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Integrating Renewable Energy Into Power Systems in China: A Technical Primer

Power System Operations

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Acronyms

AGC	Automatic Generation Control
BA	Balancing Area
CDO	County-Level Dispatch Organization
CSG	China Southern Power Grid Company
CSG-DC	China Southern Power Grid Company's Dispatch Center
DO	Dispatch Organization
EIC	Economy and Information Commission
ETC	Economic and Trade Commission
FGD	Flue Gas Desulfurization
GPG-DC	Guangdong Power Grid Corporation's Dispatch Center
MDO	Prefecture-Level Dispatch Organization
MEP	Ministry of Environmental Protection
NEA	National Energy Administration
NDO	National Dispatch Organization
NDRC	National Development and Reform Commission
PDO	Provincial Dispatch Organizations
RDO	Regional Dispatch Organization
ROR	Run-of-River
SEPA	State Environmental Protection Administration
SERC	State Electricity Regulatory Commission
SGCC	State Grid Corporation of China
SRC	Spinning Reserve Capacity

Introduction¹

This paper is part of a series of primers on the economic, institutional, political, and technological challenges of integrating renewable energy into power systems in China. Each paper in the series is designed to stand alone and focus on a different theme: electricity resource planning, power system operations, and electricity pricing. These three themes are intimately interlinked, and each of the papers draws and builds upon the others. The series was motivated by an assessment that, despite a voluminous literature on renewable energy in China, there is still very little understanding of basic institutions and practices in China's power sector, and how they shape the constraints faced by industry and regulators in expanding and integrating renewable energy into power systems.

This paper focuses on power system operations — the matching of electricity demand and supply subject to the physical constraints of the power system. The text is divided into four main sections:

- Overview
- Planning, Scheduling, and Dispatch
- Ancillary Services
- Interregional and Interprovincial Power Exchange

Although the focus in this series is on renewable integration, the descriptions and many of the conclusions have broader relevance. Each paper assumes that the reader has a basic knowledge of renewable energy developments in, and the organizational structure of, China's power sector.

¹ Authors: Fredrich Kahrl, Energy and Environmental Economics, Inc.; Wang Xuan, Regulatory Assistance Project. The authors would like to thank Rick Weston, Jim Williams, Kevin Porter, Max Dupuy, and Ryan Wiser for their valuable comments on drafts of this paper.

1. Overview

Power systems in China evolved in response to economic, social, and political forces that were very different from those in other countries. As a result, many operating institutions and practices in China are unique, rooted in the country's recent history — English translations and high-level descriptions often make them seem more familiar than they actually are. These institutions and practices were designed to support power systems dominated by heavy industrial demand and baseload coal generation for an economy in which output was, to some extent, planned. Many of these practices will need to change to accommodate the increasingly diverse needs of a dynamic economy and the government's vision of a low-carbon electricity supply powered by significant amounts of variable wind and solar generation.

