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Coal-Fired Generation Overcapacity in China

Quantifying the Scale of the Problem: A Discussion Draft[1]

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An Assessment of China's Medium-Term Generation Capacity Needs

China is at the beginning of a paradigm shift in its electricity sector, from an industry characterized by very high growth to one more focused on economic efficiency and environmental performance. Three key drivers behind this shift are: (1) slowing demand growth, resulting from structural changes in China's economy; (2) policy mandates for dramatic near-term improvements in air quality and longer-term CO_2 emission reductions; and (3) high costs, which are a legacy of stalled electricity sector reforms.

A changing paradigm suggests a need for changes in approaches to generation investment and approval. Historically, with power shortages the norm, generation companies built new generation units, and the National Energy Administration (NEA) approved them, largely without considering whether they were needed. As demand growth slows, there is a risk that China will have too much generation capacity, relative to what could be justified on reliability, economic, or environmental grounds.

This paper examines whether China already has too much coal-fired generating capacity relative to what will be needed in 2020, focusing on a generation adequacy, or reliability, perspective. It argues that existing coal-fired generation capacity at the end of 2014 is likely to be adequate to meet reliability needs until at least 2020, and likely beyond, and that continued expansion of coal-fired generation capacity poses a significant financial risk to China's electricity industry. Developing a rigorous resource planning and generation approval process to mitigate this risk is thus an urgent priority.

Background: Trends in China's Economic Growth and Electricity Demand

Recent declines in electricity demand in China are being driven by changes in the composition of the economy. While economic growth has slowed over the past two years, nominal year-on-year economic growth in has remained around 6-7 percent.[2] What has changed since 2012 is that most of this growth is now being driven by the tertiary (services) sector, while secondary (industry and construction) sector growth has fallen to 0-2 percent (Figure 1).[3]

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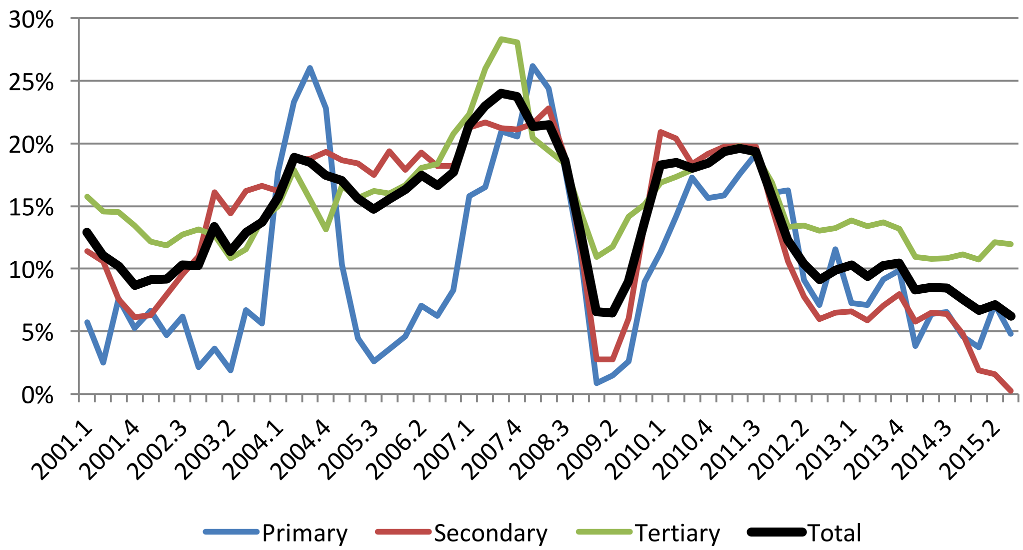
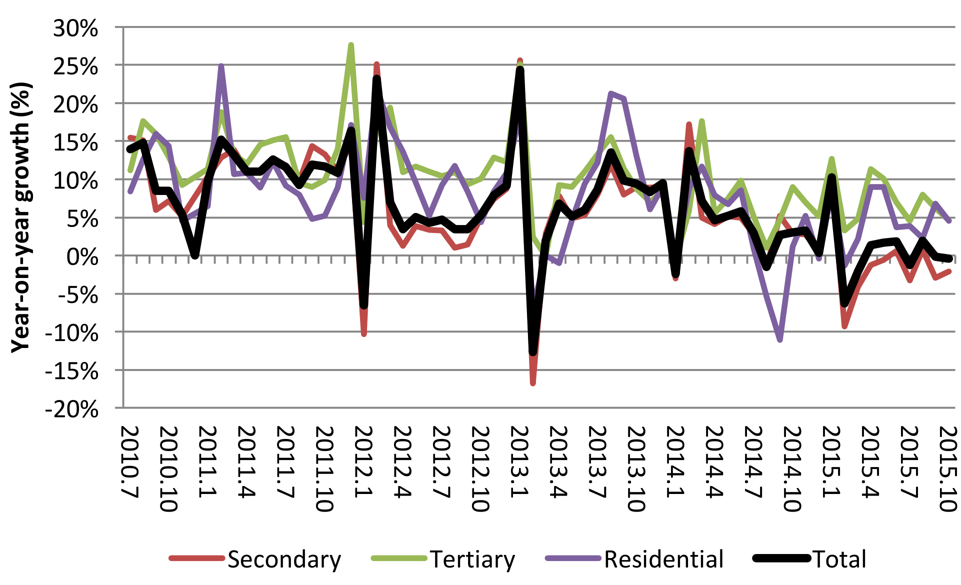
[1] The author seeks your feedback on the analysis and conclusions of this paper. Please send your thoughts to fritz@ethree.com.
[2] Year-on-year growth refers to percentage change relative to the previous year.
[3] Figure 1 somewhat overstates real compositional shifts, due to the fact that producer prices likely fell faster in the secondary than in the tertiary sector over this time period. China's National Bureau of Statistics does not publish price indices with high

Figure 1. Nominal Year-on-Year Growth Rates in Quarterly Sector and Total Value Added (GDP), 2001 (Q1) to 2015 (Q3)



Source: Data are from the National Bureau of Statistics' (NBS') Chashu Database, online at: http://data.stats.gov.cn/.

Figure 2. Year-on-Year Growth in Electricity Demand, Secondary, Tertiary, Residential Sectors and Total, July 2010 to October 2015



Source: Data are from the China Electricity Council's (CEC's) monthly electricity statistics series, online at: http://cec.org.cn/guihuayutongji/.

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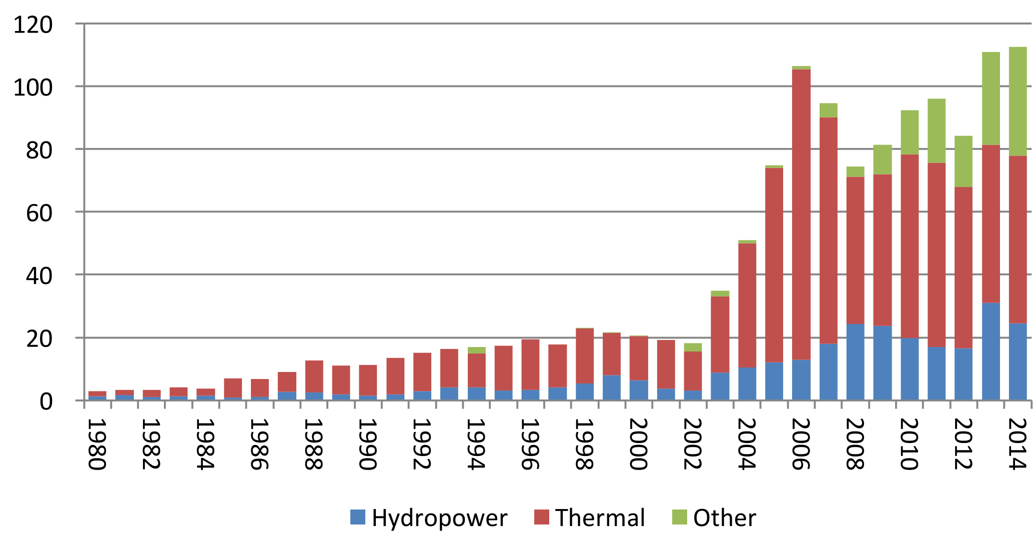
enough sector resolution to deflate value added across aggregate sectors. Although they may amplify compositional changes, nominal changes in value added are consistent with the changes in electricity demand shown in **Figure 2**.

