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China's 2020 clean energy target: Consistency, pathways and policy implications

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HIGHLIGHTS

- CO_2 emissions and energy scenarios for China into 2020 are constructed.
- The clean energy target must be raised to 17% to be consistent with GDP and energy planning.
- This target of 17% can meet international expectation on China's CO_2 control duty.
- Detailed pathways for the target are outlined and a policy package proposed.

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ABSTRACT

China has proposed its 2020 clean energy target together with the climate change target of reducing CO_2 intensity of the economy by 40–45% below the 2005 level. This article investigates the feasibility of these targets by testing their consistency under possible economic development scenarios. We analyse these targets from two perspectives: consistency with the overall economic growth and consistency with the international society's expectation on China's greenhouse gas (GHG) abatement responsibilities. The main findings are: under the recently announced 2020 target of gross domestic product (GDP) that is double the 2010 level, the adoption of a 15% clean energy target could result in excessive primary energy demand; and then with 40–45% GDP CO_2 intensity reduction, CO_2 emissions in 2020 could substantially exceed the International Energy Agency (IEA) 450 ppm scenario for China. Thus we propose a 17% clean energy target that can reconcile the domestic plan with international expectation. Our article also outlines the pathways to realise clean energy development into 2020 and proposes policy recommendations.

1. Introduction

China has long been puzzled by the dilemma of economic growth and environmental protections. Constrained by energy resource endowment, energy supply in China has long been dominated by coal. Serious pollution and greenhouse gas (GHG) emission, along with low energy efficiency, have posed enormous risk to China's energy sustainability as well as socioeconomic development. Striving to develop non-fossil energy is an urgent yet essential issue for China to ensure energy security and to respond to climate change mitigations.

In 2007, China issued the *National Program of China to Response to Climate Change* as the guide for its climate policy (State Council of China, 2007). Reducing the energy intensity of the economy (measured in energy consumption per unit GDP) by 20% in 2010 relative to the 2006 level was emphasised as a key measure. This target is to bring about conservation of primary energy consumption by 620 million tonnes coal equivalent (tce[1]) and abatement of CO_2 emissions by 1500 million tonnes (Mt). As a result, the energy intensity per unit GDP dropped by 19.5%, from 1.28 tce at 2006 to 1.03 tce at 2010 per 10,000 RMB yuan (2005-year constant price, and hereafter) (NSBC and NDRC, 2011).

Then during the 2009 Copenhagen UN Climate Change Summit, President Hu Jintao pledged to the international community to reduce the CO_2 intensity of the economy by 40–45% by 2020 on the baseline level of 2005 (Hu Jintao, 2009). Meanwhile, the share of non-fossil energy is also expected to rise to 15%. China's 2020 commitments have been incorporated into the national economic

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[1] 1 tce = 0.7 toe = 27.77824 MMBTU.

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and social development plan as two binding indices, following with statistic measurements (State Council of China, 2011a).

In 2011, China issued the *Work Program for Controlling GHG Emissions during the 12th Five-Year-Plan (FYP) Period* (State Council of China, 2011b). The programme states explicitly the overall requirements of GHG control during 2011–2015 and adopts the target of reducing CO_2 intensity of the economy by 17% in 2015 below the 2010 level. Meanwhile, it adopts another binding target of achieving 11.4% of clean energy in the total primary energy supply.

The following issues can be therefore derived from China's energy policy and the international community's requirement on climate change governance: 1) Is China's clean energy and CO_2 intensity target consistent with its overall economic target? 2) Is China's clean energy target consistent with the international community's GHG control expectation on China? 3) What is the feasible clean energy planning for China to realise these targets? Although existing literatures have addressed the feasibility of China's energy plan and the corresponding policies extensively, answer to the preceding issues remain unclear (Stern and Jotzo, 2010; Zhang, 2010; Uwasu, Jiang and Saijo, 2010; Dai et al., 2011; Steckel et al., 2011; He, Deng and Su, 2012). A relevant paper by Yuan, Hou and Xu (2012) discusses the feasibility of China's 2020 GDP CO_2 intensity target, with an emphasis on the potential of energy conservation in different sectors and power sector planning. In our article, based on the indices of China's GDP growth, energy consumption and carbon emissions, a quantitative scenario study will be presented to address the first two issues. Then consistent clean energy target and pathways will be outlined for the third issue.

The remainder of the article is structured as follows. Section 2 analyses the trajectory of economic growth, energy consumption and CO_2 emissions in China. Section 3 illustrates the methodology and key assumptions. Section 4 forecasts the energy demand and CO_2 emissions scenarios for China in the coming decade. Section 5 proposes an alternative consistent target of clean energy share and drafts the pathways. Section 6 demonstrates policy recommendations and Section 7 presents conclusions.

2. The Trajectory of Economic Growth, Energy Consumption and CO_2 Emissions in China

2.1. Economic growth

After the 1978 reform-and-open-up policy, the miracle of China's economic growth was enabled at a two-digit growth rate (Fig. 1). It sagged in 2008 due to the global financial crisis, and then quickly recovered in 2009.