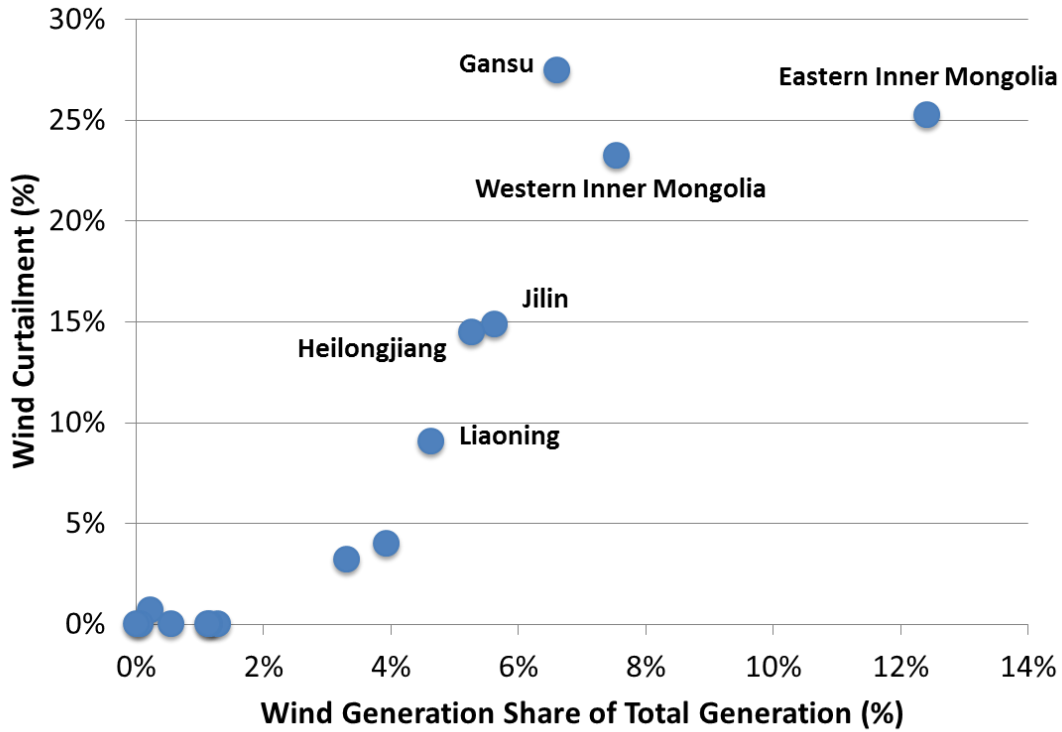
The challenges of integrating wind and solar generation into power systems in China are becoming increasingly clear. In 2011, an estimated 16 percent (12 TWh) of potential wind generation was curtailed in China's largest wind-producing region, the "Three Norths" region (三北 | San Bei),² leading to estimated economic losses of 6.6 billion yuan (US\$1.0 billion).³ As Figure 1 illustrates, curtailment was dramatically higher for the six provinces in the region with wind penetrations of more than five percent. Such high levels of curtailment, at relatively low levels of wind penetration, are not consistent with experience in other countries. They are clearly unsustainable if wind and solar energy are to be a major part of China's generation mix going forward.

Improvements in power system operations will be important for solving China's renewable integration challenges. There is, however, a dearth of systematically organized, technically nuanced information in Chinese or English that describes the current institutions and practices governing the operation of power systems in China. Without this critical context, it is difficult to identify incremental, practical, near-term opportunities for reform, and to ground options for nearer- and longer-term reforms in political and economic realities. This paper aims to provide an initial step toward addressing this information gap.

² The Three Norths region includes the northeast (Liaoning, Jilin, Heilongjiang Provinces and eastern Inner Mongolia), northern (Beijing and Tianjin Municipalities, Hebei, Shanxi, Shandong Provinces, and western Inner Mongolia), and northwest (Shaanxi, Gansu, Qinghai, Provinces and Ningxia, Xinjiang Autonomous Regions) grid regions. These three regions accounted for almost 90 percent of wind capacity and energy at the end of 2011. See SERC. (2012). Regulatory Report on Wind Integration in Key Areas 《重点区域风电消纳监管报告》.

³ *Id.* The National Energy Agency (NEA) estimates indicate that curtailment in this region fell to an average of 13% in 2013. See NEA. (2014). Wind Industry Maintained Rapid Growth in 2013. (2013 年风电产业继续保持平稳较快发展势头). Available at: http://www.nea.gov.cn/2014-03/06/c_133166473.htm.

**Figure 1. Wind Curtailment as a Function of Wind Penetration by Province
in the “Three Norths” Region, 2011⁴**



The descriptions and analysis in this paper are oriented around four overarching questions:

1. What are the organizations and institutions governing power system operations, and what is the process through which load is managed and generators are scheduled and dispatched, in China?
2. How are ancillary services defined and provided?
3. How is power traded across regions and provinces?
4. For each of these three themes — load planning, generator scheduling, and dispatch; ancillary services; and interregional and interprovincial power exchange — what kinds of challenges do current institutions and practices create for integrating variable renewable generation?

