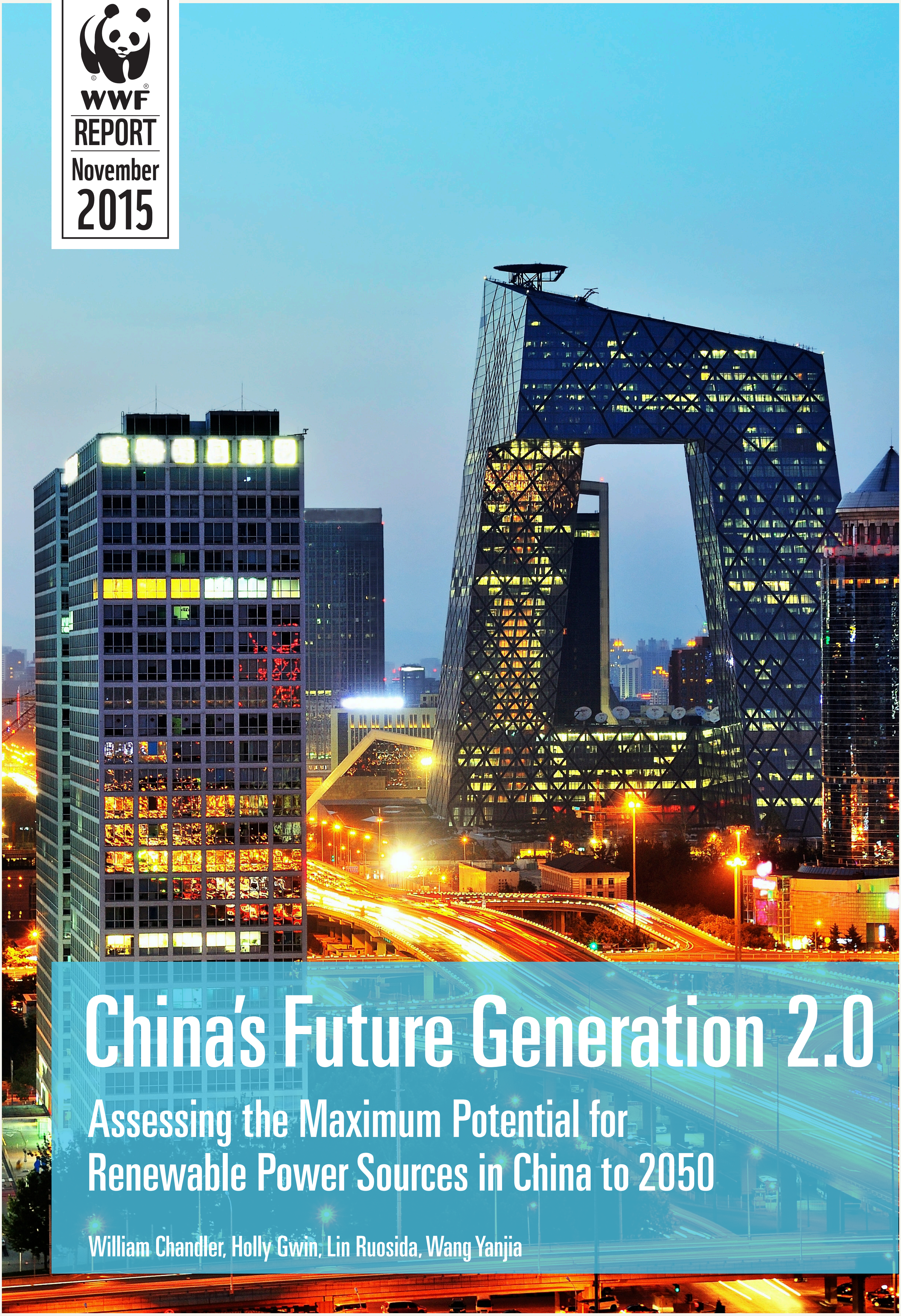

WWF

REPORT

November 2015

China's Future Generation 2.0

Assessing the Maximum Potential for Renewable Power Sources in China to 2050

William Chandler, Holly Gwin, Lin Ruosida, Wang Yanjia

ABOUT WWF

WWF is the world's leading conservation organization. WWF works in 100 countries and is supported by close to 5 million globally. WWF's unique way of working combines global reach with a foundation in science, involves action at every level from local to global, and ensures the delivery of innovative solutions that meet the needs of both people and nature.

WWF CONTRIBUTORS

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Entri

ABOUT ENTRI

Entri is a U.S.-based not-for-profit 501(c)(3) corporation created in 2010. The organization builds on decades of its founders' experience in research, institutional development, and technology deployment. The organization is a collaborative international effort with participation of top energy and climate experts from key nations.

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The authors are grateful for Chen Shiping's review of the China 8760 Grid Model and for comments and advice from Entri board member Jeffrey Logan, Gerry Stokes, and Phil Samper.

This report is one in a series of publications dedicated to providing information on the benefits and costs of policy measures in the Chinese electric power sector. Companion reports and data sets can be found at www.etransition.org.

Annapolis, Maryland
November, 2015

China's Future Generation 2.0

Framing by WWF

Analysis and Report by Entri

CHINA MUST ORGANIZE AROUND THE VISION OF "ECOLOGICAL CIVILIZATION" FROM ITS FIRST STEP. LO SZE PING

WWF FOREWORD

Lo Sze Ping
CEO, WWF China

In his work Meng Liang Lu, Mr. WU Zimu describes average daily life for people in China’s ancient Song Dynasty: “Firewoood, rice, cooking oil, salt, soy sauce, vinegar, and tea are seven daily essentials of an ordinary Chinese family.” Today, centuries later, energy—represented here by Mr. WU as “firewood”—remains one of the primary concerns for the Chinese people.

Since modern times, energy production and distribution have played an increasingly vital yet complex role in progressing the human race. In the eighteenth century, widespread coal use ignited the industrial revolution. In the nineteenth and twentieth centuries, coal, oil, natural gas, and nuclear power accelerated industries and spurred urbanization in unprecedented ways while magnifying environmental challenges.

Civilization’s reliance on fossil fuels and a high-carbon development model has, however, caused extensive global environmental damage. Burning fossil fuels at an unsustainable and excessive rate, humans have placed the planet in serious danger. Though non-renewable fossil fuels will eventually and ultimately become exhausted, past and current carbon emissions continue to affect our climate and human health across the globe.

Today, in an age when economic prosperity and progress are intrinsically tied to the environment, the Chinese people can stand out as environmental proponents with smart solutions to global environmental challenges. Two-thousand years ago, the Chinese people recognized the power of water and invented hydraulic machines, which quickly propelled agriculture and cottage industries forward. Though modern renewable energy technologies like wind and solar power were not invented in China, the Chinese have now become global leaders in manufacturing and deploying renewable energy. In fact, over the last few years, China has ranked as the world’s number one country in renewable energy investments and installation.

Looking towards the future, China will continue to promote the development of an “Ecological Civilization”[1] and make greater contributions to address climate change. In the next five years, China plans to double its wind and solar power generation. This act will be an important step towards its commitment to increase the share of non-fossil fuels in primary energy consumption to around 20% by 2030. There is thus great potential for future growth in the wind and solar power industries. A clean, low-carbon and renewable energy-powered China, as well as the experiences of enacting such a transition, will set a new green benchmark and invaluable example for the world.

Ancient China found a way to live in balanced harmony with nature. WWF aims to help China to revive this ancient wisdom and transform it into creative solutions for a better future. Though the road ahead seems to be an arduous journey of a thousand miles, China must organize around the vision of “Ecological Civilization” from its first step. Indeed, it is only through “Ecological Civilization” that China will be able to achieve the “Chinese Dream.”

[1] The concept of “Ecological Civilization” was coined by Hu Jintao in 2007 when he was general secretary of the Central Committee of the Communist Party of China. Efforts to promote this are detailed in “Central Document Number 12, Opinions of the Central Committee of the Communist Party of China and the State Council on Further Promoting the Development of Ecological Civilization.”


CHINA'S APPETITE FOR COAL, OIL, AND GAS TO POWER ITS ECONOMY HAS MADE IT THE WORLD'S LARGEST CO2 EMITTER.

WWF FRAMING

Over the past decades, China's rapid development has lifted Chinese citizens out of poverty faster and at a greater scale than any other time in human history[1]. However, this development has not occurred without significant impacts to human and environmental health in China. For example, life expectancy in northern China is now 5.5 years less due to severe air pollution from mostly coal combustion;[2] air pollution contributes to 1.6 million premature deaths per year in China, which is around 17% of all deaths in China;[3] and water overuse, contamination, and waste have produced severe shortages across the country. Yet, China is still a comparably poor country, with a per capita GDP of $US 10,000, far less than many advanced economies.[4]

China's appetite for coal, oil, and gas to power its economy has made it the world's largest CO_2 emitter. Even on a per capita basis, China's emissions are significant, and recently surpassed the EU's in 2013.[5] Considering these trends, China has a unique opportunity and responsibility to change its development model for the direct welfare of its citizens exposed to unsafe pollution levels and the impacts of climate change as well as the international community.

To get there, China must transform its 75% coal-fueled power sector.[6] In February 2014, WWF partnered with Energy Transition Research Institute (Entri) to publish *China's Future Generation: Assessing the Maximum Potential for Renewable Power Sources in China to 2050*[7] (Future Generation). This assessment concluded that around 80% of China's electricity generation could be met by renewable sources by 2050, which would be as affordable as electricity generation run primarily on coal.

Accelerating on A Clean Energy Pathway in 2014 and 2015

Since *Future Generation*'s release in early 2014, Chinese climate policies and public environmental awareness in the country have grown significantly and garnered international attention. Last November, China took the unprecedented step of committing to peak their overall GHG emissions by 2030 (and ideally earlier). As gas and oil use—especially in the transportation

[1] China helped cut world poverty rate: UN. (2015, July 9), http://usa.chinadaily.com.cn/epaper/2015-07/09/content_21229562.htm

[2] Chen, Y., Ebenstein, A., Greenstone, M., & Hongbin, L. (2013). Evidence on the Impact of Sustained Exposure to Air Pollution on Life Expectancy from China's Huai River Policy. SSRN Electronic Journal SSRN Journal,110(32), 12936–12941. doi:10.1073

[3] Rohde, R., & Muller, R. (2015). Air Pollution in China: Mapping of Concentrations and Sources. PLoS ONE PLOS ONE. http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0135749

[4] International Monetary Fund. http://www.imf.org/external/

[5] Carbon Emissions. (2013), http://www.globalcarbonatlas.org/?q=en/emissions

[6] WWF China calculates that 74.8% of power in China came from coal in 2012, based on the data published by the Chinese National Statistical Bureau.

[7] Full report can be downloaded at: http://www.wwfchina.org/content/press/publication/2014/publication-20140311-future.pdf (Mandarin), http://www.wwfchina.org/content/press/publication/2014/futuregeneration.pdf (English).

sector—continues to grow over the next two decades, China will only be able to cap its overall GHG emissions if it significantly reduces both CO_2 emissions and coal use. The government has also pledged to increase the share of non-fossil fuels in primary energy consumption to around 20% by 2030. These commitments, in addition to those made by the US in the November 2014 US-China Joint Announcement on Climate, are political game-changers. Recent pieces of domestic legislation in China, namely the revised Environmental Protection Law and the revised Law on the Prevention and Control of Air Pollution, have reinforced these high-level commitments.

Announcements like these from China matter not only because they can begin to influence investment towards a low-carbon future in China, but also because China's climate leadership creates positive momentum leading up to the UN negotiations on climate. In September 2015, on the road to the Paris climate negotiations this December, China announced further steps that could help the country meet these goals by 2030. After years of pilot projects, China confirmed it will launch a national cap-and-trade program that will cover several heavy-emitting sectors, including power generation. To incentivize solar, wind, and other renewable electricity, China will launch a "green dispatch" system to prioritize power generation from renewable sources and to establish guidelines so that electricity is first accepted from the most efficient and lowest-polluting generators.[8] China is also planning "to work towards strictly controlling public investment flowing into projects with high pollution and carbon emissions both domestically and internationally."[9] While this policy will need further clarification in the coming months, the announcement is an important signal to the coal sector in particular, the fossil fuel sector at large, and investors globally. Finally, a collection of Chinese cities and provinces accounting for approximately 1.2 GT of annual CO_2 emissions (roughly equivalent to the total emissions of Japan or Brazil) committed to peak their carbon dioxide emissions by no later than 2030; among them, Beijing and Guangzhou will reach that goal a full decade earlier.[10] These target goals have given experts greater confidence that China can beat its national goal and peak its emissions earlier than 2030.

