http://dx.doi.org/10.1080/14693062.2015.1050346

climate policy

synthesis article

China's sectoral strategies in energy conservation and carbon mitigation

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This article reviews China's energy and climate strategies in the electric power, industrial, building, and transport sectors. These four sectors account for about three-quarters of China's total energy consumption and energy-related carbon emissions. We identify major gaps in China's energy and climate polices based on the status quo: first, command-and-control policies not only are costly, but also cannot accommodate the transition of energy consumption from production sectors to consumption sectors; second, unsmooth deployment of renewable energy poses challenges for decarbonizing China's electricity system. To close these gaps, we suggest two policy priorities: a carbon market to achieve cost-effective emission reduction, and a Renewable Quota System to promote the utilization of renewable energy. Challenges associated with these policies are discussed. Furthermore, we suggest that a sectoral approach can serve as a first step for China to make meaningful commitments under a prospective international climate treaty. In particular, the cement, steel, and aluminium sectors can be among the first groups to join this sectoral approach.

Policy relevance

We argue that China's sectoral climate policies should prioritize both the development of a carbon market to achieve cost-effective carbon mitigation and the improvement of renewable supporting polices to foster long-term renewable technology investment. However, to fully explore the advantages of a carbon market, we suggest that more stringent emission caps should be set at the national level. In addition, the carbon market and existing energy and climate policies should be carefully harmonized. In particular, the overlaps between existing command-and-control mitigation polices and the carbon market should be reduced to improve cost-effectiveness. In parallel with a carbon market, we suggest a second-best policy, the Renewable Quota System, as a supplement to the carbon market to foster green technology development and to create preconditions for a more stringent cap. At the international level, a sectoral approach can serve as a first step for China to make meaningful commitments under a prospective international climate treaty. In particular, the cement, steel, and aluminium sectors can be among the first group to join this sectoral approach.

Keywords: China; climate change policies; energy policy; sectoral emissions

1. Introduction

China has become one of the most important players in combatting climate change due to the size of its CO_2 emissions. It currently accounts for over one-quarter of global carbon emissions, and it is projected to be responsible for about 40–50% of global emission growth before 2040 under the

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business-as-usual scenario (IEA, 2013a; US EIA, 2013; Yang, Zhang, & Wang, 2014). In the 2010 Cancun conference of the United Nations Framework Convention on Climate Change (UNFCCC), a proposal was made to limit average global temperature rise to two degrees Celsius (2 °C) by requiring a peak of global emissions by 2020 (Rogelj et al., 2011). To achieve this global climate target, it is crucial to involve all major emitters. As the world's largest emitter, China has been under mounting pressure to join a uniform intentional climate agreement that sets binding emissions caps for all countries.

Energy-intensive sectors in China have great potential to reduce CO_2 emissions. This article focuses on four key sectors – electric power, industrial, building, and transport – because of their enormous climate impacts. Combined, these four sectors accounted for 73% of national energy consumption and 82% of energy-related carbon emissions in 2012.[1] During the past decade, these sectors have been the dominant drivers of China's soaring energy demand, and about 70% of the increase in energy consumption came from them from 2000 to 2012. It is therefore vital for China to improve the energy efficiency and switch to low-carbon energy in these sectors to reduce carbon emissions.

This article reviews the progress made and ongoing challenges in China's energy and climate strategies in these four identified sectors. Although China has been steadily improving its energy and carbon intensities since the 11th Five Year Plan (FYP, 2006–2010), it faces significant challenges to make further progress (Wang, Lin, Cai, & Zhang, 2013). In particular, energy and climate policies have relied heavily on costly command-and-control (C&C) regulations. As China's energy consumption shifts from production to consumption sectors, C&C regulations alone will not be able to achieve similar success, because they will have a more limited impact in consumption-side regulation. Moreover, unsmooth deployment of renewable energy poses challenges for decarbonizing China's electricity system. To solve China's emission predicament, we suggest two policy priorities: a carbon market to achieve cost-effective emissions reduction, and a Renewable Quota System to promote market utilization of renewable energy. From an international perspective, we suggest that a sectoral approach can serve as a first step for China to make meaningful commitments under a prospective international climate treaty.

The remainder of the article is organized as follows. Section 2 characterizes the four key sectors. Section 3 discusses the dynamics of these sectors in energy conservation and carbon mitigation. Section 4 identifies the major sectoral barriers and challenges to reduce CO_2 emissions. Section 5 discusses a policy outlook regarding whether and how a carbon market, a Renewable Quota System, and a sectoral approach can be exploited to promote low-carbon development in China. Section 6 provides a conclusion.

2. Sectoral background

In the 11th FYP, China established extensive sectoral energy and climate polices. These policies have been further expanded and strengthened in the 12th FYP (see the Appendix for a summary of these policies). Although C&C is still the most prevalent policy instrument, the 12th FYP has called for more market-based instruments, as evidenced by its proposal on environmental taxation and a carbon market (Li & Wang, 2012). To better understand the rationale and limitation of existing policies, we need to characterize energy consumption and carbon emissions in the four sectors. It is noteworthy that our sector classification conforms to the tradition of the Intergovernmental Panel on Climate

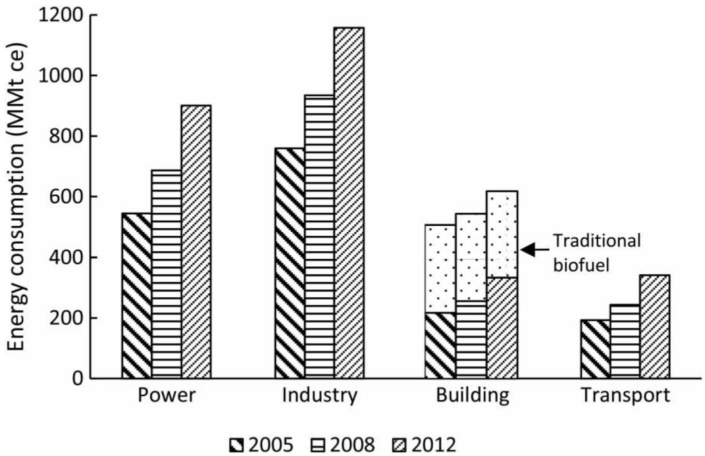

Figure 1 Sectoral energy consumption in 2005, 2008, and 2012

Change (IPCC), which divides energy activities into energy-supply and end-use sectors (IPCC, 2007).[2] The same sector classification is also used by the International Energy Agency (IEA, 2013a) and the US Energy Information Administration (US EIA, 2013).[3]

Following the IPCC guidelines (IPCC, 2006), we compute sectoral CO_2 emissions using energy consumption by fuel types from the IEA. China's official energy statistical system differs from the IPCC's sector classification. Specifically, China includes the energy supply sector in the industrial sector. Moreover, its transport energy consumption only includes the activities of transport-related enterprises, and automobile fuel use is incorporated into the statistics of the residential, industrial, and agricultural sectors (Liu, Lund, & Mathiesen, 2013). Because it is difficult to make international comparisons under the Chinese statistical system, we chose to use the IEA statistics instead. Using these data, we display, in Figures 1 and 2, sectoral energy consumption and carbon emissions in 2005, 2008, and 2012. Note that the indirect carbon emissions resulting from the consumption of electric power and heat are illustrated for the end-use sectors.