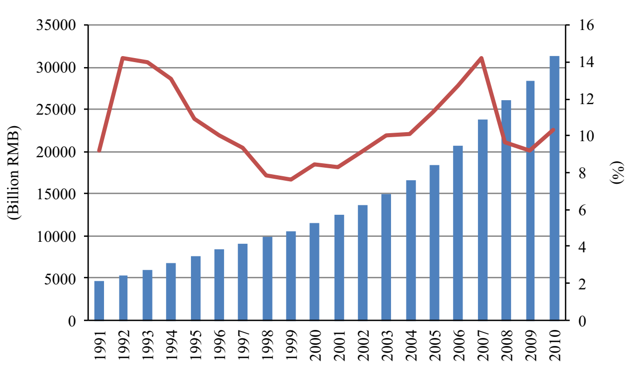

Fig. 1. China's GDP growth, 1991 to 2010 (source: NBSC, 2012).

2.2. Primary energy consumption

Energy consumption in China has increased steadily with its rapid economic growth. Primary energy consumption had increased twofold from 1037 million tce (Mtce) in 1991 to 3249 Mtce in 2010. Despite the economic downturn due to the 1997 Asian financial crisis (Zhang, 2003), volume of energy consumption sharply bounced back in 2002 when China entered the phase of rapid industrialisation (Fig. 2).

2.3. Primary energy structure

Fig. 3 shows an increase of non-fossil energy over primary energy during 1985–2010. The global average share of coal is 28% in the world, whilst it accounts approximately 70% of China's total primary energy consumption. It is worth mentioning that after 2003, despite a worldwide downturn, coal's share tended to increase in China until 2007. Afterwards, it declined to 68% in 2010 due to an active energy conservation policy during the 11th Five-Year Plan (FYP) period. Meanwhile, the share of oil over the primary energy source has increased annually, accounting for 19% in 2010. Similarly, the share of natural gas also increased, accounting for 4.4% in 2010. Meanwhile, non-fossil energy has experienced rapid growth under policy incentives since 1995, and the growth was largely accelerated since 2005 when China issued its legislation to promote renewable energy.

2.4. CO_2 emissions

As illustrated in Fig. 4, China is one of the biggest GHG emitters and its trajectory of CO_2 emissions has closely followed the trend of energy consumption. The sharp growth of CO_2 emissions reached and stayed at the peak since 2003 and later. This is caused by China's primary energy structure and the economic structure, which is dominated by the manufacturing industry.

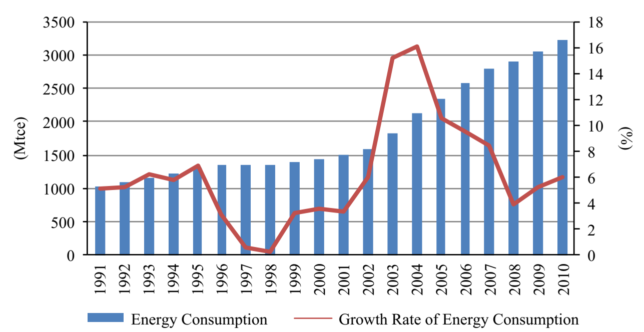

Fig. 2. China's energy consumption and its growth rate, 1991 to 2010 (source: NBSC, 2012).

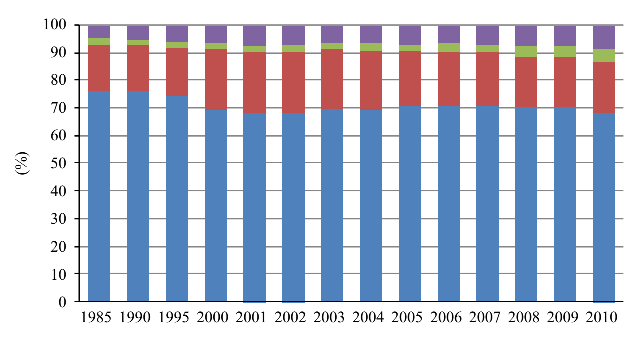

Fig. 3. The structure of primary energy in China, 1985–2010 (source: NBSC, 2012).

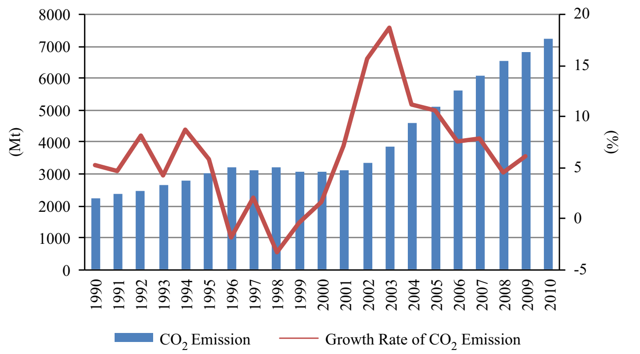

Fig.4. China's CO_2 emissions and growth rate, 1990 to 2010 (source: IEA, 2012).

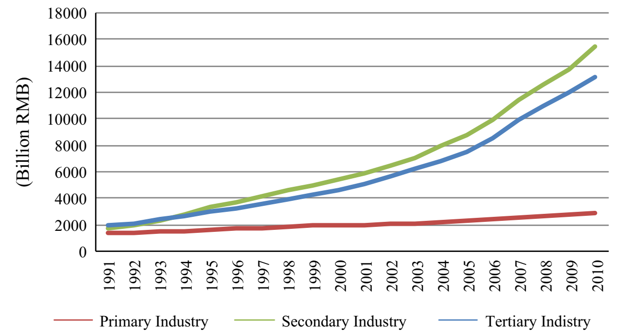

Fig. 6. Growth rate of primary, secondary and tertiary industry in China, 1991 to 2010 (source: NBSC, 2011).