In the electricity sector, the industry and construction sector has historically accounted for nearly three-quarters of total electricity demand.[4] As a result of this shift in economic structure, total year-on-year electricity demand growth has fallen to just above zero, even though the services and residential sector year-on-year demand growth has remained at greater than 5 percent (Figure 2). Year-on-year electricity demand growth in the industry and construction sector has been negative for much of 2015. Through the first 10 months of 2015, year-on-year demand growth has been 0.8 percent.

Figure 3. Net Changes in Hydropower, Thermal, and Other Generating Capacity, 1980 to 2014

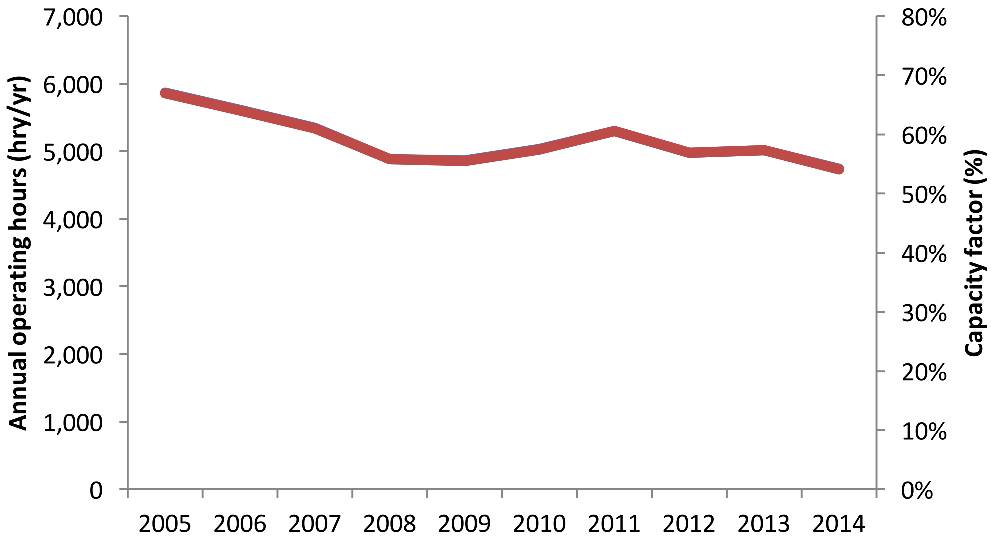


Source: Data are from the CEC's annual electricity statistics series, online at http://cec.org.cn/guihuayutongji/.

Despite slowing demand growth, generation capacity has continued to grow rapidly. In 2014, China's total generation capacity grew by 113 gigawatts (GW), more than any other previous year, though the composition of incremental capacity has diversified (Figure 3).[5] New capacity additions in 2014 included 35 GW of coal generating capacity, a significant decline from an average of 57 GW between 2008 and 2012 but still large given slowing demand growth.[6] As a result of this mismatch between supply and demand trajectories, utilization of thermal power plants, including both coal- and gas-fired plants, fell from an average capacity factor of 67 percent (5,865 hours) in 2005 to 54 percent (4,739 hours) in 2014 (Figure 4).

[4] Based on data from the NBS *Statistical Yearbook* series, online at http://www.stats.gov.cn/tjsj/ndsj/.
[5] "Incremental capacity" here refers to the difference in generation capacity between two years. The difference between this metric and "capacity additions" is any capacity that is retired over the course of the year. The CEC does not provide a longer history of either capacity additions or retirements, and data on incremental capacity, additions, and retirements are often not consistent.
[6] Data here are from the CEC's annual electricity statistics series, online at: http://cec.org.cn/guihuayutongji/.

Figure 4. Average Annual Operating Hours and Capacity Factors for Thermal Generation in China, 2005 to 2014[7]



Sources: Data for 2008 to 2014 are from the CEC's annual electricity statistics series, online at: http://cec.org.cn/guihuayutongji/*; data for 2005 to 2007 are from the China Electricity Yearbook series, online at:* http://hvdc.chinapower.com.cn/membercenter/yearbookcenter/.

Methods

To assess the extent of overcapacity in coal-fired generation in China, this paper uses a load-resource balance approach, which is often used in the U.S., as a screen to test for the need for new generation capacity. Generally, this approach consists of four basic steps:

1) Forecasting annual peak electricity demand, and adjusting for energy efficiency and demand response;
2) Adding a planning reserve margin to peak demand, to account for weather-related events and unexpected generator outages;
3) Comparing available generation capacity to peak demand; and
4) Making investment decisions: if available generation capacity is less than peak demand, additional resources (generation, transmission, demand-side) will be needed to maintain a given reliability target; if not, no additional resources are needed to maintain that target.

The analysis in this paper uses steps one (forecast peak demand) and three (compare available capacity to peak demand) to calculate an effective reserve margin, rather than using a fixed planning reserve margin. Based on the resulting reserve margin, we assess the extent of coal-fired generation overcapacity in China, using a reasoning similar to that in step four. This section provides a high-level overview of key

[7] The year 2005 here does not have special significance. It appears to be the last year in which these data are available at a national level, though the *Electricity Statistical Yearbook* series has separate data for State Grid and China Southern Grid that extend further back.

methodological decisions in this analysis. A detailed accounting of methods and inputs is provided in the appendix.

In order to forecast peak demand (in gigawatts, GW) in China, a few assumptions are necessary. Balancing areas in China are essentially provincial, implying that the appropriate level to do resource adequacy analysis is at a provincial level. Given limitations on publicly available data, however, we use a combination of regional grid-level peak demand data and national-level generation capacity data in this analysis. Interprovincial transmission constraints and institutional barriers to interprovincial power exchange may thus impose additional generation capacity needs beyond what is estimated here.

Our forecast of electricity demand (in terawatt-hours, TWh) is consistent with a 6.5 percent average annual GDP growth rate from 2015 to 2020, based on current government targets. They differ primarily in assumptions about the relationship between economic growth and electricity demand, with one scenario in which electricity intensity—kilowatt-hours (kWh) per unit real value added or household expenditure—declines over time and another where it remains constant. The former scenario is consistent with electricity demand growth of 1 percent per year; the latter with 4 percent per year.

Peak electricity demand (GW) is related to average electricity demand (TWh) through a system load factor, which is defined as the ratio of average to peak demand. The residential and commercial sectors tend to have lower load factors than the industrial sector, and as these grow as a share of China's electricity use system load factors will fall—demand will become "peakier." To capture this effect, we assume that system load factors decline by 3 and 5 percentage points by 2020. Together, these peak and electricity demand assumptions result in the electricity and peak demand forecasts shown in Table 1.

Table 1. Key Assumptions by Scenario, and Electricity and Peak Demand for 2014 (Actual) and 2020 by Scenario

	Annual Average Growth in Electricity Demand (%/yr)	Decline in System Load Factor (%)	Electricity Demand (TWh)	Peak Electricity Demand (GW)
2014			4,868	834
2020 Scenario A.1	1	3	5,167	913
2020 Scenario A.2	1	5	5,167	932
2020 Scenario B.1	4	3	5,981	1,057
2020 Scenario B.2	4	5	5,981	1,079

On the resource side, we consider two main scenarios:

1) *2014 Capacity*–central-scale generation capacity in 2020 is limited to available generation capacity at the end of 2014;
2) *2020 Policy*–central-scale generation capacity in 2020 is limited to available capacity at the end of 2014, plus incremental installed capacity targets for conventional and pumped hydropower

(+115 GW), nuclear (+38 GW), solar (+75 GW), and wind (+103 GW) generation set forth in the 12th five-year planning process.[8]

All generation resources, whether they are dispatchable or not, contribute some amount to peak generation capacity needs. For fully dispatchable generation, this contribution—captured in a resource adequacy value[9]—is typically one. For other resources, and in particular hydropower, solar, and wind, this value will be less than one. There are few, if any, analyses of what appropriate resource adequacy values for these resources should be in China, and we use commonly seen values in North America instead.

