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Authors
Lin, J
Kahrl, F
Liu, X

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A Regional Analysis of Excess Capacity in China's Power Systems

Authors

Jiang Lin[1,*], Fredrich Kahrl[2], and Xu Liu[1]

Corresponding author: Jiang Lin, Staff Scientist, Lawrence Berkeley National Laboratory, j_lin@lbl.gov

1. Lawrence Berkeley National Laboratory, 1 Cyclotron Road, Berkeley, CA, 94720

2. Energy and Environmental Economics, 101 Montgomery Street, Suite 1600, San Francisco, CA 94104

Abstract

China's economy has entered a "new normal," characterized by slower economic growth and widespread overcapacity in its industrial sectors. Nevertheless, construction of power plants, especially coal-fired plants, continues at a rapid pace. Our analysis examines the extent of overcapacity in China's regional electricity grids. We show that already in 2014, the average reserve margin across China's regional grids was roughly 28%, almost twice as high as a standard planning reserve margin in the U.S. In addition, we find large variations in reserve margins across regional power grids in China, with the highest reserve margin (64%) in the Northeastern grid. This paper examines future reserve margins across regions in China under three growth scenarios. The results suggest that the majority of China will not need new baseload coal power (at least for reliability purposes) before 2020, and potentially not until 2025, under the low- and mid-growth scenarios. Under the high-growth scenario, China's central and eastern regions will need to import more power or built new capacity by 2020. As China's energy sector enters this new normal, our results highlight the growing importance of establishing mechanisms — planning processes and markets — that coordinate generation and transmission investments across grid regions, and that align the country's energy sector investments with its longer-term air quality and climate goals.

Keywords

Excess capacity; coal-fired power plants; regional; China

Highlights

- Analyzes current and future reserve margins in China's regional grids under three scenarios of electricity demand growth
- China has more than enough power plants to meet electricity demand today, and does not need any new base-load coal power plants for reliability purposes by 2020, and potentially by 2025.
- There are large discrepancies in reserve margins among grid regions, which suggest the importance of coordination among grid regions in providing for generation adequacy across China.
- China needs a more integrated and robust planning process to meet its national environmental and reliability goals at the least social cost.

1. Introduction

Transitioning away from coal is critical for China's low-carbon growth, and for global efforts to reduce the risks of climate change. Reducing the share of coal in China's generation mix is an important part of this transition, particularly as electricity accounts for a growing share of China's final energy consumption.

China's rapid economic growth over the past two decades was driven by industry and exports and fueled by coal, leading to a sharp increase in global greenhouse gas (GHG) emissions. However, it is widely recognized that the Chinese economy has entered a so-called "new normal," characterized by a lower overall economic growth rate, a structural shift toward a service economy, and widespread overcapacity in industrial sectors [1,2]. As a consequence, in 2015, China's energy consumption grew only 1.0%, and electricity consumption growth slowed to 0.96% [3].

Despite this slowdown in electricity demand, power plant construction and permitting continued at a rapid pace. Government agencies reported that 130 gigawatts (GW) of new generation capacity was added in 2015 [4]; Yuan et al. (2016) estimates that an additional 200 GW of coal-fired generation capacity is under construction, with more in the permitting process [5].

Recently, many have posited that China's power sector likely has an excess of generation capacity, particularly coal-fired generation capacity, relative to what is needed to reliably meet demand [5–8, 31-33]. Average annual operating hours for thermal generation units, a commonly used barometer of capacity utilization, dropped to 4,364 hours in 2015 (a 50% capacity factor), reaching its lowest level since 1969 [9].

Even though, in recent years, power overcapacity in China has been widely recognized as a major issue, few analyses have taken a systematic approach to assessing overcapacity. Within China, operating hours (or "utilization hours") are often used as the principal indicator of overcapacity [5,10, 34]. However, operating hours are a measure of asset utilization, and do not necessarily provide information about reliability or economic efficiency. For instance, an electricity system with large amounts of hydropower, wind, or solar generation may have low operating hours for thermal generators, but will not have excess generation capacity.

Another, more accurate way of measuring overcapacity would be reliability metrics.Typically, reliability studies calculate the probability of power outages in the high-voltage transmission system, given demand characteristics and the probability of unexpected generator failures. This probability, referred to as a loss-of-load probability, requires detailed information on electricity demand (loads) and generator failure probabilities. This information is, however, not publicly available in China.

An alternative approach is to use reserve margins, which are defined as the percentage of available generating capacity during an annual peak demand period in excess of

2

peak demand. Many international studies have used reserve margins (or “security margins”) to evaluate power grid reliability and generating capacity needs [11–13]. This paper contributes to the current literature as the first analysis of reserve margins at the regional level in China.

In this study, we use regional grids as the unit of analysis for two reasons. First, publicly available, systematically reported data on peak electricity demand is only available for regional grids. Second, although electricity supply-demand balancing for planning purposes is typically done at the provincial level in China, for decades China’s electricity system has been organized into six regional synchronous grids. Regional grid operators play an important role in addressing supply and demand imbalances among provinces in China [14], and this role is likely to grow as regional and interregional transmission systems evolve [15–17] and China moves toward regional wholesale markets for electricity.

International trends also suggest a movement to wider-balancing areas to reduce generation costs and absorb variable renewable generation. For example, the development of U.S. Regional Transmission Organizations and Independent System Operators since Federal Energy Regulatory Commission (FERC) Order No. 2000 [18], demonstrates the benefits of coordinated regional planning and the use of electricity resources [19]. Similarly, understanding reserve margins at the regional grid level will be important to developing a more systematic approach to power system planning in China.