⁴ *Id.*

The narrative that follows describes power systems in China that are increasingly outgrowing the principles, organizations, rules, and processes that have governed them since the 1980s and 1990s. Local governments still administratively ration electricity demand and plan output annually for power plants; generating units are then scheduled and dispatched according to plan rather than through least-cost optimization. Dispatch is managed through a multilevel geographic hierarchy that mirrors a political hierarchy, in which power plants that were built to export power across regions and provinces have their output planned by the central government and receive priority in the importing province's dispatch. These institutions now appear excessively rigid relative to the diverse needs of the Chinese economy and a low-carbon electricity supply with high penetrations of wind and solar energy.

This paper identifies five main focal points for reforms in operating institutions and practices that would improve power system flexibility in China, although it does not advocate specific reform mechanisms or policy instruments. These focal points, in no particular order, are:

- **Economic demand rationing:** Transitioning from the current administratively determined, quarterly or annual allocation of firm power supplies to a more economic allocation that occurs on shorter timescales;
- **Rational unit commitment and dispatch:** Transitioning from generator output planning to a system-wide unit commitment and dispatch process that is optimized around variable cost;
- **Consolidated dispatch management:** Transitioning from the current multilevel dispatch hierarchy to a centralized regional dispatch overseen by a single organization;
- **Rational scheduling and dispatch across provinces:** Transitioning from export and import planning for cross-border power exchange to an approach that allows generator scheduling on shorter timescales and is more optimized around variable cost; and
- **Ancillary services definitions and rules:** Transitioning toward more precise ancillary service definitions and rules that better anticipate system needs.

While progress in these five areas is needed to more cost-effectively integrate variable renewable generation in China, it would also reduce costs, emissions, and improve reliability for the power system as a whole, regardless of whether there is any renewable generation on the grid. Although technology can play a role in enabling reforms in these five areas, it is complementary to, rather than a substitute for, innovations in organizations, rules, and processes.

2. Planning, Scheduling, and Dispatch

2.1 Historical Overview

The current approach to scheduling and dispatching electric generators in China has its roots in the country's pre-reform period (1949–1978). Despite relatively rapid growth in generation capacity over this time period, capacity additions were not sufficient to meet demand, and load curtailment during the day was relatively common (see Section 2.4, Annual Demand Planning). As a result, demand (load) was relatively flat over the course of a day and all available generation was run at or near its maximum capacity,⁵ effectively obviating the need for a dispatch order.

In the 1980s, after the implementation of economic reforms, most provinces experienced severe capacity shortages, and the central government responded by liberalizing investment and allowing provincial governments, private companies, and foreign investors to invest in power generation. Under this system, coal generators, which accounted for most new generation, were given contracts that specified both a yuan per MWh price and a fixed number of fully loaded operating hours. This system was designed to ensure that generators would recover their investment costs, as long as their operating hour targets were met. Scheduling and dispatch were done according to a plan that, to the extent possible, maintained operating hour targets, which were kept relatively constant across generators.⁶

This approach was very successful at encouraging investment — over the 1980s and into the 1990s generation capacity grew by ten percent per year.⁷ However, the cost of this “equal shares” approach was higher fuel costs and emissions, as less efficient coal generators were run the same number of hours as more efficient ones, and lower marginal cost hydropower, and later wind power, was at times curtailed to ensure sufficient operating hours for coal generators.

The suite of power sector reforms begun in 1998, and particularly those announced after 2002, were intended to address these shortcomings. The proposed creation of regional power pools in 2002, with pilots in the East and Northeast grids, included plans for regional market-based dispatch.⁸ However, owing to a combination of rapid demand growth, stranded cost considerations, and difficulties in reconciling the interests of competing stakeholder groups, regional markets did not materialize and the previous system of “equal shares” dispatch was continued.⁹

As larger, more efficient coal-fired generators came online during the 2000s, the economic and environmental shortcomings of equal shares dispatch became even more apparent. To address this problem, a number of provinces, beginning with Jiangsu in 2006, implemented generation rights trading

⁵ Gao, C., & Li, Y. (2010). Evolution of China's power dispatch principle and the new energy saving power dispatch policy. *Energy Policy*. 38: 7347.