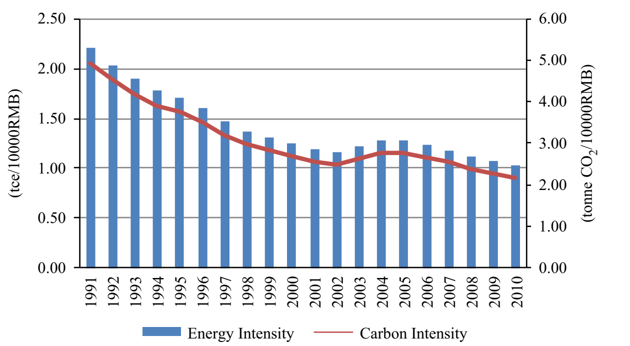

Fig. 5. China's energy and CO_2 intensity, 1991–2010 (source: NBSC, 2011; IEA, 2012).

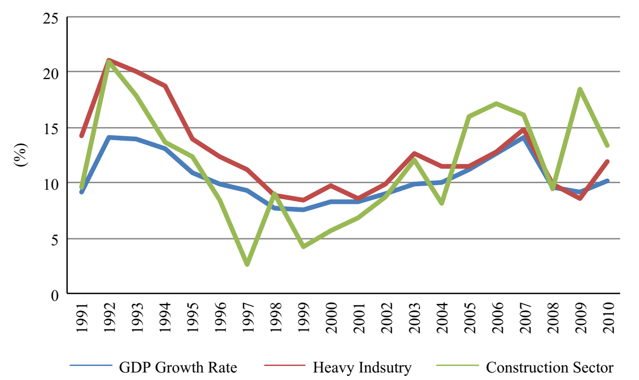

Fig. 7. Growth rate of heavy industry, construction sector and GDP in China, 1991–2010 (source: NBSC, 2011).

2.5. *Energy and CO_2 intensity*

Besides a lack of technology innovations, the high share of the manufacturing sector in the total economy, low value-added of the economic output and international transfer of energy and resource-intensive industry to China are summarised as the key factors of China's high energy intensity. The energy intensity and CO_2 intensity can represent the overall energy efficiency and the output structure of an economy. As elaborated in Figs. 5–7, China's energy and CO_2 intensities declined from 1990 to 2010, and then went up following the rising of secondary and tertiary industries, especially the growth of heavy industries and the construction sector.

3. Methodology and Assumptions of the Study

3.1. *Methodology*

Given economic growth and CO_2 intensity target, CO_2 emissions can be expressed as Eq. (1):

$$Carbon\ emission = GDP^{*}GDP\ Carbon\ intensity \quad (1)$$

Eq. (1) can be rewritten as Eq. (2):

$$GDP\ CO2\ ntensity = \frac{CO2\ emission}{GDP} = \frac{primary\ energy\ consumption}{GDP} \times \frac{CO2\ emission}{primary\ energy\ consumption} = GDP\ energy\ intensity * CO2\ emission\ factor\ of\ primary\ energy\ consumption \quad (2)$$

The CO_2 emission factor of primary energy is the weight value of the fuel emission factor as expressed in Eq. (3).

$$CO2\ emission\ factor\ of\ primary\ energy\ consumption = \; = \sum(primary\ energy\ consumption\ share^{*}\ fuel\ emission\ factor) \quad (3)$$

The process of scenario compilation and consistency testing is shown in Fig. 8. The year 2005 is regarded as the baseline year in order to calculate the 2020 CO_2 intensity under a 40% or a 45% reduction target. The scenarios of CO_2 emissions can be obtained from the GDP growth scenarios. By comparing the scenarios with the International Energy Agency (IEA) scenario, we can test whether China's CO_2 intensity target is consistent with the global expectation. GDP, primary energy consumption, CO_2 emissions and primary energy structure data can be used to calculate the CO_2 intensity and emission factor of primary energy. The CO_2 emission factor of primary energy for 2015 and 2020 can be estimated according to adopted 2015 and 2020 targets of non-fossil energy penetration and projections of fossil fuel share (coal, oil and gas). Furthermore, GDP energy intensity for 2015 and 2020 can be calculated by Eq. (2). Primary energy demand can be calculated with the GDP scenario and GDP energy intensity. Whether China's overall GDP growth target is consistent with the CO_2 intensity and clean energy development targets can therefore be tested by comparing the estimated scenarios with China's officially released schemes.