This paper is timely as China’s 13th Five-Year Plan (FYP) for Electric Power Development (the Plan) was just issued in late 2016, after a 15-year absence [20], The Plan recognizes that surplus capacity is likely to stay and demand growth is significantly slower than in the past. However, it also sets fairly aggressive targets for new generation capacity across various sources, including 200 GW of thermal coal plants. Given this newly released Plan, this paper not only assesses the current regional nature of generation overcapacity in China, but also evaluates if the power capacity goals specified in the Plan will exacerbate the overcapacity issue in the near to medium term (2020 and 2025).

The rest of this paper is organized as follows: the Background section reviews current electricity planning and project approval processes in China as well as new policies to limit coal power plants; then the Methods and Results sections show how we apply our methodology to estimate China’s current and future reserve margins by regional grids for 2020 and 2025. The final section proposes future research areas and delineates policy implications.

2. Background

Many of the current overcapacity challenges facing China’s electricity sector have their roots in an antiquated planning and project approval process which has caused several boom-and-bust cycles in the last three decades. Before 2004, electricity investment projects were reviewed and approved by different government agencies based on investment size, with larger projects approved by the central government and smaller projects approved by local governments. Declining electricity demand growth during the Asian Financial Crisis (1997–1998) led to a slowdown in central government approvals, resulting in severe power shortages in 2003 and 2004 and a surge in construction of small-scale coal-fired power plants that were approved by local governments [21].

To address this rapid expansion, China's State Council centralized approval authority for most new generation and transmission projects in 2004 [22]. However, it did so without also initiating a national planning process for electricity during the 11th FYP (2006–2010) and the 12th FYP (2011–2015). New projects were required to receive a green light from the National Energy Administration (NEA) before beginning the formal approval process, but there were no transparent, rigorous criteria with which to evaluate new projects. This gap between planning and project approval led to a disconnect among electricity demand, generation and transmission investment, and policy goals.

In mid-2014, NEA simplified the approval process for coal-fired power generation and tried to link it to a national planning process, where NEA would determine an allowed amount of new coal generation capacity for each province each year over five to seven years, and each year provincial governments would decide which projects to approve. Local governments were required to submit the entire portfolio of projects to NEA for review and approval, using transparent criteria to evaluate different projects [23].

By early 2015, the approval process for new coal-fired generation had been largely decentralized to local governments. Decentralization of authority was accompanied by a large increase in new coal generation projects. At the same time, however, electricity demand growth had begun to slow dramatically.

In April 2016, the National Development and Reform Commission (NDRC) and NEA issued three policies to limit the permitting and construction of new coal power plants and the retirement of inefficient power plants: (1) *Announcement on Promoting Proper Development of Coal-fired Power Plants* [24], (2) *Announcement on Further Eliminating Inefficient Capacity for Coal-fired Power Plants* [25], and (3) *Announcement on Establishing a Risk Warning System for Coal-fired Power Plant Planning and Construction* [26]. It is too early to tell whether these policies will reduce the number of coal plants to be built by 2020.

In addition to policies controlling coal power plants, NEA released a *Management Guidelines for Electricity Planning* in June 2016 [27], which was the first official guideline for electricity planning published by the government since 2003. The document designated the NEA to develop national electricity plans, including regional electricity plans, and designated provincial energy departments to develop provincial electricity plans, which were required to be harmonized both between national and provincial electricity plans and between electricity export provinces and electricity import provinces. The electricity plan is meant to be a five-year plan, and it can allow adjustments to be made in two or three years after the plan is published. However, the document does not explicitly state whether or how project approval and investment decisions should follow the electricity plans.

Then on November 7, 2016, NEA published the long-awaited 13th FYP on Electric Power Development (2016–2020) [20]. In addition to setting forth key principles on shifting China's generation sources toward clean technologies, increasing system efficiencies and flexibility, optimizing location of generating resources, and further development of the power market, the Plan also set numeric targets for overall demand growth of 3.6%–4.8% per year, and targets for total generation capacity of various generation technologies by 2020 as follows: hydro, 340 GW; wind, 210 GW; solar, 110 GW; nuclear, 58 GW; coal, 1,100 GW; and gas, 110 GW.

Given the ongoing economic transition and slowdown in demand growth, the range of total power demand growth remains on the high side. In particular, the target of 1,100 GW of coal generation implies that 200 GW of added coal capacity is envisaged in a time when many coal plants are significantly underutilized. It shows that China's energy planning has yet to develop a transparent and rigorous process to assess the capacity adequacy and the economic trade-offs between different generating resources, as well as demand-side resources. Further it is also unclear how environmental and climate goals are incorporated into the current planning process, especially at the provincial level. Although the Plan recommends enhancing electricity import and export within and between regional grids, it does not specify how to develop systematic electricity planning at the regional grid level and how to balance electricity demand and supply within and between regional grids.

3. Methods

There are three different ways to evaluate "overcapacity" for electricity generation:

- *Reliability* — How does the current level of generation capacity compare to what is needed to meet demand under most conditions?
- *Economic* — How does the current capacity level of individual resources (e.g., baseload, peaking) compare to what would be most economic?
- *Environmental* — How does the current level of coal-, oil-, and natural gas-fired power generation compare to what is required to meet air quality and greenhouse gas emission reduction goals?

Reliability is, in many ways, the least stringent of these criteria. However, it is reasonably straightforward and offers important insights for planners and decision-makers. Planning reserve margin is a commonly-used method to evaluate power system reliability. In this paper, we use planning reserve margin to assess overcapacity of coal power plants in China.

3.1. Planning Reserve Margins

The planning reserve margin (PRM) is defined as the percentage of available generating capacity (G) during an annual peak demand period in excess of peak demand (P):

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

Planning reserve margins should, in principle, be set using a loss-of-load probability (LOLP) model, which matches a desired loss-of-load expectation (LOLE) to a planning reserve margin level. However, in some instances, including those in the U.S., planning reserve margin targets are used in lieu of more detailed LOLP analysis.

In China, there are no formal analytical methods used to evaluate and prescribe planning reserve margins.