⁶ Kahrl, F., Williams, J. H., & Hu, J. (2013). The political economy of electricity dispatch reform in China. *Energy Policy*. 53: 362.

⁷ China Energy Group. China Energy Databook. 7: Table 2B.14.

⁸ Gao & Li, 2010, p 7349.

⁹ Ibid.

(发电权交易 | fadian quan jiaoyi) schemes intended to allow larger, more efficient generators to purchase generation rights from smaller, less efficient generators. Following on the Jiangsu model, generation rights trading in other provinces has taken three forms: (1) bilateral deals between individual power plants, with individually negotiated quantities and prices; (2) internal transfers between generators within an individual generating company; and (3) centralized “matchmaking” markets (撮合交易 | cuohe jiaoyi), in which sellers and buyers are matched in a centralized trading platform.¹⁰

In Jiangsu’s case, the centralized matchmaking markets are overseen by the Jiangsu Economy and Information Commission (EIC, 经济和信息化委员会 | Jingji he Xinxihua Weiyuanhui) and the regional State Electricity Regulatory Commission (SERC) office and run by its grid company’s Grid Power Exchange Center (电网电力交易中心 | Dianwang Dianli Jiaoyi Zhongxin), which was set up to facilitate interregional and interprovincial trading (see Section 4.2, Market-Based Exchange). In these markets, sellers bid a quantity to supply (MWh) and a selling price (yuan/MWh), buyers bid a quantity to purchase and a purchasing price, and the Exchange Center then matches lowest-cost sellers and buyers based on the resulting supply and demand curves and awards each party the average of the two prices.¹¹

Generation rights trading expanded after 2006, first within provinces and then between provinces and regions. In 2009, SERC’s Northeast Bureau released rules facilitating rights trading across provincial boundaries (“interprovincial trading”),¹² and the total interprovincial traded volume across China peaked at 145 TWh in that year.¹³ By 2011, interprovincial trading systems had expanded to all grid regions and the Northwest and Northern Grids had established trading mechanisms across regional grids (“interregional trading”). Total interprovincial and interregional traded volumes, however, fell to 108 TWh,¹⁴ in part because many small, inefficient units had already been fully retired.¹⁵ Over 2007 through

¹⁰ Interestingly, in Jiangsu’s first round of trading, more than half of eligible generators reportedly participated, with 325 GWh cleared through the centralized market and 109 GWh cleared bilaterally. The former price (204 yuan/MWh) was reportedly almost ten percent lower than the latter (223 yuan/MWh), but both appear to be high relative to the levelized cost of a new subcritical coal unit (~120 yuan/MWh). It also appears that some generators both sold and bought generation rights, as the number of participating generators (25) was smaller than the sum of sellers (7) and buyers (20). See Jiangsu Electric Power Company. (2006, September 13). Jiangsu grid successfully implements “Generation Substitution” Program, first centralized and bilateral exchange program clears 433.5 GWh (江苏电网成功推行“替代发电”，首次撮合成交和协商替代电量合计达4.335 亿千瓦时). Available at: <http://njb.serc.gov.cn/news/2006-9/2006913121557.htm>.

¹¹ For instance, if the lowest bidding seller bids 25 MW at 250 yuan/MWh and the lowest bidding buyer bids 50 MW at 150 yuan/MWh, the two will be matched at 25 MW and a price of 200 yuan/MWh. The Exchange Center then moves up the supply curve and matches all buyers below the highest selling price. For a description, see: Jiangsu EIC and SERC Nanjing Office. (2011, February 18). Operating rules for Jiangsu’s Generation Substitution Exchange 《江苏省节能发电调度替代电量交易运作规则（试行）》.

¹² SERC Northeast Bureau. (2009). Temporary measures for cross-provincial generation rights trading in the Northeast Region 《东北区域跨省发电权交易暂行办法》.