In the next four subsections we will discuss the key characteristics of sectoral energy consumption and carbon emissions, from which we establish the following key findings:

- Electric power and industrial sectors dominate carbon emissions (Section 2.1)
- Building and transport show accelerated growth (Section 2.2)
- There is still improvement potential for China's sectoral energy efficiency (Section 2.3)
- Low-carbon energy has a small share in the coal-dominated energy mix (Section 2.4)

2.1. Electric power and industrial sectors

The electric power and industrial sectors dominate China's CO_2 emissions. The electric power sector's energy consumption is defined as the difference between energy input and electricity output. As shown in Figure 1, the electricity sector consumed 901 million metric tonnes of coal equivalent (ce) in 2012, or 22% of total national energy consumption. As such, it represented 44% of national CO_2 emissions in

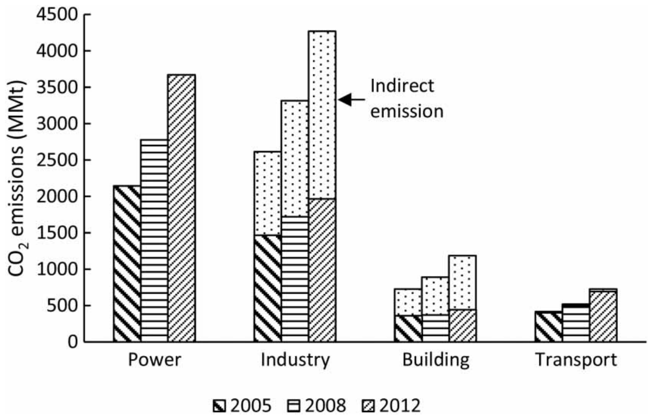

Figure 2 Sectoral CO_2 emissions in 2005, 2008, and 2012
Note: Indirect emissions of end-use sectors are direct emissions of the electric power and heat sectors allocated to the end-use sectors based on the consumption of electric power and heat.

2012. Because electricity is consumed mainly by the end-use sectors, carbon mitigation relies not only on the power generation efficiency improvement and decarbonization of power generation, but also on the management of electricity demand.

A major driving force of carbon emissions in the electric power sector is the soaring electricity demand from end-use sectors. During the period 2005 to 2012, electricity generation in China doubled, and China has overtaken the US and the EU to become the world's largest electricity generator. Additionally, the electrification level has been increasing in the industrial and building sectors. The share of electricity in final energy consumption increased from 22% in 2005 to 30% in 2012 for the industrial sector, and from 10% to 17% for the building sector.

The industrial sector consumed 1.16 billion metric tonnes ce in 2012, or 28% of national energy consumption. The carbon emissions of the industrial sector include indirect emissions due to electricity and heat consumption, which can be calculated based on the corresponding emission factors in the electric power sector. Following this calculation, the industrial sector emitted about 52% of national CO_2 emissions in 2012.

Industrial carbon emissions are tightly associated with energy-intensive manufacturing, and about half of the world's cement and steel are produced in China. However, the industrial sector's energy consumption has slowed since 2008, partly due to the lower demand for energy-intensive goods after the global financial crisis. However, the more important reason is China's ongoing economic transition. It is expected that the fast growth of industrial energy consumption in the past decade is unlikely to continue in the future.

2.2. Building and transport

The building sector accounted for 15% of China's national energy consumption in 2012. IEA statistics reveal that nearly half of building energy consumption is attributable to the traditional biofuel used in rural areas, as also confirmed by Liu, Wang, and Mol (2012) and Liu, Wang, and Mol (2013). Biofuel is treated as carbon neutral when calculating carbon emissions. Total building CO_2 emissions, including direct and indirect emissions, accounted for 14% of national emissions in 2012, while the transport sector accounted for 8% of national energy consumption and 9% of national carbon emissions in 2012. Although the building and transport sectors represent a relatively small share of national carbon emissions, the two sectors have experienced an acceleration of growth in overall energy usage in recent years. The annual growth rate of transport energy consumption increased from 8.0% during the 2005–2008 period to 8.8% during 2008–2012, and increased from 5.6% to 6.9% for the building sector during the same period.[4]

Urbanization and income growth are the main causes for the rapidly increasing energy consumption and carbon emissions in both sectors. From 2005 to 2013, China's urban population increased by about 170 million, and in 2013 alone, China added 2.0 billion square metres of floor space, which is bigger than Australia's total housing inventory (NBS, 2014). The increasing income allows residents to afford larger houses and more appliances, which leads to increases in energy consumption. In addition, China has been the world's largest car market since 2009. Per capita motor vehicle ownership increased nearly fourfold from 2005 to 2013, reaching 93 vehicles per thousand people (NBS, 2014). With China's ongoing transition to a consumption-driven economy, the building and transport sector will continue their rapid growth in energy use and CO_2 emissions.

2.3. Energy efficiency improvement

Since the start of the 11th FYP in 2006, China has launched a series of programmes designed to improve sectoral energy efficiency, and these programmes have made substantial progress. Indeed, the energy efficiency of some sectors is approaching the international advanced level. However, there is still the potential to improve domestic sectoral energy efficiency to approach international best practice.