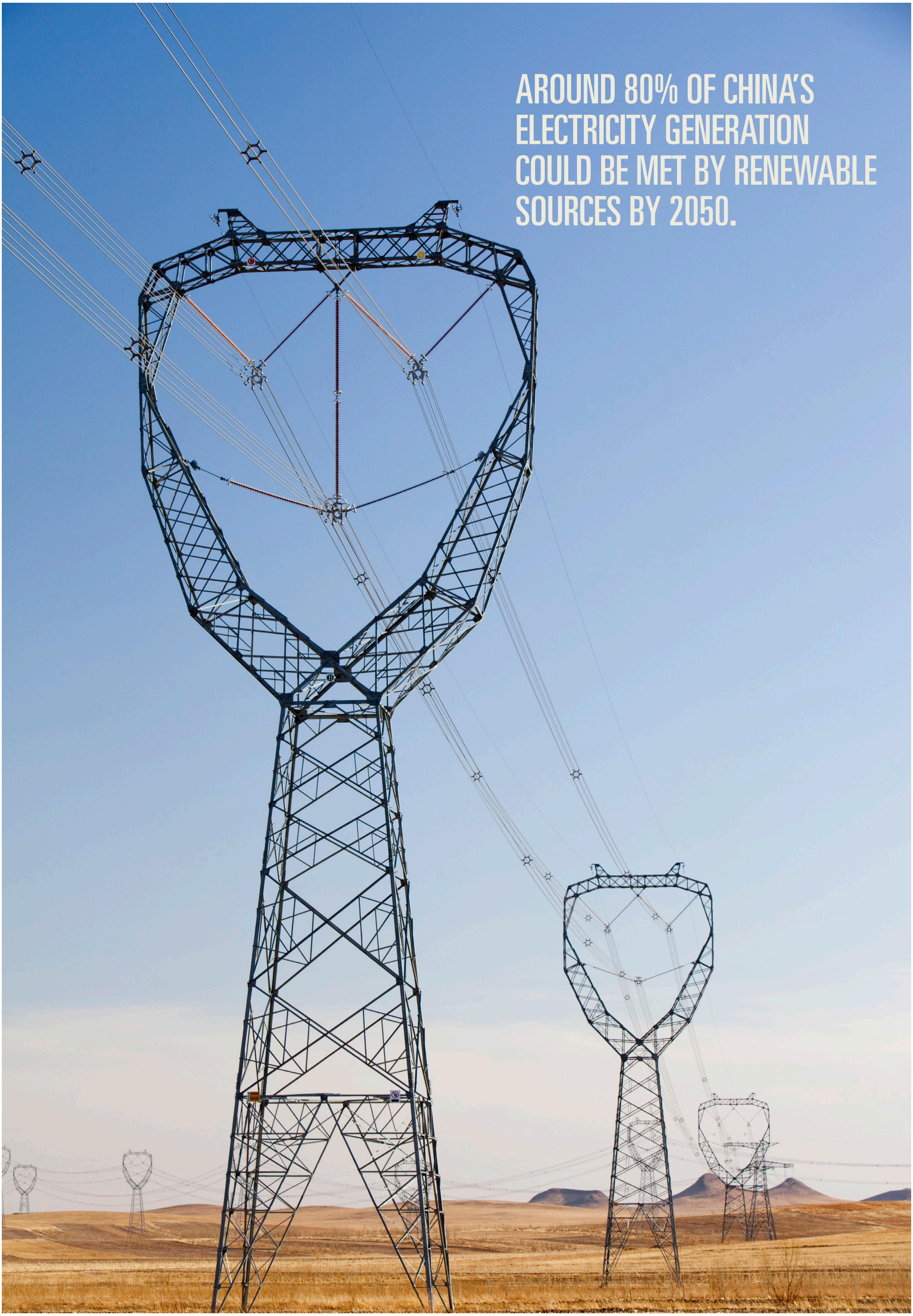
Beyond making these important commitments, China saw some very positive energy trends in 2014 and 2015. Throughout 2014, for example, China added about 35 GW of solar and wind energy generation capacity combined,[11] the most ever by a country in a single year. China also improved its energy intensity (energy use per unit of GDP) by at least 5%, which is more than

[8] This comes just in time, as China saw the rate of renewables integration dip in 2014 after years of progress towards reducing curtailed wind. Liu, C. (2015, September 24). As China's energy growth slows, coal-fired power blocks more wind, solar and hydro. http://www.eenews.net/climatewire/2015/09/24/stories/1060025204

[9] FACT SHEET: The United States and China Issue Joint Presidential Statement on Climate Change with New Domestic Policy Commitments and a Common Vision for an Ambitious Global Climate Agreement in Paris. (2015, September 25), https://www.whitehouse.gov/the-press-office/2015/09/25/fact-sheet-united-states-and-china-issue-joint-presidential-statement 中美元首气候变化联合声明（全文）. (2015, September 26), http://www.gov.cn/xinwen/2015-09/26/content_2939222.htm

[10] Fact Sheet: U.S. – China Climate Leaders Summit. (2015, September 15). https://www.whitehouse.gov/the-press-office/2015/09/15/fact-sheet-us-—-china-climate-leaders-summit

[11] REN 21, 2015; Global Status Report of Renewables, Paris 2015; http://www.ren21.net/status-of-renewables/global-status-report/ pages Figure 17, p. 59; Figure 23, p. 71


AROUND 80% OF CHINA'S ELECTRICITY GENERATION COULD BE MET BY RENEWABLE SOURCES BY 2050.

twice as much as the global rate. These changes indicate the strong success of domestic energy efficiency programs.[12] The combined effect of these trends, as well as a drop in coal consumption in China for the first time since 2000, have caused China's energy-related CO2 emissions to flatline or even to decrease.[13]

China's Future Generation 2.0: The Future is Even Brighter

Taking into account these policy developments alongside updated data and modeling capabilities, Entri has written a report: *China's Future Generation 2.0: Assessing the Maximum Potential for Renewable Power Sources in China to 2050*. This report employs Entri's improved China 8760 Grid Model to generate four scenarios: Baseline, High Efficiency, High Renewables and Low Carbon Mix.

WWF favors the High Renewables scenario (see chart at right) because of its low emissions and low economic costs, as well as the various negative impacts it avoids. These impacts—which are not modelled by Entri[14]—include human health impacts,[15] lowers industrial demand for water, and creates higher quality and quantity of employment.[16] The report finds that:

- **Around 84% of China's electricity generation can be met by renewable sources by mid-century** if appropriate policies and measures are taken, including—and conditional upon—aggressive energy efficiency improvements.
- **China could meet or beat both of its commitments to peak its overall carbon emissions and have non-fossil fuels in primary energy use representing 20% by 2030** if the country pursues aggressive, low-carbon development scenarios for the power sector by, for example, peaking carbon emissions from the power sector by 2020. Both the High Renewables scenario and the Low Carbon Mix scenario indicate that China could reach 50% non-fossil fuel power generation by 2030, which could be the foundation upon which China achieves its 20% non-fossil fuel energy transition target by 2030. This argument similarly mirrors recent research completed by London School of Economics researchers Fergus Green and Nicholas Stern, which shows that, if the country takes the right steps, China can peak its total emissions by 2025 or even earlier.[17]

[12] IEA, 2015. Energy and Climate Change, Paris 2015. https://www.iea.org/publications/freepublications/publication/WEO2015SpecialReportonEnergyandClimateChange.pdf. Page 22

[13] Ibid. Figure 1.9, Page 30

[14] Rohde, R., & Muller, R. (2015). Air Pollution in China: Mapping of Concentrations and Sources. PLoS ONE PLOS ONE.

[15] UK Energy Research Center. November 2014. Low carbon jobs: The evidence for net job creation from policy support for energy efficiency and renewable energy, http://ecowatch.com/wp-content/uploads/2014/11/UKERC-Low-Carbon-Jobs-Report.pdf

[16] Similarly, in the 2014 Future Generation report these negative externalities cost were not modelled; only economic costs were.

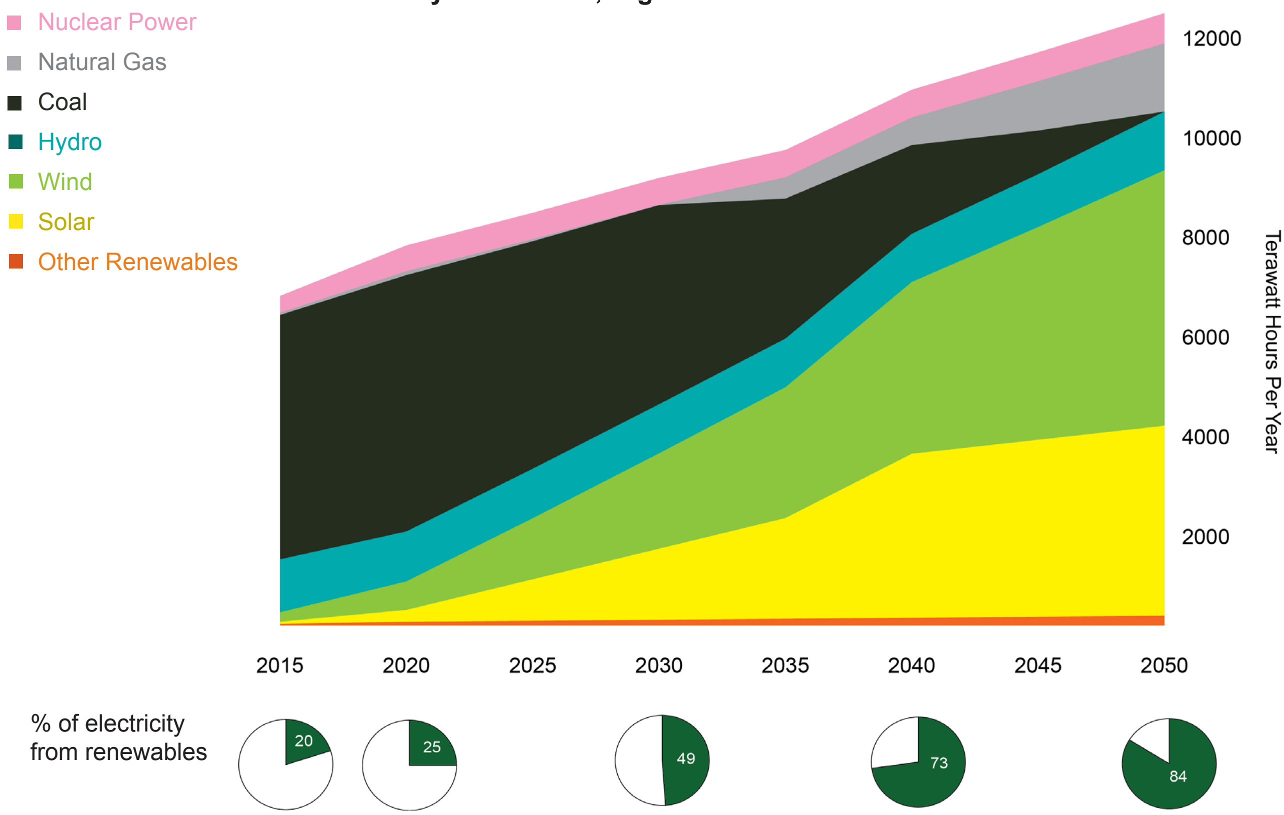
[17] Green, G. & N. Stern. June 2015. China's "new normal": structural change , better growth, and peak emissions. http://www.lse.ac.uk/GranthamInstitute/wp-content/uploads/2015/06/China_new_normal_web1.pdf

- **Coal can be eliminated from the power mix by 2050** or even earlier, but this will require considerable political courage and enabling policies that would regulate and/or price carbon in the electricity sector at an appropriate level.

- **Over the period 2015-2050, the total costs for an electric power system run mainly with renewables would be less emissions-intensive and cheaper than a system dominated by coal.** *Future Generation 2.0* shows that a high-penetration renewables scenario would be about 14% cheaper and emit 3% fewer carbon emissions than what was projected in the first *Future Generation* report released in 2014. The identified economic costs for either scenario do not however take into account the various external costs and benefits from a renewably-based scenario compared to a more coal-based trajectory, such as avoided carbon pollution, better human health, reduced freshwater needs, and more new and clean jobs. In the future, China might see much lower wind and solar costs that would economically outcompete coal[18] and thus lead to a fully renewable electricity system by mid-century.

- **Improved cost and emissions results** are primarily due to the China 8760 Model's inclusion of technologies that allow "demand dispatch"—a smart grid approach to efficiently manage electricity loads.

Electricity Generation, High Renewables Scenario



[18] Michael Liebreich, Bloomberg New Energy Finance, London, 12 October 2015. Global trends in clean energy investment, http://about.bnef.com/content/uploads/sites/4/2015/10/Liebreich_BNEF-Summit-London.pdf; page 50

Policy Recommendations

The recommendations from WWF and Entri's *Future Generation* report in 2014 concluded with several policy recommendations to achieve a pathway to a high-renewables energy model built on energy efficiency, carbon reduction investments, power pricing reforms, and data collection and transparency, all of which still are applicable today. *Future Generation 2.0* offers some new additional recommendations.

Appliance Efficiency Standards

Entri specifically recommends new stringent standards for air conditioners, water heaters, motors, and lighting, some to be enacted in 2017 and others to be achieved by 2030.

Abandon Plans for Coal Gasification

Officially, China plans to address some of its air pollution problems by producing synthetic natural gas from coal. This would shift some of the problems with coal from the densely populated east to the less-developed western provinces, but would also increase rather than reduce carbon emissions. Therefore, WWF recommends that China take extreme precaution with coal gasification by approaching it only as a last-resort technology and ensuring that proper economic cost-benefit and environmental impact assessments are performed for potential coal gasification facilities. Eschewing coal gasification would prevent unnecessary environmental degradation and avoid a long-term commitment to high-carbon, economically inefficient energy infrastructure. Furthermore, if coal gasification facilities were built and began operating but then closed as a result of environmental concerns, the loss of jobs would be a blow to the social fabric of certain western provinces.

