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China's 2020 carbon intensity target: Consistency, implementations, and policy implications

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ABSTRACT

China has pledged to reduce its CO_2 emissions per unit of GDP by 40–45% by 2020 as of 2005 level. This research examines China's 2020 carbon intensity target and its interdependence with the overarching national economic and social development goals. The results show that, with annual GDP growth rate at 7% during the 12th Five-Year-Plan (FYP) period and 6% during the 13th FYP period, the 45% CO_2 intensity reduction target implies annual CO_2 emissions of 8600 million tonnes by 2020, close to 8400 million tonnes, the UNFCCC 450 ppm scenario for China. However, achieving only the 40% reduction target will lead to 9380 million tonnes CO_2 emissions in 2020 which largely surpass the UNFCCC 450 ppm scenario. We conclude that China's 45% CO_2 intensity reduction target is not only within international expectations but also self-consistent with its overall economic and social development strategy. Then primary energy and power planning for implementing the 45% carbon intensity reduction target is proposed. Related investment requirements are also estimated. To achieve the target, China needs to restructure the economic structure for significant improvements in energy conservation.

Contents

1. Introduction

In November 2009, just before the United Nations Climate Change Conference (UNFCCC) in Copenhagen (COP15), China officially pledged to reduce its CO_2 emissions per GDP (or CO_2

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intensity) by 40–45% from the 2005 level and increase the share of non-fossil energy in primary energy to 15% by 2020 [1]. Given the role that China is playing in global climate change governance, the pledge has instigated a number of studies in literature since its announcement. Zhang challenged the reliability of government statistics as well as the central government's ability to achieve these targets, given that China has faced great difficulty meeting its 2010 energy-saving goals [2,3]. Michinori et al. criticized the ambiguity of the target, but argued that the pledge is consistent with China's domestic agenda to pursue economic growth and energy security [4]. Later studies mainly focused on the feasibility of these targets and pathways to realize them. Stern and Jotzo used a stochastic frontier model to decompose China's energy intensity targets concluding that the targets are par with those implicit in the US and EU targets and China needs ambitious policies to achieve these targets [5]. He et al. complied scenarios for China's energy related carbon emissions and concluded that, besides developing renewable and nuclear energy, the "energy conservation first" policy and adjustment in economic output structure are of policy priority [6]. Steckel et al. used the Kaya-decomposition method to examine the growth of CO_2 emissions in China and the contribution of three underlying drivers including economic growth, energy intensity change, and the dominance of coal in energy mix [7]. Dai et al. affirmed the feasibility of these targets with affordable costs using a hybrid AIM/CGE model [8]. Zhou et al. used an output-based method to study the carbon allocation issue in China, while Yi et al. studied the allocation issue from a regional perspective [9,10]. Wang et al. explored low carbon solutions in provincial level using two provinces, Fujian and Anhui, as case studies [11].

In March 2011, China formulated the intermediate targets to reduce CO_2 intensity by 17% from the 2010 level and increase the share of non-fossil energy to 11.4% by 2015, the end of the 12th Five-Year-Plan (FYP) [12]. Naturally, the following questions are of great importance to both China's energy policy and international climate governance: 1) are China's 12th FYP intermediate targets consistent with its 2020 targets? 2) Is China's 2020 carbon reduction target consistent with its economic growth target, given Chinese government's "building a well-off society in an all-around way at 2020" plan? 3) Is China's carbon reduction target within the international expectations on China's responsibility in global GHG stabilization? 4) What is the viable primary energy and power planning for China to facilitate the realization of these targets? Although existing literature addressed important aspects of China's climate and energy targets such as credibility, ambitiousness, feasibility, and possible policy solutions, the abovementioned issues remain largely uncovered. This research is an attempt to fill in these research and knowledge gaps.

The layout of the paper is as follows. Section 2 introduces background information on energy and climate policies in China. Section 3 projects CO_2 emissions under different economic and social development scenarios and different carbon intensity trajectories. Section 4 develops the primary energy and power planning in line with the carbon intensity targets. Section 5 concludes.

2. Energy and climate policies in China

Since 1971–2007, population in China had increased from 841 to 1320 million, while the economy began to take off since 1979 with GDP increasing for more than 12-fold from 183 to 2387 billion US dollars (2000 price and hereafter) (Fig. 1) [13]. This in turn results in an almost 10-fold increase of per capita GDP, from 186 US dollars in 1980 to 1808 in 2007.

China's economic growth is anything but balanced. Being "capital intensive and industry dominated", the breath-taking growth has been fueled by extensive energy consumption. Primary energy consumption has increased from 392 in 1971 to 1956 million tonnes oil equivalent (toe) in 2007, a more than five-fold growth (Fig. 1). In a sense, China has successfully managed to fuel the economic growth with less growth in energy consumption, at least during the 1979–2000 periods when economy grew more than six-fold with only less than doubled primary energy consumption (Fig. 2). However, energy intensity has been increased since China's entry into the WTO in 2001 (Fig. 3). In 2009, energy intensity was about 4% higher than that in 2002, in spite of significant reduction achieved since 2005 [14].

Increasing energy consumption driven by rapid economic growth has led to increasing CO_2 emissions in China. Ever since 2003, China has contributed more than half of global CO_2 emission increase [7]. In 2007, China has surpassed the US becoming the world's largest CO_2 producer, putting China in a unique position in international negotiation on GHG reduction [13]. Recent data showed that growth of energy production and consumption in China has outpaced many recent reputable predictions [15,16]. CO_2 intensity follows a reverse trend similar to energy intensity during the recent years. According to [17], three factors are underlying the reversal including the structural bias towards energy intensive heavy industry, a slowdown of technology progress, and a return to coal as the main energy resource. These factors exacerbated concerns not only about domestic energy security, resource scarcity, and environmental pollution, but also towards global GHG stabilization and reduction.

To fulfill its international responsibility in climate mitigation and, more importantly, reduce dependence on fossil fuels for domestic economic growth, in the long term, the Chinese government has pledged to reduce its CO_2 intensity by 40–45% from the 2005 level and increase the share of non-fossil energy in primary energy to 15% by 2020. In the short term, the central government plans to reduce CO_2 intensity by 17% from the 2010 level and increase the share of non-fossil energy to 11.4% by 2015 in the 12th FYP. To meet these targets, the Chinese government has formulated and implemented extensive energy and climate policies (Table 1). In general, these policies address the energy and climate challenges China is facing from two aspects: developing renewable energy and improving energy efficiency. China has been the world's largest investor in renewable energy in 2010, mainly driven by its gigantic investment in wind energy. Saving energy in electric power and manufacturing sectors, especially energy-intensive sectors such as steel, cement, and chemical product, etc., is the current focus of energy efficiency policy, while in the future saving energy in building and transportation sectors will be added to the policy mix [12]. More details on the progress of energy conservation policy and renewable energy development during the 11th FYP can be referred to [18–20].