China has taken aggressive action to enhance energy efficiency in the electricity and industrial sectors. Taking coal-fired power generation as an example, in the 11th FYP the efficiency of coal-fired power generation was greatly improved by replacing small inefficient plants with larger, more-efficient plants. However, the efficiency improvement potential is shrinking, with there being fewer inefficient plants left. However, besides closing small power plants, thermal power generation efficiency can also be improved through the optimization of operations and dispatch systems (Xu, Yang, & Xuan, 2013). Moreover, more efficient gas power generation technology (e.g. combined cycle gas turbine technology) can further reduce emissions from power generation because of the low-carbon content of natural gas (Cai, Wang, Wang, Zhang, & Chen, 2007; Oda et al., 2012). Although the previously massive use of natural gas led to concerns about energy security, China's gas contracts with neighbouring countries have now secured the majority of gas imports up to 2030 (Odgaard & Delman, 2014). Furthermore, gas supply will be secured by China's technology breakthroughs in shale gas exploration and exploitation.[5]

In the transport sector, China has been raising its fuel efficiency standards to conserve energy and reduce emissions. Improvements in the fuel economy of light-duty vehicles slashed the emissions intensity for new vehicles in China by about 3% from 2008 to 2011, reaching 180 gCO_2/km in 2011 (IEA, 2013b). However, the emissions intensity of new vehicles in China remains much higher than in the EU, at 136 gCO_2/km in 2011 (IEA, 2013b).

In the building sector, although China's building codes have become increasingly stringent, they are still loose compared to European standards (Colombier & Li, 2012). The energy intensity of large-scale public buildings in China is close to that of the US, which is higher than the international average level (Weng, Zhang, & Chen, 2011).

2.4. Coal dominance in the energy mix

Coal dominates China's primary energy consumption because of its abundance and its low price compared to either oil or natural gas. The electricity and industrial sectors are the two largest coal consuming sectors, accounting for 46% and 22% of national coal consumption in 2012, respectively. Meanwhile, low-carbon energy sources, including nuclear and renewables, account for less than 10% of national total energy consumption. Electric power generation is the main use for this low-carbon energy. Although China's low-carbon electricity development has accelerated in recent years, its share in total electricity generation only increased by about 2.4% from 2005 to 2012 (specifically, from 18.9% in 2005 to 21.3% in 2012). The dominance of coal (and the corresponding small share of low-carbon energy sources) has been one of the major drivers of China's surging carbon emissions. However, recent policy progress signals a changing picture for coal consumption in China. Severe pollution from coal consumption has stimulated China's government to control national total coal consumption, and even to reduce coal consumption in the Beijing-Tianjin-Hebei area, Yangtze River Delta, and Pearl River Delta.[6] This policy provides an opportunity for developing renewable energy to replace coal.

3. Trends and forecasts

3.1. Shifting sectoral importance

China's CO_2 emissions will keep rising, at least in the near future, but the relative contribution from each sector is likely to change over time. If China successfully transitions from an investment-led to a consumption-led economy, the growth of industrial emissions will probably slow down, while those for the building and transport sectors will accelerate.[7] This prediction is supported by existing studies (US EIA, 2013; IEA, 2013a; Zhao, Zhang, Zou, & Yao, 2013). Their baseline scenarios forecast that in the next two to four decades, energy consumption will grow annually at about 2.8–3.6% for building[8], 3.4–4.1% for transport, 2.8–3.1% for electric power[9], but only 1.3–1.9% for the industrial sector. With climate policy limiting CO_2 emissions, energy consumption will grow annually at about 1.3–2.0% for building, 2.3–3.1% for transport, 0.7% for electric power, and only 0.8–1.0% for the industrial sector. Both scenarios clearly show a slowdown in industrial energy consumption.

The slowdown in industrial energy consumption is mainly due to the peaking demand for energy-intensive products. For example, as urbanization approaches its natural limit, construction of residential buildings and infrastructures will slow down correspondingly. Cement and steel production, which is triggered by large-scale construction, is thus likely to peak sometime between 2015 and 2020 (Ke, Zheng, Fridley, Price, & Zhou, 2012; Zhou, Kyle et al., 2013). As a result, China's industrial energy consumption is likely to peak before 2040 or even as early as 2030 (Zhou, Fridley et al., 2013; Zhou, Kyle et al., 2013).

By contrast, energy consumption in the building and transport sectors is growing quickly due to rising incomes. According to Eom, Clarke, Kim, Kyle, and Patel (2012), China's residential and commercial floor space per capita will reach the current UK level by 2050. The stock of light-duty vehicles will increase by about eight times from 2011 to 2050, exceeding the US level by as early as 2022 (Huo & Wang, 2012). Consequently, building and transport energy consumption is expected to keep increasing until 2050 (Xiao, Wei, & Wang, 2014; Zhou, Fridley et al., 2013).

Building and transport are the two key sectors to achieve emission reductions in the context of an energy market transformation in China. Both IEA (2013a) and Zhou, Fridley et al. (2013) estimate that the combined potential for energy conservation and carbon mitigation of the two sectors will be comparable to or even exceed the potential of the industrial sector at the end of their scenario ranges (2035 and 2050, respectively). On the one hand, this potential is due to the increasing share of building and transport in national energy consumption. On the other hand, with the exhaustion of low-hanging fruit for improving industrial energy efficiency – such as closing inefficient small plants and building advanced large plants – future improvements in industrial energy efficiency will be increasingly difficult (Cai, Wang, & Chen, 2010; Xu et al., 2013). For these reasons, it is expected that the building and transport sectors will play an increasingly important role in emission reductions.

3.2. Role of nuclear and renewable energy

Based on a review of mitigation scenarios, the IPCC (2014) found that carbon emissions from electricity generation must approach zero in the second half of the 21st century in order to meet the 2 °C target. Considering the size of China's electricity generation and coal-dominated electric power system, low-carbon energy development in China is a crucial determinant for the decarbonization of global electricity generation. Because coal and gas power equipped with carbon capture and storage (CCS) still emits between 65 and 396 gCO_2e/kWh (IPCC, 2012), renewable energy (mainly hydro, wind, and solar) and nuclear power are the main options to achieve near-zero GHG emissions per kilowatt.

Because nuclear power technology is mature and it can meet the base load requirement, China aims to increase its nuclear power generation capacity to above 400 GW in 2050 (CAE, 2011). This is an ambitious target given that China's nuclear power capacity was only 20 GW in 2014. Experts have very different opinions about the role of nuclear power. One study suggests that nuclear power capacity will reach 520 GW by 2050, or 54% of national power generation (Zhou, Fridley et al., 2013).[10] Another study suggests that the share will only be between 17% and 25% under a carbon constraining scenario (Chen, Yin, & Zhang, 2013). This difference reflects the fact that the large-scale development of nuclear power in China faces numerous uncertainties, including the treatment of nuclear waste, public acceptance, the long lead time for construction, and a lack of trained personnel (US EIA, 2013; Zhou, Rengifo, Chen, & Hinze, 2011). It is therefore still uncertain to what extent nuclear power can contribute to China's low-carbon energy development.