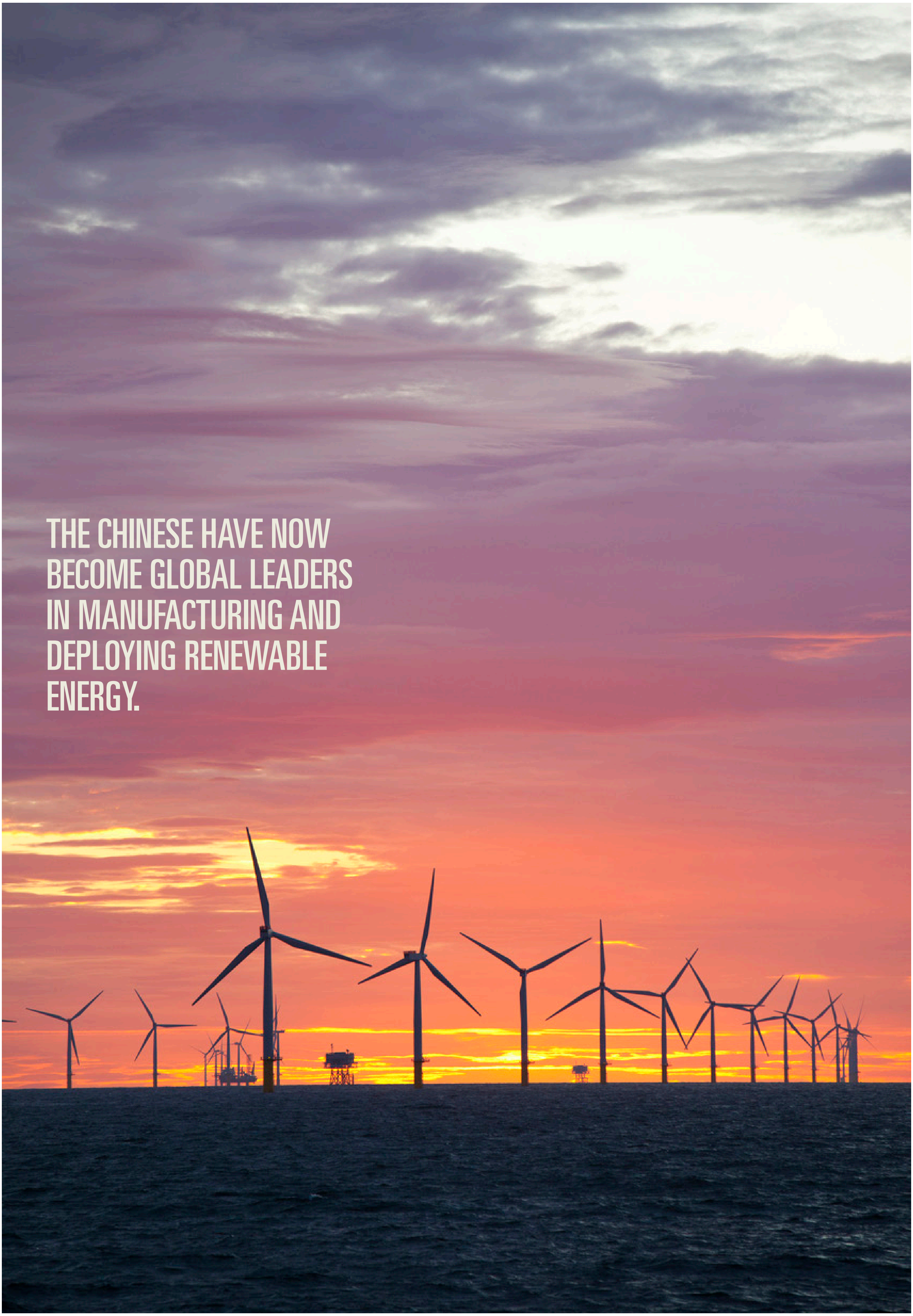
Accelerating Power Sector Reforms

Any delay in China's adoption of the policies and technologies that reduce demand for electricity would strengthen coal's grip on the power system. Entri notes with concern that:

- China's first electric sector reform document in over a decade contains no discussion of the need to separate the control of electricity distribution and transmission and pays little attention to optimizing the dispatch of electricity. Both of these reforms are essential for the rapid penetration of renewables in the power system.
- With little progress on using electricity prices for peak load management, vital reforms must be implemented across all sectors. Residential electricity consumers pay about half the real cost of their electricity, and this is a huge barrier to controlling electricity demand growth in buildings.

Beyond the common sense reforms that would have consumers pay the real economic cost of electricity (subsidy removal), WWF would like to highlight that, as in the first *Future Generation* report, additional implicit (emissions


IN THE NEXT FIVE YEARS, CHINA PLANS TO DOUBLE ITS WIND AND SOLAR POWER GENERATION.



THE CHINESE HAVE NOW BECOME GLOBAL LEADERS IN MANUFACTURING AND DEPLOYING RENEWABLE ENERGY.

standards) or explicit pricing reforms (carbon pricing) are absolutely critical to effectively transition to a future modeled by the High Renewables scenario.

Coal-fired power generation is declining in many developed countries in Europe and the US. One critical reason for this is the fact that these countries are implementing policies like carbon emissions standards, emissions taxes, and/or emissions trading so the true cost of electric power is reflected. Yet, with the recent announcement to cover the power sector under a national cap-and-trade system starting in 2017, China seems to be catching up.

A New Narrative of Economic Growth to Achieve the Chinese Dream

Overall progress on clean energy and emissions reduction policies from the government has been laudable, and has debunked the myth held by many in China and throughout the world that China cannot stop its dependence on fossil fuels, and particularly coal. However, to sustain this momentum and lead the Chinese economy to a cleaner, safer, more prosperous future, China must close the book on the old narrative of economically and environmentally unsustainable growth and begin a new story of China as a clean and efficient "Ecological Civilization."

Much of this new story has already begun, written in a mandate from China's top leadership to further promote the development of an "Ecological Civilization".[19] Meanwhile, China has entered into a "New Normal" phase of its economic growth with an enhanced focus on clean energy development.

China's "New Normal" is characterized by more moderate rates of economic growth and a greater reliance on services, domestic economic demand, and innovation. While China boasted an average annual GDP growth rate of 10% between 2003 and 2007,[20] that rate has since slowed to around 7%. Profits and growth are now more than ever stemming from innovation and high-value added industries as opposed to China's previous dependence on energy-intensive, pollution-heavy industries.

As the Chinese government and leadership lay the groundwork for President Xi Jinping's "Energy Revolution" mandate[21] and begin to implement the 13th 5-year plan in March 2016, there is a need for these policies to reflect the "New Normal" and place China and its citizens on a pathway towards an "Ecological Civilization." It is only through this Ecological Civilization that will China be able to achieve the "Chinese Dream."[22]

[19] 中共中央国务院关于加快 推进生态文明建设的意见. (2015, April 25), http://paper.people.com.cn/rmrb/html/2015-05/06/nw.D110000renmrb_20150506_3-01.htm

[20] Xinhua, Xi's "new normal" theory, http://news.xinhuanet.com/english/china/2014-11/09/c_133776839.htm

[21] Stanway, D. (2014, June 13). China's president calls for energy revolution, http://www.reuters.com/article/2014/06/13/china-energy-idUSL4N0OU2ZB20140613

[22] The "Chinese Dream" was first coined by President Xi Jinping in 2013. Official government statements have defined the term to means the "rejuvenation of the Chinese nation" and "the dreams of the Chinese people" including the dream of a better environment, http://www.china.org.cn/china/Chinese_dream_dialogue/2013-12/07/content_30827106.htm

Entri

China's Future Generation 2.0

Assessing the Maximum Potential for Renewable Power Sources in China to 2050

William Chandler, Holly Gwin, Lin Ruosida, Wang Yanjia

China's demand for electricity has grown on average as fast as the nation's economy over the past decade, and most of that electricity has come from coal-fired plants.[1] China's evident commitment to play a significant role in reducing global carbon emissions will be challenged by the momentum of its large and growing electric power sector.

We used our econometric and engineering model, the China 8760 Grid Model, to assess the potential for low-carbon power resources to satisfy China's electric power demand in the year 2050. In doing so, we found that:

- Energy efficiency and demand-side management technologies are carbon-free and the most cost-effective options for keeping China's electricity demand within reasonable boundaries.
- Renewable power sources could supply 80% or more of China's 2050 China's electricity needs without sacrificing grid reliability, assuming high levels of energy efficiency throughout the economy.

To realize such a low carbon power system, China will need to reform the power sector; impose and enforce strong new regulations on energy-using consumer devices; deploy a nationwide network of grid communications and controls (i.e., smart grid technologies); and mandate additional shifts to non-carbon sources of energy for power generation. Neither market mechanisms nor existing policy mechanisms will bring about any of these necessary sets of measures, much less all of them.

This report updates our 2014 study, *China's Future Generation: Assessing the Maximum Potential for Renewable Power Sources in China to 2050* (*Future Generation*). It summarizes recent improvements to the China 8760 Grid Model, and readers can refer to the 2014 report for full details on assumptions and methodology.[2] We describe the economic costs of implementing various power sector technology scenarios and the impact those scenarios would have on carbon emissions (comparing our 2014 and 2015 modeling results).

This report confirms our 2014 finding that China will face little technical difficulty in reducing carbon emissions from its power sector, but technical difficulties pale before the policy obstacles that will require great political will to implement. Points of discussion new to this report include:

- An assessment of how electric power generation might affect China's ability to meet its economy-wide goals of reaching peak carbon emissions by 2030 and supplying at least 20% of economy-wide primary energy from non-fossil sources by that time. We conclude that aggressive low-carbon development of the power sector can help China succeed in meeting these goals.
- An assessment of the potential of peak load management technologies to reduce capacity requirements. We find a potential for reductions of 300 GW or more.

Remapping China's Power Future

Entri developed the China 8760 Grid Model to improve understanding of China's power system and its effect on the Chinese economy and global environment.[3] The model starts with the year 2011 and uses actual data for years 2011-2014 where they are available. We used standard references for certain types of assumptions such as demographic data, exchange rates, and discount rates. More information on these details and how the model works is available in *Future Generation* and in Entri's methodology report.[4] Tables 1 and 2 present some of our key assumptions and Table 3 describes China's installed grid-connected power generating capacity and output.

TABLE 1 GDP Assumptions in the Grid Model

(Annual Economic Growth Rate)

	2010-2015	2015-2020	2020-2030	2030-2040	2040-2050
Baseline scenario: 2014	7%	7%	4%	3%	2%
Baseline scenario: 2015	8%	6%	5%	3%	2.8%
High Renewables, High Efficiency and Low Carbon Mix scenarios: 2014	7%	6%	4%	4%	3%
High Renewables, High Efficiency and Low Carbon Mix scenarios: 2015	8%	5%	4%	4%	2.8%

Source: Entri

For *China's Future Generation 2.0*, we have re-benchmarked model data to 2015; updated new policy mandates—defined as "targets" by the Chinese government—for wind, solar, hydroelectric power and nuclear power; and we revised GDP growth down for 2015-2020. Some of these changes are substantial, and we compare and explain differences from our 2014 results throughout the text.

Users of the China 8760 Grid Model can generate different scenarios of future electricity supply and demand by changing assumptions (for example, the projected price of various technologies) or by imposing constraints (for example, requiring the addition of a certain type of power generation source). We present four scenarios to illustrate the range of potential costs and carbon emissions.

Baseline: This scenario projects a future in which China implements no specific clean energy or efficiency policies other than the ones currently on the books and effects no fundamental economic restructuring to move away from the dominance of energy-intensive industrial production. This extrapolation of recent trends yields a five-fold increase in electricity demand by 2050 and continued dominance of coal in the supply mix. That scenario would be an atmospheric catastrophe that neither China nor other countries want, but changing course presents enormous challenges to the status quo.

TABLE 2 Key Assumptions (2014 and 2015 Models)

	2011	2015	
		Baseline	High Efficiency, High Renewables, Low Carbon Mix
Population[5] (Million)	1,347	1,300	1,300
Urbanization Level[6]	50%	79%	79%
GDP Per Capita (Constant 2011 US$[7])	3,690	24,500	27,000
Contribution by the Service Sector	43%	59%	75%
Price Elasticity of Electric Power Demand[8]	-0.21	-0.21	-0.21

Source: Entri

TABLE 3 Chinese Electric Power Generating Capacity and Output by Type, Estimated 2015

Type	Gigawatts	Terawatt Hours
Solar PV (3 MW)	41	61
Concentrating Solar Power	1	5
Wind Power	101	295
Hydroelectric	301	1,673
Geothermal	<1	1
Biomass	14	58
Coal	787	4,138
Nuclear Power	43	338
Natural Gas	26	46
Total	1,430	6,615

Source: Estimated by Wang Yanjia, Tsinghua University, 2015, from China Statistical Bureau data

High Efficiency: This scenario projects a future in which China successfully implements very aggressive energy efficiency requirements and makes a substantial shift away from energy-intensive manufacturing as the basis for economic growth. Relatively low electricity demand, achievable only through the full-blown commitment to efficiency, is the sine qua non for an affordable, low-carbon electric power system, and the demand projections in this scenario become the baseline for the next two scenarios.

High Renewables: This scenario builds on High Efficiency demand projections and requires the model to satisfy demand with renewable power sources if they are available. Availability depends on several factors, including: time of day (e.g., whether the sun is shining); weather (e.g., whether the wind is blowing); and resource constraints (i.e., whether all economically-recoverable domestic supplies of wind, solar, and hydropower have been exhausted).