3.2. *Key assumptions*

3.2.1. *GDP growth*

The 18th National Congress of the Communist Party of China (CPC) proposed to double the GDP and personal disposable income

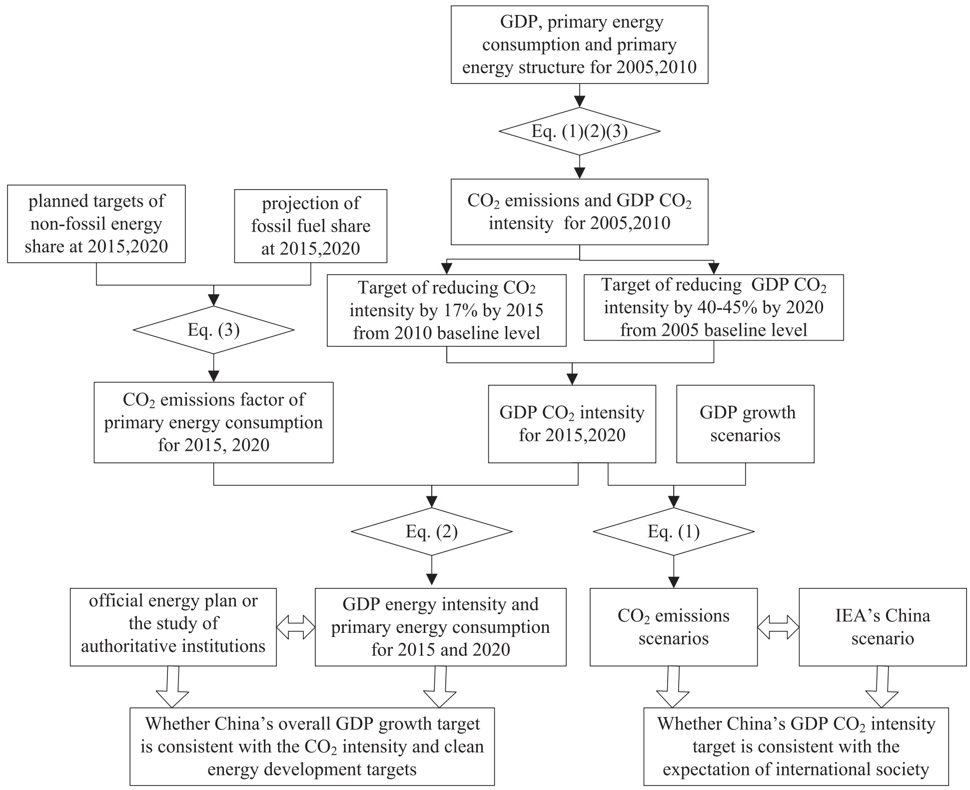

Fig. 8. Methodology of the study.

Table 1
Assumption on GDP growth scenarios in our study.

Scenario	2010-15 annual growth rate (%)	2016–2020 annual growth rate (%)	2020/2010 growth
High	8	7	2.06
Baseline	7.5	7.0	2.01
Low	6.5	6	1.83

Table 2
Estimation of 2015 and 2020 CO_2 emission factor for primary energy supply.

Year	Share over primary energy (%)				CO_2 emission factor of primary energy supply (tonnes/tce)	CO_2 emissions (Mt)	GDP CO_2 intensity (tonnes/ 10000 RMB)
	coal	oil	gas	Non-fossil			
2005	70.8	19.8	2.6	6.8	2.10	5103.0	2.76
2010	68.0	19.0	4.4	8.6	2.23	7258.5	2.31
2015	65.1	18.0	5.5	*11.4*	2.15	-	1.91*(-17%)*
2020	60.5	17.5	7.0	*15*	2.04	-	1.65*(-40%)* 1.51*(-45%)*

Note: The italic data are official planning while the underlined data are estimated based on the planning and other assumptions.

in 2020 based on the 2010 levels. Suppose that GDP growth will slow down during the 13th FYP (2016–2020), the economic growth target can be converted into a baseline scenario. Considering the fact that actual economic growth rates have been faster than China's official planning in the past two decades, a High-growth scenario with 0.5 percent point higher than the baseline during 12th FYP is compiled. On the opposite, since the global economy still suffers from the 2008 financial crisis, as well as considering the high uncertainty of China's economy, a Low-growth scenario with one percent point lower than the baseline is also presented (Table 1).

3.2.2. Compositions of primary energy supply

China's 2020 GDP CO_2 intensity target is based on the 2005 level while the intermediate target of 17% reduction in 2015 is based on the 2010 level. We thus need the CO_2 emissions factor of primary energy supply, in order to estimate primary energy demand for 2015 and 2010. EIA (2011) provides fuel emissions factors of different fuel products, but due to variation in the quality of fuel, they vary in different countries and in different years. We use the official data of fossil fuel from the NSBC (2012) and fuel CO_2 emissions data from the IEA (2012) for China during 2005–2010 (Table 2) to estimate the factors. It is evident that deterioration of coal quality had increased the CO_2 emissions factor of coal during 2005–2010. Because coal supply will be constrained by the capacity limit, this condition can hardly be changed in the future. Therefore, we assume that the emissions factor of coal would not change much during the scenario period. We also assume that oil share would be slightly reduced and the share of gas would be gradually increased in the coming decade due to improvements in extraction facility and transportation systems (Table 2).

4. Energy Consumption and CO_2 Emissions Scenarios into 2020

4.1. Scenario results

CO_2 emissions scenarios under GDP scenarios are projected in this section. Primary energy demand in 2015 and in 2020 can be calculated with available CO_2 emissions data and assumption on CO_2 emissions factor of primary energy supply (Table 3).