3.2. Regional Grids

The focus of this paper's analysis is China's six regional electric grids (Figure 1). These grid regions were established in the early 2000s, with the dismantling of China's national State Power Corporation. Although accompanying power sector reforms were originally intended to culminate in regional power pools established around these regional grids, reforms ultimately stalled and were not restarted again until 2015. The regional grids have never been balancing areas, strictly defined, and balancing is still ultimately done at a provincial level [28]. However, in the future, regional grids may be considered as balancing areas, as China aims to integrate more variable renewable generation resources into its electricity grids.

Figure 1. Regional Electric Grids in China[1]

[1] Inner Mongolia is divided into west and east. The western part of the province operates an independent grid, although it is often included in the Northern grid; the eastern part of the province is part of the Northeastern grid.

Peak demand data for China is officially reported at a regional grid level, making this a convenient level of analysis. Using regional grids as the focus of a reserve margin analysis, however, requires assumptions that interprovincial transmission constraints and institutional limitations on generation capacity sharing across provinces do not exist, which is an aggressive assumption. For instance, an institutional limitation might be the lack of cost allocation mechanisms to ensure that an importing province pays a reasonable wholesale price to the generator in the exporting province. Interprovincial transmission and resource sharing constraints would tend to overstate regional reserve margin estimates. For instance, a regional reserve margin of 15% might correspond to provincial reserve margins of zero if provinces are completely isolated.[2]

There is, however, a significant amount of interprovincial transmission capacity in China, and these links could be expanded over the time horizons (five to ten years) analyzed in this paper. The question of institutional constraints to generation capacity sharing is, to a large extent, a question of political economy and political will. Thus, we use a regional reserve margin analysis to provide indicative results and useful insights.

3.3. Peak Electricity Demand Forecast

We forecast peak electricity demand (in gigawatts) in 2020 and 2025 using a forecast of electricity (in gigawatt-hours, GWh) consumption and system load factors for China's regional grids. System load factors (SLFs) are defined as the relationship between system average load (SAL) and system peak load (SPL):

$$SLF = \frac{SAL}{SPL}$$

where average load is the annual electricity consumption divided by 8,760 hours per year. Load factors are a convenient way to convert between electricity consumption and peak demand. Residential and commercial customers tend to have lower load factors; whereas, industrial customers tend to have higher load factors.

Table 1 shows that load factors in 2014 varied significantly among grid regions in China, ranging from 69% in the less industrial Eastern grid to 93% in the more industrial Northwestern grid.[3]

Electricity consumption in China is currently difficult to forecast, given the recent structural changes in the Chinese economy. Since 2010, the tertiary sector has been the primary driver of gross domestic product (GDP) growth, while the secondary sector GDP growth has fallen to its lowest level in the last two decades (Figure 2).

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2 For instance, consider two power systems, A and B, which have non-coincident peak demands of 10 GW (A) and 5 GW (B), and a coincident peak demand of 13 GW. A 15% reserve margin for the regional coincident peak would require 15 GW of qualified generating capacity. If A has 10 GW of generating capacity and B has 5 GW, they are able to meet a 15% regional reserve margin, but their individual (i.e., non-coincident) reserve margins are zero.

3 Consumption data here, and for all 2014 installed capacity by fuel type (thermal, nuclear, hydro, wind, solar, and others) for each province, is from the 2015 *China Electricity Statistical Yearbook* [29].

Table 1. Electricity Consumption, Peak Demand, and System Load Factors for Regional Grids in China, 2014

Grid Region	Electricity Consumption (TWh)	Peak Demand (GW)[4]	System Load Factor (%)
Central	1,063	151	81
Eastern	1,333	221	69
Northern	1,306	192	78
Northeastern	402	55	84
Northwestern	579	72	93
Southern	950	136	80

TWh = terawatt-hours

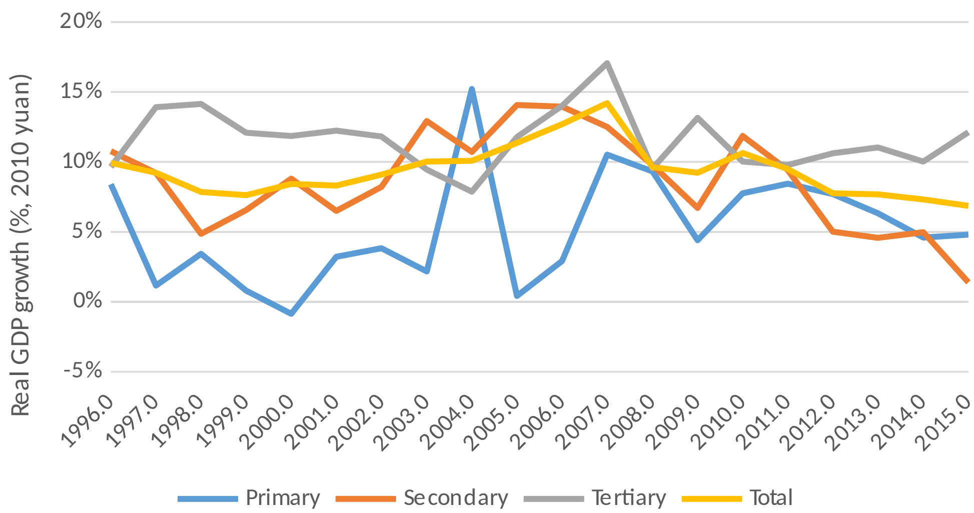


Figure 2. Real Economic Growth Rates by Sector in China, 1995 to 2015[5]

These changes in economic structure are visible in electricity consumption data. Year-on-year growth in monthly total electricity consumption fell steadily after 2010, and fell to nearly zero for most of 2015 before increasing slightly in 2016 (Figure 3). Changes in total electricity consumption were driven by the secondary sector, which experienced declining year-on-year electricity demand growth throughout much of 2015. Over the course of the year, secondary sector electricity consumption fell by 1.4% relative to 2014, with consumption by heavy industry falling by 1.9%.[7] Falling secondary sector GDP and electricity consumption have led to a decoupling of GDP growth and electricity consumption growth.