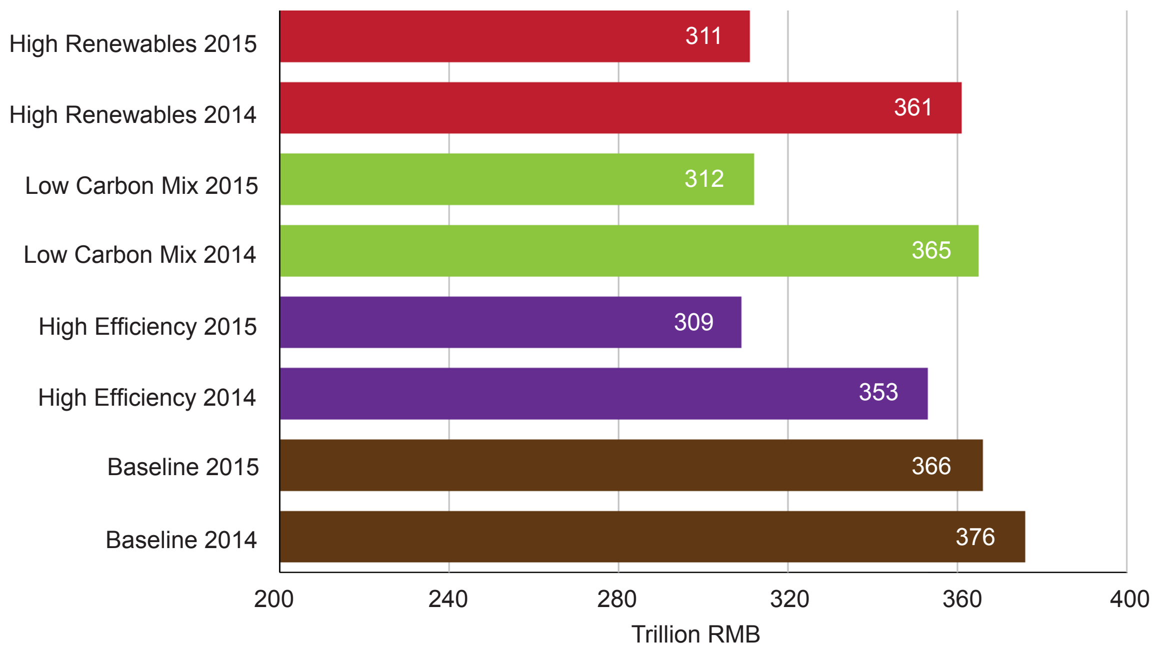
Low Carbon Mix: This scenario builds on the High Efficiency scenario demand projections and requires the model to satisfy demand with low carbon sources—renewable (with greatly reduced use of hydropower), natural gas, and nuclear.

Future Generation and Entri's methodology paper describe the demand, supply, transmission, and storage technologies used in or excluded from the China 8760 Grid Model. For this update, we improved the data sets for efficiency technologies and integrated additional peak management technologies, and these changes to the model are explained in the following discussion of the costs and carbon emissions of each scenario.

Is a Low-Carbon Power System Affordable?

Each technology scenario generated by the China 8760 grid model in 2015—High Efficiency, High Renewables, and Low Carbon Mix—is less expensive to build and operate than the Baseline scenario. Our conclusion about costs is the same in 2015 as in 2014, but our detailed results are different (Figure 1). The factors that contribute to these differences are discussed next. Please note that the model does not include costs external to the power system, such as the social, public health, and environmental costs of electricity generation.

FIGURE 1 Comparison of Scenario Costs, Future Generation and Future Generation 2.0



We re-benchmarked the model. We updated the model with all available published annual data. The biggest impact this step had on our analysis was to lower the costs of the Baseline scenario by about 5% compared to the 2014 projection. This effect was mostly due to lower costs of coal and coal-fired generating capacity. The model still projects increasing coal costs through 2050, but the projections start from a lower base. We harbor some concern that softening coal costs could make it more difficult to achieve the policy "pushes" needed to overcome the momentum of current practice, but the model illustrates that the economics point to a phase out of coal.

We improved the industrial demand subsector of the model. We initially incorporated structural economic change in the model only at the level of the increasing share of services versus industry in generating GDP. For this analysis, we divided the industrial sector into more than a dozen subsectors to assess two additional trends: the rate of electrification of each sector (which increases power demand); and the rate of growth of higher value-added industries such as computer manufacturing (as opposed to cement making). We found that at 0.5-1.0% of the annual 3.0% rate of decline we project in electric power intensity will come from this restructuring in the future. That rate is net of the increasing power intensity most sub-sectors are experiencing, meaning the electric intensity reduction will in a sense be "free." A portion of the savings estimates we made last year, all of which came with cost of 0.4-0.7 RMB kWh can, in effect, come at no incremental cost. The biggest impact this step had on our analysis was to lower the costs of energy efficiency measures, because more of the savings will be accomplished through economic restructuring and without cost to the power system. This change reduces the total costs of the High Efficiency, High Renewable, and Low Carbon Mix scenarios compared to 2014.[9]

We added peak load management options to the model. The model now incorporates switches for water heaters, on-off-cycling for air conditioners, and peak load pricing for industry (Box 1).[10] These demand management technologies cut requirements for installed capacity in 2050 perhaps more than 400 GW. The biggest impact this step had on our analysis was to lower the costs of the High Efficiency, High Renewable, and Low Carbon Mix scenarios, introducing a savings worth about $200 billion in capital alone. The potential of these technologies makes it possible to reconsider the necessity of some potentially destructive storage projects, such as a massive commitment to pumped hydroelectric systems,[11] and to reduce concerns about grid reliability when using renewables to supply peak demand.

BOX 1 Demand Management Assumptions and Results

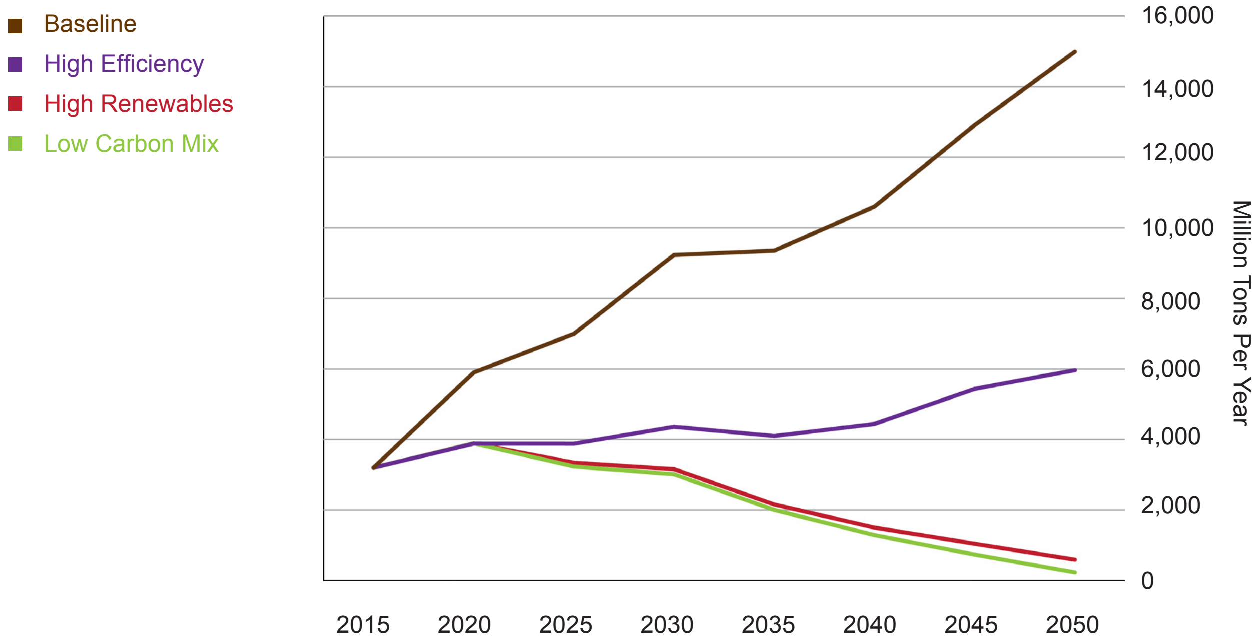
Our modeling of demand management measures focuses on load-shifting technologies, including those described here, organized by sector.

Sectors (Peak Reductions in GW)	2030	2050
Residential water heating	134	127
Residential AC	85	150
Commercial AC	35	30
Commercial Lighting	8	5
Industrial Load Shifting	67	63
Total	>300	>400

How Low Can Power Sector Carbon Emissions Go?

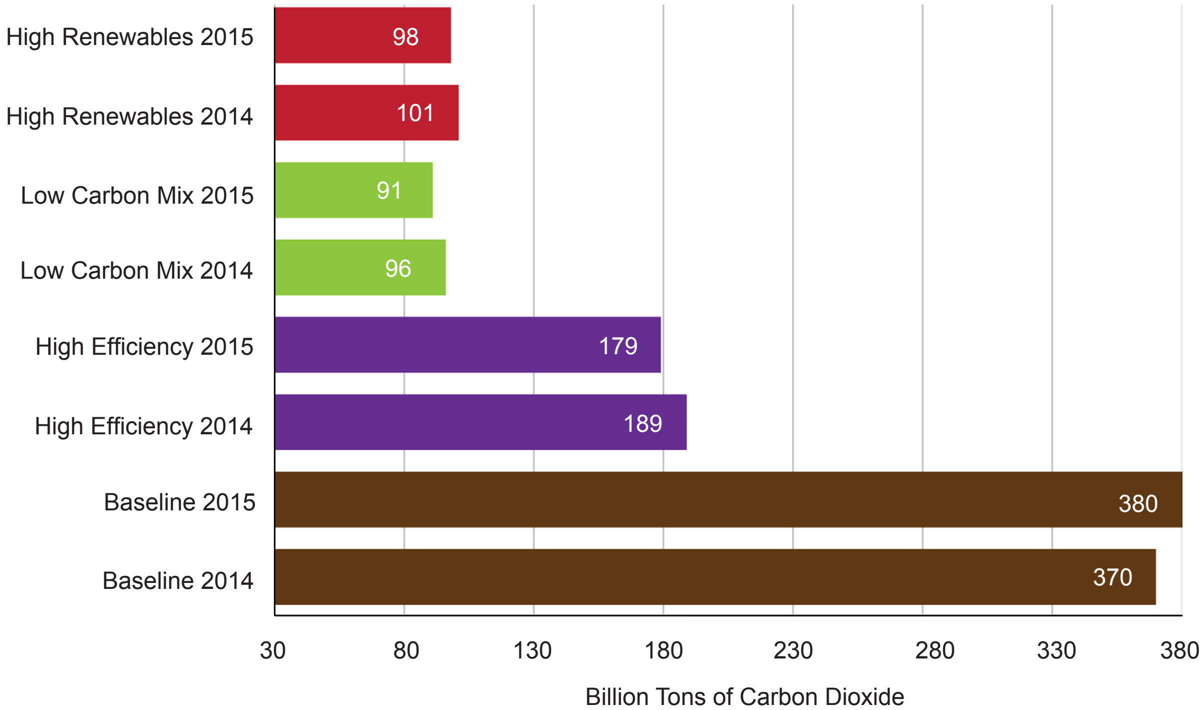
Each technology scenario generated by the China 8760 Grid Model in 2015—High Efficiency, High Renewables, and Low Carbon Mix—substantially reduces 2050 power sector carbon dioxide emissions compared to the Baseline scenario (Figure 2). The High Renewable and Low Carbon Mix scenarios, which build on the low carbon technologies built into the High Efficiency scenario, reduce carbon emissions by nearly 75% compared to the Baseline Scenario.

FIGURE 2 Chinese Power Sector Carbon Dioxide Emissions by Scenario



Our conclusion about carbon emissions reductions is the same in 2015 as in 2014, but our detailed results are different (Figure 3). Emissions are lower in the new scenarios in part because a higher level of use of variable renewable sources is made possible by "demand dispatch," or peak load management technologies. It is worth noting that demand management technologies also account for a substantial share of the reduction in total cost projections between 2014 and 2015. Those technologies permit "demand dispatch" to better match the availability of variable renewable supply systems and to permit a lower overall level of capacity and capital investment.

FIGURE 3 Comparison of Emission by Scenario, Future Generation and Future Generation 2.0, Total Power Sector Emissions, 2015-2050



How Big a Role for Renewables?

The 2015 updates to the China 8760 Grid Model produced a High Renewables scenario that uses renewable resources (and peak demand management technologies) to generate 84% of China's power demand in 2050 at a reasonable cost and with confidence that generating capacity and demand could be balanced (Figure 4).

Figure 5 represents an increase in the potential role of renewables compared to our 2014 results. The integration of additional peak management technologies into the model is largely responsible for this difference.