4.2. Discussions

In the *Energy Development Plan during the 12th FYP Period*, the Chinese Government adopted 3800 Mtce as the 2015 target of primary energy demand (NDRC, 2012). Several research institutions conducted scenario analyses to forecast the target for 2020. For example, the IEA (2009a) scenario ranged between 4110 and 4450 Mtce, the EIA (2009) scenario ranged between 4280 and 4670 Mtce and the ERI (2010) scenario ranged between 3900 and 4820 Mtce (Table 4). Considering the potential improvement in energy efficiency, the feasible energy demand in 2020 should range between 4200 and 4600 Mtce. For total CO_2 emissions, Chinese Government did not propose any numerical target; however, IEA (2009b) proposed a 450-ppm scenario of an 8600-Mt target for China in 2020.

The projected primary energy demand in 2015 will range between 4050 and 4350 Mtce, substantially larger than 3800 Mtce. Considering that GDP growth in the first two years of the 12th FYP was much higher than the High scenario, energy demand is very likely to exceed 4300 Mtce in 2015. For 2020, energy demand at a 40% or a 45% reduction of CO_2 intensity is also substantially larger than the feasible range.

The projected CO_2 emissions scenarios are also inconsistent with international expectation regarding China's GHG responsibilities. In 2020, only the Low-growth scenario can marginally achieve the range of 8600 Mt. All other scenarios substantially exceed the upper limit. It is also worth noting that under the Government's official scheme, China's CO_2 emissions could reach 8600 Mt in 2015, which is 5 years ahead of IEA's prediction.

Under the Baseline or High scenario, the 15% clean energy target and 45% CO_2 intensity reduction cannot meet the international expectation. Although the Low scenario is marginally acceptable by international society, it does not enable double GDP growth in 2020 and is definitely politically unacceptable. Therefore, in order to ensure the GDP growth as well as control CO_2 emissions, a feasible way is to increase the share of clean energy substantially. Furthermore, the characteristic of coal-dominated power supply is a severe challenge for China's environmental commitments. To ensure China's energy security and sustainable economic growth, a promising solution is to develop clean energy and cut reliance on fossil energy.

Table 3
China's CO_2 emissions and primary energy demand scenarios in 2015 and 2020.

Year	Scenario	GDP (Billion RMB)	CO_2 intensity reduction target	CO_2 intensity of the economy (tonnes/10000 RMB)	CO_2 emissions (Mt)	Primary energy demand (Mtce)
2015	High	46202.7	17%	1.91	8850	4347
	Baseline	45143.0			8647	4248
	Low	43082.1			8252	4054
2020	High	66330.0	40%	1.65	10986	5681
	Baseline	63315.5			10487	5423
	Low	57653.5			9549	4938
2020	High	66330.0	45%	1.51	10070	5208
	Baseline	63315.5			9613	4971
	Low	57653.5			8753	4527

Table 4
Forecast of China's 2020 primary energy demand by different institutions.

Institution	Scenario	Primary energy demand (Mtce)
International Energy Agency (IEA, 2009a)	baseline	4450
	low	4110
Energy Information Administration DOE, USA (EIA,2009)	baseline	4470
	High economic growth	4670
	Low economic growth	4280
Energy Research Institute of NDRC, China (ERI,2010)	baseline	4820
	Low carbon	4000
	Enhanced low carbon	3920

5. Pathways for China's Clean Energy Development into 2020

5.1. Resource analysis

China has implemented several plans on renewable energy development (NDRC, 2007 a and b). For most of the clean energy resources, the actual development is much faster than the planning (not including biomass power and ethanol) (Table 5). As a result, with proper policy instruments, the planning objective in 2020 can be enlarged to a great extent.

5.1.1. Hydropower

China has hydropower resources of 542 GW (He, 2007). During the 11th FYP period, hydropower was kept at a steady growth. By the end of 2010, the total installed capacity reached 216 GW and was nearly twice the 2005 level. In 2010, electricity generated from hydropower was 687 terawatt hours (TWh), representing 16.2% of the total electricity supply, which was approximately 7% of primary energy consumption. At present, the installed hydropower accounts for roughly half of the economically exploitable resource, while the wholesale price of hydropower is far lower than the benchmark price of desulphurised coal power. Further, with the construction, commissioning and operation of giant high-dam stations such as Three Gorges, Xiaowan and Longtan, China holds a leading position in the design and construction techniques of hydropower.

However, most of the hydropower resource is located in southwestern regions with a fragile ecology system. The development of these hydropower stations is constrained by factors such as ecology carrying capacity, arrangement of migrate, soil erosion, etc. In addition, the adverse development conditions in the southwestern regions, along with the prolonged construction time, will increase the cost of hydropower. Therefore, our planning sets the installed capacity of hydropower between 240 and 260 GW for 2015. While for 2020, the total installation is set between 340 and 360 GW.

5.1.2. Wind power

In 2009, China ranked first in the global annual growth of wind power. There are currently more than 70 wind turbine manufacturers with a total manufacturing capacity growth of 10 GW annually. Presently, domestic manufacturers can produce more than 1.5 MW wind turbines. In 2010, the total on-grid wind capacity was 31 GW and the power generation was 50 TWh.