Currently, hydropower is the main renewable energy in China, accounting for 77% of renewable electricity capacity in 2012. However, the development potential for hydropower is bounded: 62% of China's 400 GW economically exploitable hydro resources are already utilized, and the rest will be exploited by 2035. Given the uncertainty of nuclear power and the bounded potential of hydropower, wind and solar power will play an irreplaceable role in decarbonizing China's electricity system. To follow a low-carbon development path, 19% of China's power generation needs to come from wind and solar power in 2035 (IEA, 2013a). However, the share of generation of wind and solar in 2012 is only 2% (CNREC, 2013). It is clear that a large gap exists between the current status of renewable energy and a low-carbon electricity system in the future.

4. Barriers and challenges

4.1. Costly C&C policy

Command-and-control (C&C) is the most commonly used policy instrument to improve energy efficiency in China, as is evident in both the 11th and 12th FYPs. Its popularity can be explained by the ease of its design and implementation, as well as its effectiveness in meeting predetermined targets. For example, during the 11th FYP, China launched the Top-1000 Energy-Consuming Enterprises programme (Top-1000 programme), which set energy-saving targets for 1008 enterprises in nine energy-intensive industrial sectors.[11] The programme proved to be very effective, and the target was surpassed by 50% by the end of the 11th FYP.[12] The success of this C&C policy is partly due to the role of the state-owned and state-holding enterprises in this framework. Specifically, incorporating energy-saving targets into the performance evaluation system creates an incentive for managers of state-owned enterprises to engage in energy conservation.[13]

However, the main concern for C&C is its inefficiency in terms of the social costs of compliance. For example, since the 11th FYP, China has stipulated that coal-fired power plants with capacity below a certain threshold be phased out. This indiscriminative policy has ignored the fact that many small power plants play an irreplaceable role in the local environment. Small power plants may serve to relieve local electricity shortages or to meet peak load demands (Cai et al., 2010). It is also likely that small firms create more job opportunities for local people (Cai, Wang, Chen, & Wang, 2011; Wang, Zhang, Cai, & Xie, 2013). The mandatory closure of these plants, without carefully balancing the social costs and benefits, can lead to high compliance costs. The second concern is about the perverse incentives C&C can create in short-term compliance behaviour. One particular example occurred at the end of the 11th FYP. Under pressure to achieve energy intensity targets, some local governments resorted to blackouts to restrict electricity use. The high social costs of C&C have therefore motivated policy makers to consider market-based options.

4.2. Inadequate policy on the consumption side

China's C&C energy policy is not only costly, but also inadequate for the consumption side. Regulation alone, without a properly designed policy mix, is difficult to make appealing to consumers for sustainable consumption. As a result, the energy efficiency of the consumption side, including building and transport, shows slower improvement. For example, although China implemented phase 1 and phase 2 fuel economy standards in 2006 and 2008, the average emission intensity of new light-duty vehicles actually increased from 180 gCO_2/km in 2006 to 186 gCO_2/km in 2008, but then dropped back to the 2006 level in 2011 (IEA, 2012, 2013b). In the building sector, although residents are willing to save on domestic energy use, they are discouraged by barriers including limited know-how and financial constraints (Dianshu, Sovacool, & Vu, 2010; Ma, Andrews-Speed, & Zhang, 2013; Wang, Zhang, Yin, & Zhang, 2011).

Chinese consumers arguably have a low willingness to pay for energy efficiency. For example, they pay more attention to vehicle performance – e.g. size, safety, and quality – and give very little consideration to environmental factors (Zhang, Wang, Hao, Fan, & Wei, 2013). These consumers are not alone in undervaluing energy efficiency, in what is termed the so-called 'energy paradox' (Jaffe & Stavins, 1994). Information dissemination and financial incentives are both needed in order to assist consumers in making rational choices in terms of energy efficiency (Wang, Cai, Lu, & Chen, 2007).

4.3. Deployment of renewable energy

China considers renewable energy manufacturing as a key industrial sector to boost economic growth, create new jobs, and increase exports. It has designated wind turbine and solar photovoltaic (PV) manufacturing as 'new strategic industries', which are eligible for preferential policy treatment in land, loans, and taxation (Grau, Huo, & Neuhoff, 2012). As a result, renewable energy manufacturing has grown rapidly since 2005. In less than one decade, China has become the world's largest producer of solar PV cells and wind turbines. China's solar PV production accounts for almost half of the world's total production (EC, 2011). Four Chinese wind-turbine companies are listed as the world's top 10 manufacturers (REPN21, 2012).

Unfortunately, the success of renewable energy manufacturing does not naturally lead to a similar success in the deployment of renewable energy. China's wind and solar energy has indeed experienced rapid growth, with total capacity increasing from close to zero to 5.7% of national power generation capacity in 2012 (CNREC, 2013). However, the deployment of this rapid growth in renewable energy is hindered by institutional, technological, and financial barriers.

China's Renewable Portfolio Standard sets the targets for generation capacity instead of electricity generation, so the power grid companies in China have few incentives to integrate renewables. Additionally, because a wind farm generates fewer tax revenues than a thermal power plant, local governments may favour thermal power over wind power due to the higher local incomes (Zhao et al., 2013). Furthermore, slow grid integration of renewables is also attributed to technological barriers.[14] The intermittency of solar and wind energy requires the power system to have a high peak shaving capacity. However, China's power system, which is dominated by coal, is suited for providing base load, and lacks interregional power grid connection. These two characteristics lead to limited peak adjusting capacity and prevent the utilization of large amounts of solar and wind energy. Moreover, the deployment of renewable energy requires high upfront investment costs for renewable power generation, transmission, and distribution.