China also has a significant amount of behind-the-meter generation, including smaller-scale generating units located in industrial facilities but also industrial cogeneration units. With the right incentives, these units can contribute to system peak generation capacity needs, though it is unclear what arrangements behind-the-meter customers currently have with grid companies in China. To account for this uncertainty, we consider a scenario in which all estimated behind-the-meter generation capacity is counted toward resource adequacy, and one in which half of it is.

Because we allow behind-the-meter generation to scale with electricity demand, this results in ten scenarios of generation capacity. The "2014 Capacity, Scenario A" scenario thus includes generation capacity in 2014 and the increase in behind-the-meter generation capacity consistent with demand growth in Scenario A. The "2020 Policy, Scenario A" scenario includes all generation capacity at the end of 2014, additional policy-driven capacity[10] in 2020, and the increase in behind-the-meter generation capacity consistent with demand growth in Scenario A.

[8] Chinese representatives at the Conference of Parties (COP) 21 in Paris in December 2015 raised the possibility that the 2020 capacity targets for wind and solar may rise to 250 GW and 150-200 GW, respectively. This translates to incremental capacity of 153 GW and 125-175 GW by 2020, relative to 2014 capacity. See "China Raises its Targets for Renewable Energy," *The New York Times*, December 8, 2015.

[9] 'Resource adequacy value' is defined here as the maximum capacity available during peak demand hours.

[10] 'Policy-driven capacity' refers to capacity investment that is driven by policy targets, and includes biomass, hydropower, nuclear, solar, and wind generation.

Table 2 shows generation capacity that is qualified to contribute to resource adequacy in these 10 scenarios.

Table 2. Generation Capacity Qualified to Contribute to Resource Adequacy by Scenario

Scenario	Qualified Capacity (GW)	
	All BTM	50% BTM
2014 Capacity	1,069	1,040
2014 Capacity, Scenario A	1,072	1,042
2014 Capacity, Scenario B	1,081	1,047
2020 Policy, Scenario A	1,221	1,191
2020 Policy, Scenario B	1,231	1,196

Results

In 2014, we estimate that China had a national effective reserve margin[11] of 25 percent to 28 percent. Relative to commonly seen planning reserve margins in the U.S.—the North American Electric Reliability Corporation's (NERC's) default planning reserve margin is 15 percent[12]—this suggests that China had significant surplus generation capacity in 2014.

Figure 5 shows effective reserve margins across the four scenarios in 2020. The "2014 Scenario A" bars indicate that, if most behind-the-meter generation is counted toward resource adequacy, China's existing generation capacity as of the end of 2014 would be sufficient to maintain a planning reserve margin of 15 percent in 2020. In other words, any new net additions to coal-fired generation capacity, including generation capacity added in 2015, will be unutilized in 2020.[13]

The "2020 Scenario A" bars in Figure 5 indicate that, with lower electricity demand growth, meeting 2020 goals for hydropower, nuclear, solar, and wind generation capacity will lead to very high reserve margins in 2020. Even in this lower growth scenario, it may still be prudent to meet 2020 capacity targets for non-fossil fuel generation in order to comply with air quality goals. This will, however, lead to significant reductions in annual operating hours (capacity factors) for thermal generators.

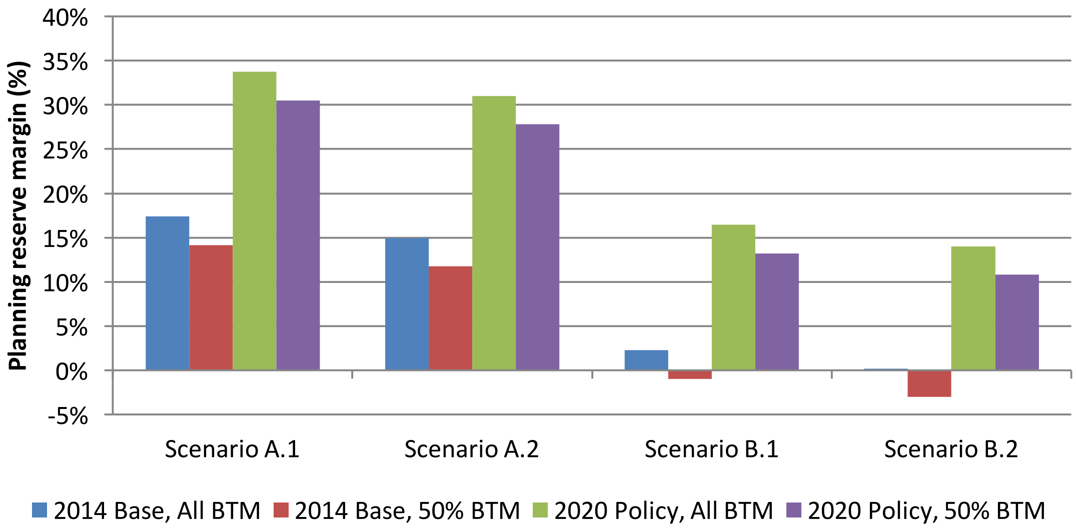
[11] Planning reserve margin (PRM) is defined as available ("qualifying") generation (G) minus peak demand (P) divided by peak demand (P)

$$PRM = \frac{G - P}{P}$$

[12] See NERC, "Planning Reserve Margin," http://www.nerc.com/pa/RAPA/ri/Pages/PlanningReserveMargin.aspx.

[13] "Net" here refers to net of retired capacity. With economic dispatch, new coal-fired generation capacity will likely have high utilization rates, but it will displace existing coal capacity on a one-to-one basis.

Figure 5. Reserve Margins in 2020 by Scenario (Scenario Descriptions Shown in Table below Figure)

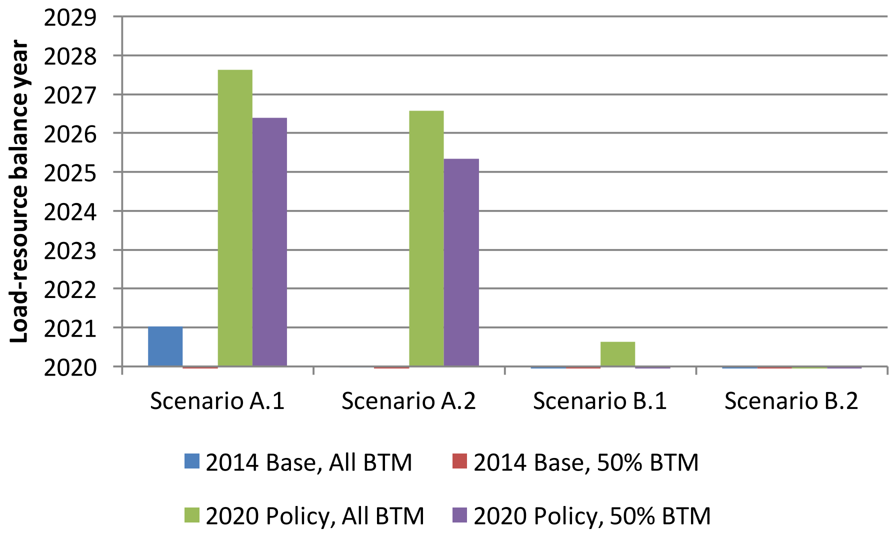


Scenario A.1	1% per year demand growth, system load factor declines by 3%
Scenario A.2	1% per year demand growth, system load factor declines by 5%
Scenario B.1	4% per year demand growth, system load factor declines by 3%
Scenario B.2	4% per year demand growth, system load factor declines by 5%
2014 Capacity	2014 generation capacity
2020 Policy	2014 generation capacity plus installed capacity targets
All BTM	All behind-the-meter generation capacity counted toward adequacy
50% BTM	50% of behind-the-meter generation capacity counted toward adequacy

The "2014 Scenario B" bars in Figure 5 show that with higher growth, existing generation capacity at the end of 2014 will likely be insufficient to meet reliability needs. However, the "2020 Scenario B" bars indicate that policy-driven generation capacity would likely be able to fill most of the residual capacity gap.