Currently, the biggest challenge for wind power in China is grid access (Zhao, Wang and Wang, 2012). This issue can be resolved by constructing an ultra-high-voltage transmission system and expanding grid capacity in the long run. Hence, the establishment of large-scale inland wind power bases would be the priority, but the development of distributed generation should also be encouraged and offshore wind projects could take off after pilot projects. The installed capacity of wind power is expected to reach 70–90 GW in 2015 when China's wind turbine industry will become internationally competitive. In 2020, wind power

Table 5
China's official medium-and-long term clean energy planning into 2020.

	2010 planning	2010 actual	2020 planning
1.Power generation (GW)			
Hydropower	190	216	300
Wind power	5	31	30
Solar power	0.3	0.8	1.8
Biomass power	5.5	5.5	30
Nuclear power	12	10.8	40–45
2.Heat and gas supply			
biogas/billion m^3	19	14	44
Solar water heater/million m^2	150	168	540
Solid fuel/million tonnes	1	3	50
3.Transporation fuel			
Fuel ethanol/million tonnes	2	1.8	10
Biodiesel/million tonnes	0.2	0.5	2

generation is expected to reach 160–180 GW and become one of the major sources of primary energy supply in China.

5.1.3. Nuclear power

In 2010, the total nuclear capacity was 10.8 GW, accounting for 1.13% of China's total generation capacity; 23.5 GW was under construction and another 8.5 GW was approved. In response to the Fukushima nuclear accident, China suspended the approval of new nuclear projects in 2011 and began to review and revise the standards of nuclear power plants. However, due to the important role for the diversity of energy mix, nuclear power is still attractive in China (Yuan, Xu and Hu, 2012). A clear signal was given by the fact that in the end of 2012, after comprehensive safety review and design standard revision, China lifted the ban and approved a new nuclear plant.

China has more than 20 years of experience on nuclear power; further improvements are under the way. By comprehensively considering factors of siting resources, the status of preliminary work, construction time, uranium supply and others, an annual installation of 7 GW is desirable. Hence, it is estimated that by 2020, nuclear capacity will range between 60 and 65 GW. By 2015, the total capacity is expected to reach no less than 40 GW.

5.1.4. Solar power

Solar power in this article refers to photovoltaics (PV) generation and solar heat/thermal generation. Propelled by a strong international market, China's PV manufacturing industry is globally competitive. In 2011, China manufactured 21 GW solar cells, accounting for 60% of the global market (Xu et al., 2012). However, 90–95% was exported to Europe and North America. Compared with the doubling of the international wind power market within 5 years, the domestic solar market remains small. However, the Golden Sun Demonstration programme and the Solar PV Concession Bidding programme initiated China's domestic market after 2009. The installed capacity of solar power was 800 MW in 2010 and 2500 MW in 2011 (Wang, 2012).

The main obstacle for solar power is the high cost. The net generation cost of solar power is about 1 RMB KWh^{-1}, which is 0.2 RMB higher than the expected mass generation cost of 0.8 RMB KWh^{-1}. However, the learning curve is expected to drive down the cost by copying the success story of wind power. It is expected that solar power installation will reach 15 GW in 2015 and 40–50 GW in 2020.

5.1.5. Solar water heaters

Solar water heaters are widely used in urban and rural China. The Home Appliances to the Countryside programme further expands its application in rural areas. In the end of 2010, there were 168 million square meters of installed solar heaters, with an annual primary energy saving of 20 Mtce. The total installation is very likely to reach 250 million square meters in 2015 and at least 600 million square meters in 2020.

5.1.6. Biomass and biomass power generation

Biomass in China consists of forestry residuals, livestock excrement, industrial organic wastewater, domestic sewage and garbage, etc. Biomass power generation is technically mature and the medium-and-large-scale biogas technology is also being progressively improved. At the end of 2010, the total supply of biomass was about 20 Mtce, including 5.5 GW of installed biomass generation capacity, 3 Mt biomass briquettes supply, 1.8 Mt biofuel ethanol supply and 0.5 Mt biodiesel supply.

The slow development of biomass generation in China is due to the inadequate supply of fuel sources and the high cost. It is evident that the 30 GW target in 2020 is not achievable. We expect biomass generation capacity to reach 13 GW in 2015 and 20–25 GW in 2020. Together with biomass briquettes, ethanol and biodiesel, biomass can contribute 30–40 Mtce primary energy supply in 2015 and 60–80 Mtce in 2020.

5.1.7. Carbon capture and storage

Globally, the technology research and development (R&D) and industrial application of carbon capture and storage (CCS) move slowly due to the lack of a unified global climate policy. CCS is currently the only available technology to mitigate GHG emissions from large-scale fossil fuel usage. Since China is relying heavily on coal, CCS could be an indispensable choice for China. In the short run, CCS can serve as the buffer to secure primary energy supply in response to a faster-than-expected economic growth. In the long run, CCS will contribute to energy security in China to maintain a stable primary energy supply by making the coal “cleaner”.