Renewable energy has great potential in China (Table 2) [21]. A Pew Charitable Trusts report revealed that China led other G-20 members in clean energy investment in the amount of \$34.6 billion [22] in 2010. In particular, wind power has experienced spectacular growth in China during the 11th FYP. Despite still marginal share in total generation mix, the actual installation of wind power increased from 1 GW in 2005 to 45 GW in 2010, ranking China top in the world on installed wind power capacity.

Second, improving energy efficiency in the power sector has been and will continue to be the key of China's energy and climate policy. The past two decades have witnessed rapid electrification in China with electrification level increasing from 9% in 1990 to 20% in 2009 [23]. Meanwhile, electricity consumption has experienced a seven-fold growth, remarkably faster than the growth of primary energy consumption (Fig. 3). However, there is still huge gap for China to catch up with its developed counterparts in terms of per capita power consumption. Power generation capacity also experienced rapid growth to meet the increasing power demand. Especially since 2002, when the power sector reform started, the construction of new

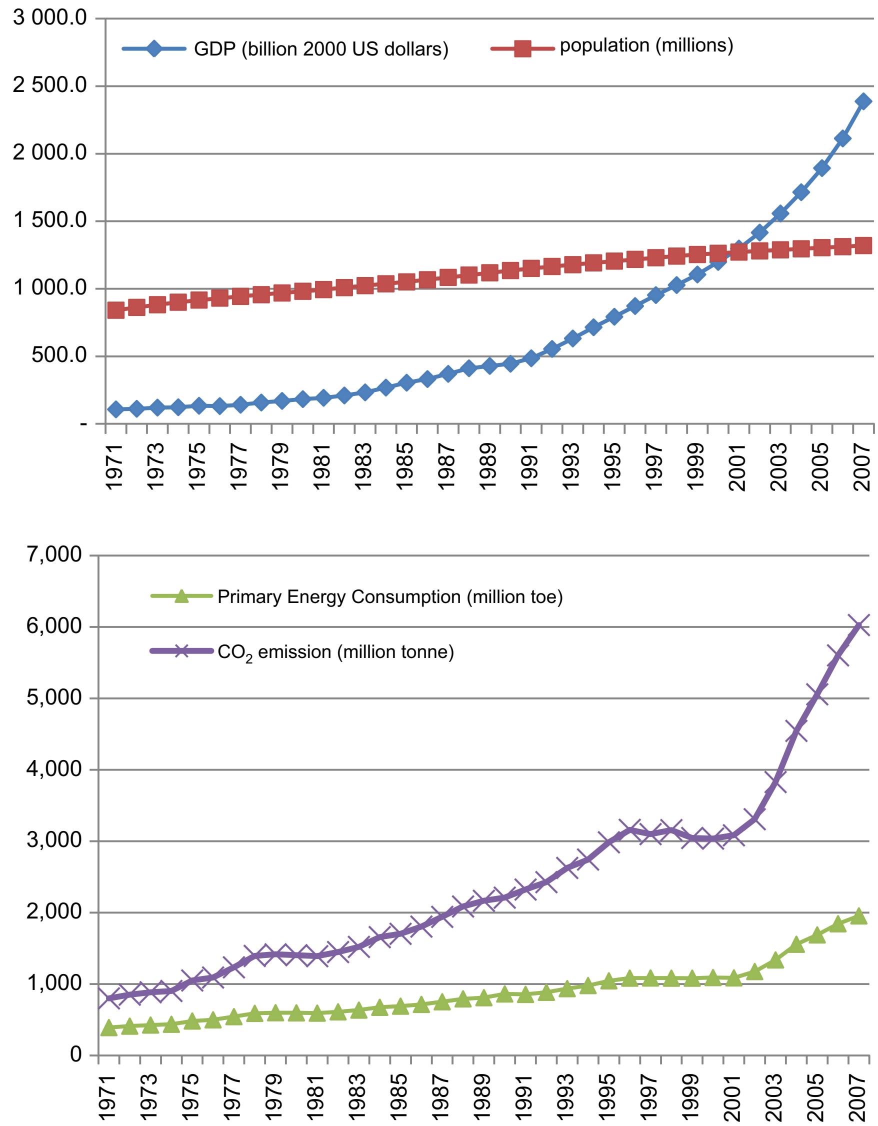

Fig. 1. GDP, population, energy consumption and CO_2 emissions in China, 1971–2007.
Source: [13].

capacity has established new record in the world power history with yearly new addition of installed capacity ranging between 60 and 100 GW. Dominated by coal (Fig. 4), power generation in China alone consumed about 1.6 billion tonnes crude coal, accounting for 49% of China's total coal production in 2010. As the result, the power sector is the largest CO_2 producer in China, accounting for about 45% of total CO_2 emissions, as well as 45.2% and 45.4% of the country's total SO_2 and particulate emissions, respectively.

Given the great challenges and uncertainties facing China's future energy supply and demand, understanding options and pathways to meet both short and long term energy and climate targets becomes crucial for China's policy making as well as international climate governance. We examine this by designing a series of carbon emission scenarios for China which are presented in the next section.

3. Carbon emission projection

3.1. Assumptions and scenarios

GDP growth projection and CO_2 intensity are the two driving variables for compiling carbon emission scenarios. Given the planned economic growth rate and carbon intensity reduction targets, the total carbon emissions caused by energy consumption can be calculated as

$$\textit{Carbon emssions} = \textit{GDP} \times \textit{GDP carbon intensity} \tag{1}$$

The scenarios are compiled in the following ways: 1) GDP growth towards 2015 is projected based on the 12th FYP [12], with an planned annual growth of 7%, while GDP growth towards 2020 is projected in line with Chinese government's 2020 long-term vision with an annual growth rate of 6%; 2) CO_2 intensities in 2015 and 2020 are calculated according to the proposed emission reduction targets. Two scenarios, C40 and C45, are compiled to represent 40% and 45% carbon intensity reduction by 2020, respectively. Finally, as revealed by [7], GDP growth rate is the most important factor on carbon emissions in China. Thus two alternative scenarios are compiled with GDP growth rate one percent point higher than that in C40 and C45; and 3) a reference scenario is compiled based on the UNFCCC 450 ppm scenario for examining the feasibility and desirability of China's target from an international perspective [26]. In particular, from 1996 to 2005, carbon intensity in China experienced an annual decrease of 3%. However from 2003 an upward trend was witnessed because of

