.7</td>
<td>41.42</td>
<td>35.86</td>
<td>31.77</td>
<td>27.54</td>
<td></td>
</tr>
<tr>
<td>Construction</td>
<td>6.6</td>
<td>7.31</td>
<td>7.87</td>
<td>8.96</td>
<td>10.19</td>
<td></td>
</tr>
<tr>
<td>Transport, storage and post</td>
<td>5</td>
<td>4.01</td>
<td>3.99</td>
<td>3.51</td>
<td>2.81</td>
<td></td>
</tr>
<tr>
<td>Wholesale/retail trades, hotels and catering services</td>
<td>10.5</td>
<td>9.97</td>
<td>9.86</td>
<td>9.58</td>
<td>8.99</td>
<td></td>
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<tr>
<td>Other sectors</td>
<td>27.5</td>
<td>28.2</td>
<td>35.45</td>
<td>40.11</td>
<td>44.4</td>
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### Table 2 – Assumptions of energy structure.
*Source: Guo et al. (2011).*

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Fuel replacement</th>
<th>2020</th>
<th>2030</th>
<th>2040</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>BaU</td>
<td>Energy structure will be adjusted with the adjustment of industrial structure.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CR and ILCE</td>
<td>Replacement of coal by natural gas</td>
<td>10% of coal in industrial sector and 20% in residential sector</td>
<td>12% of coal in industrial sector and 20% in residential sector</td>
<td>14% of coal in industrial sector and 20% in residential sector</td>
<td>16% of coal in industrial sector and 20% in residential sector</td>
</tr>
<tr>
<td></td>
<td>Replacement of coal gas by natural gas</td>
<td>15% of coal gas in industrial sector and 25% in residential sector</td>
<td>17% of coal gas in industrial sector and 25% in residential sector</td>
<td>19% of coal gas in industrial sector and 25% in residential sector</td>
<td>21% of coal gas in industrial sector and 25% in residential sector</td>
</tr>
<tr>
<td></td>
<td>Replacement of transport fuel by renewable energy</td>
<td>5% of gasoline, diesel oil, kerosene and fuel oil</td>
<td>7% of gasoline, diesel oil, kerosene and fuel oil</td>
<td>9% of gasoline, diesel oil, kerosene and fuel oil</td>
<td>11% of gasoline, diesel oil, kerosene and fuel oil</td>
</tr>
<tr>
<td></td>
<td>20% of coal in industrial sector and 40% in residential sector</td>
<td>22% of coal in industrial sector and 40% in residential sector</td>
<td>24% of coal in industrial sector and 40% in residential sector</td>
<td>26% of coal in industrial sector and 40% in residential sector</td>
<td>28% of coal in industrial sector and 40% in residential sector</td>
</tr>
<tr>
<td></td>
<td>30% of coal gas in industrial sector and 50% in residential sector</td>
<td>32% of coal gas in industrial sector and 50% in residential sector</td>
<td>34% of coal gas in industrial sector and 50% in residential sector</td>
<td>36% of coal gas in industrial sector and 50% in residential sector</td>
<td>38% of coal gas in industrial sector and 50% in residential sector</td>
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<td></td>
<td>10% of gasoline, diesel oil, kerosene and fuel oil</td>
<td>12% of gasoline, diesel oil, kerosene and fuel oil</td>
<td>14% of gasoline, diesel oil, kerosene and fuel oil</td>
<td>16% of gasoline, diesel oil, kerosene and fuel oil</td>
<td>18% of gasoline, diesel oil, kerosene and fuel oil</td>
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<td>30% of coal in industrial sector and 50% in residential sector</td>
<td>32% of coal in industrial sector and 50% in residential sector</td>
<td>34% of coal in industrial sector and 50% in residential sector</td>
<td>36% of coal in industrial sector and 50% in residential sector</td>
<td>38% of coal in industrial sector and 50% in residential sector</td>
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<td>40% of coal in industrial sector and 60% in residential sector</td>
<td>42% of coal in industrial sector and 60% in residential sector</td>
<td>44% of coal in industrial sector and 60% in residential sector</td>
<td>46% of coal in industrial sector and 60% in residential sector</td>
<td>48% of coal in industrial sector and 60% in residential sector</td>
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<td>60% of coal gas in industrial sector and 70% in residential sector</td>
<td>62% of coal gas in industrial sector and 70% in residential sector</td>
<td>64% of coal gas in industrial sector and 70% in residential sector</td>
<td>66% of coal gas in industrial sector and 70% in residential sector</td>
<td>68% of coal gas in industrial sector and 70% in residential sector</td>
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<td>5% of gasoline, diesel oil, kerosene and fuel oil</td>
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<td>11% of gasoline, diesel oil, kerosene and fuel oil</td>
<td>13% of gasoline, diesel oil, kerosene and fuel oil</td>
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3.3.6. Carbon intensity
Carbon intensity will keep dropping from 2009 to 2050 under all scenarios, as is shown in Fig. 8. The Chinese government made a commitment during the United Nations Climate Change Conference held in Copenhagen in 2009 to reduce its carbon intensity by 40 to 45% by 2020 from 2005 levels. Based on this analysis, carbon intensity will reduce by 38.7%, 47.2% and 54.5% from 2009 to 2020 under the BaU, CR and ILCE scenarios, respectively, which means that it is most likely that China will achieve its energy intensity targets by 2020.