Although China is a latecomer to CCS, thanks to the great importance attached by the government, industry and research institutes, encouraging progress has been made on policy formulation, technology R&D, pilot project implementation and international co-operation in China (Yuan and Lyon, 2012). Until 2010, in China there were five CCS pilot projects in operation and another four projects under construction, mostly in the power generation sector. It is worthwhile noting that the Ordos coal liquefaction project by the Shenhua Group is the first whole-process CCS saline aquifer-sequestration project with a prospective annual capacity of 3 Mt CO_2. Moreover, in Tianjin a 265-MW integrated gasification combined cycle (IGCC) project with an annual CO_2 abatement capacity of 1.1 Mt was put in operation in the end of 2011. Another 450-MW IGCC CCS project with an annual CO_2 capture capacity of 1.6 Mt is under planning and is expected to be commissioned in 2016. In total, there are 12 IGCC or polygeneration projects under planning or construction in China.

5.2. Clean energy planning and pathways into 2020

In this section, we will propose an alternative energy planning with 8600 Mt CO_2 emissions as a constraint. First, it is necessary to determine the primary energy demand. With an active policy in place, the GDP energy consumption elasticity was 0.54 during the 11th FYP period. For the 12th FYP period, with the official planning of 3800 Mtce, the GDP energy elasticity will be reduced to 0.39. For the 13th FYP period, with 4500 Mtce primary energy demand as the baseline scenario, the GDP energy consumption elasticity would be 0.46, slightly higher than that during the 12th FYP period. However, GDP is likely to grow according to the High scenario because of the Chinese Government's preference for economic growth. If so, the elasticity of energy consumption would possibly remain the same as in the 12th FYP period. However, the energy intensity in 2020 could be cut by 45% below

Table 6
China's clean energy planning into 2020 proposed by our study.

Year	primary energy demand (Mtce)	GDP energy intensity (tce/10000 RMB)	GDP CO_2 intensity (t/10000 RMB)	Fossil share (%)			Clean share (%)					
				coal	oil	gas	hydropower	nuclear	wind	solar	biomass	subtotal
2010	3250	1.03	2.308	68.0	19.0	4.4	7	0.9	0.7	8.6		
2015	3800	0.84	1.799	64.5	18.0	5.5	6.3	2.6	1.3	1.0	0.8	12
2020	4500	0.71	1.358	58.5	17.5	7.0	7.9	3.1	2.3	2.1	1.6	17

Table 7
Pathways for China's clean energy planning into 2020 proposed by our study.

Planning	2010	2015	2020
Hydropower/GW	216	240	350
Nuclear power/GW	10.8	40	60–65
Wind power/GW	31	80	160–180
Solar power/GW	0.8	15	40–50
Solar water heater/million m^2	168	250	600
Biomass power/GW	5.5	13	20–25
biogas/billion m^3	14	25	44
Solid fuel/Mt	3	30	50
Fuel ethanol/Mt	1.8	6	10
Biodiesel/Mt	0.5	1	2
CCS (number of large-scale facilities/Mt CO_2 avoided)	0	2/2.1	25/50

the 2005 level if we set 4500 Mtce as the primary energy demand in 2020. According to the experience during the 11th FYP period, a 45% reduction is an attainable but challenging target (Yuan, Kang, Yu and Hu, 2011; Price et al. 2011). Hence, it is reasonable to set 4500 Mtce as the objective of primary energy demand for 2020.

Second, the primary energy structure in China is also worth studying. Supposing clean energies are utilised to substitute only coal and the shares of oil and natural gas remain the same as in our previous assumption, we find that the share of clean energy should be 17% in order to satisfy emission reductions and primary energy constraints. Accordingly, the clean energy share for 2015 should be adjusted to 12% (Table 6).

Given the adjusted clean energy share and the resource potential of different options, detailed pathways for China's 2020 clean energy development are illustrated in Table 7. Hydropower will represent 7.9% of the primary energy supply and contribute the biggest portion of China's clean energy supply. Nuclear power will represent 3%, which is 60–65GW. Wind power of 160–180 GW will contribute about 2.3%. Taking power generation and solar heaters together, solar energy will contribute about 2.1%. Finally, biomass and other renewables such as geothermal and ocean energy will contribute the rest, 1.6%. With the proposed CCS capacity, our planning will leave a buffer of about 50 Mt CO_2 for the possibility of faster GDP growth.

6. Policy Package for Clean Energy Development

The Government plays central role in clean energy development by formulating and implementing a proper energy policy. According to the above analysis, the following policy recommendations are proposed.

6.1. Hydropower

Hydropower is technically the most mature and economically the most sound renewable source. It should be considered the first priority to increase the non-fossil share.

- Speed up the approval and verification process of hydropower projects.
- Boost the construction of large-scale as well as small hydropower plants, and speed up the construction of bump-storage hydropower stations.
- Establish a national institution to manage resident migrations incurred by hydropower projects.
- Increase the wholesale price of hydropower to compensate migration, ecology recovery and other substantial costs.
- Improve the developmental pattern of hydropower and switch to multistage low dams.
- Address issues of ecological recovery and environmental protection properly during the development process.

6.2. Wind power

It is important to promote the concentrated development of wind power. Proper planning and the overall arrangement considering resource distribution, transmission capacity and market absorption are also vital. Meanwhile, following the principle of attaching equal importance to concentrated and distributed exploitation, it is also necessary to establish power dispatch and operation mechanisms adapted to distributed wind power development.