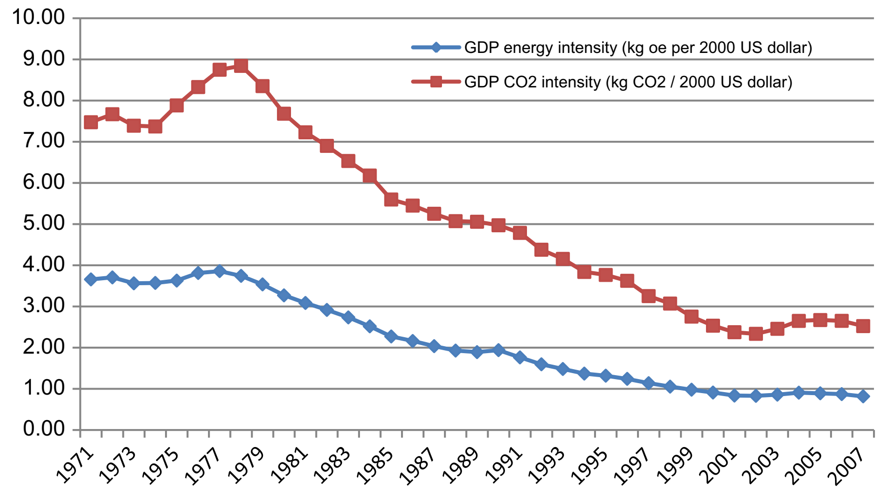

Fig. 2. Energy and CO_2 intensities in China, 1971–2007.
Source: [13].

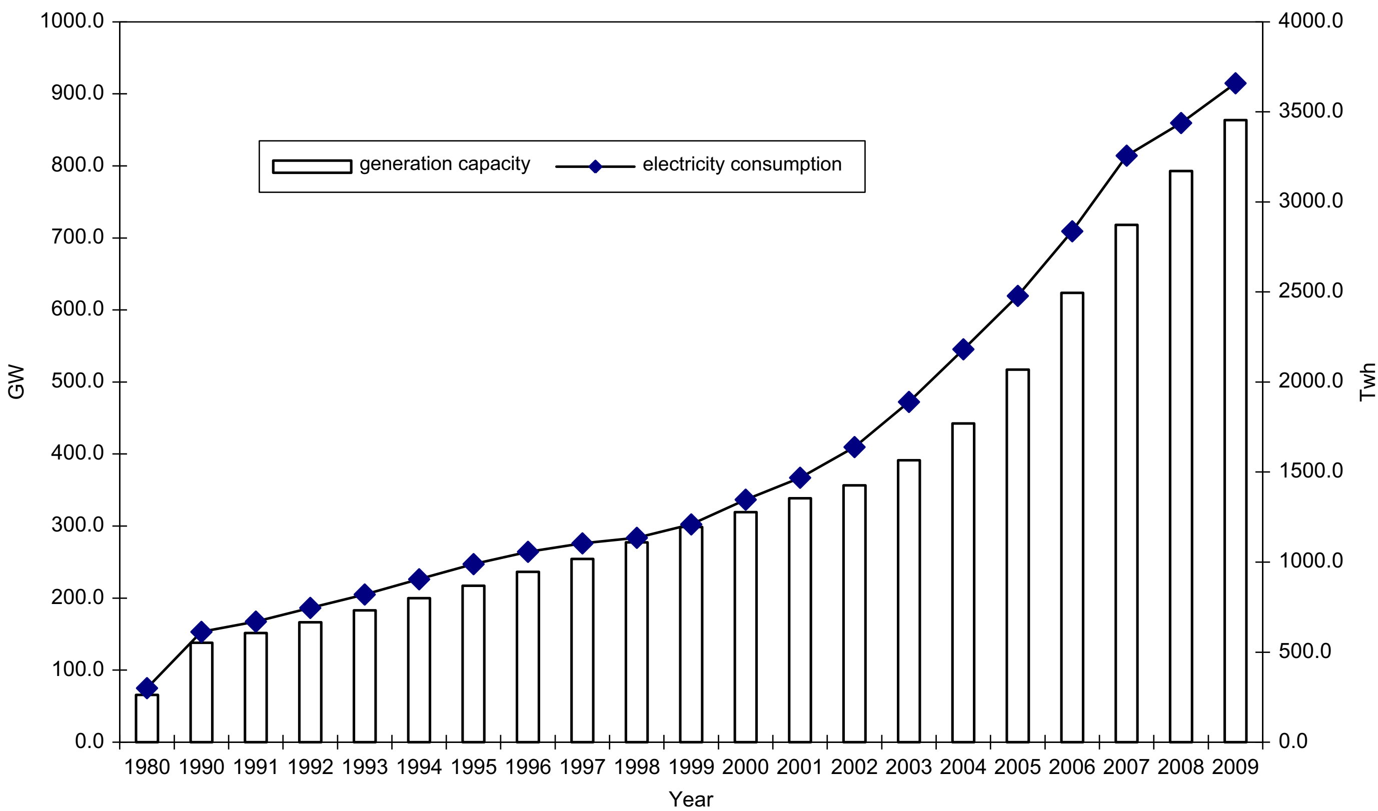

Fig. 3. Power generation capacity and electricity consumption in China, 1980–2009.
Source: [22].

the economic output structure and increasing share of coal in primary energy mix [7]. Because of the intensive policy formulation and implementation, the trend of carbon intensity has already been reversed since 2006. Therefore we assume that, without active policy interventions since 2006, carbon intensity would annually decrease by 1.5% for the 2006–10 period, 2.5% for the 2010–15 period, and 3% for the 2016–20 period.

To address the data quality issue highlighted by [2], data used for scenario compilation in this study are obtained from reputable international agencies as much as possible. Historical data for 2007 and earlier are from UNFCCC2009 [13], while data covering the 2008–2010 period are from NBSC statistics yearbooks or statistics communiqués because of the unavailability of international statistics [26,27].

According to UNFCCC2009, in 2005 China's CO_2 intensity was 2.67 kg CO_2 per US$ (2000 constant price and hereafter). Accordingly, it ranges between 1.47 and 1.60 kg CO_2 per US$ in 2020 under the 40% and 45% reduction targets, respectively.

As a medium target, China plans to decrease carbon intensity by 17% at 2015 as of 2010 level. However, there is yet no official data by Chinese government or international institution reporting China's 2010 carbon emissions or intensity. Thus we first estimated the 2010 carbon intensity for China according to the publically available consumption data of coal, oil, gas and production of

Table 1
Key energy policies and initiatives implemented during the 11th FYP.