In the scenarios in Figure 5 with higher reserve margins, it is instructive to calculate the year in which, at an assumed peak demand growth rate, China returns to a target reserve margin. For scenarios in Figure 5 where the reserve margin exceeds 15%, Figure 6 shows the year in which China would return to a 15 percent reserve margin, assuming 2 percent per year peak demand growth. For instance, for "Scenario A.1, 2020 Policy All BTM," China would not return to a 15 percent reserve margin until around 2028. This suggests that, in a lower growth scenario with continued expansion of non-fossil fuel generation capacity, China would not need new generation resources for capacity (reliability) purposes until the mid- to late-2020s, in order to maintain a 15 percent planning reserve margin.

Figure 6. Year in which China Returns to 15% Planning Reserve Margin, Assuming 2% Per Year Peak Demand Growth



Conclusion and Discussion

Based on analysis described in more detail in the appendix, we argue that the most likely scenario for electricity demand growth in China between 2015 and 2020 is closer to 1 percent per year (Scenario A) than 4 percent per year (Scenario B). As its economy shifts away from industry and toward services, structural changes within aggregate sectors—for instance, from heavier to lighter manufacturing—will continue to reduce the electricity intensity of value added in the secondary and tertiary sectors. Improvements in building and appliance efficiency will continue to reduce the electricity intensity of expenditure in the residential sector.

To some extent, the difference between higher and lower forecasts for electricity demand will be a function of government policies and priorities. Historically, most of China's investments in energy efficiency have been in the industrial sector. With changes in demand, the highest value energy efficiency will be in the commercial and residential sectors. Building codes and appliance standards will thus have an important impact on overall electricity demand growth in China over the next decade.

From a policy perspective, energy efficiency provides an important tool for risk management, much as it has done in the U.S. since the 1980s. For instance, the difference between peak demand in the A and B scenarios in this analysis is roughly 100-150 GW. If all of this demand were met by thermal generation, it would represent a cost of about 50-70 billion yuan (US$7-11 billion) per year.[14] If higher electricity demand does not materialize, a significant portion of this investment will be unrecoverable, or "stranded." Energy efficiency provides a lower risk, more modular approach to meeting electricity demand growth in China in the near-term future.

[14] This calculation assumes a capital cost of around 4,000 yuan/kW, a weighted average cost of capital of 8%, a 15-year financial lifetime, and a CNY/USD exchange rate of 6.5.

China's policy targets for nuclear, wind, and solar generation capacity also provide a lower risk strategy for meeting medium-term capacity needs. Most of this generation capacity, and potentially even more, is likely needed to meet nearer-term air quality, medium-term renewable energy, and longer-term CO_2 emission reduction goals. It will also likely provide sufficient capacity to meet China's growth needs over the next five to ten years, and potentially longer.

Relaxing the assumptions in this study does not make a stronger case for additional coal-fired capacity. If system load factors fall more than assumed here, gas-fired generation is likely to be a more cost-effective source of capacity than coal-fired generation, because of its lower capital costs.[15] If transmission or political economy constraints between provinces make aggregate national peak demand requirements higher, or available generation capacity lower, than levels identified in this analysis, new transmission or regional markets are likely to be a more cost-effective strategy for meeting peak demand than additional supply.

The discussion above raises the important question of how to deal with coal-fired generation that came online in 2015 or is under construction and scheduled to come online in the coming years. China's policymakers must decide the extent to which to resolve this problem of generation surplus—a stranded asset problem—through regulatory strategy (e.g., through stranded asset payments) or through markets (e.g., by forcing generating companies, banks, or shareholders to absorb losses). Both North American and European experience in this area could prove to be a useful reference for China.

As a final note, this screening analysis is not a substitute for more detailed reliability study at a provincial and regional level. Such a study should be combined with an assessment of air quality and CO_2 compliance strategies, to determine levels of coal-fired generation capacity that are consistent with reliability targets and environmental goals. It should be integrated into a resource planning process, conducted either by the NEA or system operators, and should be linked to the approval of new generation projects.

[15] See Hu Junfeng, Gabe Kwok, Wang Xuan, James H. Williams, and Fredrich Kahrl, "Using Natural Gas Generation to Improve Power System Efficiency in China," *Energy Policy* 60 (2013): 116-121.

Appendix: Electricity Data in China

Accounting

Electricity consumption data in China are typically reported as "total societal electricity consumption" (全社会用电量 | quan shehui yongdian liang), which includes four components:

- Electricity sales (售电量 | shoudian liang)
- Transmission and distribution (T&D) line losses (线损电量 | xiansun dian liang)
- Generator own-use (厂用电量 | chang yongdianliang)
- Behind-the-meter generation (自备电厂电量 | zibei dianchang dianliang)

Electricity sales plus T&D line losses are equivalent to "on-grid" consumption (供电量 | gongdian liang)

$$\text{On grid consumption} = \text{electricity sales} + \text{line losses}$$

Behind-the-meter (BTM) generation is the residual between total societal electricity consumption minus total on-grid consumption minus generator own-use

$$\text{BTM generation} = \text{total societal electricity consumption} - \text{on grid consumption} - \text{own use}$$

Reported values for these five variables in 2014 are shown in Table 3.

Table 3. Key Electricity Consumption Data in 2014

English	Chinese	Consumption (TWh)
Grid company sales	售电量	4,544.2
T&D line losses	线损电量	323.4
Total on-grid electricity	供电量	4,867.6
Behind-the-meter generation	自备电厂电量	425.5
Generator own-use	厂用电量	270.6
Total societal electricity consumption	全国全社会用电量	5,563.7

Source: Data are from the CEC's annual electricity statistics series, online at: http://cec.org.cn/guihuayutongji/.

Behind-the-meter generation accounted for approximately 4-5 percent of total societal electricity consumption over 2008-2013 (Figure 7). Unlike metered generation data, behind-the-meter generation is typically reported and it is unclear how accurate these data are. Since 2008, it has ranged from 3.6 percent to 7.6 percent of total societal electricity consumption. Figure 7 gives a sense of the shares of this and other key variables from 2008 to 2014.

Figure 7. Share of Electricity Sales, Generator Own-use, Line Losses, and Behind-the-meter Generation in Total Societal Electricity Consumption, 2008 to 2014

Source: Data are from the CEC's annual electricity statistics series, online at: *http://cec.org.cn/guihuayutongji/*.

Total generation (发电量 | fadianliang) includes on-grid net generation, generator own-use, and behind-the-meter generation. Discrepancies between total generation and total societal consumption are due to net exports to other countries, which are a very small (< 1%) part of generation.

Data Sources

There are generally three main sources for electricity data in China:

- The National Bureau of Statistics (NBS), which publishes electricity balance tables as part of its annual *Statistical Yearbook* series;[16]
- The China Electricity Council (CEC), which publishes monthly and annual data tables (电力统计基本数据一览表) on its website;[17]
- The *Electricity Statistical Yearbook* (电力统计年鉴), which is published collaboratively by NEA and the electricity industry.[18]

There are often discrepancies among these three sources. The latter two are generally more consistent, whereas NBS data differs significantly. For this reason, we are careful to clearly identify data sources in this paper.