4 Here we use the CEC's "peak net generator load" (□□□□□□□) as a measure of peak within-region demand. These are "generator-side" demands, in that they already include transmission losses.

5 Sectoral and total GDP data for year 1995 to year 2014 are from China Statistical Yearbook of 2015. Sectoral and total GDP data for 2015 are from Statistical Communiqué of the People's Republic of China on the 2015 National Economic and Social Development. All sectors were deflated using a national GDP deflator from the World Bank.

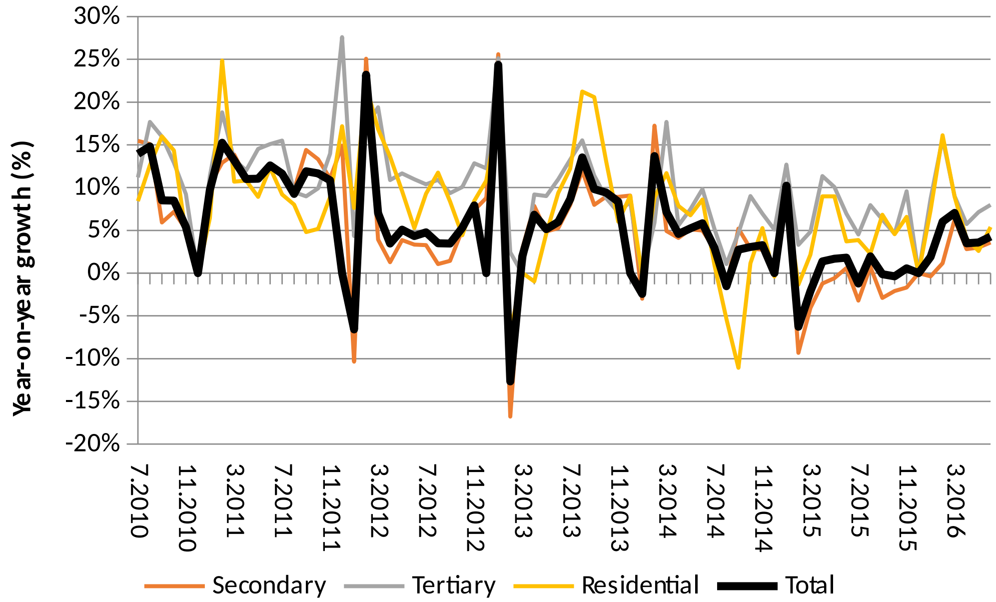


Figure 3. Year-on-Year Growth in Secondary, Tertiary, Residential, and Total Electricity Consumption, July 2010 to June 2016[6]

Changes in economic structure create a number of challenges for forecasting electricity consumption in China. Forecasts using aggregate linear secondary and tertiary sector GDP as explanatory variables tend to overstate the individual effects of these sectors. Using non-linear explanatory variables likely provides more realistic long-term forecasts, but creates nearer-term discontinuities. Greater sectoral disaggregation could likely address these issues, but requires a larger number of assumptions about real value added growth rates by sector. For this reason, simpler regression forecasting models tend to give unsatisfactory results.

For this analysis, we began with an income- and population-driven regression model of provincial electricity consumption, using real provincial GDP by aggregate sector, real household expenditure, and population as explanatory variables.[7] We aggregated these provincial electricity consumption forecasts to a regional grid level,[8] and we explored a number of different functional forms.[9] However, given the difficulties described in the previous paragraph, we ultimately settled on a simpler, scenario-based approach.

6 Data are from the CEC, http://cec.org.cn/guihuayutongji/.

7 All of these data are from the China Statistical Yearbook series, accessed through China Data Online. Data for electricity consumption by sector were extracted from the Energy Balance Sheet for each province in the China Energy Statistical Yearbooks. For some provinces, electricity consumption by sector data were missing for multiple years. To fill in the gaps, we interpolated data by assuming an equal growth rate during the period of the year before the first year of missing data and the year after the last year of missing data. For one-year gaps, the growth rate was the average annual growth rate of the years immediately before and after.

8 Inner Mongolia is a challenge in this respect because the western part of the province operates an independent grid, though it is often included in the Northern grid; the eastern part of the province is part of the Northeastern grid. We allocated generation capacity and demand between Western and Eastern Inner Mongolia using available historical data.

In this approach, we developed scenarios of with low, medium and high assumptions of national electricity consumption growth rates from 2015 to 2020 and 2020 to 2025, and translate these to forecasts of regional grid electricity consumption using projected regional grid shares of total consumption. These projected shares are based on our GDP-driven forecasts, described in the preceding paragraph. Interestingly, the shares do not change significantly from base year (2014) shares (Table 2).

Table 2. Grid Region Shares of Total Electricity Consumption, 2014 Actual and 2020 and 2025 Projected

Grid Region	2014 (%)	2020 (%)	2025 (%)
Central	19	20	20
Eastern	25	25	25
Northern	23	22	22
Northeastern	7	7	6
Northwestern	9	9	9
Southern	17	17	17

For the low scenario of national electricity consumption growth rates, we assume an annual average growth of 1.5% between 2015 and 2020, and 1.0% between 2020 and 2025 (Table 3). For the medium scenario of national electricity consumption growth rates, we assume annual average growth rates of 3.6% between 2015 and 2020 (the lower bound of electricity consumption growth rate in the 13th FYP on Electric Power Development) which then slow to 2.0% between 2020–2025, respectively. For the high scenario we assume annual average growth rates of 4.8% between 2015 and 2020 (the higher bound of electricity consumption growth rate in the 13th FYP on Electric Power Development) which then slow to 3.0%, respectively. We scale national electricity consumption to 2015 using the NEA's reported actual growth rate.