Type	Policy	Date effective	Responsible agency
Laws	Formulation of the *Renewable Energy Law*	January 2006	National People's Congress (NPC)
	Revision of the *Energy Conservation Law*	October 2007	NPC and National Development and Reform Committee (NDRC)
Comprehensive policies	Medium and long-term plan for energy conservation	2005	NDRC
	11th FYP	March 2006	NDRC
	The State Council decision on strengthening energy conservation	August 2006	State Council
	Implementation program of 10 key projects during 11th FYP	October 2006	NDRC
	11th Five-year energy development plan	April 2007	NDRC
	Medium and long-term plan for renewable energy development	August 2007	NDRC
	State Council yearly energy conservation plan	2008–2010	State Council
Fiscal policies	Reduced export tax rebate for low value-added and energy intensive products	September 2009	NDRC and Ministry of Finance (MOF)
	Interim management measures for incentive to energy conservation technology reform and phase-out program	2007–2010	MOF
	Regulation on corporate income law (tax reduction or exemption for energy conservation projects and investments)	July 2008	State administration of Tax
	Reform on tax and due of gasoline products	January 2009	NDRC
Sector policies industry	Top-1000 energy-consuming enterprises program	April 2006	NDRC
Buildings	National energy efficiency design standard for public buildings	2005	Ministry of Housing and Urban-rural Development (MOHURD)
	Interim administrative method for incentive funds for heating metering and energy efficiency retrofitting for existing residential buildings in China's northern heating areas	2007	MOF
Appliances	Appliances standard and labeling	Various years	General Administration of Quality Supervision, Inspection and Quarantine (AQSIQ)
	Government procurement program	2005–2007	NDRC and MOF
Transportation	Fuel consumption limits for passenger cars	2004	AQSIQ
	Revised consumption tax for large energy-inefficient vehicles	April 2006	MOF, State administration of Tax
	National phase III vehicles emission standards	July 2007	Ministry of Environment Protection (MEP)
	Pilot popularization program on energy conservation and new energy vehicles	2009	MOF, Ministry of Science and Technology (MOST)

Note: revised by authors based on [18] with updated policy release.

Table 2
Renewable energy resource and generation potential in China.
Source: [21].

Energy source	Available resource	Annual generation potential
Hydropower	390 GW (125 GW small hydro)	1700 TWh
Wind power	10 m high attitude: 250 GW (onshore) 750 GW (offshore); 50 m high attitude: 2000–2500 GW	2000 TWh (10 m) 4000–5000 TWh (50 m)
Solar	1700 billion tce/annual(theoretical) 2200 sunshine hours with 5000 MJ/sq.m for 2/3 land area	128,000 TWh (85.14 million sq. km desert)
Biomass	600–700 Mt/annual	1500–1750 TWh

non-fossil electricity in 2010 using fuel emission factors from [28]. We use currently available primary energy carbon emission factors from 2005 to 2008 by IEA and primary energy consumption structure by NBSC for the estimation based on Eqs. (2) and (3). The emission factors are reported in Table 3 while the 2010 primary energy carbon emission factor is reported in Table 4.

$$\begin{aligned} GDP\ carbon\ intensity &= \frac{carbon\ emssions}{GDP} \\ &= \frac{primary\ energy\ consumption}{GDP} \times \frac{carbon\ emissions}{primary\ energy\ consumption} \\ &= GDP\ energy\ intensity \\ &\times carbon\ emission\ factor\ of\ primary\ energy\ consumption \end{aligned} \quad (2)$$

$$\begin{aligned} &Carbon\ emission\ factor\ of\ primary\ energy\ consumption \\ &= \sum (primary\ energy\ consumption\ share \times fuel\ emission\ factor) \end{aligned} \quad (3)$$

CO_2 emissions of China in 2010 are estimated at 6852 Mt. According to the projected GDP growth and carbon intensity targets, in 2015 China's total CO_2 emissions would reach to 7976 Mt, while in 2020 it would be 8601 and 9382 Mt under C45 and C40 scenarios, respectively. Under reference scenario without new active abatement measures based on UNFCCC09, China's carbon emissions would be 9600 Mt, while 8400 Mt under the 450 ppm scenario [26]. Fig. 5 shows the trajectories of China's carbon emissions to 2020 under different scenarios.

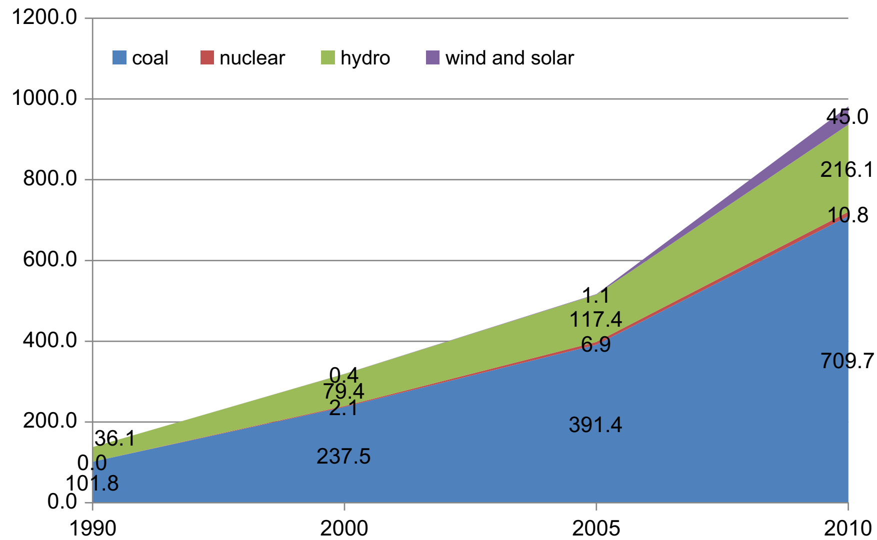

Fig. 4. Power generation mix in China in selected years.
Source: [24,25].

Table 3
Fuel emission factors for calculating primary energy CO_2 emissions.
Source: [26].

Fuel type	Coal	Oil	Gas	Primary electricity (hydro, nuclear and wind power, etc.)
Emission factors (kg/MMBtu)	89	68	52	0
Fuel carbon emission (tonne/toe)	3.53	2.70	2.06	0

Note: though CO_2 emission factor for specific oil or gas product is only with little variation, different coal products have rather wider variation. However, year to year variation would be marginal and has only relatively marginal impact on primary energy emission factor.

Table 4
Estimate of primary energy CO_2 emission factors in China.
Source: [13,29,30].