[16] See http://www.stats.gov.cn/.
[17] See http://cec.org.cn/guihuayutongji/.
[18] Older versions are available online at http://hvdc.chinapower.com.cn/membercenter/yearbookcenter/.

Energy and Peak Demand Forecasts

Forecast of Total Electricity Demand Growth Rates to 2020

Forecast Equations

Historically, a common approach to long-term electricity demand forecasting in the U.S. electricity sector has been to use dependent variables that capture economic growth, demographic change, and per capita income.[19] In China, because of recent structural changes, standard regression forecasting with these kinds of measures may produce unreliable results.

In this paper, we generate separate top-down and bottom-up forecasts, and discuss the differences in results that follow from different assumptions about functional forms. All forecasts include the same five dependent variables, shown in the below table. To capture residential demand, we use population rather than households, as the NBS does not regularly publish estimates of households. We use per capita expenditure rather than income, as the former is a more reliable indicator of purchasing power in China. All economic data are from the NBS.

Table 4. Variables used in Demand Forecasts

Variable		Description
Y	DEM	Electric energy demand
X1	PVA	Primary sector real value added
X2	SVA	Secondary sector real value added
X3	TVA	Tertiary sector real value added
X4	POP	Population
X5	EXP	Annual real per capita expenditure

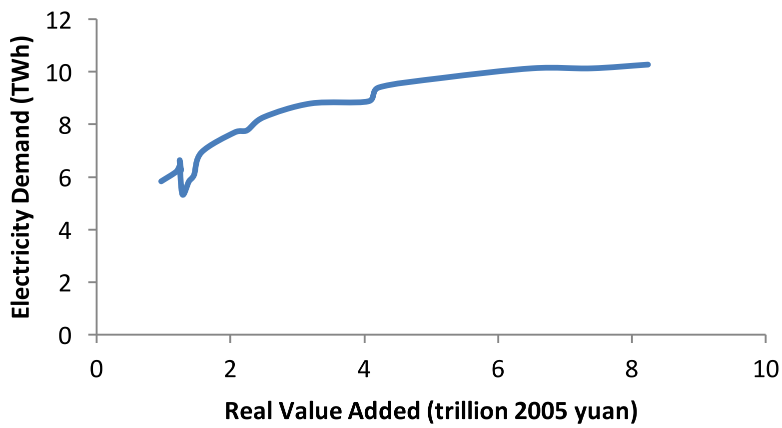
For the top-down forecast, the demand (DEM) variable is total electricity supply (电力可供量) from the NBS electricity balance tables. For the bottom-up forecast, DEM variables are end-use sector-specific, also based on the NBS electricity balance tables.

The relationship between electricity demand and the dependent variables is generally non-linear. Thus, whether dependent variables are log transformed has a significant impact on the results. For the value added variables, a linear functional relationship assumes that average sector electricity intensities remain fixed over time; a linear-log relationship assumes that they decline. As Figure 8 shows, the second assumption may better reflect the relationship between sector electricity demand and sectoral value added.

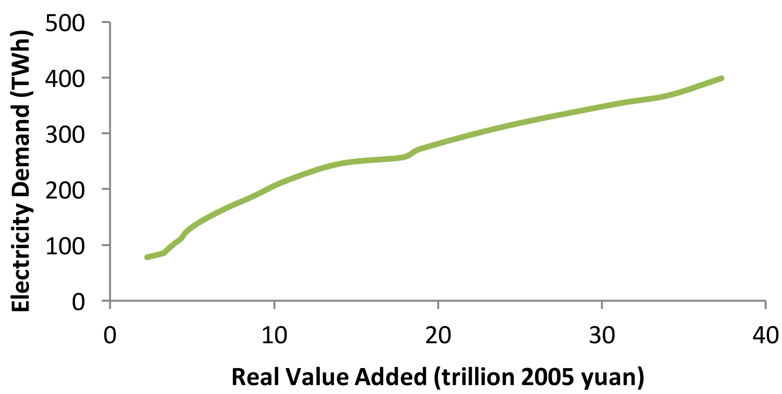
[19] In China, the three principal approaches to electricity demand forecasting, often used in tandem, are: (1) electricity elasticity method (弹性系数法), based on the historical relationship between the change in electricity demand and the change in GDP, (2) average annual growth rates method (年平均增长率法), based on projected growth rates, and (3) electricity intensity methods (用电单耗法), using electricity intensities (electricity demand per value added).

Figure 8. Relationships between Sector Electricity Demand and Sector Economic or Demographic Variable, Primary, Secondary, Tertiary, and Residential Sectors, 1995-2014

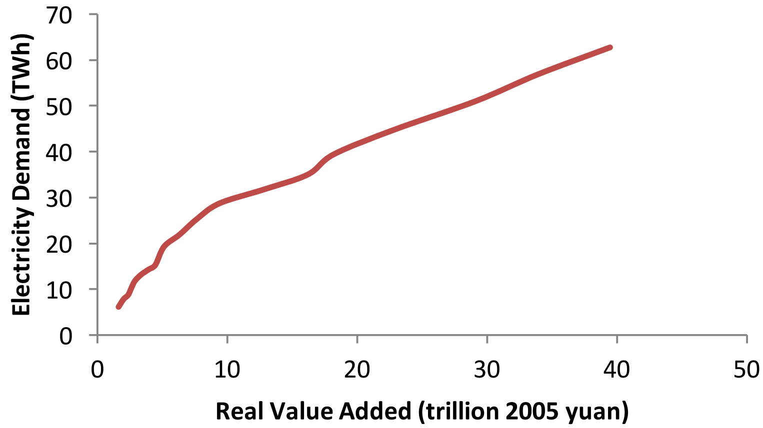
Primary Sector



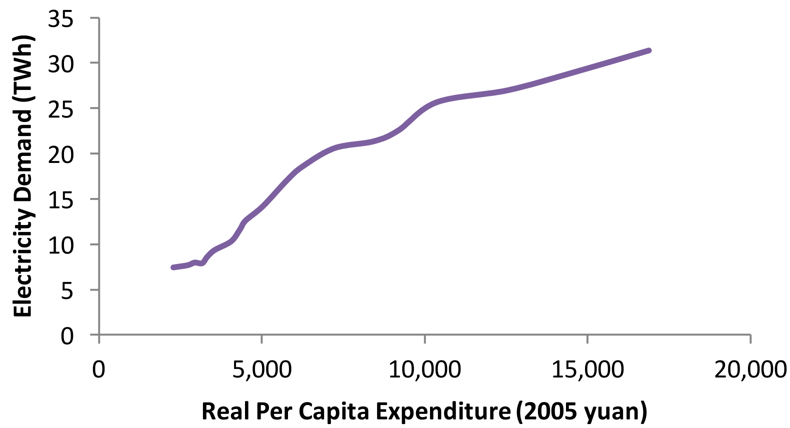
Secondary Sector



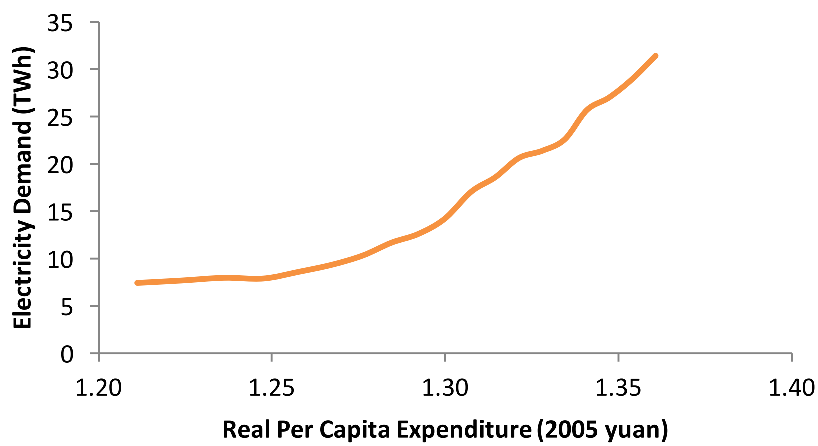
Tertiary Sector



Residential–Per Capita Expenditure



Residential–Population



Based on these, consider two scenarios. In the first, we log transform all of the dependent variables, as per equation 1 ("log transformed scenario"). In the second, we log transform all variables except for secondary and tertiary value added ("linear scenario"). In both cases, all of the dependent variable coefficients have wide confidence intervals (i.e., high p values).