Carbon intensity will decline by 84.3%, 87.2% and 91.1% under the BaU, CR and ILCE scenarios, respectively in 2050. Compared with the BaU scenario, by 2050, carbon intensity will be lower by 18.9% and 43.2% under the CR and ILCE scenarios.

4. Pathway for low-carbon economy development strategy in China

The simulation results in Section 4 show that compared with the BaU scenario, both total energy demand and total CO2 emissions in the target years will decrease substantially under the CR and ILCE scenarios. This means that China would be able to achieve a relatively lower growth rate of energy demand and make a significant reduction in carbon emissions if it could adopt more vigorous and stringent energy and environmental policies while maintaining a certain rate of economic growth. To achieve the long-term socio-economic development goal, China must decarbonize its economy through the following measures.

4.1. Transformation of economic development mode

CCICED (2012) describes China’s current economic development mode as “unbalanced, uncoordinated and unsustainable”. One of the prominent features of China’s economic structure is the large share of secondary industry, contributing to over 40% of GDP. In the secondary industry, energy-intensive and highly-polluting heavy industry accounts for more than 70% of gross industrial output value. As a result, more than 70% of China’s energy is consumed by the industrial sector. Low-carbon tertiary industry only contributed to 43.4% of GDP in 2011, which is much lower compared with 71.4% in Japan and 79.7% in the US (Economy Watch, 2013a,b). To address its energy and environmental problems, China has to push forward the green transformation of conventional high-polluting industries and promote new low-carbon emerging industries, including the energy-saving and environmental protection industry, new emerging information industry, bio-industry, new energy industry, new-energy automobile industry, high-end equipment manufacturing and new material industry, which are identified by the Chinese government as seven strategic emerging industries. CCICED (2012) estimates by 2020, these strategic emerging sectors have the potential to prevent 4.6 Gt of CO2 emissions.

4.2. Further improvement of energy efficiency and energy conservation

The industrial sector is the largest energy consumer in China and accounts for the bulk of China’s total carbon emissions. Energy efficiency for major industrial products in China is still much lower than the international advanced level (IAL). Compared with IAL, China uses 8.7% more energy per kWh to generate electricity, and 17.5%, 45.3%, 51.7%, 52.1% and 80.9% more energy to produce 1 ton of cement, oil, ethylene, ammonia, and paper and paperboard, respectively (LCIS Task Force analysis of industry sources, cited in CCICED, 2012). If China were to adopt existing energy conservation technologies in these industries, by 2020, 456 million tce of energy consumption and 1.22 Gt of CO2 emissions would be avoided, while if all the existing and emerging energy efficiency technologies were widely used, 6.5–7.5 Gtce of energy demand would be reduced,
equivalent to 17–19 Gt of CO₂ emissions (CCICED, 2012). Simulation results in this study also show that by large scale deployment of advanced low-carbon technologies to improve energy efficiency, energy demand and CO₂ emissions will decline by 19.6% and 42.9% in 2050 under the ILCE scenario compared with the BaU scenario.

The transport sector accounts for 7.7% of total energy consumption at present. With the continued improvement of living standards and increase in personal income, China’s private vehicle population has been increasing dramatically, from 40 million in 1998 to 105.78 million in 2011 (NBSC, 2012). China should further encourage the use of energy-saving and fuel-efficient vehicles. China has benefited from the introduction of more efficient energy and transmission technologies. Between 2003 and 2006, more than 600 million gallons of gasoline and $1.2 billion in fuel spending were saved, which are equivalent to reducing 5.4 million tons of CO₂ emissions (Sustainable Energy for All, 2013). CCICED (2012) estimates that by introducing energy-saving vehicles, about 300 million tons of CO₂ emissions could be prevented by 2020.

4.3. Diversification of energy structure

The biggest problem of energy use in China is the coal-based energy structure. Natural gas and coalbed methane can be the alternative clean fuels to power the economy. Burning natural gas produces 44% and 80% less CO₂ and NOₓ than burning coal, while particulate emissions from coal combustion are 392 times that of burning natural gas (US EIA, 1999: 58). However, the share of natural gas is very low in China and only accounts for 5% in the energy consumption structure in 2011, which is much lower than the world average of 23.7% (BP, 2012; NBSC, 2012).

Another alternative fuel that burns cleaner than coal is coalbed methane. According to Su et al. (2010), replacing coal by coalbed methane can reduce CO₂, NOₓ and SO₂ emissions by 40.38%, 25% and 100%, respectively under the condition of sufficient combustion to produce the same heat value. China’s coalbed methane resource ranks the third in the world after Russia and Canada, which is equivalent to 450 billion tons of standard coal, 350 billion tons of standard oil and the same amount of conventional terrestrial natural gas reserve (IEA, 2000).