4.4. Technological innovation

Technology is the ultimate solution for energy and climate change problems. However, China's indigenous green technologies still lag behind those of developed countries. Generally, the R&D intensity and patent output of solar PV firms in China are less than those of their foreign competitors (Zheng & Kammen, 2014). China's solar PV industry has specialized in downstream PV cell manufacturing, with its low technological barriers. Not until recently have domestic production chains integrated upstream silicon purification, e.g. those developed by domestic firms such as Ying-Li Solar. In the wind power industry, Chinese manufacturers still lag behind developed countries on two important technological fronts. The first is the production of large wind turbines, which are more efficient and cost-effective. Some multinational companies are able to mass-produce 7 MW units, but Chinese manufacturers are only able to mass-produce turbines less than 3 MW. The second technological lag is in the development of offshore wind power, to better utilize wind resources. In China, the indigenous production of offshore wind turbines is still at the prototype design and experimental stage.

5. Policy outlook

5.1. Carbon pricing

Climate policies that rely on C&C regulations are costly. Moreover, with poor enforcement, C&C is less effective on the consumption side where there are a large number of economic agents. Theory shows that market-based instruments, such as a carbon tax or a cap-and-trade system, are cost-effective in reducing emissions. In practice, explicit carbon pricing is more efficient than implicit carbon pricing mechanisms (OECD, 2013).

Carbon pricing is currently the subject of heated debate in China. The Ministry of Finance has been researching a carbon tax since 2007, but it still appears far from being ready for implementation. On the other hand, an emission trading pilot programme has gained traction in seven provinces and cities.[15] This pilot programme includes developed regions that have a large share of service economy, as well as regions still undergoing fast industrialization. These carbon exchanges were launched in 2013. The carbon price in Shenzhen was around 50–70 RMB/tCO_2 in 2014, which was close to the price level in California.[16] The pilot projects provide valuable learning experiences for building capacity, expertise, and infrastructure for a national carbon trading scheme that will be implemented in 2016.[17]

The pilot programme mainly targets energy-intensive industrial sectors, including electric power, iron and steel, chemicals, and cement. This sector focus is reasonable for regions such as Hubei, which have a heavy reliance on secondary industries. However, in more highly developed regions such as Beijing, Shanghai, and Shenzhen, the service sector accounted for 76.5%, 60.4%, and 55.6% of gross domestic product (GDP), respectively, in 2012 (NBS, 2013). Due to their increased consumption level, the building and transport sectors have grown rapidly, resulting in increased emissions from the consumption side. To accommodate this transition, all three cities have included large commercial and public buildings into the carbon market (Zhang, Karplus, Cassisa, & Zhang, 2014). Furthermore, Shanghai has included aviation and harbour services, and Shenzhen is considering including public transport – including buses and taxis – into the carbon market (Jiang, Ye, & Ma, 2014; Wu, Qian, & Li, 2014). Although it remains to be seen how effectively these prospects can be realized, as all the pilot programmes have been running for only one year, it is clear that the pilot carbon markets are dealing with emissions from both production and consumption standpoints. This being said, it is clear that China's pilot carbon market is still in the 'learning by doing' stage. To maximize the effects of the pilot programme on emission reductions, and to provide useful experiences for building a national carbon market, three main challenges need to be solved.

First, economic growth remains a higher priority than climate mitigation, because China is still a developing country. To accommodate rapid economic growth while limiting CO_2 emissions, the pilot programme has adopted intensity-based targets, and the majority of allowances are freely allocated (Zhang et al., 2014). A target on carbon intensity allows the emission cap to be adjusted with real output, thereby reducing its constraint on economic growth. Furthermore, Hubei province, a less developed province with more concerns about GDP growth, stipulates that if a participant's emissions exceed the cap by 20% or 20,000 t, the extra emissions will be covered or recycled by a government allowance reserve (Qi, Wang, & Zhang, 2014). These rules are built to avoid large negative effects from climate mitigation on the economy, but also lead to laxer carbon regulations.

A more stringent cap or higher carbon price may be rationalized not only by the climate benefits but also by the environmental benefits. CO_2 and air pollutants are mainly co-emitted from fossil fuel consumption. According to the Chinese Academy of Environmental Planning under the Ministry of Environmental Protection, the total external costs of coal in China were as high as 556 billion RMB in 2010, of which less than 30% have been internalized by existing policies (CAEP, 2014). The co-benefits of carbon markets can contribute to cost-effective solutions to serious air pollution problems (Zhang & Wang, 2011). We suggest that in the second phase of the pilot programme, more stringent caps and mechanisms should be considered. Furthermore, more allowances should be auctioned off rather than being freely allocated to the emitter.

Second, the carbon market and existing energy and climate policies should be carefully harmonized. If climate change is only attributed to the market failure associated with the negative externalities of GHG emissions, a cap-and-trade system or a carbon tax should be the first-best policy (Requate, 2015; Van der Ploeg, 2015). Additional policies only increase the abatement cost and do not lead to greater emission reduction (Goulder, 2013). Currently in China, a large number of energy and climate policies coexist with the pilot carbon markets, such as energy efficiency requirements for top energy-consuming enterprises and the phase-out of backward production capacity. Because the coverage of these policies is mainly energy intensive sectors therefore overlaps with the carbon market, these polices hamper the cost-effectiveness and run the risk of rendering the carbon market redundant. After all, the most important motivation for launching a carbon market is to improve efficiency by replacing costly C&C polices. It is therefore suggested that the overlaps between existing C&C mitigation polices and the carbon market should be reduced.

However, in addition to the market failure associated with the negative externalities of emissions, market failure associated with technology innovation and diffusion is another reason why abatement technology is not created and utilized to an efficient degree. The public-good nature of knowledge determines that knowledge can spill over, and innovators may not be able to reap all the benefits of innovation. Furthermore, with respect to technology diffusion, the 'learning-by-doing' effect creates positive externalities for others (Jaffe, Newell, & Stavins, 2005; Lehmann & Gawel, 2013). Therefore, a complete response to climate change needs to combine technology policies that internalize the positive externalities related to technology innovation and diffusion with emission pricing policies that internalize the negative externalities of emissions (Goulder, 2013; Jaffe et al., 2005; Van der Ploeg, 2015). In practice, most countries have focused their climate technology policies on renewable energy, considering the determining role of energy supply decarbonization in combatting climate change (Lipp, 2007). Therefore, in addition to a carbon market, in Section 5.2 we propose a Renewable Quota System to improve China's renewable energy supporting policy.

Moreover, the carbon market alone may not achieve the desired result in the highly regulated electricity market. With an emission cap, the carbon cost has to be included in the electricity price. However, China's electricity price is tightly regulated to prevent inflation. It is difficult to raise electricity prices to fully reflect climate costs, so price signals cannot create sufficient incentive to stimulate behavioural change in electricity consumption. The current regional pilot carbon markets address this issue by accounting for both direct emissions due to fossil fuel consumption and indirect emissions due to electricity and heat consumption (Zhang et al., 2014). However, this treatment leads to double counting and should be avoided in a national market.