Table 3. Low, Medium and High Scenario Assumed Annual Average Growth Rates for National Total Electricity Consumption (%/yr)

Scenario	2014–2015	2015–2020	2020–2025
Low	0.5	1.5	1.0
Mid	0.5	3.6	2.0
High	0.5	4.8	3.0

These assumptions lead to the 2020 and 2025 electricity consumption forecasts shown in Table 4.

9 More specifically, we looked at "bottom-up" specifications where we used linear and linear-log forecasts for individual sectors and then aggregated these into a regional grid total, and "top-down" specifications where we used linear and linear-log forecasts of total electricity consumption, with sectoral variables as explanatory variables.

Table 4. 2014 Actual and 2020 and 2025 Forecasted Electricity Consumption by Grid Region (TWh)

Grid Region	2014	Low		Mid		High	
		2020	**2025**	**2020**	**2025**	**2020**	**2025**
Central	1091	1204	1285	1334	1496	1413	1664
Eastern	1381	1536	1634	1701	1902	1802	2115
Northern	1311	1369	1410	1516	1641	1606	1826
Northeastern	397	403	411	447	478	473	532
Northwestern	520	565	592	626	689	663	766
Southern	932	1021	1076	1131	1253	1198	1393
National	5632	6098	6409	6755	7458	7156	8295

We use these consumption projections to forecast peak demand by grid region. To do so, we assume that system load factors fall by 5% (total) in each of the 2014–2020 and 2020–2025 time frames. This leads to the regional system load factors shown in Table 5.

Table 5. System Load Factors by Grid Region, Actual 2014 and Forecasted 2020 and 2025

Grid Region	2014 (%)	2020 (%)	2025 (%)
Central	81	77	73
Eastern	69	65	62
Northern	78	74	70
Northeastern	84	80	76
Northwestern	93	88	84
Southern	80	76	72

The values in Table 4 and Table 5 can be used to calculate regional grid peak demands, using the equation below:

$$RGP = \frac{RGC}{RLF \times 8760}$$

where RGP is regional grid peak, RGC is regional grid consumption, and RLF is regional system load factor. This leads to the forecasted peak demands shown in Table 6. “National” peak demand in the table is the sum of regional (non-coincident) grid peak demands.

Table 6. Peak Demand by Grid Region, Actual 2014 and Forecasted 2020 and 2025 (GW)

Grid Region	2014	Low		Mid		High	
		2020	**2025**	**2020**	**2025**	**2020**	**2025**
Central	155	180	202	199	235	211	261
Eastern	229	268	300	297	349	314	388
Northern	193	212	230	235	268	249	298
Northeastern	54	58	62	64	72	68	80
Northwestern	64	73	81	81	94	86	105
Southern	134	154	171	171	199	181	221
National	828	944	1045	1046	1216	1108	1353

3.4. Effective Generation Resources

Different generation resources contribute differently to generation adequacy. Thermal (natural gas, coal, nuclear) plants, for instance, will generally be able to contribute as much as their nameplate (rated) capacity during peak system conditions. Hydropower’s maximum output, and thus its contribution to generation adequacy, alternatively, will be affected by seasonal changes in precipitation, constraints imposed by water release schedules, and reservoir capacity, and will be less than 100% of its rated capacity. Solar and wind generation’s contribution to generation adequacy are shaped by the coincidence of incremental solar and wind generation and peak demand.

The “effective” capacity of hydro, wind, and solar power—their contribution to generation adequacy—can be assessed quantitatively using probability-based techniques. We are unaware of any such analysis for China. As a substitute, we use typical values for effective capacity of hydro, wind, and solar power in North America, shown in Table 7 [6]. For simplicity, we assume that these values are constant across grid regions, which is unlikely to be the case. However, in lieu of better data, we argue that this a reasonable assumption.

Table 7. Capacity Credit Given to Hydro, Wind, and Solar Generation Resources

Region	Hydro (%)	Wind (%)	Solar (%)
Central	55	10	30
Eastern	55	10	30
Northern	55	10	30
Northeastern	55	10	30
Northwester	55	10	30

n			
Southern	55	10	30

Two other adjustments to installed capacity data are necessary to convert it to effective capacity. First, China has a significant amount of behind-the-meter thermal generation, and the extent to which this generation is able to contribute to resource adequacy is unclear. As a middle-of-the-road assumption, we assume that the share of behind-the-meter generation remains at 2014 levels (8%), that it has a load factor of 90%, and that half of it would be available to meet peak demand.[10] Second, installed capacity data in China is reported as gross, rather than net, of generator own-use; whereas, effective capacity should be net of own-use. To convert gross to net generation, we use the values in Table 8.

Table 8. Generator Own-use by Resource Type[11]

Resource	Own-use (%)
Hydro	1
Thermal	5
Nuclear	5
Wind	1
Solar	1
Others	5

Total effective capacity (EC) is the sum of the total gross installed capacity (IC) of each resource, multiplied by one minus its own-use (OU), multiplied by its capacity credit (CC):

$$G = \sum_i IC_i \times (1 - OU_i) \times CC_i$$

3.5. Generation Resource Forecast

Our generation resource forecast begins with 2014 generation resources by region, shown in Table 9.

Table 9. Actual Generation Resources by Grid Region in 2014 (GW)

Region	Hydro	Thermal	Nuclear	Wind	Solar	Other
Central	130	144	0	3	1	0
Eastern	27	222	11	7	4	0
Northern	8	239	0	34	4	0

10 2014 values for behind-the-meter are based on CEC data, http://cec.org.cn/guihuayutongji/. All other values are assumed. For a more detailed discussion of these issues, see Kahrl (2016) [6].