Year	Primary energy mix (%)				Primary energy carbon emission factor (tonnes/toe)	
	Coal	Oil	Gas	Primary electricity (nuclear, hydro and wind)	IEA data	Estimated by authors
2005	70.8	19.8	2.6	6.8	2.99	2.99
2006	71.1	19.3	2.9	6.7	3.04	3.04
2007	71.1	18.8	3.3	6.7	3.08	3.08
2008	70.3	18.3	3.7	7.7	3.07	3.07
2010	68.7	18.6	4.2	8.3	–	3.01

3.2. Primary energy supply mix

Given the government's 2015 and 2020 non-fossil energy development targets, fossil-based energy will continue playing a critical role in China's primary energy supply. The coal reserve in China could be exploited for more than 100 years under the current production and consumption rate, while the remaining proven recoverable reserves of crude oil and natural gas could be exploited for only 20 years and 37 years, respectively [31]. However, the exploration on gas reserves (including technically recoverable coal bed methane and methane hydrate reserves) in recently years has encouraging progress and may significantly expand its exploitable time [14,32–35]. Because CO_2 emission factor of natural gas is significantly lower than that of coal, gas supply growth could contribute to China's low carbon development and reduce China's reliance on oil import.

Let x and y represent the share of coal and natural gas, respectively, in total primary energy supply in 2015. Because the fossil-based primary energy is planned to be 88.6% in 2015, the primary energy emission factor f can be expressed as

$$f = xf_{coal} + (0.886 - x - y)f_{oil} + yf_{gas} \tag{4}$$

where $0.886 \geq x,y \geq 0$; $0.886 \geq x+y \geq 0$; and f_{coal}, f_{oil}, *and* f_{gas} stand for emission factors for coal, oil, and natural gas in tonne/toe as shown in Table 3. Thus,

$$f = 3.53x + 2.7(0.886 - x - y) + 2.06y = 0.83x - 0.64y + 2.39$$

Similarly, for 2020, given the planned non-fossil energy is 15%,

$$f = 3.53x + 2.7(0.85 - x - y) + 2.06y = 0.83x - 0.64y + 2.30$$

To minimize f, the primary energy emission factor, smaller x (share of coal) and larger y (share of natural gas) are desired, implying to reduce the share of coal and increase the share of natural gas in the primary energy mix. The optimized solution would be as large share of gas as possible. However, considering the reality that there is huge inertia in energy system, construction of extraction and transportation infrastructure for gas needs lead times of several years, and there is strong demand for oil because of increasing private vehicle ownership, it is assumed that oil share would drop slightly and the share of gas would increase only gradually in the coming decade.

3.3. Discussions on the carbon emissions study

According to the above carbon emissions scenarios analysis, the following conclusions can be drawn: 1) the carbon intensity targets proposed by Chinese government are consistent with the macro-level economic and social development planning; and 2) the 45% reduction target is in line with international expectations on China's responsibility of carbon stabilization under the 450 ppm scenario. However, there is great uncertainty regarding the second conclusion because heavy burden is imposed for the 13th FYP period on energy conservation to realize the CO_2 intensity reduction target.

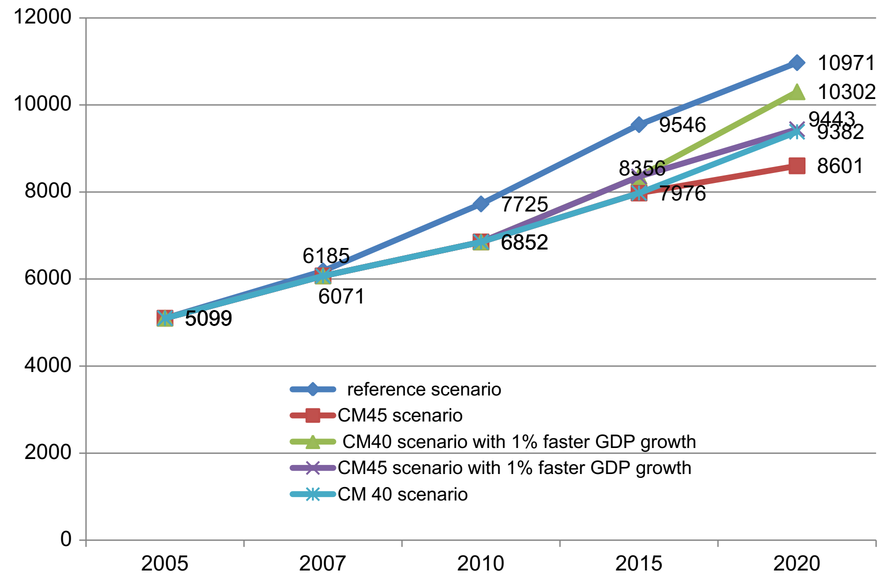

Fig. 5. Different carbon emissions scenarios for China.

Table 5
Decomposition of China's energy related CO_2 emissions over the next decade (Unit: Mt).

	Scale effect (GDP growth)	Energy intensity	Primary energy mix	Total increase
2010–15	2757	−1349	−284	1124
2015–20	2697	−1616	−454	627

The good news is that under the planned economic growth rate, if the 45% carbon intensity reduction target is realized, China's annual CO_2 emission by 2020 would likely stay close to the international expectations. China's CO_2 emissions would be flat after 2015 because of efforts on improving energy efficiency and developing non-fossil energy. On the other side, the bad news is that if economic growth were faster than planned (one percent point faster than planned), which is very likely to happen given China's conspicuous economic growth achievement in the past three decades, a 40% decrease in carbon intensity would result in total CO_2 emissions at 10,302 Mt in 2020, while the 45% decrease target would also amount to 9443 Mt CO_2 emissions in 2020. Both results would be well above the 450 ppm scenario. Interestingly, under the current plans for economic growth, carbon intensity reduction, and non-fossil primary energy, China would only be able to increase its CO_2 emissions by 600 million tonne from 2015 to 2020 which would exert a heavy burden for the 13th FYP on energy efficiency enhancement (Fig. 5). To accomplish such tremendous task, China must be devoted to energy efficiency by all means (including not only the successful experience of technology advancement but also economic restructuring) on the one hand, and optimize primary energy supply, especially power supply, on the other hand. In the next section, we examined China's primary energy and power planning in more details.

4. Primary energy and power planning

4.1. Requirements on energy efficiency and economic restructuring

To realize the proposed CO_2 intensity reduction targets, energy conservation by efficiency enhancement and economic restructuring would be of first priorities. A decomposition analysis indicates that, without decrease in energy intensity and primary energy emission factor, growth in GDP would result in 2757 Mt CO_2 emissions from 2010 to 2015. To keep the total CO_2 emissions under 1124 Mt to meet the intermediate target, the 11.4% non-fossil energy share could contribute a decrease of 284 Mt, while the remaining 1349 Mt would come from a reduction in energy intensity. During the 2015–2020 period, GDP growth would result in 2697 Mt CO_2 emissions, while a 454 Mt reduction could from primary energy structure (15% non-fossil energy share) and another 1616 Mt reduction could from the reduction of energy intensity (Table 5).