Third, the rules of carbon markets vary across pilot provinces and cities because of heterogeneous regional economic and emission characteristics. Regional differences should be properly considered in a national carbon market. China's economic development has been highly unbalanced, with the level of development generally increasing from western China to eastern China. Correspondingly, the pilot programmes in eastern China (e.g. Beijing, Shanghai, and Shenzhen) include the service sector in the carbon market, while Hubei province mainly includes large firms from the electric power and industrial sectors. In less developed regions the service sector is not a major contributor to CO_2 emissions, but including this sector would enrol a large number of small entities and greatly increase administrative costs.

5.2. Renewable Quota System

Positive externalities associated with technology innovation and diffusion imply that a complete response to climate change needs to include climate technology polices in addition to emission pricing policies. Although, in practice, most countries have adopted renewable energy supporting policies (Lipp, 2007), such as feed-in tariffs or renewable quota policies, these policies are not necessarily the most efficient option to address technology-related market failures (Requate, 2015). However, renewable energy supporting policies are warranted from a second-best perspective if the external cost of emissions is not fully internalized (Jaffe et al., 2005; Fischer, 2008). In fact, even in the EU Emissions Trading Scheme, it has been hard to raise the carbon price to an efficient level due to political feasibility and public acceptance (Lehmann & Gawel, 2013). For China, although we propose a more stringent emission cap, we may not expect the carbon price to reach an efficient level in the near future, because China still needs economic growth to bring a good quality of life to the population. Compared to raising the price of emissions, renewable energy supporting policies are more feasible, because they create a positive incentive for abatement, while the cost is dispersed. If emissions cannot be properly priced for feasibility reasons, renewable energy supporting policies can serve as a second-best policy to foster green technology development and to create preconditions for a more stringent cap (Jaffe et al., 2005; Lehmann & Gawel, 2013).

China's renewable energy deployment faces barriers from various areas: institutional, technological, and financial. However, from the policy perspective, the top priority should be improving the current Renewable Portfolio Standard. Setting renewable development targets based on installed capacity instead of power generation is one of the main reasons for the unsmooth grid integration and utilization of renewable energy. The government has sought to address this barrier through the use of a Renewable Quota System, which has been discussed for several years and is now under final approval.[18] Under this quota system, not only are power generators required to produce certain quotas of renewable power, but grid companies are also required to buy renewable power quotas. Moreover, regional governments are allocated renewable power quotas. These power quotas will be achieved because the generation and grid companies under regional administration will be required to fulfil their respective quotas.

By setting explicit targets for relevant players, the proposed Renewable Quota System has great potential to solve the current predicament of renewable power integration. However, to achieve this effect, three main challenges will need to be addressed. First, strict penalties should be set for non-compliance. The 2007 Mid-Term and Long-Term Development Plan for Renewable Energy stipulated a target for 2010 whereby power generation companies with over 5 GW power capacity should achieve 3% of installed capacity from non-hydro renewable power. Only 8 out of 18 generation companies fulfilled this goal by 2010,[19] but there was no report as to whether these companies were subject to penalties. For the proposed Renewable Quota System to succeed, a penalty higher than the cost of renewable electricity is necessary. Second, the intermittency of renewable power poses technical difficulties to grid integration. Supportive measures like increasing peaking generators are essential to increase the flexibility of the power system. Third, the cost-effectiveness of the Renewable Quota System can be further improved by building a trade market of renewable energy certificates. Renewable energy certificates are credits that can be earned by generation companies once they produce a certain amount of renewable energy, or by grid companies once they integrate a certain amount of renewable energy. Similar to a carbon market, this trade market allows participants to fulfil their quota in a cost-effective way. However, this trading system needs substantial preparation in terms of legislation, implementation, and monitoring. A pilot scheme can be developed as a first step to accumulate experience.

5.3. Sectoral approach

In 2013, the 19th session of the Conference of the Parties (COP) in Warsaw agreed that all countries may propose their Intended Nationally Determined Contributions (INDCs) to tackle climate change. INDCs can take different forms, e.g. absolute or relative emission reduction targets, climate policy action, and projects (Höhne, Ellermann, & Li, 2014). However, the diversity of INDCs makes it difficult to assess whether the aggregated action of all INDCs is sufficient to achieve the required global mitigation pathway (Wyns, 2015). Moreover, after INDCs are submitted, the analysis and negotiation process is not yet agreed upon. Based on the most recent progress, China's INDC will mainly consist of a 40–45% carbon intensity reduction target by 2020 and a target to peak carbon emissions by 2030, which is ambitious considering the fast growth of China's emissions at present.[20] However, to promote international climate cooperation further, we suggest that there is still potential for China to contribute to a uniform and maybe more timely international climate action framework. The sectoral approach, which was proposed in the Bali Action Plan in 2007, is such an option. This approach aims to limit emissions of specific sectors rather than economy-wide emissions in developing countries (Meckling & Chung, 2009). For example, one proposal is for developed countries to adopt economy-wide emission targets and for high-emitting developing countries to adopt 'no-lose' sectoral targets (Schmidt, Helme, Lee, & Houdashelt, 2008).[21] In fact, the idea that China could commit to a national carbon intensity target together with an emission cap at a sector level during the post-Kyoto climate negotiation has been envisioned by early studies (Zhang, 2000a, 2000b). Although China used to be skeptical about the sectoral approach, it has recently shifted its stance by considering certain sectoral approaches as a starting point to join an international climate treaty that sets universal emission limitations for all countries (Cai et al., 2009; Cai, Wang, Chen, & Wang, 2012).

China's attitude towards a sectoral approach is influenced not only by international pressure in climate negotiations but also by its domestic economic transition. Some energy-intensive sectors, such as cement, steel, and aluminium, are likely to peak sometime between 2015 and 2020 due to

China's infrastructure construction slowdown. Correspondingly, emission growth in these sectors will decelerate or even reverse (Ke et al., 2012; Wang, Wang, Lu, & Chen, 2007; Wen, Meng, & Chen, 2014). This provides an opportunity for China to take proactive steps to further exploit the mitigation potential in these sectors without impairing economic growth. Based on the criteria proposed by Bodansky (2007), we suggest the first sector to join a sectoral approach is cement, followed by steel and aluminium.