$$DEM = \propto + \beta_1 ln(PVA) + \beta_2 ln(SVA) + \beta_3 \ln(TVA) + \beta_4 ln(POP) + \beta_4 ln(EXP) + \varepsilon \qquad 1$$

The bottom-up forecast uses separate regressions for each sector, including: (1) a regression of demand on value added for economic sectors, and (2) a separate regression of demand on population and per capita expenditure for the residential sector. For the bottom-up forecast, we also consider separate scenarios in which all dependent variables are all log transformed, as shown in equations 2 and 3, and in which the secondary and tertiary variables are not transformed.

$$DEM = \alpha + \beta \ln(VA) + \varepsilon \qquad 2$$

$$DEM = \propto + \beta_1 \ln(POP) + \beta_2 \ln(EXP) + \varepsilon \qquad 3$$

In the bottom-up forecast, each equation produces a forecast for electricity demand in a given sector, which are then summed to arrive at total electricity demand. The bottom-up approach produces much tighter confidence intervals around the dependent variable coefficients, but does not capture and isolate potential interactive effects among sectors.

Independent Variable Projections

The coefficients from the forecast equations require forecasts of sector value added, expenditure, and population to 2020. We consider two scenarios: (1) a target growth scenario, where sector value added growth is in line with a national GDP of 6.5 percent annual average growth in the 13th Five-Year Plan; (2) a lower growth scenario, where growth is slightly lower than target growth. We assume that growth in per capita expenditure tracks aggregate GDP growth. In the lower growth scenario, we use the UN"s "medium variant" population growth estimates from 2015 to 2020; in the target scenario we use the "high variant."[20] Growth rate assumptions are shown in Table 5.

Table 5. Annual Average Growth Rate Projections for Dependent Variables, 2015 to 2020

Variable	Target Growth Scenario	Lower Growth Scenario
Primary	5%	4%
Secondary	3%	2%
Tertiary	10%	8%
Total GDP	6.5%	5.0%
Expenditure	6.5%	5.0%
Population	0.6%	0.3%

[20] See the UN Department of Economic and Social Affairs' *World Population Prospects, the 2015 Revision*, online at: http://esa.un.org/unpd/wpp/Download/Standard/Population/.

Forecast Results

Table 6 shows the annual average electricity demand growth rates that result from this analysis. These range from a demand reduction of 0.1 percent, in the lower growth, log transformed scenario to a demand increase of 4.8 percent in the target growth, linear scenario.

Table 6. Total Electricity Demand Growth Rates by Forecast Approach and Scenario

Scenario		Forecast Approach	
Growth scenario	Secondary value added variable	Top down	Bottom up
Target growth	Log transformed	0.8%	0.2%
Target growth	Linear	3.7%	4.8%
Lower growth	Log transformed	0.7%	-0.1%
Lower growth	Linear	2.8%	3.8%

Two factors drive the range of results in Table 6. First, log transforming the secondary sector value added variable implicitly assumes that the electricity intensity (kWh per unit value added) declines, which results in lower demand growth. Second, the bottom-up forecast results in higher growth in the linear scenarios, and lower in the log transformed ones. This accentuation is presumably the result of interactive effects, which are captured in the top-down but not in the bottom-up forecast. Differences between target and lower growth rates are only important in the linear cases.

For the bottom-up forecast results, implied changes in electricity from 2013 to 2020 can be benchmarked against historical declines in sector electricity intensity, to gauge their plausibility. As Table 7 shows, the linear scenarios imply no changes in electricity intensity, relative to 2013. The log transformed scenarios generally are within historically bounds, except for the tertiary sector and, to a lesser extent, the residential sector.

Table 7. Implied Changes in Sector Electricity Intensity from 2013 to 2020, and Historical Changes from 1995 to 2013

Sector	Growth Scenario		Historical
	Target	Lower	
Primary	-4 %	-3%	-8%
Secondary–log	-4%	-3%	-6%
Secondary–linear	0%	0%	-6%
Tertiary–log	-9%	-8%	-5%
Tertiary –linear	0%	0%	-5%
Residential–expenditure	-5%	-1%	-4%

It is important to emphasize that these electricity demand growth rates are consistent with reasonably high GDP growth rates. In the case of the “lower growth, log transformed” scenario, what drives electricity demand into negative territory is continued reductions in electricity intensity. In real terms, reductions in aggregate electricity intensity are the result of changes in industry structure (e.g., a shift from heavy to light manufacturing in the secondary sector) and improvements in the efficiency of end-use equipment (e.g., more efficient motors that lead to less electricity per unit output).

Forecast of On-Grid Electricity to 2020

Forecasting on-grid electricity requires separate forecasts of electricity sales, which reflect underlying demand, and total T&D line losses, which reflect both technology and the timing of demand.[21] In principle, electricity sales should be forecasted separately. Due to the lack of a longer-term data series for electricity sales, however, we use the total on-grid electricity forecasts from the previous section, and estimate line losses separately.

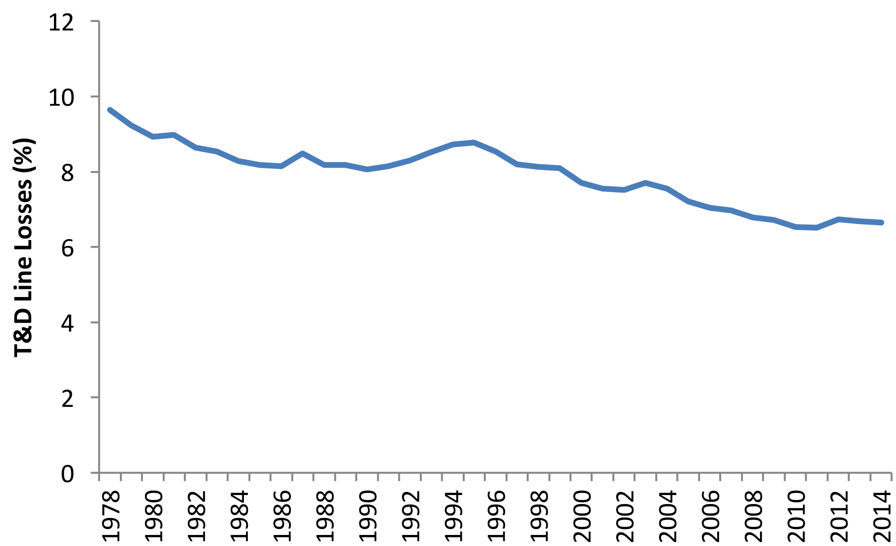
For 2015, we estimate sales growth based on monthly total electricity consumption data through October 2015. This data indicates that total electricity demand has increased 0.8 percent year-on-year since October 2014.[22] If demand in November and December 2015 grows at the same rate as it did between 2013 and 2014, growth in total electricity consumption in 2015 will be 0.9 percent.[23] Electricity sales growth has sometimes led and sometimes lagged total electricity consumption data, depending mainly on changes in behind-the-meter generation. Changes in the latter in 2015 are still uncertain. As a reasonable estimate for annual electricity sales growth, we thus use a value of 1 percent for 2015.

For 2015 to 2020, we use two representative points—a lower and a higher value—from the range of estimates in Table 6, rather than attempting to choose a correct value. For a lower value ("Scenario A"), we use 1 percent, consistent with both GDP growth scenarios but with continued declines in secondary and tertiary sector electricity intensity. For a higher value ("Scenario B"), we use 4 percent, more consistent with higher GDP growth and little change in the electricity intensity of these sectors.