The implication is that, from 2010 to 2015, reduction of 1349 Mt CO_2 emissions or primary energy conservation in the amount of 450 million toe (640 million tce) needs to be realized. From 2015 to 2020, reduction of 1616 Mt CO_2 emissions or 545 million toe (780 million tce) primary energy conservation needs to be realized from energy efficiency enhancement, which would come mainly from technology advancement and structural adjustment. In this paper, we assume that the current policy in the power and manufacturing sectors during the 11th FYP will continue, while similar policy will be implemented in building and transportation sectors. Thus the energy conservation plan is mainly drafted from four sectors: power, manufacturing, building, and transportation. Finally we attribute the gap with the primary energy conservation goal to economic restructuring. In the manufacturing sector, decrease in energy intensity would contribute most to energy conservation, considering the existing large gap of energy intensity of main energy-intensive products between China and international best practices [35,36] as shown in Table 6. The production scale of different products is projected for energy conservation potential estimate based on different predictions as shown in Fig. 6 [37–39]. Energy conservation in buildings mainly comes from green lighting, efficient appliances, and improved Heating Ventilating and Air Conditioning (HVAC) system. In the transportation sector, energy saving comes from improving fuel economy in traditional vehicles, penetration of hybrid and electric vehicles, and the substitution of private transportation by public transportation. In the coal mining sector, the recovery and utilization of coal bed methane could contribute significantly to energy conservation. According to various estimates, there is 30 million tce potential during the 12th FYP if only 20% of the technologically feasible methane with density below 30% is utilized. Another 30 million tce would be possible if the recovery rate increases to 40% during the 13th FYP. While large portion of the energy conservation potential would come from energy efficiency improvement in manufacturing, building, and transportation, the remaining would come from economic restructuring, i.e., output structure toward service industry and the light of manufacturing, especially in the 13th FYP (Table 7). It would thus pose a tremendous challenge for China to realize the CO_2 intensity reduction target considering that historically the influence of structural effect on carbon growth has never been negative ever since 1990s [40].

According to [18], during the 11th FYP, energy efficiency policy in China has been restricted by issues of deficiency in institution design, lack of systematic policy implementation, discordance between energy conservation goal and development pattern, and most importantly, lack of coordination between market mechanism and command-and-control. Chinese government has been heavily relies upon command-and-control as the main policy instrument. As the market mechanism becomes more and more dominate in Chinese economy, the effectiveness of command-and-control policy has been significantly weakened. Though our analysis indicates that it is possible to realize even more ambitious energy conservation target in the coming decade, China needs to first address the above issues properly to assure the effectiveness of its policy instruments. Furthermore, the transition of economic growth to a quality-oriented pattern, which is beyond the scope of energy policy, will certainly pose larger challenge to China's energy sustainability.

4.2. Primary energy planning

The basic assumptions underlying primary energy planning are

- The share of fossil fuel for coal, oil and gas is set as 65.1:18:5.5 at 2015 and 60.5:17.5:7 at 2020.
- The resource availability and technological feasibility of different in-shelf energy options as hydropower, nuclear, USC, CHP and gas power, etc.; and the resource potential and technological-economic potential of different niche energy options as wind, solar and biomass power, etc.
- Electricity production would grow quickly in the sense that most of the clean energy (nuclear, hydro, wind, solar and others) utilization would be used for power generation. Accordingly, non-fossil electricity production would reach 1523 TWh and 2188 TWh to fulfill the 11.4% and 15% non-fossil share targets in 2015 and 2020, respectively. Meanwhile, with per capita GDP at 3150 and 4050 US$ (2000 constant price), we assume that per capita electricity consumption would reach 3950 and 5000 KWh respectively. Therefore, the total electricity consumption would reach 5500 TWh and 7200 TWh in 2015 and 2020, respectively. Supposing the sum of power plant own consumption (6% in 2008) and line loss (T&D) (6.8% in 2008) decrease by 1% point every five years, the total electricity production would reach 6180 and 8 010 TWh respectively in 2015 and 2020, and the ratio of clean generation would increase to 24.6% and 27.3% respectively.

Table 6
Planning of energy intensity for selected energy-intensive products for 2015 and 2020.

Product	2000	2007	2015	2020
Cement (kWh/tonne)	140	115	100	90
Steel (kg sce/tonne)	840	600	500	400
Aluminum (tce/tonne)	9.9	9.55	5.5	4.7
Ammonia (kg sce/tonne)	1670	1600	1400	1300
Ethylene (kg sce/tonne)	850	690	600	510
Oil refinery (kg soe/tonne factor)	14	12.5	11	9.5
Coal in power generation (grammes sce/KWh)	410	356	315	300

According to estimated CO_2 emissions and primary energy mix, primary energy demand is projected to reach 2944 Mtoe in 2015 and 3110 Mtoe in 2020. The demand for coal, oil, gas and primary electricity are calculated according to the planned energy mix as shown in Table 8.

Note: the population for calculating per capita energy consumption and CO_2 emissions is based on the 12th FYP control target (1.39 billion) for 2015 and the assumption that population grows at the same rate during the 13th FYP period (1.44 billion).

Among the gas supply, 24 Bcm would come from coal bed gas during 12th FYP, contributing about 14% of total gas supply, while additional 60 Bcm would come from coal bed gas. Gas hydrate would contribute 24% of total gas supply in China. For oil, the most optimistic situation is that domestic oil production would stabilize at around 200 Mt in the coming decade and the import dependence of oil consumption in China would range between 58 and 60%, imposing another significant challenge for China in energy security.

4.3. Power planning

Since most of the renewable energy will be developed for power generation, power planning is central to energy planning

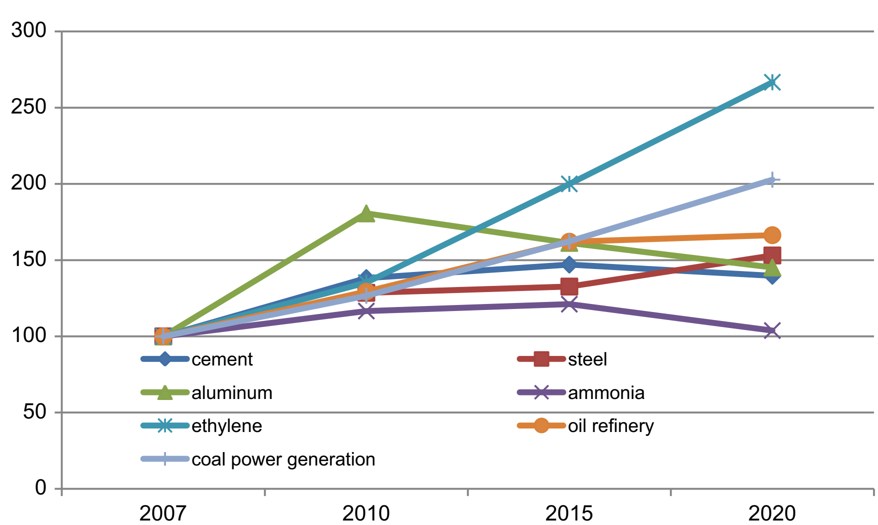

Fig. 6. Assumption on the production of energy-intensive products for 2015 and 2020 (2007 = 100).