FIGURE 4 Electricity Generation, High Renewables Scenario

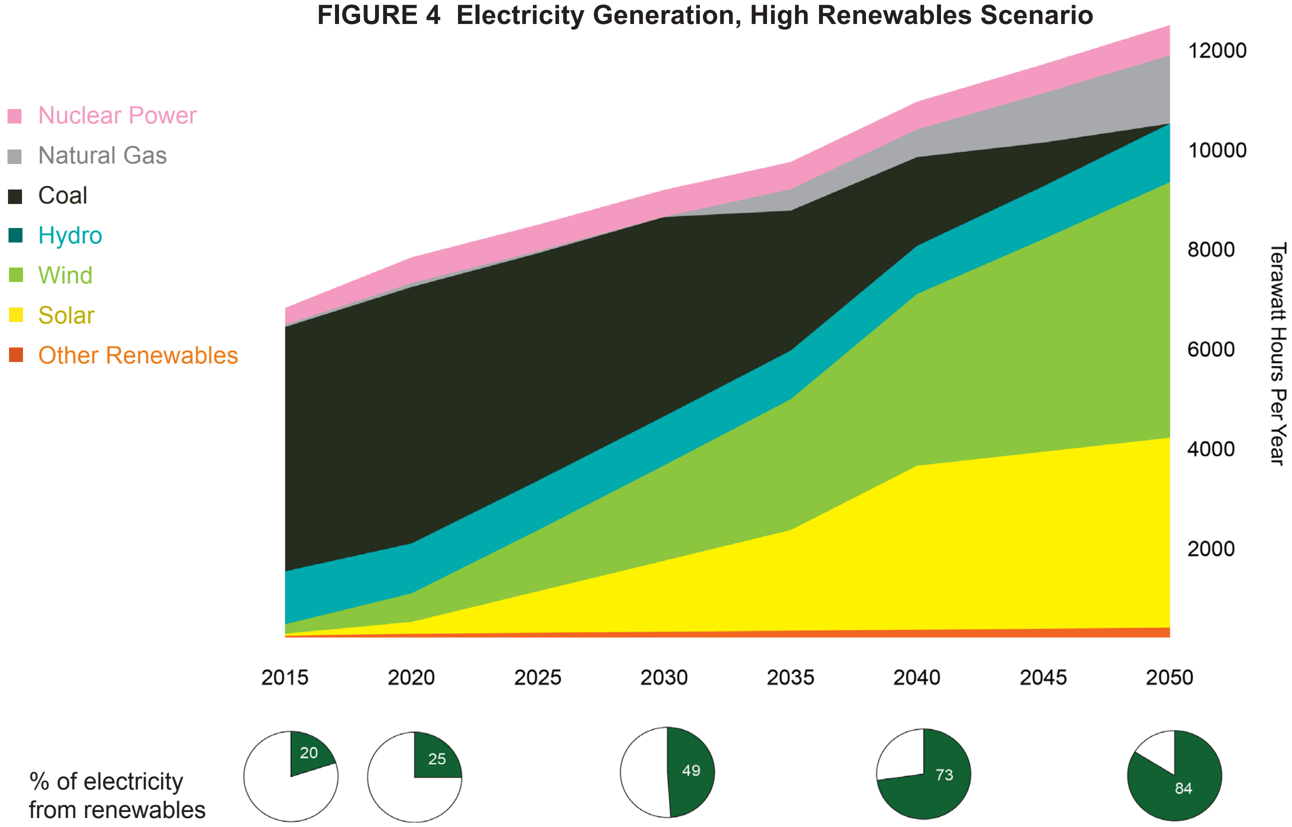
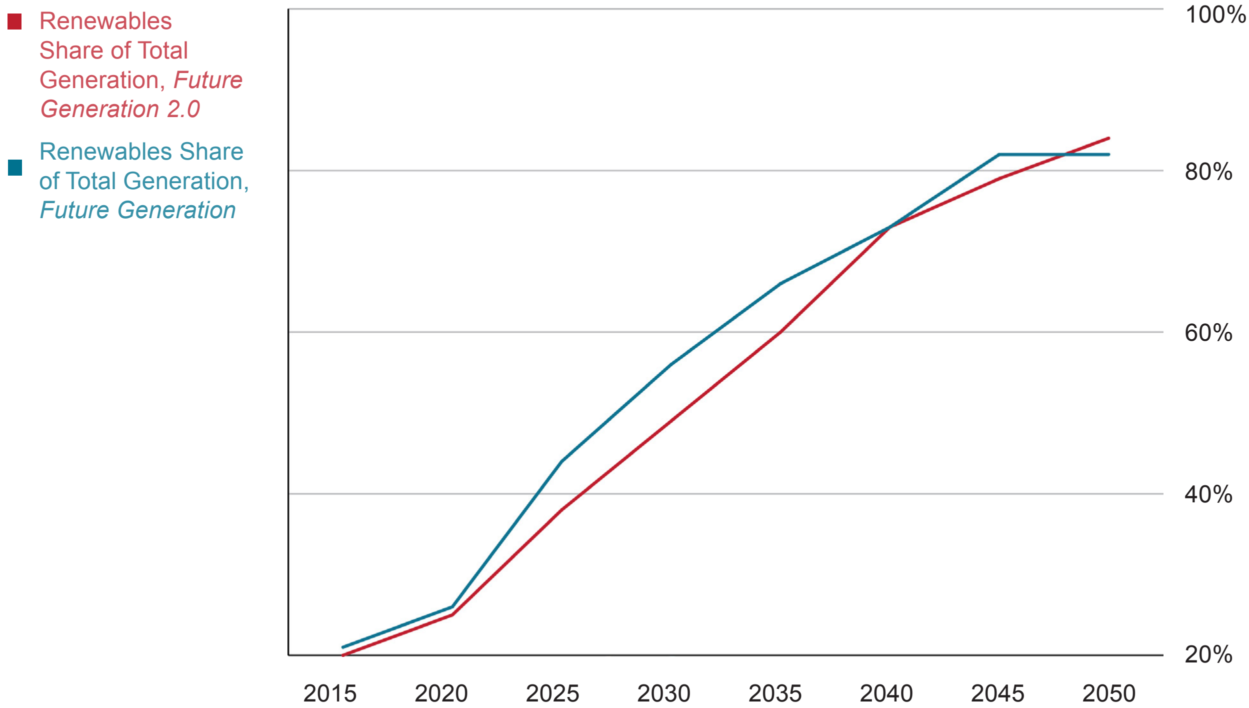


FIGURE 5 High Renewables Scenario, Renewables as a Share of Total Generation



Policy Review

In *Future Generation* in 2014 we examined China's power sector policies, laws, and regulations and concluded that ambitious goals were rarely accompanied with the specific regulatory strategies and enforcement resources needed to implement them. Despite some hopeful notes over the past year, our assessment has not changed. China's leaders continue to give mixed signals about their commitment to a low carbon future.

Signs that China Wants a Low Carbon Future

China and the United States made a Joint Announcement on Climate Change in November 2014 to strengthen bilateral cooperation and inject momentum into multilateral negotiations.[12] China announced two intentions at that time:

- To peak carbon dioxide emissions by 2030, sooner if possible, and
- To increase the share of non-fossil fuels in primary energy consumption to 20% by 2030.

President Xi's public commitment to these goals could provide a real boost to efforts to direct China's power sector toward a low-carbon path. Many of the barriers to achieving the goal are political rather than technical, so political leadership is vital. China made no specific statements about the power sector in the Joint Announcement, but high level advisors have suggested that as much as 1200 GW of zero-emission capacity (hydro, wind, solar, and nuclear) will be installed by 2030.[13]

In March 2015, China finalized a document, *Deepening Reform of the Power Sector*,[14] intended to serve as a roadmap for power sector development. The document focuses on the need for reliability, a bigger role for market mechanisms, consumer protections, and better governance. It calls for greater emphasis on energy savings, emissions reductions, and increased use of renewables. The document contains no specifics.

Elsewhere China has made specific increases in its targets for installed capacity of wind, solar, and nuclear power in 2020.[15] It doubled the target for wind power to 200 GW (up from 95.8 GW). It almost quadrupled the 2020 target for solar power to 100 GW (up from 26.5 GW). It committed to build almost 100 GW of nuclear capacity, after a hiatus on new capacity following the Fukushima disaster. The 2014-2020 action plan calls for 738 GW of zero-emission capacity installed or under construction (including hydropower) in 2020, nearly a doubling of 2013 capacity.[16]

China's State Grid Company has recognized a need for a major expansion of power storage capacity—as much as 300 GW in 2050 compared to 18 GW (almost all pumped storage hydro) in 2012. State Grid expects to have over 50 GW of pumped storage hydro in 2020 and 100 GW in 2025.[17]

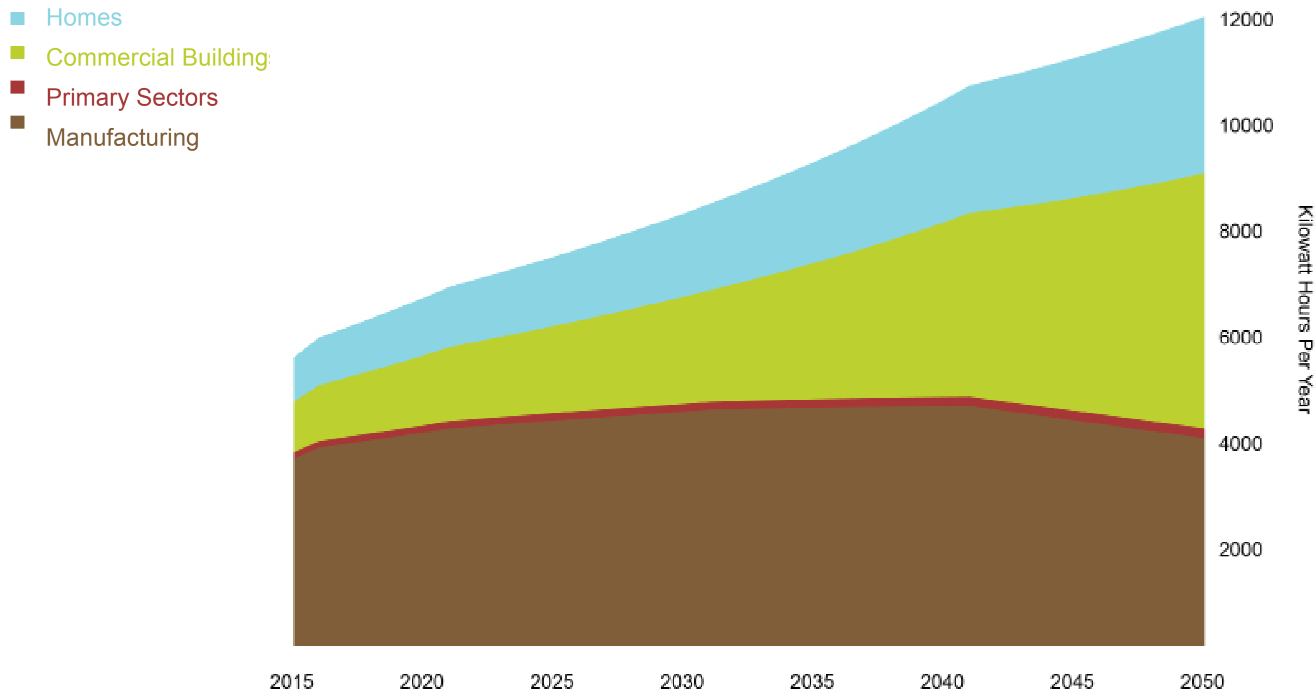
China reports that it remains on course for a 16% reduction of energy intensity during the 12th Five Year Plan period (2011-2015). Energy intensity decreased by 4.8% in 2014, and the target for reduction in 2015 is 3.1%.[18]

Signs that China Will Extend Its Dependence on Coal

Any delay in China's adoption of the policies and technologies that will drive down the demand for electricity, even as the economy grows, strengthens the hold of coal on the power system. We note with concern that:

- China's first power sector reform document in over a decade contains no discussion of the need to separate control of distribution and transmission and pays little attention to optimizing dispatch. Both of these reforms are essential for rapid penetration of renewables in the power system.
- China has not instituted price reforms. The price for coal used in power generation has gone down. Residential electricity consumers pay about half the real cost of their electricity, and this is a huge barrier to controlling electricity demand growth in buildings (Figure 6). There has been little progress on using electricity prices for peak management, which is vital across all sectors.[19]

FIGURE 6 The Growing Importance of Homes and Commercial Buildings for Electricity Demand in China



- Planning for coal gasification, an element of the 2013 air pollution action plan that would shift the geographical location of carbon emissions (rather than reduce them), continued throughout 2014. Experts in China and internationally are raising technical and financial concerns, but this major potential source of increased carbon emissions remains official policy.[20]

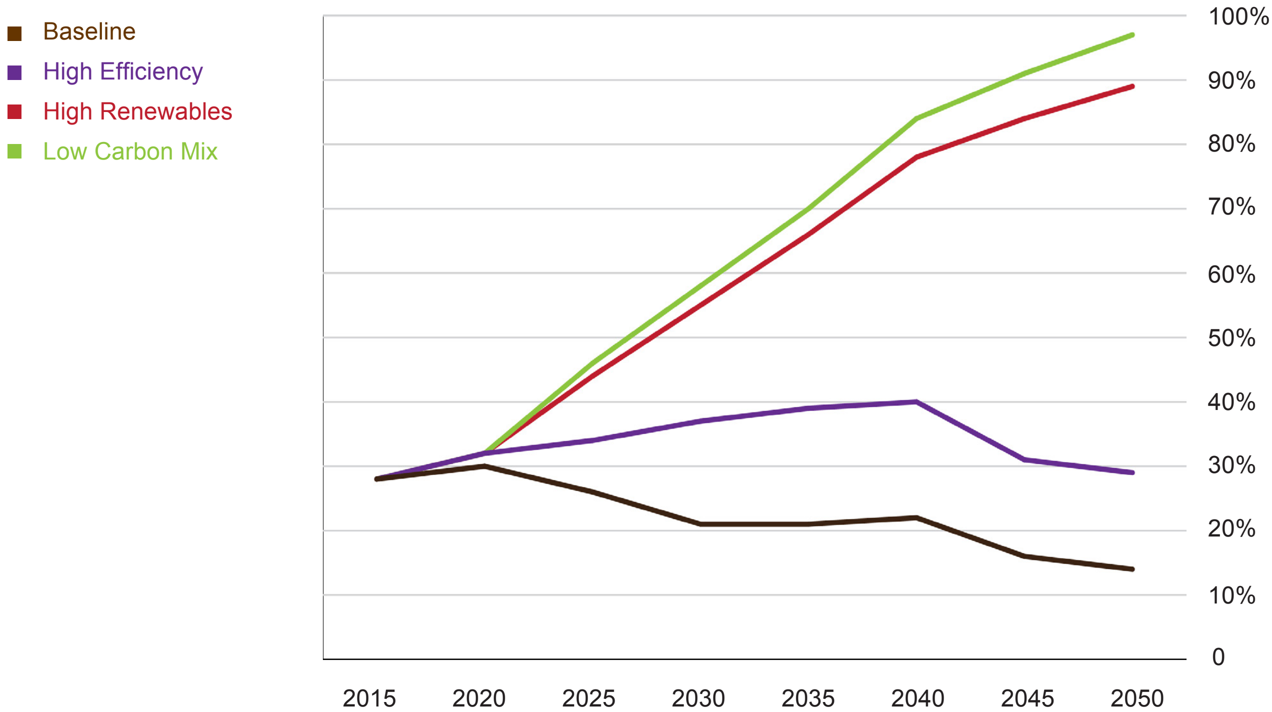
Peak Carbon in China's Power Sector

China has a goal of peaking CO_2 emissions by 2030, and developments in the power sector will greatly influence progress toward that goal. In the High Renewables and Low Carbon Mix scenarios generated by the China 8760 Grid Model, CO_2 emissions from China's power sector peak in 2020 (see Figure 2).