11 Thermal values are based on CEC data, http://cec.org.cn/guihuayutongji/. All other values are assumed.

Northeastern	8	90	2	23	1	0
Northwestern	28	102	0	23	15	0
Southern	104	127	7	8	1	0
National	304	923	20	97	25	0

We make two key adjustments to 2014 resources. First, we extend thermal resources to 2015, to account for the significant increase (67 GW) in online thermal generation between 2014 and 2015 (Table 10). We allocate these new thermal resources across grid regions using data from Myllyvirta and Shen [8].

Table 10. Generation Resources by Grid Region, with Thermal Additions (GW)

Region	Hydro	Thermal	Nuclear	Wind	Solar	Other
Central	130	161	0	3	1	0
Eastern	27	233	11	7	4	0
Northern	8	252	0	34	4	0
Northeastern	8	91	2	23	1	0
Northwestern	28	102	0	23	15	0
Southern	104	144	7	8	1	0
National	304	982	20	97	25	0

Second, we assume that current public policy goals for thermal, hydro, nuclear, solar, and wind generation capacity, specified in the 13 FYP for Electricity Development, are met in 2020. Given the physical limitations on further hydropower development and potential social limitations on nuclear development, we assume that only solar and wind continue to expand into 2025. These values are shown in Table 11.

Table 11. Assumed Installed Capacity of Hydro, Nuclear, Solar, and Wind Generation in 2020 and 2025 (GW)

Region	2020	2025
Hydro	380	380
Thermal	1210	1210
Nuclear	58	58
Solar	210	240
Wind	110	150

We allocate these resources to different grid regions based on each region's share of total capacity for that resource in 2014. This leads to the installed capacity forecasts for each regional grid in 2020 and 2025 shown in Table 12.

Combining the capacity credits in Table 7, assumptions about behind-the-meter generation, own-use values from Table 8, the installed capacity values in Table 9 and Table 12, and net interregional exports[12] gives the total effective capacity values shown in Table 13.

These values can then be directly compared against the peak demand values in Table 6.

Table 12. Installed Capacity by Grid Region in 2020 and 2025 by Grid Region (GW)

2020

Region	Hydro	Thermal	Nuclear	Wind	Solar	Other
Central	162	189	0	6	3	0
Eastern	34	291	31	14	16	0
Northern	10	313	0	74	20	0
Northeastern	10	118	6	49	2	0
Northwestern	35	133	0	50	65	0
Southern	129	166	21	17	4	0
National	380	1210	58	210	110	0

2025

Region	Hydro	Thermal	Nuclear	Wind	Solar	Other
Central	162	189	0	7	4	0
Eastern	34	291	31	16	22	0
Northern	10	313	0	85	27	0
Northeastern	10	118	6	56	3	0
Northwestern	35	133	0	58	89	0
Southern	129	166	21	19	6	0
National	380	1210	58	240	150	0

Table 13. Total Estimated Effective Capacity Values by Grid Region in 2014, 2020, and 2025 (GW)

Region	2014	2020	2025
Central	173	234	235
Eastern	255	348	350

12 Net interregional exports are kept constant as the base year (2014) value from 2014 to 2025, as we do not have a good sense of generation and transmission build over the coming decade. Net interregional exports at the base year are the difference between regional peak generation and peak consumption, reported by CEC.

Northern	237	317	320
Northeastern	90	124	125
Northwestern	107	158	166
Southern	184	250	251
National	1054	1440	1455

4. Results and Discussion

4.1. Current Reserve Margins in China

Our analysis shows that at the end of 2014, the average reserve margin for China as a whole was roughly 28%, almost twice as high as a typical planning reserve margin in the U.S. [30] However, this national average masks huge variations in reserve margins across major regional power grid areas: the Northeastern region has the highest reserve margin of 64%, followed by the Northwestern region at 49%, and the Southern grid area at 35% (Figure 4).

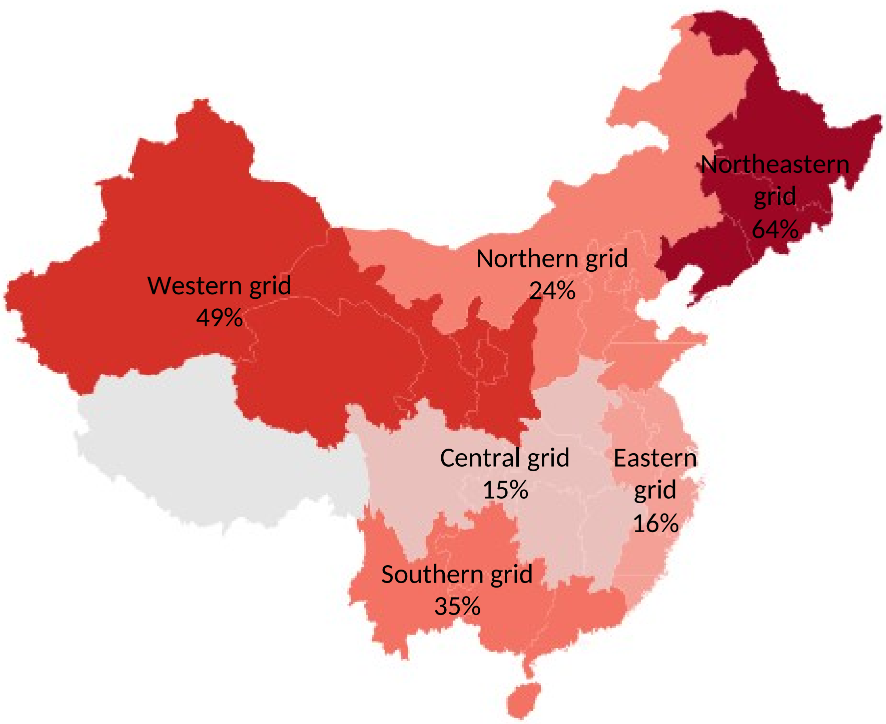


Figure 4. Estimated Reserve Margin in 2014

Note: A darker color represents a higher reserve margin.