Table 7
Energy conservation planning for 12th and 13th FYPs (Unit: Mtce).

	Energy conservation planning by sector	Period	
		2015/2010	2020/2105
Manufacturing	Ferrous metal	70	80
	None-ferrous metal	80	50
	Chemical products	25	25
	Construction material	15	10
	Other sectors	50	30
Power sector	Thermal power generation (small plant closure and building CHP)	80	80
	Power grid	20	20
Coal mining	Coal bed methane generation	10	30
Building	Green lighting	60	80
	Efficient appliances	55	65
	Improved HAVC and insulation	45	60
Transportation	Improved fuel economy (penetration of electric car)	5	10
	Public instead of private transportation	25	40
Output restructuring		100	200
Total		640	780

Note: 1) in the manufacturing sector, energy conservation (EC) potentials in energy-intensive sectors are calculated according to the energy intensity index (Table 6) and expected production (Fig. 6), while potential from other sectors is estimated based upon the efficiency potential in industry kilns and electric motors; 2) in the power sector, EC potential from power generation is estimated based upon the improvement of coal consumption for generating per KWh electricity, while potential from power grid is based upon the assumption of line loss rate decrease by one percent point every five years in the coming decade; 3) potential in the coal mining sector is estimated based upon the recollection and utilization rate of low density coal bed methane at 7.5 and 22.5 Billion cubic meters (Bcm) natural gas equivalents respectively during the 12th and 13th FYPs; 4) in the building sector, potential from green lighting is based on the assumption that 15% bulbs in the total lighting bulbs realize energy efficiency by 60% during the 12th FYP and another 15% is realized 60% energy efficiency during the 13th FYP, while lighting accounts for about 12% of total electricity consumption. Potential from appliances is calculated based upon the assumption that resident accounts for 15% of electricity consumption in 2015 and 2020, while 10% more of 70% energy efficient appliances is popularized in the total inventory during each of the 12th and 13th FYPs. Potential from HVAC is calculated based on the assumption that 1.2 billion square meters resident buildings are retrofitted during both 12th and 13th FYPs, and 60% and 80% of new buildings constructed can meet with the 65% energy efficiency standard during the 12th and 13th FYPs, respectively; 5) in the transportation sector, potential from improved fuel economy is based on the assumption that the total cars would reach 140 million and 200 million in 2015 and 2020, respectively. The fuel economy would reach 40 miles per gallon (mpg) and 45 mpg, and the share of new energy vehicles would reach 1% and 5%, respectively, in 2015 and 2020. Potential from substitution by public transportation is calculated based on the assumption that with proper policy, the annual mileage of private cars would reduce by 30%.

Table 8
Energy planning for China, 2010–2020.

	Primary energy (million toe)	GDP energy intensity (kg soe/US$)	GDP CO2 intensity (kg CO2/US$)	Energy per capita (toe/person)	CO2 per capita (tonne/person)	Coal (million tonne)	Oil (million tonne)	Gas (billion cubic meters)	Non-fossil electricity (TWh)	Electricity consumption (TWh)	Electricity production (TWh)	Clean power generation (%)
2010	2272	0.73	2.20	1.69	5.46	3135	425	105	797	4198	4227	18.9
2015	2944	0.63	1.82	2.12	5.74	3838	475	174	1523	5500	6180	24.7
2020	3110	0.53	1.47	2.16	5.97	3769	523	234	2187	7210	8011	27.3

Table 9
Capacity factor of different power generation types for power planning in China.

	Natural gas (%)	Coal (%)	Biomass (%)	Nuclear (%)	Wind (%)	Hydro (%)	Solar (%)
2010	30	57	25	89	23	37	19
2015	32	70	25	89	26	40	19
2020	35	80	25	89	30	42	19

Table 10
Power planning for China, 2010–2020.Unit: GW

	Natural gas	Coal power	Biomass (waste and waste heat)	Nuclear	Wind	Hydro	Solar	Total
2010	12.0	695.0	0.0	10.8	45.0	216.0	0.3	979.1
2015	25.0	747.9	15.0	45.0	92.0	260.0	12.0	1196.9
2020	50.0	809.1	25.0	75.0	180.0	295.0	25.0	1459.1

Note: 5 GW and 10 GW IGCC plant are included in the coal power plant at year 2015 and 2020 respectively.

and clean energy development [23]. The capacity factors for different generation technologies are parameterized in Table 9. We assume that during the planning period, with proper policy formulation and implementation, the wind capacity factor will reach its upper limit and that of coal will also reach as high as 80%. The capacity factor of nuclear power will stabilize at about 89% and that of hydropower will reach 42%. The capacity factor of natural gas power will stay at about 35% because it is relatively more expensive and is mainly used for peak generation. Biomass and solar power will keep stable capacity factor during the periods (Table 9).

Accordingly, the power planning for 2010–2020 is compiled and provided in Table 10. Among the gas power plant, in 2015, 7.5 GW units of coal bed gas turbine are included. In 2020, 22.5 GW such units are included. Among the biomass power plants, 5 GW waste heat turbine units in manufacturing industries (for example cement and steel) are included in 2015, while 10 GW such units are included in 2020. We then compile the detailed power planning based on efficiency improvement by closure of small inefficient coal units and the decommissioning projections of the operating coal and hydropower units (Table 11).

4.4. Investment requirements

When calculating the investment requirements, the following assumptions are made: 1) for energy production and conversion sector, only the investment in power generation and power grid will be included. The unit investment cost for matured technology of coal, natural gas, hydropower and nuclear is assumed to be stable, while that of wind, solar and IGCC-CCS is assumed to have a learning effect (Table 12); 2) because of the difficulty of separating the investment on energy efficiency from other purposes in different sectors, only the government's public money in terms of customer buy-down or investment subsidy will be included (Table 13). And the government input will be calculated according to the current implemented support policy and the projected energy conservation targets in different sectors; and 3) all the investment cost is calculated based on 2010-year constant price RBM.