The Baseline and High Efficiency curve are included to illustrate the magnitude of the task facing China. It will be a policy stretch to get to full efficiency, and with deployment of those technologies alone, CO_2 emissions from the power sector do not peak until 2035. Coupling the effort to reach full efficiency throughout the economy with the policies needed to motivate the utilities to replace coal will require enormous political will.

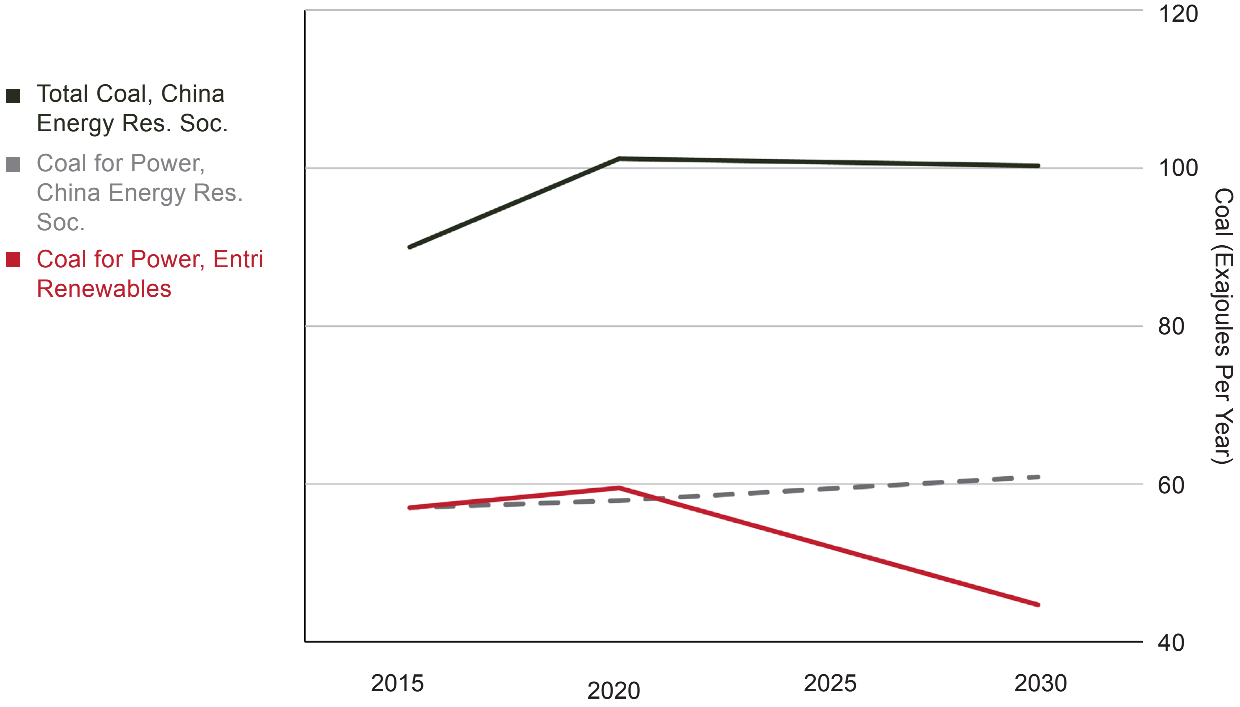
China also has a goal of increasing the share of non-fossil fuels in primary energy use to 20% by 2030. China already generates more than 20% of its electricity from non-fossil fuels because it uses so much hydropower. The High Efficiency, High Renewables and Low Carbon Mix scenarios project non-fossil sources will provide approximately 40% of power generated in 2020 (Figure 7).

FIGURE 7 Share of Non-Fossil Power Generation



Pursuing aggressive, low carbon development scenarios for the power sector could help China meet or beat both of its 2030 commitments. For reference, Figure 8 shows the projections of the China Energy Research Society for coal use in the economy and in the power sector out to 2030. This study is typical of several such studies which show a similar relationship.[21]

FIGURE 8 Total Coal Versus Coal for Power Generation



Recommendations

In *Future Generation*, we made suggestions for high priority actions within four overarching policy recommendations:

- Double down on energy efficiency.
- Make carbon-saving the top criterion for all decisions about electricity supply investment.
- Allow prices to reflect the cost of service.
- Collect, publish, and analyze the data that matter.

We encourage Chinese leaders to address all the action items identified in our 2014 report. This 2015 analysis leads us to make two new recommendations:

- In the category of energy efficiency, we make specific suggestions for appliance standards.
- In the category of carbon saving, we recommend China abandon plans for coal gasification.

Appliance Efficiency Standards

In our 2014 report, we noted China's intention to issue strengthened standards for manufacture of appliances and equipment, and urged them to review and adapt the standards frequently to keep up with or exceed international standards. Our ongoing research leads us to make the following specific recommendations for appliance standards. We used these recommended standards in the 2015 runs of the China 8760 Grid Model to achieve low demand projections and implement peak load management.

TABLE 4 Stringent Standards to Manage Chinese Power Demand

Domestic Items	Current Standard	Recommended Standard
Domestic AC	SEER = 15	SEER = 30 by 2030
Domestic AC Switches	None	All new ACs by 2017
Domestic Water Heaters	Efficiency Factor = 0.9	Efficiency Factor = 3.0 (Heat pump water heaters)
Water heater switches	None	All water heaters by 2020
Residential Lighting	Watts/100 W equip = 15	Watts/100 W equiv. = 5

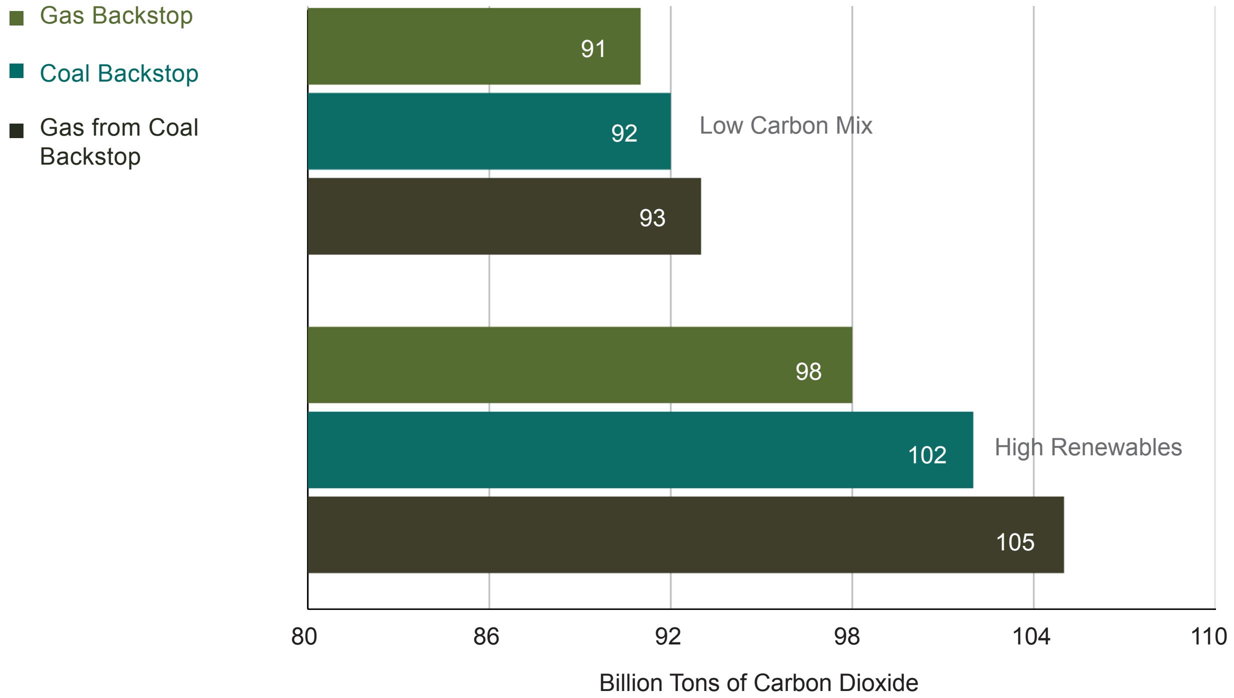
Industrial Items	Current Standard	Recommended Standard
Motor Efficiency	0.9 Conversion Eff.	0.95 Conversion Eff.
Motor Controls	None	All industrial motor systems
AC	SEER = 13	SEER = 30 by 2030
AC Switches	None	All new ACs by 2017
Lighting	Watts/100 W equiv = 20	Watts/100 W equiv. = 10

Abandon Plans for Coal Gasification

China plans to address some of its air pollution problems by producing synthetic natural gas from coal. This will shift some of the problems with coal from the densely populated east to the less-developed western provinces, but it will increase rather than reduce carbon emissions. Power generation using a natural gas substitute made through coal gasification would, depending on the technology used, produce 10-30% more carbon dioxide than typical modern coal-fired power plants.[22] Synthetic natural gas produces seven times more greenhouse gases than natural gas.[23 24 25]

By 2040, some 15-20% of power generation in our scenarios would be provided by either natural gas or coal. We note that China is encountering difficulties in developing domestic sources of natural gas and seems unwilling to become dependent on large amounts of imported gas. The result for carbon emissions of using coal or coal gas instead of natural gas as the peak load and backstop technology is an increase of carbon dioxide emissions of 3-12 billion tons from 2030-2050 (see Figure 9). Note that this result assumes that any natural gas substitute made from coal would be used in highly-efficient combined cycle (Brayton cycle) gas turbines, the efficiency of which would offset the conversion losses from converting coal into gas rather than using coal directly (Rankine cycle) in steam systems. Because of the higher level of carbon emissions from any form of coal use, we recommend China abandon its plans for coal gasification and divert those resources to an enhanced search for low-carbon means to backstop a high renewables electric system and increase emphasis on controlling air pollution sources locally.

FIGURE 9 Carbon Emissions With Gas, Coal, and Gas-from-Coal as a Backstop Generating Source, 2015-2050



Sources: China Energy Research Society and Entri [26]

Appendix: Summary of Results

Baseline Scenario

	2011	2015	2020	2025	2030	2035	2040	2045	2050	Total
Demand (TWh/Year)	4,540	5,701	9,182	11,565	14,236	16,592	19,068	21,740	24,736	636,800
Installed Capacity (GW)	1,019	1,484	2,314	2,882	3,182	3,691	4,218	4,476	4,973	N/A
Generating Cost (Billion RMB)	-	2,845	4,567	5,734	7,427	8,470	10,212	12,515	15,400	335,852
Cost of Transmission (Billion RMB/ Year)	-	209	345	446	554	654	757	799	890	23,274
Cost of Dem./Peak Red. Measures (Billion RMB/Yr)		-	-	-	-	-	-	-	-	-
Cost of Storage (Billion RMB/Year)	0	-	17	20	27	41	56	64	73	N/A
Cost of All Measures (Billion RMB/ Year)	0	3,054	4,929	6,200	8,008	9,165	11,025	13,378	16,364	360,615
Revenues (Billion RMB/Year)	2,629									N/A
Price Feedback Coefficient		-	-	-	-	-	-	-	-	N/A
Population (Millions)	1,347	1,369	1,386	1,393	1,374	1,355	1,337	1,319	1,300	N/A
GDP (2010 USD per Capita)	5,601	6,608	8,898	10,976	13,540	16,069	18,886	22,026	25,639	N/A
Power Use per Capita (kWh)	3,370	4,165	6,625	8,301	10,360	12,242	14,264	16,488	19,021	N/A
Carbon Dioxide Emissions (Million Tons/Year)	-	4,022	5,901	6,992	9,231	9,352	10,598	12,909	14,991	369,986
Power Demand Growth (GDP Growth)	1.00	0.92	1.09	1.11	1.12	1.12	1.11	1.10	1.09	N/A
CAPACITY (GW)										
Solar PV (3 MW)	3	27	149	148	147	147	147	147	147	N/A
Concentrated Solar Power (30 MW)	-	0	3	3	3	3	3	3	3	N/A
Wind Power, On Shore (30 MW scale)	48	88	231	469	707	955	1,205	895	873	N/A
Wind Power, Off Shore (30 MW scale)	-	1	30	30	30	30	30	30	30	N/A
Hydro, Large Scale	157	242	228	202	176	150	124	118	118	N/A
Hydro, Small Scale	58	61	58	48	38	29	19	17	17	N/A
Geothermal	0	0	0	0	0	0	0	0	0	N/A
Biomass (25 MW)	2	9	19	19	19	19	18	18	18	N/A
Sub-Critical Coal	177	153	124	94	65	35	6	-	-	N/A
Sub-Critical Coal w/ Biomass	0	0	0	0	0	0	0	-	-	N/A
Super-Critical Coal (>600 MW)	530	832	1,387	1,791	1,926	2,253	2,594	3,173	3,688	N/A
Reserved	0	0	0	0	0	0	0	0	0	N/A
IGCC CCS Coal (1,000 MW)	-	-	-	-	-	-	-	-	-	N/A
Nuclear Power	13	43	67	68	69	71	72	75	78	N/A
Natural Gas, Peak Load	-	0	0	0	0	0	0	0	-	N/A
Natural Gas, Base Load	33	26	18	10	2	-	-	-	-	N/A
Total	1,019	1,484	2,314	2,882	3,182	3,691	4,218	4,476	4,973	N/A
Storage	-	-	25	30	40	60	80	90	100	N/A