T&D line losses in China have fallen dramatically since the late 1970s, but appear to have started to level off over the last five years (Figure 9). As a conservative estimate, we assume that the T&D loss rate remains at its 2014 value of 6.64 percent.

[21] Line losses are driven by loading on the lines, which means that peak period losses tend to be significantly higher than average losses.
[22] Data are from the China Electricity Council's (CEC's) monthly electricity statistics series, online at: http://cec.org.cn/guihuayutongji/.
[23] Ibid.

Figure 9. T&D Line Losses in China, 1978 to 2014



Source: Data are from the CEC's annual electricity statistics series, online at: http://cec.org.cn/guihuayutongji/

These assumptions lead to the on-grid electricity forecasts shown in Table 8.

Table 8. On-Grid Electricity Forecasts to 2020

	Annual Growth Rate (%/yr)	Electricity Sales (TWh)	Line losses (TWh)	On-grid Electricity (TWh)
Base 2014	n/a	4,544	323	4,868
2015	1%	4,590	326	4,916
2020–Scenario A	1%	4,824	343	5,167
2020–Scenario B	4%	5,584	397	5,981

The results in Table 8 do not include behind-the-meter generation. Even though it does not contribute to system peak capacity needs, behind-the-meter generation is important to forecast and account for because the generation capacity can contribute to system resource adequacy.

The future of behind-the-meter generation in China is uncertain. There is strong central government support for distributed natural gas generation and industrial cogeneration. However, the NDRC also announced stronger regulations for behind-the-meter generation in November 2015. Additionally, behind-the-meter generation has historically been driven by the industrial sector, where demand is beginning to slow. More rapid growth in behind-the-meter generation is likely to be at the expense of sales and central-scale generation, which will tend to strengthen the conclusions in this study.

As a reasonable, conservative approach, we assume that behind-the-meter generation grows by 5 percent between 2014 and 2015, and at the same rate as overall sales growth in Scenarios A and B, or 1 percent and 4 percent, respectively. These assumptions lead to the generation totals in Table 9.

Table 9. Behind-the-meter Assumed Annual Growth Rates and Total Generation

	Annual Growth Rate (%/yr)	Total Generation (TWh)
2014	5	447
2020 Scenario A	1	470
2020 Scenario B	4	544

Peak Demand Forecast

A traditional indirect approach to estimating peak demand is through the use of system load factors, defined as the ratio between average and peak load

$$System\ load\ factor = \frac{Average\ Load}{Peak\ Load} \qquad 4$$

If the system load factor and average load[24] are known, peak load can be estimated by dividing average load by system load factor. The CEC reports coincident on-grid generator-side coincident peak (最高发电电力) both at a national level and for the regional grids. It is not clear whether this data includes only centrally-dispatched (统调) units or whether it includes all on-grid generation.[25] We assume that it does include all on-grid generation, but does not include behind-the-meter generation.

Using the national coincident generator peak of 797 GW (2014) as a measure of resource adequacy implicitly assumes that there are no transmission limits between balancing areas, which is an aggressive assumption.[26] As an alternative, we use the sum of the coincident generation peaks for regional grids, 834 GW, from which we calculate a system load factor of 67 percent in 2014.[27] Although this does not reflect all transmission constraints among provinces, it is nonetheless a useful proxy for resource adequacy needs.

Changes in the composition of electricity demand in China will drive reductions in system load factors, as sectors that have traditionally had lower load factors (residential, commercial) account for a larger share of demand. We consider two scenarios to account for these changes. In the first ("Scenario 1"), load factors decline by 3 percent; in the second ("Scenario 2"), they decline by 5 percent.

Combined with the two electricity demand scenarios (Scenarios A and B), the addition of these two peak demand scenarios leads to four total scenarios, described below (Table 10). These lead to forecasted generator-side peaks of 913 to 1,079 GW in 2020.

Table 10. Generator-side Peak Forecasts to 2020

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[24] "Average load" is defined as total energy divided by 8,760 hours/yr. Here, to maintain consistency with the generator-side peak demand data, load is on-grid energy (i.e., gross of T&D losses).

[25] Some generators in China are dispatched by lower voltage grid operators. On-grid electricity will include this generation.

[26] These data are from the CEC's annual electricity statistics series, online at: http://cec.org.cn/guihuayutongji/.

[27] Using the on-grid electricity data in Table 8, this is 4,868 TWh / 8,760 / 834 = 67%.

	On-grid Electricity (TWh)	System Load Factor (%)	Generator Peak (GW)
Scenario A.1	5,167	65	913
Scenario A.2	5,167	63	932
Scenario B.1	5,981	65	1,057
Scenario B.2	5,981	63	1,079

Generation Technologies and 2014 Net Generation Capacity

We use the CEC's generation technology categories and estimates of generation capacity at the end of 2014 (Table 11).[28] This includes generation capacity from all sources, including behind-the-meter generation. Some, if not most, of this behind-the-meter generation should be grid connected, and in principle can contribute to resource adequacy with the right incentives.

Table 11. Total Installed Generation Capacity in China at the End of 2014

English	Chinese	Total Gross Installed Capacity (GW)
Conventional hydropower	水电	283
Pumped hydropower	抽水蓄能	22
Coal	燃煤	832
Natural Gas	燃气	57
Oil	燃油	5
Nuclear	核电	20
Wind	风电	97
Solar	太阳能发电	25
Cogen	余温、余气、余发电	18
Waste incineration	垃圾焚烧发电	5
Biomass	秸秆、蔗渣、林木质发电	5
Other	其他	1
Total		**1,370**

Source: Data are from the CEC's annual electricity statistics series, online at: http://cec.org.cn/guihuayutongji/.

To calculate behind-the-meter generation capacity, we make four assumptions: (1) behind-the-meter load has a load factor of 90 percent; (2) all industrial cogeneration is behind-the-meter, and its capacity remains at 2014 levels to 2020; (3) all oil-fired generation is behind-the-meter; (4) natural gas accounts for 10 percent of existing (2014) behind-the-meter generation; and (5) all new behind-the-meter generation is natural gas. Building on assumptions about growth in behind-the-meter generation from the previous section (under the "2020 Scenario" column headings), these five assumptions result in the net generation capacities shown in Table 12.

[28] These data are from the CEC's annual electricity statistics series, online at: http://cec.org.cn/guihuayutongji/.

Table 12. Estimated Behind-the-Meter Generation

Generation Technology	Generation Capacity (GW)		
	2014	2020, Scenario A	2020, Scenario B
Industrial cogen	18	18	18
Oil	5	5	5
Coal	30	30	30
Natural Gas	3	6	15
Total	**57**	**60**	**69**

Generation capacity data is China is often reported on a gross basis, rather than net of generator own-use. The CEC does not specify whether its installed capacity data is gross or net. We assume that central-scale capacity is gross of own-use, and make a high-level adjustment to convert it to net. The CEC reports generator own-use of 5.84 percent for thermal units, and 0.5 percent for hydro units in 2014. These are aggregated values — gas-fired units, for instance, typically have much smaller auxiliary loads than coal-fired units. Nonetheless they are useful point estimates, and these inputs have a small to negligible impact on the results. We apply the CEC's thermal own-use estimate to all thermal units (coal, natural gas, oil, nuclear, cogen, waste incineration, biomass) and the hydro estimate to all other units (hydropower, wind, solar, other). For behind-the-meter generation, we assume that it is net of own-use.

Table **13** shows the total central-scale and behind-the-meter installed capacities that result from this gross-to-net adjustment. The 2020 scenarios only reflect increases in behind-the-meter generation.