Renewable energy can offer alternative energy sources that will not run out and are free from pollution and climate implications. China has abundant renewable energy resources. Total technologically exploitable hydropower installed capacity is estimated to be 540 GW with annual power generation potential of 2.47 trillion kWh, while total exploitable terrestrial and coastal wind energy is estimated to be 1000 GW (NDRC, 2007). However, the share of renewable energy in the total energy consumption mix was only about 7% in 2010, with hydropower and wind power only accounting for 17% and 1% of the total electricity generation, and only 29% of China’s potential for hydropower being tapped (NDRC, 2007; NBSC, 2012). The potential for energy, pollution and carbon reductions
from using renewable energy resources is very significant and cannot be underestimated. According to McElroy et al. (2009), if 30% of additional electricity generated by coal could be replaced by wind power by 2030 in China, the annual CO₂ emission reduction would reach 1.1 billion tons, equal to more than 10% of the projected total energy-related CO₂ emissions in 2030 under the BaU scenario.

4.4. Promotion of clean coal technology

Given the large coal reserve in China, development and large-scale application of clean coal technologies to improve energy efficiency of coal use will help decarbonize China’s power generation and energy-intensive industrial sectors. It is estimated that the application of supercritical and ultra-supercritical systems, CCS, NGCC and IGCC technologies on a large scale can reduce 70%–95% of sulfur and 50%–80% of NOₓ, and increase the generation efficiency by 45% (Chen and Xu, 2010). Scenario analysis in this study shows that under the ILCE scenarios where advanced power generation technologies will be applied on a large scale, total energy demand will decline by 1.65 billion tce in 2030 and 2.17 billion tce in 2050, compared with the BaU scenario. Correspondingly, CO₂ emissions will drop by 24% and 43%.

4.5. Policy measures

Currently, the enormous environmental and health costs from burning fossil fuels are not included in the energy price. The negative externalities should be internalized through policy interventions.

4.5.1. Removal of fossil fuel subsidies

At present, fossil fuels are still subsidized in many countries. It is estimated that the total amount of fossil fuel consumption subsidies reached $523 billion in 2011, almost 30% higher than those in 2010, while China spent over $31.05 billion on fossil fuel consumption subsidies, ranking the fifth in the world.

The environmental impacts of energy subsidy removals are very positive. It is estimated that removal of the energy subsidies of 356.73 billion yuan in China would result in 65.07 million tons of energy saving and 172.3 million tons of CO₂ emission reduction (Lin and Jiang, 2011). OECD (2011) estimates that by removing fossil fuel subsidies in China, GHG emissions from fossil fuels will be reduced by 7%.

Given the negative environmental impacts from energy subsidies in China and to address domestic and global environmental challenges, China needs to revamp its energy policy and energy pricing and remove its fossil fuel subsidies. China should price energy in a way that can reflect the real costs of production and environmental externalities, and encourage the improvement of energy efficiency and the use of renewable energy.

4.5.2. Energy and carbon taxation

Levying environmental taxes including energy and carbon taxes is generally regarded as one of the most effective market-based economic instruments to address market failure in taking into account the environmental impacts of fossil fuel use, optimize existing energy consumption patterns, increase energy efficiency, find least-cost environmental solutions, and reduce pollution and carbon emissions (Wang et al., 2010; OECD, 2011; CCICED, 2012; European Commission, 2013). Using market-based instruments for pollution and carbon reduction and natural resources management has been promoted around the world. It is estimated that in 2013, carbon pricing schemes were expected to be implemented in 33 countries and 18 sub-national jurisdictions to tackle climate change, covering 30% of global economy and 20% of global carbon emissions at 2005 levels (Climate Commission, 2012). The benefits gained from the implementation of energy and carbon taxes are very encouraging. According to Andersen (2010), the introduction of European environmental taxes has resulted in a reduction in GHG emissions by 3.1% on average in six member countries as of 2004. Zhou et al. (2011) estimate that imposing a carbon tax of 30 yuan per ton CO₂ would result in 3.94% of energy saving and 4.52% CO₂ reduction in 2020, while a 90 yuan carbon tax would lead to 9.28% of energy saving and 12.26% of CO₂ reduction in 2020 in China.

Given the huge benefits of carbon reductions, energy saving and improvement of energy efficiency from introducing energy/carbon taxes, launching an energy/carbon tax system in China could be an important policy option to move to a low-carbon economy.

5. Conclusions

As a developing country, China’s economy will continue to grow at a certain rate, which will inevitably lead to future increases in pollution and carbon emissions. It is not possible for China to solve its environmental problems with just one solution. China needs to make a long-term low-carbon development strategy aimed at further improving energy efficiency, optimizing energy structure, investing in low-carbon technology development and deployment, and establishing market-based economic instruments, e.g. removal of energy subsidies and introduction of energy/carbon taxes. Only by taking comprehensive measures can China move to a low-carbon economy.
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Aims and scope

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