First, as the world's largest producer of cement, steel, and aluminium, China has tremendous mitigation potential in these three sectors. For example, the cement sector alone emitted 1.25 billion metric tonnes of CO_2 in 2011 (Xu, Fleiter, Fan, & Eichhammer, 2014), which is more than twice the total CO_2 emissions of the UK in the same year.[22] Second, limiting carbon emissions in the three sectors will not greatly harm China's economy, because the demand for their products will peak without climate policy interventions. Third, the cement sector is highly concentrated, which significantly reduces administrative and monitoring costs in the sectoral approach. By comparison, the market concentration of the steel and aluminium sector is lower. Among the first group of sectors in a sectoral approach, we do not suggest the electric power sector, because of potential political barriers. China's growing electricity demand and tight regulation of electricity prices make this sector sensitive to any regulation that increases costs.

A carbon market can serve as an instrument for the domestic implementation of a sectoral approach. A sectoral approach requires setting limits for the participating sectors at the national level, which aligns with China's incentive to cap the emissions of energy-intensive sectors and trade carbon credits nationally. In fact, it is reported that the national market that will be started in 2016 will include not only the sectors that we recommend above, but also electricity, aviation, and other energy-intensive sectors.[23] If China decides some of these sectors will also join a sectoral approach, China can earn benefits by setting stringent caps for these sectors to over-achieve the sectoral mitigation targets under the sectoral approach. In this manner, China can make a meaningful commitment to an international climate treaty and prepare itself for more stringent and economy-wide emission reduction targets in the future.

6. Conclusion

This article reviews the progress and challenges in China's energy and climate policies in the electric power, industrial, building, and transport sectors. These four sectors account for about three-quarters of China's total energy consumption and energy-related carbon emissions. The sectoral policies on energy conservation and carbon mitigation are facing two major challenges. First, command-and-control policies not only are costly, but also cannot accommodate the transition of energy consumption from production sectors to consumption sectors. Second, unsmooth deployment of renewable energy poses challenges for decarbonizing China's electricity system.

To address these challenges, we suggest two policy priorities: a carbon market to achieve cost-effective emission reduction, and a renewable quota system to promote the utilization of renewable energy. China has been implementing regional carbon market pilot programmes since 2013, and it will begin a national carbon market in 2016. However, three main challenges need to be solved to maximize the effects of a carbon market on controlling carbon emissions. First, China's top priority is still economic growth, although climate mitigation has emerged as a policy issue in recent years. The current pilot programme sets lax emissions targets to avoid tight restrictions on gross domestic product growth. We argue that more stringent caps on carbon emissions can be justified by the domestic needs for clean air in addition to climate mitigation. Second, the carbon market and existing energy and climate policies should be carefully harmonized. On the one hand, the overlaps between existing C&C mitigation polices and the carbon market should be reduced to improve cost-effectiveness. On the other hand, low-carbon technology supporting polices need to be developed in parallel with carbon pricing policies in order to correct the market failure associated with technology innovation and diffusion. Third, a national carbon market should accommodate regional heterogeneities, because China has a tremendous regional imbalance in both economic and social development.

However, considering the fact that China's carbon price is unlikely to reach an efficient level in the near future, we suggest a second-best policy, the Renewable Quota System, as a supplement to the carbon market, to foster green technology development and to create preconditions for a more stringent cap. The Renewable Quota System aims at solving the unsmooth deployment of renewable energy. This policy sets generation-based targets for relevant players including generation companies, grid companies, and regional governments. To ensure the effect of this system, three aspects need to be addressed. First, strict penalties should be set for non-compliance. Second, supportive measures are essential to increase the flexibility of the power system. Third, the cost-effectiveness of the Renewable Quota System can be further improved through the creation of a trade market of renewable energy certificates.

At the international level, in addition to China's Intended Nationally Determined Contributions (INDCs), which commit to peak emissions by 2030, China could contribute to a uniform and maybe more timely international climate action framework by participating in a sectoral approach. This approach allows China to not only make a meaningful commitment to contribute to global climate mitigation, but also to test the impact of a more stringent emission limitation on the economy for the future. Based on the characteristics of China's energy-intensive sectors, we suggest the cement, steel, and aluminium sector as the first group to join the sectoral approach. Given China's economic transition, the participation of these sectors has limited impacts on the economy, because the demand for their products will peak anyway. In addition, the domestic carbon market can be linked to the international commitment of a sectoral approach. These combined policy instruments will reduce China's cost in switching to low-carbon development.

Acknowledgments

This research was financially supported by a National Natural Science Foundation of China project (no. 71273153) and a Tsinghua-Rio Tinto Joint Research Center for Resource Energy and Sustainable Development project entitled 'Potentials and Policies of Water and Energy Comprehensive Utilization in China's Industrial Sector'.

Disclosure statement

No potential conflict of interest was reported by the authors.