Baseline Scenario (Continued)

	2011	2015	2020	2025	2030	2035	2040	2045	2050	Total
GENERATION MIX (GENERATION IN TWH)										
Solar PV (3 MW)	-	41	221	220	219	219	219	219	219	1,578
Concentrated Solar Power (30 MW)	-	1	16	16	16	16	16	16	16	111
Wind Power, On Shore (30 MW scale)	-	188	507	1,057	1,637	2,268	2,935	2,234	2,234	13,061
Wind Power, Off Shore (30 MW scale)	-	2	66	68	69	71	73	75	77	501
Hydro, Large Scale	-	849	799	708	616	525	433	415	415	4,759
Hydro, Small Scale	-	213	202	168	134	100	66	60	60	1,002
Geothermal	-	0	1	1	1	1	1	1	1	6
Biomass (25 MW)	-	37	78	77	76	75	73	73	73	562
Sub-Critical Coal	-	805	650	495	340	186	31	-	-	2,507
Sub-Critical Coal w/ Biomass	-	0	0	0	0	0	0	-	-	0
Super-Critical Coal (>600 MW)	-	4,373	7,291	9,413	11,811	13,814	15,908	19,455	22,615	104,680
Reserved	-	0	0	0	0	0	0	-	-	0
IGCC CCS Coal (1,000 MW)	-	-	-	-	-	-	-	-	-	-
Nuclear Power	-	338	519	529	538	548	558	580	606	4,217
Natural Gas, Peak Load	-	0	0	0	0	0	0	0	-	0
Natural Gas, Base Load	-	46	79	43	7	-	-	-	-	174
Share of Renewables (Ratio to total TWh)	0.00	0.19	0.18	0.18	0.18	0.18	0.19	0.13	0.12	N/A
Share of Non-Fossil (Ratio to total TWh)	0.00	0.24	0.23	0.22	0.21	0.21	0.22	0.16	0.14	N/A
Total	-	6,892	10,428	12,794	15,465	17,822	20,314	23,127	26,315	133,157
YEAR-BY-YEAR RESULTS										
Demand (TWH)	4,593	5,768	9,290	11,701	14,403	16,786	19,291	21,994	25,026	N/A
Generation (TWH)	4,593	6,892	10,428	12,794	15,465	17,822	20,314	23,127	26,315	N/A
Demand - Generation Balance (TWH)	-	(1,125)	(1,138)	(1,093)	(1,062)	(1,036)	(1,022)	(1,133)	(1,289)	N/A
Share of Abandoned Generation			0.11	0.09	0.07	0.06	0.05	0.05	0.05	N/A
Capacity (GW)	1,019	1,484	2,314	2,882	3,182	3,691	4,218	4,476	4,973	N/A
Cost (Billion RMB)	-	3,054	4,912	6,180	7,981	9,124	10,969	13,314	16,290	N/A
Total Cost (Billion RMB)	0	3,054	4,929	6,200	8,008	9,165	11,025	13,378	16,364	N/A
%age of Demand Not Met	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	N/A
Max Load Shedding Required (GW)	-	-	-	-	-	-	-	-	-	N/A

High Efficiency Scenario

	2011	2015	2020	2025	2030	2035	2040	2045	2050	Total
Demand (TWh/Year)	4,523	5,441	6,540	7,312	8,133	9,111	10,296	11,094	11,883	371,665
Installed Capacity (GW)	1,019	1,431	1,560	1,738	1,804	2,065	2,359	2,280	2,382	N/A
Generating Cost (Billion RMB)	-	2,748	3,524	3,953	4,539	4,939	5,678	6,489	7,430	196,507
Cost of Transmission (Billion RMB/ Year)	-	201	265	316	368	509	571	550	572	16,755
Cost of Dem./Peak Red. Measures (Billion RMB/Yr)		18	271	804	1,374	2,300	3,531	4,851	5,777	94,627
Cost of Storage (Billion RMB/Year)	0	-	17	21	28	42	57	65	74	N/A
Cost of All Measures (Billion RMB/ Year)	0	2,968	4,077	5,093	6,308	7,790	9,836	11,955	13,853	309,404
Revenues (Billion RMB/Year)	2,619									N/A
Price Feedback Coefficient		-	-	-	-	-	-	-	-	N/A
Population (Millions)	1,347	1,369	1,386	1,393	1,374	1,355	1,337	1,319	1,300	N/A
GDP (2010 USD per Capita)	5,601	6,608	8,567	10,468	12,913	15,929	19,649	23,138	26,932	N/A
Power Use per Capita (kWh)	3,358	3,975	4,719	5,248	5,919	6,722	7,702	8,414	9,137	N/A
Carbon Dioxide Emissions (Million Tons/Year)	-	3,814	3,884	3,882	4,362	4,100	4,439	5,435	5,967	179,411
Power Demand Growth (GDP Growth)	1.00	0.88	0.81	0.74	0.67	0.62	0.58	0.53	0.50	N/A
CAPACITY (GW)										
Solar PV (3 MW)	3	27	149	148	147	147	147	147	147	N/A
Concentrated Solar Power (30 MW)	-	0	3	3	3	3	3	3	3	N/A
Wind Power, On Shore (30 MW scale)	48	88	231	469	707	955	1,205	895	873	N/A
Wind Power, Off Shore (30 MW scale)	-	1	30	30	30	30	30	30	30	N/A
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Hydro, Small Scale	58	61	58	48	38	29	19	17	17	N/A
Geothermal	0	0	0	0	0	0	0	0	0	N/A
Biomass (25 MW)	2	9	19	19	19	19	18	18	18	N/A
Sub-Critical Coal	177	153	124	94	65	35	6	-	-	N/A
Sub-Critical Coal w/ Biomass	0	0	0	0	0	0	0	-	-	N/A
Super-Critical Coal (>600 MW)	530	779	634	646	548	627	735	977	1,096	N/A
Reserved	0	0	0	0	0	0	0	0	0	N/A
IGCC CCS Coal (1,000 MW)	-	-	-	-	-	-	-	-	-	N/A
Nuclear Power	13	43	67	68	69	71	72	75	78	N/A
Natural Gas, Peak Load	-	0	0	0	0	0	0	0	-	N/A
Natural Gas, Base Load	33	26	18	10	2	-	-	-	-	N/A
Total	1,019	1,431	1,560	1,738	1,804	2,065	2,359	2,280	2,382	N/A
Storage	-	-	25	30	40	60	80	90	100	N/A

High Efficiency Scenario (Continued)

	2011	2015	2020	2025	2030	2035	2040	2045	2050	Total
GENERATION MIX (GENERATION IN TWH)										
Solar PV (3 MW)	-	41	221	220	219	219	219	219	219	1,578
Concentrated Solar Power (30 MW)	-	1	16	16	16	16	16	16	16	111
Wind Power, On Shore (30 MW scale)	-	188	507	1,057	1,637	2,268	2,935	2,234	2,234	13,061
Wind Power, Off Shore (30 MW scale)	-	2	66	68	69	71	73	75	77	501
Hydro, Large Scale	-	849	799	708	616	525	433	415	415	4,759
Hydro, Small Scale	-	213	202	168	134	100	66	60	60	1,002
Geothermal	-	0	1	1	1	1	1	1	1	6
Biomass (25 MW)	-	37	78	77	76	75	73	73	73	562
Sub-Critical Coal	-	805	650	495	340	186	31	-	-	2,507
Sub-Critical Coal w/ Biomass	-	0	0	0	0	0	0	-	-	0
Super-Critical Coal (>600 MW)	-	4,096	4,480	4,888	5,318	5,856	6,577	8,130	8,941	48,286
Reserved	-	0	0	0	0	0	0	-	-	0
IGCC CCS Coal (1,000 MW)	-	-	-	-	-	-	-	-	-	-
Nuclear Power	-	338	519	529	538	548	558	580	606	4,217
Natural Gas, Peak Load	-	0	0	0	0	0	0	0	-	0
Natural Gas, Base Load	-	46	79	43	7	-	-	-	-	174
Share of Renewables (Ratio to total TWh)	0.00	0.20	0.25	0.28	0.31	0.33	0.35	0.26	0.24	N/A
Share of Non-Fossil (Ratio to total TWh)	0.00	0.25	0.32	0.34	0.37	0.39	0.40	0.31	0.29	N/A
Total	-	6,615	7,617	8,269	8,972	9,864	10,982	11,803	12,641	76,764
YEAR-BY-YEAR RESULTS										
Demand (TWH)	4,576	5,504	6,617	7,398	8,229	9,218	10,417	11,225	12,022	N/A
Generation (TWH)	4,576	6,615	7,617	8,269	8,972	9,864	10,982	11,803	12,641	N/A
Demand - Generation Balance (TWH)	-	(1,111)	(1,000)	(871)	(743)	(646)	(565)	(578)	(619)	N/A
Share of Abandoned Generation		0.17	0.13	0.11	0.08	0.07	0.05	0.05	0.05	N/A
Capacity (GW)	1,019	1,431	1,560	1,738	1,804	2,065	2,359	2,280	2,382	N/A
Cost (Billion RMB)	-	2,949	3,789	4,269	4,907	5,448	6,249	7,039	8,002	N/A
Total Cost (Billion RMB)	0	2,968	4,077	5,093	6,308	7,790	9,836	11,955	13,853	N/A
%age of Demand Not Met	0.00%	0.00%	0.00%	0.00%	0.00%	0.04%	0.18%	0.01%	0.00%	N/A
Max Load Shedding Required (GW)	-	-	-	-	0	4	19	1	0	N/A

High Renewables Scenario

	2011	2015	2020	2025	2030	2035	2040	2045	2050	Total
Demand (TWh/Year)	4,523	5,441	6,552	7,325	8,144	9,119	10,300	11,093	11,876	371,853
Installed Capacity (GW)	1,019	1,431	1,781	2,224	2,569	3,170	4,111	4,590	5,049	N/A
Generating Cost (Billion RMB)	-	2,743	3,486	4,183	4,011	5,069	5,736	6,431	7,083	193,707
Cost of Transmission (Billion RMB/ Year)	-	201	265	357	449	532	718	772	823	20,582
Cost of Dem./Peak Red. Measures (Billion RMB/Yr)		18	272	808	1,381	2,313	3,551	4,881	5,813	95,189
Cost of Storage (Billion RMB/Year)	0	-	17	21	27	43	58	66	74	N/A
Cost of All Measures (Billion RMB/ Year)	0	2,963	4,039	5,369	5,867	7,957	10,063	12,150	13,793	311,008
Revenues (Billion RMB/Year)	2,619									N/A
Price Feedback Coefficient		-	-	-	-	-	-	-	-	N/A
Population (Millions)	1,347	1,369	1,386	1,393	1,374	1,355	1,337	1,319	1,300	N/A
GDP (2010 USD per Capita)	5,601	6,608	8,567	10,468	12,913	15,929	19,649	23,138	26,932	N/A
Power Use per Capita (kWh)	3,358	3,975	4,727	5,258	5,926	6,728	7,705	8,413	9,132	N/A
Carbon Dioxide Emissions (Million Tons/Year)	-	3,814	3,893	3,341	3,158	2,159	1,502	1,045	594	97,533
Power Demand Growth (GDP Growth)	1.00	0.88	0.81	0.74	0.67	0.62	0.58	0.53	0.50	N/A
CAPACITY (GW)										
Solar PV (3 MW)	3	27	149	373	597	822	1,500	1,500	1,500	N/A
Concentrated Solar Power (30 MW)	-	0	3	52	102	151	201	250	300	N/A
Wind Power, On Shore (30 MW scale)	48	88	231	469	707	941	1,205	1,455	1,705	N/A
Wind Power, Off Shore (30 MW scale)	-	1	30	75	120	165	210	255	300	N/A
Hydro, Large Scale	157	242	228	223	217	212	207	223	243	N/A
Hydro, Small Scale	58	61	58	60	63	66	69	79	92	N/A
Geothermal	0	0	0	0	1	1	1	1	1	N/A
Biomass (25 MW)	2	9	19	24	29	34	38	43	48	N/A
Sub-Critical Coal	177	153	124	94	65	35	6	-	-	N/A
Sub-Critical Coal w/ Biomass	0	0	0	0	0	0	0	-	-	N/A
Super-Critical Coal (>600 MW)	530	779	855	774	596	427	285	142	-	N/A
Reserved	0	0	0	0	0	0	0	0	0	N/A
IGCC CCS Coal (1,000 MW)	-	-	-	-	-	-	-	-	-	N/A
Nuclear Power	13	43	67	68	69	71	72	75	78	N/A
Natural Gas, Peak Load	-	0	0	0	0	245	317	566	781	N/A
Natural Gas, Base Load	33	26	18	10	2	-	-	-	-	N/A
Total	1,019	1,431	1,781	2,224	2,569	3,170	4,111	4,590	5,049	N/A
Storage	-	-	25	30	40	60	80	90	100	N/A