Accordingly, the investment requirements for implementing the energy planning during 12th and 13th FYP periods are estimated and provided in Table 14. During the 12th FYP period, a total of 5054 billion RMB energy-related investments are estimated, while the power sector alone needs 4267 billion and the rest 787 billion will be energy efficiency investment. During the 13th FYP period, a total of 5611 billion RMB investments are required, 4662 billion for power investment and the rest 950

Table 11
Change in power generation capacity according to the planning. Unit: GW.

Periods		Natural gas	Coal	Biomass	Nuclear	Wind	Hydro	Solar
2010–2015	Net increase	13.0	52.9	15.0	34.2	47.0	44.0	11.7
	Closure of small units	–	−40.0	–	–	–	–	–
	Retirement units	–	−40.0	–	–	–	−10.0	–
	New construction	13.0	132.9	15.0	34.2	47.0	54.0	11.7
2015–2020	Net increase	25.0	61.2	10.0	30.0	88.0	35.0	13.0
	Closure of small units	–	−10.0	–	–	–	–	–
	Retirement units	–	−40.0	–	–	–	−10.0	–
	New construction	25.0	111.2	10.0	30.0	88.0	45.0	13.0

Table 12
Unit investment cost for different generation types. Units: RMB/KW.

year	IGCC-CCS	Natural gas	Coal	Biomass (waste)	Nuclear	Wind	Hydro	Solar
2010	11000	7000	3700	6000	15000	8000	10000	20000
2015	9000	7000	3700	6000	15000	7000	10000	14200
2020	8000	7000	3700	6000	15000	6000	10000	11600

Notes: 1) unit investment cost data for 2010 is sourced from and 2) the investment cost of IGCC-CCS doesn't include CO_2 transportation and storage cost [25].

Table 13
Government subsidy policy and implementation on energy conservation in China.

Sector	Subsidy policy	Implementation requirements
Coal power	600 RMB/KW for closure of small units	40 GW during 12th FYP periods and 10 GW during 13th FYP periods
Industry	1000 RMB/tonne sce conservation	240 and 215 million tce conservation capacity during 12th and 13th FYP periods
Green lighting	30–50% sale price of the bulb to end-users	Popularizing 500 million pieces high efficient lightings in household during 12th and 13th FYP periods, realizing 100% green lighting in all public and commercial buildings
Building refurbishment	45–55 RMB/m2	Refurbishing 1.2 billion m2 resident space during 12th and 13th FYP periods
Appliances	Subsidy to end-customers: air conditioner: 300–850 RMB/ unit washing machine: 200–600 RMB/unit refrigerator: 200–800 RMB/unit	Covering all energy-intensive appliances as AC, washing machine, refrigerator, etc.
Transportation	Subsidy to end-customers: pure electric car 50000 RMB/ vehicle hybrid car 30000 RMB/vehicle	1% penetration of electric vehicles at 2015 and 5% at 2020

Notes: 1) according to study on cost and benefit of closing small in-efficient coal plant during the 11th FYP, a total of 32.77 billion fund is input for closing 54.07 GW small units from 2006 to 2009 [41], which translates 600 RMB/KW government fund support for closing small coal units; 2) during the 11th FYP period, a total of 235 billion RMB fund from the central government is provided in industry for energy efficiency and resulted in about 240 million tce energy conservation capacity [42]. Though the State Council encourages local governments to provide special fund for energy efficiency also, the amount is difficult to trace. According to the fund from the central government, it is roughly calculated as 1000 RMB/ tonne sce conservation realized in industry.

Table 14
Investment requirements for the energy planning at 12th and 13th FYP periods. Units: Billion RMB.

	Power industry				Energy efficiency			Total
	Generation	Clean generation	Power grid	Subtotal	Industry	Building	Transportation	
12th FYP	2081	1004	2498	4267	240	165	70	5054
13th FYP	2274	1275	2729	4662	208	200	200	5611

Notes: 1) coal bed gas generation and waste heat generation investment requirements are included in power generation; 2) historically, the investment on power grid in China is insufficient. During the 8th and 9th FYP periods, power grid only accounted for only 13% and 37% of total power investment, which is significantly lower than the level of developed countries (well above 50%). However, since 2008, investment on power grid has outnumbered that on power plant. With the massive investment on smart grid, we assume that the investment ratio on power plant and power grid will be 45:55 in the coming decade.

billion for energy efficiency investment. The massive investment requirement would pose another challenge for China to realize low carbon development.

5. Concluding remarks

Sustainable development is the inevitable choice of China. The analysis in the paper indicates that the 2020 45% CO_2 intensity reduction target is not only within the international expectation, but also self-consistent with the long-term vision of China's overall socio-economic planning. If accomplished, it will make significant contribution to global climate mitigation. Moreover, China has formulated a host of policies to implement the target even since 2005 and made encouraging progress in the past five years.

On the other hand, the target is unprecedented and formidable in that energy conservation by technology advancement alone is not enough to ensure the accomplishment of the target. Even though the government is determined to preserve the route of energy policy during the 11th FYP, our study indicates that adjusting output structure would be imperative in the coming decade, especially in the 13th FYP. According to the above analysis, the viable policy options for China are as follows:

1. Maintain a balanced economic growth with intensified efforts to raise the share of the service industry in its economy and curb the growth of heavy industry. China must incorporate energy and environment targets within its overall socio-economic planning and coordinate energy policy with industry, taxation and finance policies to attain the maximum effects of the policy mix.
2. Develop non-fossil "clean" alternatives according to the proposed target, including nuclear, regular hydro, wind, solar and biomass energy as early as possible to decrease primary energy emission factor. Considering the past experiences of quicker than planned economic growth, China should not just confine itself to the proposed non-fossil share target. Also, developing clean energy technology itself could serve as a very opportunity for facilitating economic output restructuring. However, to promote the take-off of renewable energy in China, the government must formulate systematic and practical policies covering upstream research & development and downstream commercialization & deployment [43].
3. Strengthen energy conservation in building and transportation sectors while the manufacturing sector still possesses vast potential. With the rising income, building and transportation sectors will consume more and more energy. By proactive measures as building codes, vehicle fuel economy standards, priority of public transportation, etc., huge energy demand could be avoided in the future.
4. Adjust the coal plant mix could still contribute large portion on energy saving since it will continue to dominate the generation mix in the coming decade. Increase energy efficiency in coal power plants by replacing outdated inefficient small-scale units with ultra-super critical and (or) cogeneration units. Implement CCS technology in commercial scale at least from 2015 in large-scale coal generation plants to provide more growth space for primary energy demand.
5. Deregulate energy market with strong determination and formulate level playing field to attract investments for private and foreign capital. Establishing strong partnerships with developed countries on low carbon energy development also would be policy priority for China.

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