Notes

1. The sectoral energy consumption data are from the International Energy Agency (IEA), available at http://www.iea.org/statistics/. Following the IPCC guidelines (IPCC, 2006), sectoral CO_2 emissions are computed using sectoral energy consumption by fuel types. In the following text, the sectoral energy and emissions data, and the derived growth rates and proportions, are computed in the same way (unless noted explicitly).
2. The energy-supply sector includes energy extraction, conversion, storage, transmission, and distribution. Among others, power, heat, and petroleum refining are typical subsectors in the energy-supply sector. The end-use sectors comprise industry, building, transport, agriculture, and forestry. The IPCC definition of the coverage of the industrial sector is different from that of China because energy-supply sectors are not included. The IPCC classifies energy consumption in places where people reside, work, and buy goods and services into the building sector. The transport sector contains the energy use for moving people and goods (IPCC, 2007).
3. Confusion may arise for those who are familiar with China's official energy statistics. According to China's sector classification, the energy-supply sector belongs to the industrial sector. In addition, China does not classify the building sector as a separate one. However, the building sector stands out as an important energy consumption sector in IPCC, IEA, and EIA reports. The widely used IPCC's sector classification is more appropriate in grouping and analyzing highly complex and intertwined energy activities. Therefore, our sector classification follows the IPCC standard.
4. Here, we exclude the traditional biofuel, because its use will decrease with continued urbanization and rural development in China, while commercial energy use in the building sector will increase.
5. 'China's shale gas production is projected to reach 6.5 billion cubic meters in 2015'. See http://finance.ifeng.com/a/20141019/13197641_0.shtml.
6. 'Is China ready for controlling total coal consumption'. See http://cppcc.people.com.cn/n/2014/0925/c34948-25732481.html
7. China's economy has relied heavily on investment to drive economic growth, especially during the 2000s. Only in recent years has consumption surpassed investment in driving GDP.
8. Traditional biofuel is excluded.
9. The relatively fast growth rate of energy consumption of the electric power sector is mainly due to the growing demand for electricity from end-use sectors.
10. Nuclear capacity is inferred from power generation by assuming 8000 hours utilization time per year.
11. NDRC, 2011. The energy saving target of the Top-1000 Energy-Consuming Enterprises programme is surpassed. See http://xwzx.ndrc.gov.cn/mtfy/wlmt/201111/t20111128_447242.html.
12. In the 12th FYP, the programme has been expanded as the Top-10,000 Energy-Consuming Enterprises programme (Top-10,000 programme), which covers 17,000 key energy-consuming enterprises. Because the programme is still under implementation, it is too early to evaluate its performance.
13. NDRC, 2010. The assessment result of the energy saving target of the top-1000 energy-consuming enterprises. See http://bgt.ndrc.gov.cn/zcfb/201007/t20100705_500081.html.
14. 'China's wind energy develops fast but has low utilization rate'. See http://www.yicai.com/news/2014/07/3999584.html.
15. The pilot regions include Beijing, Shanghai, Tianjin, Chongqing, Guangdong, Hubei, and Shenzhen.
16. The carbon price in Shenzhen is reported at http://www.cerx.cn/Portal/home.seam. For California, see http://calcarbondash.org/.
17. 'National carbon market to be on trial in 2016'. See http://jingji.21cbh.com/2014/9-2/wNMDA2NTFfMTI5MzIwNg.html.
18. The Renewable Quota System is expected to be implemented after electricity reform. See http://finance.ifeng.com/a/20150108/13415742_0.shtml.
19. Using data from the China Electricity Yearbook 2011.

20. The carbon intensity target was announced by China in the 2009 Copenhagen Accord. The emission peak target was announced in the joint climate announcement of China and the US in 2014.
21. 'No-lose' target means the country will be rewarded if overfulfilling the target, but will not be penalized if missing the target.
22. Oak Ridge, Global, Regional, and National Fossil-Fuel CO_2 Emissions. See http://cdiac.ornl.gov/trends/emis/overview.html.
23. The national carbon market is going to start in 2016. See http://politics.people.com.cn/n/2015/0204/c70731-26509409.html.
24. NDRC, 2007. Medium- and long-run development plan for renewable energy. See http://www.gov.cn/zwgk/2007-09/05/content_738243.htm.
25. State Council, 2013, 12th Five Year Plan of energy development. See http://www.gov.cn/zwgk/2013-01/23/content_2318554.htm.
26. NDRC, 2009. Notice on adjusting feed-in tariff for wind power. See http://www.gov.cn/gzdt/2009-07/24/content_1373827.htm.
27. NDRC, 2013. Notice on adjusting the feed-in tariff for solar photovoltaic power. See http://www.gov.cn/gzdt/2013-08/30/content_2477833.htm.
28. NDRC, 2012. Action plan of the 10,000 Energy-Consuming Enterprise Program. See http://www.gov.cn/banshi/2012-05/23/content_2143552.htm.
29. NDRC, 2007. Comprehensive working plan for energy conservation and pollution mitigation. See http://www.gov.cn/zwgk/2007-09/05/content_738243.htm.
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31. Ministry of Housing and Urban–Rural Development, 2012. 12th FYP for building energy conservation. See http://www.gov.cn/zwgk/2012-05/31/content_2149889.htm.
32. Ministry of Housing and Urban–Rural Development, 2014. Monitoring report of building energy conservation in 2013. See http://www.mohurd.gov.cn/zcfg/jsbwj_0/jsbwjjskj/201404/t20140416_217682.html.

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Appendix: Relevant policies in the 11th and 12th FYP

Low-carbon energy development:

- *Renewable portfolio standard*: The target share of renewable energy is raised to 15% of national energy consumption in 2020. Electric power companies with a generation capacity over 5 GW are required to increase the ratio of non-hydro renewables in the total installed capacity to 8% by 2020.[24] The targets of the installed generation capacity for hydro, wind, and solar electricity in 2015 are 290 GW, 100 GW, and 21 GW respectively.[25]
- *Feed-in tariff*: Wind power's feed-in tariff ranges from 0.51 RMB/kWh to 0.61 RMB/kWh after the adjustment in 2009.[26] Solar power's feed-in tariff ranges from 0.9 RMB/kWh to 1.0 RMB/kWh after the adjustment in 2013. In addition, the subsidy for the distributed solar power generation is 0.42 RMB/kWh.[27]

Industry and thermal power:

- *Top-10,000 Energy-Consuming Enterprise Program*: This programme is a continuation of the Top-1,000 Energy-Consuming Enterprise Program established in the 11th FYP. With the start of the

12th FYP in 2011, the programme has been expanded to enrol 17,000 key energy-consuming enterprises from almost every industrial sector, aiming at saving 250 million metric tonnes ce of energy in the 12th FYP.[28]

- *Phase-out of backward production capacity*: The 11th FYP mandated the acceleration of closures of small plants and backward capacity in 13 energy-intensive sectors. The energy saving is estimated to be 118 million metric tonnes ce during the 11th FYP.[29] In the 12th FYP, the programme has been expanded to cover 19 sectors.[30]

Building sector:

- *Building energy codes*: China sets the efficiency of the buildings constructed in the 1980s as the baseline. In the 11th FYP, new buildings were required to improve energy efficiency by 50% relative to the baseline. In the 12th FYP, the target for improvement has been raised to 65%.[31] Beijing and Tianjin set a more stringent target of 75% improvement in energy efficiency in 2013, which will be expanded nationally.[32]

Transport sector:

- *Fuel economy*: The phase 1 and phase 2 fuel economy standards for passenger vehicles were implemented in the 11th FYP. The phase 3 standard is to be adopted in the 12th FYP, aiming to reduce the average fuel consumption of new passenger vehicle fleet in 2015 to 7 L/100 km. In addition, the standard will be tightened to 5 L/100 km in 2020 (Wang, Jin, Wang, & Wei, 2010).