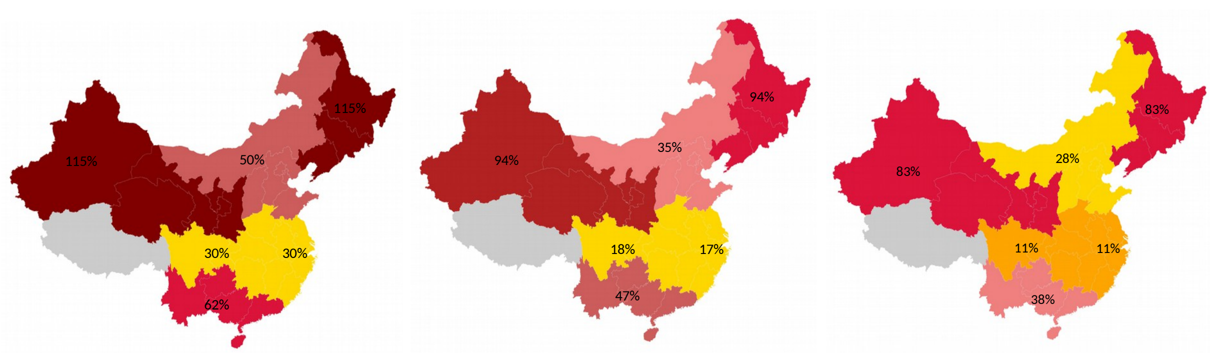
Power generation overcapacity has increased since 2014, as China added significant new generation capacity in 2015. Based on preliminary data, the national average reserve margin increased to 38% at the end of 2015.

4.2. Future Reserve Margins in China

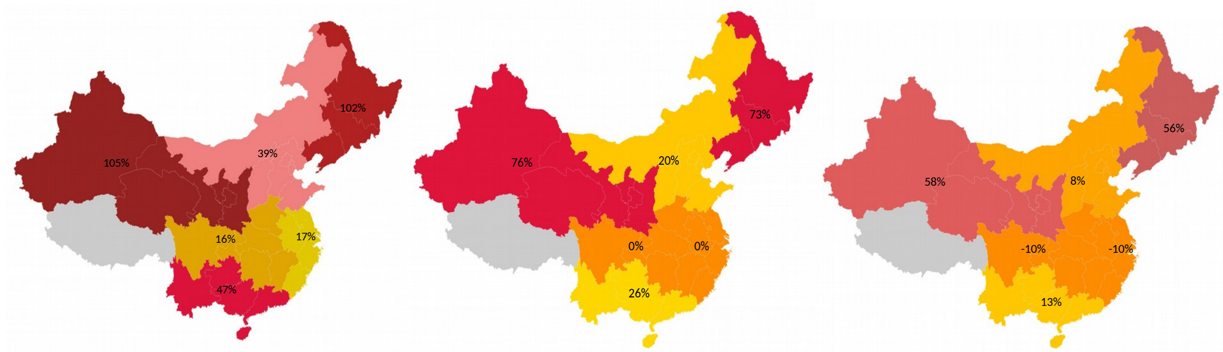
Under the low-growth scenario, the national average reserve margin would grow to 53% by 2020, and would remain at 39% by 2025. Overcapacity in the Northern, Northeastern, Northwestern, and Southern regions would be even more pronounced than 2014 levels in the low-growth scenario, becoming a multi-decadal problem. For the Central and Eastern regions, reserve margins would reach 30% by 2020 and remain 16% to 17% by 2025 (Figure 5).

Under the medium-growth scenario, China's national reserve margin would reach 38% by 2020 and fall to 20% by 2025. The Northern, Northwestern, Northeastern, and Southern regions would continue to have a large amount of overcapacity by 2020, all above 30%. By 2025, the Northern and Southern regions would still have adequate reserve margins (20% and 26%, respectively), but Northwestern and Northeastern regions would continue to have a lot of overcapacity, with reserve margins over 70%. Central and Eastern regions would still have adequate resources by 2020, with reserve margins slightly above 15%; however, by 2025 would need imports or additional capacity by 2025, when reserve margins fall to zero (Figure 5).

Under the high-growth scenario, China's national reserve margin would fall to 30% by 2020 and continue fall to 8% by 2025 (Figure 5). The Northwestern and Northeastern would continue to have a large amount of overcapacity by 2025, with reserve margins over 50%. Southern and Northern regions would have sufficient capacity for their own use by 2020, but would need more capacity by 2025, with reserve margins below 15%. Only the Eastern and Central regions would need additional imports from other regions or new generation capacity by 2020, as their reserve margins would fall to about 11% by 2020.



(a) (b) (c)



(d) (e) (f)

Figure 5. Planning Reserve Margins in 2020 under the Low (a), Mid (b), and High (c) Growth Scenarios, and Planning Reserve Margin in 2025 under the Low (d), Mid (e) and High (f) Growth Scenarios

Note: Red colors represent a severe excess of capacity, increasing in seriousness as the color becomes darker. Yellow colors represent a fair amount of reserve margin and may potentially be receiving excess power from the red-colored regions. The darker the yellow color, the more potential the region has of receiving power.

5. Conclusions and Policy Implications

In this analysis, we examined current and future reserve margins in China's regional grids under three scenarios of electricity demand growth. Figure 6 shows the reserve margins in 2020 under the three growth scenarios. In general, China has more than enough power plants to meet electricity demand today, and does not need any new thermal power plants for reliability purposes by 2020, and potentially by 2025. China may need certain clean generation technologies, such as wind and solar, to meet its climate goals under the Paris Agreement, and domestic air quality goals. It may also need more flexible technologies to cost-effectively integrate these low-emission resources into the grid. Such renewable and flexible power resources may displace some thermal baseload capacity in the next five to ten years.