- Enhance the general survey of wind resource, establish a national wind resource research centre and compile a national wind resource map to guide wind power development.
- Accelerate the formulation of detailed planning for wind power and incorporate it into the overall national power grid development planning.
- Implement the related articles of the *Renewable Energy Act* and work out detailed supporting measures to encourage renewable (especially wind power) development. Levy a resource or emissions tax to subsidise renewable energy.
- Establish a national technology research platform for wind power. Reinforce R&D and speed up the serialisation and standardisation of wind turbines.
- Enhance the research on grid-access technology and solve the puzzle of trans-regional transmission.

6.3. Solar energy

The utilisation of solar power in China can be promoted by two means: power generation and heat utilisation.

- Release a national medium-and-long-term industry policy for solar power, incorporating issues such as PV generation, PV equipment, large capacity solar power generation systems, etc., and work out a clear-cut policy on technical support, industrial development and overall planning.
- Establish funds to provide fiscal subsidies and tax credit for solar power industries; encourage industrialisation and commercialisation of solar power in China.
- Incorporate solar heat utilisation products, such as solar heat water systems, into the national fiscal subsidy programmes; popularise the integrated application of solar water heaters

with building designs, and promote centralised solar heat water systems.
- Demonstrate pilot projects of desalination of seawater by solar power, solar heating and cooling, cumulate technical expertise on seawater desalination in the coastal cities where fresh water is in shortage and promote large-scale and high-temperature industrial application of solar heating and cooling.

6.4. Nuclear power

On the basis of nuclear safety, nuclear technologies can be further improved and thus create strong market demands in China.

- Increase R&D investment in nuclear power. On the basis of assimilation and mastery of third-generation nuclear technology, boost the construction of fast reactor power plants; continue with the basic R&D on the fusion technology.
- Reinforce the exploration and development of the uranium resource, enhance international co-operation and increase the strategic reserve of uranium resource.
- Boost the acquisition of post-processing technology for nuclear waste.
- Revise the technology roadmap for nuclear power according to market conditions; encourage the building of improved second-generation nuclear power plants in the near future before full mastery of third-generation technology.
- Establish a national education and training system to develop human resource for nuclear power development.

6.5. Biomass

The prospective of developing renewable energy in rural areas is urgent and the convenient option can be biogas. Biogas power is suitable for rural villages to meet the daily energy demand.

- Promote small-scale household biogas, medium-and-large-scale biogas and gas supply from biomass gasification.
- Optimise the development of biomass generation and develop projects of direct power generation from forestry residuals; build biomass combined heat and power (CHP) plants to meet the regional heat demand; and promote the development of power generation from livestock excrement and municipal refuse.
- Build a production base and a logistics system for biomass briquettes; promote centralised heating with biomass briquettes in urban areas and popularise biomass briquettes as clean fuels for cooking and heating in rural areas.
- Develop bio-liquid fuels with a steady pace; rationally develop marginal land, such as saline-alkali soil, wild grass ground and hilly land, for non-food biomass cultivation.

6.6. Green buildings

Green buildings hold a key role for energy conservation and integration of renewable energy in urban areas.

- Enhance the planning of green buildings and provide a preferential policy to substantially increase the share of green buildings.
- Implement compulsory codes for green buildings.
- Advance the Roof Solar Power project.
- Encourage projects of retrofitting heating systems in northern China.

6.7. Ethanol and electric vehicles

Globally, ethanol has attracted widespread attention with rapid technical improvements. Fuel substitution by ethanol can help diversify the energy supply in China.

- Enact a national standard for ethanol production.
- Formulate a subsidising policy for ethanol produced from non-food sources.
- Provide strong support for energy crop selection and cultivation.
- Provide R&D and fiscal support on vegetable fibres.

The experience gained from developing and promoting electric vehicles (EVs) in developed countries can provide a valuable reference for China.

- Formulate policy to encourage the R&D, production and sales of EVs in China.
- Formulate a preferential policy to attract investment in charging stations and the recycling of batteries.
- Provide fiscal subsidies to consumers of EVs.

6.8. Coal and CCS

Coal consumption can be optimised in two means. First, increase the efficiency of power generation. Second, encourage CCS in order to optimise coal development in China.

- Establish a special public fund to support CCS demonstration projects.
- Establish a compensation mechanism for the implementation of CCS and provide a secured fund source to support CCS projects.
- Encourage private investment on CCS by a public–private partnership mechanism.
- Enhance international co-operation on R&D and the demonstration projects of CCS.

7. Conclusion

This article is a prompt response to the recently announced target of double GDP in 2020 on the 2010 baseline level. We constructed different scenarios based on various economic growth rates, in consideration of the 40–45% GDP CO_2 intensity reduction and 15% clean energy share target. Three findings can be drawn from our study. First, the 15% clean energy share target is not consistent with China's overall economic growth and primary energy planning. Under the double GDP scenario, primary energy demand will greatly exceed the official plan. Second, even with 45% CO_2 intensity reduction, China's CO_2 emissions will substantially surpass the IEA's 450-ppm scenario. Finally, to reconcile clean energy development with overall economic growth and primary energy planning, the clean energy share in 2020 should be increased to 17%.

The contribution of this article is twofold. On the one hand, the article tests not only the internal consistency among China's 2020 GDP vision, energy planning and emissions control, but also the external consistency between China's planning and global expectation. On the other hand, it proposes an alternative consistent target for clean energy penetration and outlines detailed pathways and policy packages.

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