High Renewables Scenario (Continued)

	2011	2015	2020	2025	2030	2035	2040	2045	2050	Total
GENERATION MIX (GENERATION IN TWH)										
Solar PV (3 MW)	-	41	221	555	889	1,224	2,234	2,234	2,234	9,633
Concentrated Solar Power (30 MW)	-	1	16	276	536	796	1,056	1,317	1,577	5,574
Wind Power, On Shore (30 MW scale)	-	188	507	1,057	1,637	2,234	2,935	3,633	4,361	16,552
Wind Power, Off Shore (30 MW scale)	-	2	66	169	278	392	512	637	767	2,822
Hydro, Large Scale	-	849	799	781	762	744	725	780	853	6,292
Hydro, Small Scale	-	213	202	212	222	232	242	279	322	1,922
Geothermal	-	0	1	2	3	4	5	5	6	26
Biomass (25 MW)	-	37	78	97	116	135	153	173	193	982
Sub-Critical Coal	-	805	650	495	340	186	31	-	-	2,507
Sub-Critical Coal w/ Biomass	-	0	0	0	0	0	0	-	-	0
Super-Critical Coal (>600 MW)	-	4,096	4,492	4,068	3,655	2,621	1,747	874	-	21,553
Reserved	-	0	0	0	0	0	0	-	-	0
IGCC CCS Coal (1,000 MW)	-	-	-	-	-	-	-	-	-	-
Nuclear Power	-	338	519	529	538	548	558	580	606	4,217
Natural Gas, Peak Load	-	0	0	0	0	429	556	992	1,368	3,345
Natural Gas, Base Load	-	46	79	43	7	-	-	-	-	174
Share of Renewables (Ratio to total TWh)	0.00	0.20	0.25	0.38	0.49	0.60	0.73	0.79	0.84	N/A
Share of Non-Fossil (Ratio to total TWh)	0.00	0.25	0.32	0.44	0.55	0.66	0.78	0.84	0.89	N/A
Total	-	6,615	7,630	8,283	8,984	9,543	10,754	11,503	12,288	75,599
YEAR-BY-YEAR RESULTS										
Demand (TWH)	4,576	5,504	6,629	7,411	8,240	9,226	10,421	11,223	12,015	N/A
Generation (TWH)	4,576	6,615	7,630	8,283	8,984	9,543	10,754	11,503	12,288	N/A
Demand - Generation Balance (TWH)	-	(1,111)	(1,001)	(872)	(744)	(317)	(333)	(280)	(273)	N/A
Share of Abandoned Generation		0.17	0.13	0.11	0.08	0.03	0.03	0.02	0.02	N/A
Capacity (GW)	1,019	1,431	1,781	2,224	2,569	3,170	4,111	4,590	5,049	N/A
Cost (Billion RMB)	-	2,944	3,751	4,539	5,309	6,210	6,860	7,406	7,905	N/A
Total Cost (Billion RMB)	0	2,963	4,039	5,369	5,867	7,957	10,063	12,150	13,793	N/A
%age of Demand Not Met	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.01%	0.00%	0.00%	N/A
Max Load Shedding Required (GW)	-	-	-	-	-	-	1	0	0	N/A

Low Carbon Mix Scenario

	2011	2015	2020	2025	2030	2035	2040	2045	2050	Total
Demand (TWh/Year)	4,523	5,441	6,552	7,325	8,144	9,119	10,300	11,093	11,876	371,853
Installed Capacity (GW)	1,019	1,431	1,781	2,126	2,399	2,730	3,679	4,078	4,437	N/A
Generating Cost (Billion RMB)	-	2,743	3,486	4,211	4,164	5,064	5,824	6,478	7,132	195,511
Cost of Transmission (Billion RMB/ Year)	-	201	265	337	412	475	679	739	784	19,457
Cost of Dem./Peak Red. Measures (Billion RMB/Yr)		18	272	808	1,381	2,313	3,551	4,881	5,813	95,189
Cost of Storage (Billion RMB/Year)	0	-	17	21	27	43	57	66	74	N/A
Cost of All Measures (Billion RMB/ Year)	0	2,963	4,039	5,377	5,984	7,895	10,111	12,163	13,803	311,680
Revenues (Billion RMB/Year)	2,619									N/A
Price Feedback Coefficient		-	-	-	-	-	-	-	-	N/A
Population (Millions)	1,347	1,369	1,386	1,393	1,374	1,355	1,337	1,319	1,300	N/A
GDP (2010 USD per Capita)	5,601	6,608	8,567	10,468	12,913	15,929	19,649	23,138	26,932	N/A
Power Use per Capita (kWh)	3,358	3,975	4,727	5,258	5,926	6,728	7,705	8,413	9,132	N/A
Carbon Dioxide Emissions (Million Tons/Year)	-	3,814	3,893	3,234	3,014	2,004	1,289	738	230	91,080
Power Demand Growth (GDP Growth)	1.00	0.88	0.81	0.74	0.67	0.62	0.58	0.53	0.50	N/A
CAPACITY (GW)										
Solar PV (3 MW)	3	27	149	309	468	629	1,415	1,500	1,500	N/A
Concentrated Solar Power (30 MW)	-	0	3	52	102	151	201	250	300	N/A
Wind Power, On Shore (30 MW scale)	48	88	231	469	707	941	1,205	1,455	1,705	N/A
Wind Power, Off Shore (30 MW scale)	-	1	30	50	70	90	110	130	150	N/A
Hydro, Large Scale	157	242	228	202	176	150	124	118	118	N/A
Hydro, Small Scale	58	61	58	48	38	29	19	17	17	N/A
Geothermal	0	0	0	0	1	1	1	1	2	N/A
Biomass (25 MW)	2	9	19	22	24	26	28	30	32	N/A
Sub-Critical Coal	177	153	124	94	65	35	6	-	-	N/A
Sub-Critical Coal w/ Biomass	0	0	0	0	0	0	0	-	-	N/A
Super-Critical Coal (>600 MW)	530	779	855	748	570	427	285	142	-	N/A
Reserved	0	0	0	0	0	0	0	0	0	N/A
IGCC CCS Coal (1,000 MW)	-	-	-	-	-	-	-	-	-	N/A
Nuclear Power	13	43	67	122	177	232	286	343	400	N/A
Natural Gas, Peak Load	-	0	0	0	0	19	-	90	213	N/A
Natural Gas, Base Load	33	26	18	10	2	-	-	-	-	N/A
Total	1,019	1,431	1,781	2,126	2,399	2,730	3,679	4,078	4,437	N/A
Storage	-	-	25	30	40	60	80	90	100	N/A

Low Carbon Mix Scenario (Continued)

	2011	2015	2020	2025	2030	2035	2040	2045	2050	Total
GENERATION MIX (GENERATION IN TWH)										
Solar PV (3 MW)	-	41	221	460	698	937	2,107	2,234	2,234	8,931
Concentrated Solar Power (30 MW)	-	1	16	276	536	796	1,056	1,317	1,577	5,574
Wind Power, On Shore (30 MW scale)	-	188	507	1,057	1,637	2,234	2,935	3,633	4,361	16,552
Wind Power, Off Shore (30 MW scale)	-	2	66	113	162	214	268	325	384	1,532
Hydro, Large Scale	-	849	799	708	616	525	433	415	415	4,759
Hydro, Small Scale	-	213	202	168	134	100	66	60	60	1,002
Geothermal	-	0	1	2	3	4	5	6	7	29
Biomass (25 MW)	-	37	78	86	94	103	111	120	129	758
Sub-Critical Coal	-	805	650	495	340	186	31	-	-	2,507
Sub-Critical Coal w/ Biomass	-	0	0	0	0	0	0	-	-	0
Super-Critical Coal (>600 MW)	-	4,096	4,492	3,930	3,494	2,621	1,747	874	-	21,254
Reserved	-	0	0	0	0	0	0	-	-	0
IGCC CCS Coal (1,000 MW)	-	-	-	-	-	-	-	-	-	-
Nuclear Power	-	338	519	946	1,373	1,799	2,226	2,666	3,109	12,975
Natural Gas, Peak Load	-	0	0	0	0	34	0	158	373	564
Natural Gas, Base Load	-	46	79	43	7	-	-	-	-	174
Share of Renewables (Ratio to total TWh)	0.00	0.20	0.25	0.35	0.43	0.51	0.64	0.69	0.72	N/A
Share of Non-Fossil (Ratio to total TWh)	0.00	0.25	0.32	0.46	0.58	0.70	0.84	0.91	0.97	N/A
Total	-	6,615	7,630	8,283	9,094	9,552	10,986	11,805	12,648	76,613
YEAR-BY-YEAR RESULTS										
Demand (TWH)	4,576	5,504	6,629	7,411	8,239	9,225	10,420	11,223	12,015	N/A
Generation (TWH)	4,576	6,615	7,630	8,283	9,094	9,552	10,986	11,805	12,648	N/A
Demand - Generation Balance (TWH)	-	(1,111)	(1,001)	(872)	(855)	(326)	(565)	(583)	(633)	N/A
Share of Abandoned Generation		0.17	0.13	0.11	0.09	0.03	0.05	0.05	0.05	N/A
Capacity (GW)	1,019	1,431	1,781	2,126	2,399	2,730	3,679	4,078	4,437	N/A
Cost (Billion RMB)	-	2,944	3,751	4,548	5,388	6,149	6,908	7,420	7,916	N/A
Total Cost (Billion RMB)	0	2,963	4,039	5,377	5,984	7,895	10,111	12,163	13,803	N/A
%age of Demand Not Met	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.41%	0.62%	0.57%	N/A
Max Load Shedding Required (GW)	-	-	-	-	-	0	43	70	68	N/A

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[1] Annual growth over the past decade in constant RMB (GDP) and in electricity demand (Elec.). Source: *China Statistical Yearbook 2014*, and 中华人民共和国2014年国民经济和社会发展统计公报，来源：　新华社 2015年02月26日 19:17:29. 新华社北京2月26日电（授权发布）中华人民共和国2014年国民经济和社会发展统计公报[1]，中华人民共和国国家统计局，2015年2月26日.

Year	Elec.	GDP
1996	7.4	10
1997	4.8	9.3
1998	2.8	7.8
1999	6.1	7.6
2000	9.5	8.4
2001	9.3	8.3
2002	11.8	9.1
2003	15.6	10
2004	15.4	10.1
2005	13.5	11.3
2006	14.6	12.7
2007	14.4	14.2
2008	5.6	9.6
2009	7.2	9.2
2010	13.2	10.4
2011	12.1	9.3
2012	5.9	7.7
2013	8.5	7.7
2014	4.7	7.4

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[3] The China 8760 Grid Model is a combined econometric and engineering model developed by Entri to assess the cost, carbon emissions, land use impacts, and transmission line requirements of China's electric power system. The 2014 *Future Generation* report contains a description of the model's assumptions.

[4] For a detailed presentation of the China 8760 Model methodology, see William Chandler, Chen Shiping, Lin Ruosida, *China 8760 Grid Model Methodology, 2015 Revisions*, forthcoming, Entri, June 2015 (www.etransition.org/publications).

[5] Although China's population is large, it is not expected to grow or shrink markedly during the time periods in the model, and has very little impact on model results. Population figures are included mainly to enable per capita results for comparison purposes. Population data for 2011 come National Statistical Bureau, "China Statistical Yearbook 2012", 2013, Beijing; and Population Reference Bureau, "World Population Data Sheet 2011," 2012, www.prb.org

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[7] Conversion from base year dollars (generally year 2005 constant U.S. dollars) to year 2011 values was done using the consumer price index values provided by the U.S. Department of Labor, Bureau of Labor Statistics, http://www.bls.gov, mid-2013

[8] Based on regression analysis by the authors.

[9] Industrial value-added and electricity consumption compiled from *China Statistical Yearbooks 1996–2013*, Chinese National Statistics Bureau, Beijing, China. Analysis performed by Lin Ruosida and Wang Yanjia. See also, Ali Hasanbeigi, Lynn Price, Cecilia Fino-Chen, Hongyou Lu, Jing Ke, "Retrospective and Prospective Decomposition Analysis of Chinese Manufacturing Energy Use, 1995-2020," China Energy Group, Energy Analysis and Environmental Impacts Department, Environmental Energy Technologies Division, Lawrence Berkeley National Laboratory, January 2013; Power sector capacity data from http://www.stats.gov.cn/tjsj/ndsj/2014/indexeh.htm; Additional electric power elasticities from http://www.stats.gov.cn/tjsj/ndsj/2014/zk/html/Z0908E.JPG.

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Province	Yuan/kWh
Beijing	0.49
Tianjin	0.49
Hebei	0.52
Shanxi	0.48
Inter-Mongolia	0.43
Liaoning	0.50
Jilin	0.53
Heilongjiang	0.51
Shanghai	0.62
Jiangsu	0.53
Zhejiang	0.54
Anhui	0.57
Fujian	0.50
Jiangxi	0.60
Shandong	0.55
Henan	0.56
Hubei	0.57
Hunan	0.61
Guangzhou (Guangdong Province)	0.61
Shenzhen (Guangdong Province)	0.68
Shantou (Guangdong Province)	0.70
Huizhou (Guangdong Province)	0.65
Nanning, Beihai (Guangxi Province)	0.53
Liuzhou (Guangxi Province)	0.46
Hainan	0.61
Chongqing	0.52

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