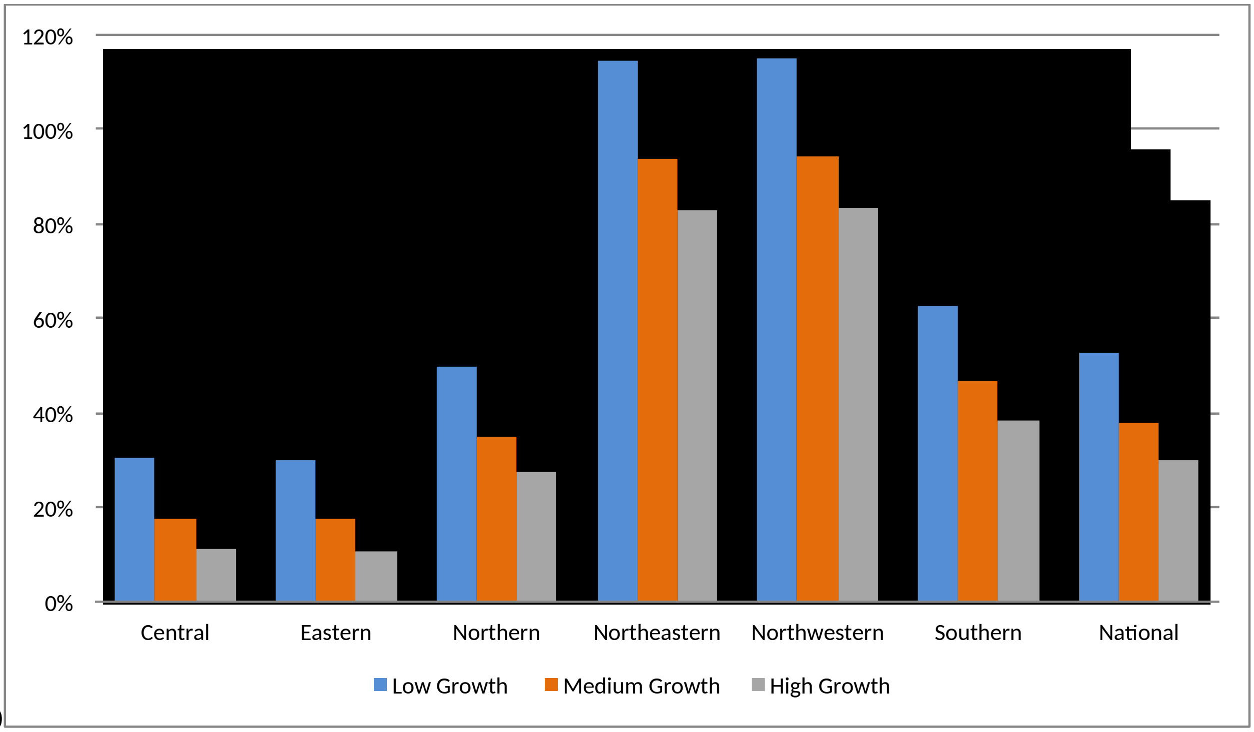


Figure 6. Reserve Margins in 2020 under Three Growth Scenarios

Results for regional reserve margins show a clear regional pattern: the Northwestern and Northeastern grid regions would likely have overcapacity regardless of demand scenarios in the next ten years; the Central and Eastern regions may need new resources as early as 2020; and the Northern and Southern grid regions may need new resources in 2025 only under a high-growth scenario. However, there are significant uncertainties in demand growth in the future. Therefore, government agencies need more robust and integrated planning tools to manage investment risks.

The current large discrepancies in reserve margins among grid regions also suggest the importance of coordination among grid regions in providing for generation adequacy across China. Resource sharing among provinces and regions, such as through regional power markets, could improve efficiency and push back the time before new investment is needed. The Eastern and Central regions' potential shortfalls, for instance, could be most cost-effectively supplied by using existing resources in the Southern region. The Northern region's shortfalls could be supplied through imports from the Northwest and Northeast. Greater coordination in generation adequacy across grid regions would require mechanisms for cost allocation, such as bilateral contracts. An expansion of bilateral exchanges across grid regions has been part of the NDRC's proposed power sector reform framework. However, the trading and dispatch systems to allow interregional exchange have yet to take shape. Creating them should be a priority.

As China transitions from a coal-dominant to a low-carbon power system, the big question becomes: which non-coal generation resources (as well as demand-side resources) will be needed in China by 2020 and 2025? Current levels of coal-fired generation may already be too high relative to least-cost and environmental planning goals. The current window of overcapacity provides a useful respite to examine this question with greater rigor, and highlights the importance of strengthening electricity planning processes and methods in China, and of refining China's regulatory governance structure and operating practices.

More specifically, in considering near-term steps to address electricity resource needs in China, we suggest that government agencies prioritize four key areas:

- More stringent policies, regulations, and mechanisms to halt the construction of new coal-fired generating units, including changes to their incentives.[13]
- A more scientific and workable planning process for the electricity sector that: (a) better coordinates among different geographic and administrative levels (provincial, regional, central) and across different resources (generation, demand-side, transmission), (b) uses economic evaluation methods and a scenario-based approach to forecasting and risk management, and (c) has clearer links between planning and investment decisions.
- Explicit consideration of the potential to use, and option the value of using, energy efficiency and demand response to meet longer-term generation capacity needs, lengthening the window of time in which the government can design and implement reforms before new generation resources are needed.
- The continued development of markets and regulatory institutions that facilitate economic dispatch, ideally across regions, which will in turn support longer-term resource adequacy by enabling greater sharing of generation resources across provinces.

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13 As this paper was being finalized, the NEA issued an new guideline to stop new coal power plant construction. In addition, NDRC issued an opinion on generation planning in 2016, requiring that new coal plants online after March 2017 not be included in the annual operating hour planning process, which will address an important shortcoming in incentives for coal-fired generation. Source: NDRC. *Notice of Orderly Opening Up Power Generation and Utilization Planning (Draft of Soliciting Opinions)*. July 13, 2016

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