Table 13. Installed Net Generation Capacity by Technology, with Behind-the-Meter (BTM) Generation Listed Separately, 2014

Generation Technology	Generation Capacity (GW)		
	2014	2020, Scenario A	2020, Scenario B
Hydropower	281	281	281
Pumped hydropower	22	22	22
Coal central-scale	755	755	755
Coal BTM	30	30	30
Natural gas central-scale	51	51	51
Natural gas BTM	3	6	15
Oil central-scale	0	0	0
Oil BTM	5	5	5
Nuclear	19	19	19
Wind	96	96	96
Solar	25	25	25
Cogen BTM	18	18	18
Waste incineration	4	4	4
Biomass	5	5	5
Other	1	1	1
Total	**1,316**	**1,319**	**1,329**

Resource Adequacy Values

'Resource adequacy value' is defined here as the share of generation capacity that contributes to meeting system peak needs, or resource adequacy. For a unit with a resource adequacy value of 1, all (100 percent) of its net installed capacity contributes to resource adequacy. Conversely, for a unit with a value of zero, none (0 percent) of its capacity contributes to adequacy.

Where a planning reserve margin is being used, the appropriate resource adequacy value for dispatchable generation is 1—the reserve margin accounts for forced outages. For conventional hydropower, resource adequacy values are somewhat more complicated. Dispatchable (reservoir) hydropower is generally thought to be energy rather than capacity limited, as operators can control the timing and amount of water released through the turbines within reservoir-related constraints. However, reservoir hydropower also typically has a number of non-energy constraints, and is typically not perfectly dispatchable.

The CEC's estimates of conventional hydropower capacity also include a substantial amount of non-dispatchable run-of-river generation, though it is unclear how much. Incorporating these limits on its dispatchability, we use a resource adequacy value of 0.5 for conventional hydropower. This is consistent with, and conservatively lower than, the value used in California, which has a significant amount of run-of-river generation.[29]

Solar and wind energy are intermittent, and contribute to resource adequacy on a probabilistic basis. Initially, many state regulators and system operators in the U.S. calculated resource adequacy values for these resources on an exceedance probability basis, based on the coincidence between their historical output and peak demand. Currently, many are transitioning to an effective load carrying capacity (ELCC) approach, which captures the declining resource adequacy value of these resources as their penetration increases. We use a more heuristic approach here, based on commonly used values in North America. For wind, we use a value of 10 percent; for solar, we use 30 percent.[30]

Behind-the-meter generation may be limited in its ability to provide system-level capacity. In the U.S., resource adequacy values for behind-the-meter generation are typically based on historical performance, though in principle a significant portion of it can contribute to resource adequacy. We examine a scenario in which all behind-the-meter generation capacity is counted toward resource adequacy (Scenario i), and one in which only half of it is (Scenario ii).

Waste incineration and biomass are resource limited. Biomass relies on a steady supply of feedstock, which is limited by seasonal harvesting and storage constraints. Waste incineration facilities also may not have a sufficient supply of feedstock to operate at rated capacity throughout the year. To account for these limitations, we use a value of 0.8 for both biomass and waste incineration. It is not clear what is included in the CEC's "other" category; to be conservative, we assign it a resource adequacy value of zero.

These assumptions lead to the resource adequacy values shown in Table 14. Again, in Scenario i all behind-the-meter generation is counted toward resource adequacy; in Scenario ii only 50 percent of it is.

[29] In 2014, for instance, California had a 7,666 MW of net qualifying hydropower capacity, out of a total of 13,977 of large and small hydropower capacity (including pumped hydro), equivalent to an average resource adequacy value of 0.55. California net qualifying capacity value is from California Independent System Operator, *2014 Summer Loads & Resources Assessment*, May 2014, https://www.caiso.com/Documents/2014SummerAssessment.pdf; total capacity values are from California Energy Commission, "California's Installed Electric Power Capacity and Generation," October 2015, http://www.energy.ca.gov/renewables/tracking_progress/documents/installed_capacity.pdf.

[30] For a survey of commonly used resource adequacy values for solar and wind in North America, see California Public Utilities Commission, "Effective Load Carrying Capacity and Qualifying Capacity Calculation Methodology for Wind and Solar Resources," January 2014, http://www.cpuc.ca.gov/NR/rdonlyres/D05609D5-DE35-4BEE-8C9A-B1170D6E3EFD/0/R1110023ELCCandQCMethodologyforWindandSolar.pdf.

Table 14. Resource Adequacy Values for Different Generation Technologies

Generation Technology	Resource Adequacy Value (%)	
	Scenario i	Scenario ii
Hydropower	50%	50%
Pumped hydropower	100%	100%
Coal central-scale	100%	100%
Coal BTM	100%	50%
Natural gas central-scale	100%	100%
Natural gas BTM	100%	50%
Oil central-scale	100%	50%
Oil BTM	100%	50%
Nuclear	100%	100%
Wind	10%	10%
Solar	30%	30%
Cogen BTM	100%	50%
Waste incineration	80%	80%
Biomass	80%	80%
Other	0%	0%

2020 Policy-Driven Generation Capacity

China's central government has made aggressive domestic and international commitments to expand clean generation capacity over the next five years. These include installed capacity targets for conventional hydropower, pumped hydropower, nuclear, solar, and wind in 2020.[31]

Table 15. Installed Capacity Targets for 2020

Generation Technology	Installed Capacity Target for 2020 (GW)
Hydropower	350
Pumped hydropower	70
Nuclear	58
Wind	200
Solar	100
Total	**778**

[31] Targets for conventional hydropower, nuclear, wind, and solar are from the State Council's *Energy Development Strategy for 2014-2020* (能源发展战略行动计划（2014-2020年）), http://www.gov.cn/zhengce/content/2014-11/19/content_9222.htm; target for pumped hydropower is from the 12[th] *Five-Year Plan for Energy Development*, based on http://paper.people.com.cn/zgnyb/html/2015-02/09/content_1532928.htm.

There is some concern that actual expansion of hydropower and nuclear generation capacity will fall slightly short of its 2020 target, due to a lack of projects in the pipeline.[32] This shortfall, however, is expected to be on the order of 10 to 30 gross installed GW combined,[33] and thus has a relatively small impact on the results.

Final Generation Capacity Scenarios

The assumptions above lead to six different scenarios for qualified (i.e., for resource adequacy) net generation capacity, shown in Table 16. At the first tier (Scenarios i and ii), these scenarios are distinguished by how much behind-the-meter generation is counted toward resource adequacy. At the second tier, they are distinguished by year (2014 or 2020) and low and high electricity demand scenarios for 2020 (Scenario A and B).

Table 16. Qualified Net Generation Capacity by Generation Technology and Scenario in 2020

Generation Technology	Qualified Net Generation Capacity (GW)					
	Scenario i (all BTM)			Scenario ii (50% BTM)		
	2014	2020 A	2020 B	2014	2020 A	2020 B
Hydropower	141	174	174	141	174	174
Pumped hydropower	22	70	70	22	70	70
Coal central-scale	755	755	755	755	755	755
Coal BTM	30	30	30	15	15	15
Natural gas central-scale	51	51	51	51	51	51
Natural gas BTM	3	6	15	1	3	8
Oil central-scale	0	0	0	0	0	0
Oil BTM	5	5	5	3	3	3
Nuclear	19	55	55	19	55	55
Wind	10	20	20	10	20	20
Solar	7	30	30	7	30	30
Cogen BTM	18	18	18	9	9	9
Waste incineration	4	4	4	4	4	4
Biomass	4	4	4	4	4	4
Other	0	0	0	0	0	0
Total	**1,069**	**1,221**	**1,231**	**1,040**	**1,191**	**1,196**

[32] See, for instance, Jia Kehua, "Bai Jianhua: Generation Capacity will Expand by 100 GW per year during the 13th Five-year Planning Period" (白建华："十三五"每年新增装机1亿千瓦), September 2015, http://paper.people.com.cn/zgnyb/html/2015-09/28/content_1617660.htm.
[33] Ibid.