¹³ SERC. (2010). 2009 Annual Electric Power Regulatory Report (电力监管年度报告 (2009)) p 66.

¹⁴ SERC. (2012). 2011 Annual Electric Power Regulatory Report (电力监管年度报告 (2011)) p 66.

¹⁵ Small units (<200 MW) that were slated to be closed (关停机组 | guanting jizu) were given a grace period under which their generation quota was still given to them. Once that grace period ended, those trades were no longer available.

2011, the volume of generation rights traded each year (in TWh per year) was equivalent to between two percent and five percent of total thermal generation.¹⁶

Generation rights traded led to significant improvements in economic and resource efficiency, as less efficient generators were replaced in dispatch order by larger, more efficient units. SERC reports that, between 2010 and 2011, rights trading led to a 0.6-percent, or approximately 2 kgce/MWh (~60 MMBtu/kWh), reduction in average net heat rates for thermal power plants.¹⁷ However, it became clear that there were limits to what generation rights trading alone could achieve in terms of dispatch efficiency improvements. For instance, in some provinces only a small number of generators were allowed to trade; in others, incentives to trade were not necessarily consistent with an efficient dispatch order.¹⁸ Recognition of these limits led to consideration of alternative approaches to dispatch reform.

In 2007, the National Development and Reform Commission (NDRC), SERC, and the Ministry of Environmental Protection (MEP) announced a pilot “energy efficient” dispatch (节能调度 | *jienerg diaodu*) system, in Guangdong, Guizhou, Henan, Jiangsu, and Sichuan Provinces. This system specifies a dispatch order, with renewable, large hydropower, nuclear, and cogeneration units given priority over conventional thermal units, and conventional thermal units within each category (e.g., coal-fired units) dispatched according to efficiency (heat rates) and emissions rate. This system sought to achieve two goals: (1) to reduce wind and hydropower curtailment, by prioritizing it in dispatch order; and (2) to capture additional fuel cost and coal resource savings above and beyond what the generation rights trading system induced voluntarily by administratively forcing less energy efficient generators to cede more operating hours to more efficient ones.

In 2010, energy efficient dispatch was extended to the five provinces in the Southern Grid. However, although the original pilots are ongoing, energy efficient dispatch has not been expanded to the national level. While there have been concerns with the accuracy of heat rate and emissions data, the most difficult challenge to implementing energy efficient dispatch has been the generation pricing system, which has not changed to accommodate changes in dispatch. As a result, dispatchable generator

¹⁶ As a share of thermal generation, the volume of generation rights traded was lowest in 2007 (2.0 percent, 54 TWh of 2669 TWh) and highest in 2009 (4.9 percent, 145 TWh of 2838 TWh). By 2011, traded volumes had fallen to 2.8 percent (108 TWh of 3726 TWh). Traded volumes are from the SERC Annual Electric Power Regulatory Report series; thermal generation data are from NBS website. Available at: <http://data.stats.gov.cn>. Accessed November 25, 2013.

¹⁷ In this case, the change in heat rate is $\Delta HR = \frac{\text{energy savings}}{\text{total thermal generation}}$ and the percentage change is $\% \Delta HR = -\frac{\Delta HR}{HR}$, where thermal generation is for year 2011 and HR is the average heat rate in 2011. SERC reports that energy savings from generation rights trading were 8.35 Mtce between 2010 and 2011, that total thermal generation was 3897.5 TWh in 2011, and that the average thermal heat rate for units over 6 MW was 330 kgce/MWh in 2011. See SERC, 2012, pp 66, 80.

¹⁸ For example, in a number of provinces rights trading was only set up for small, inefficient units that were slated to be retired; power plants are also subject to different incentives in China than in the U.S. See, for instance, Yanhua Ge. (2012, August 27). Heilongjiang's Generation Rights Trading Decreases: Amount of Power to be Transferred by Plants Slated for Closure Decreases. *China Electric Power News*. (黑龙江发电权交易下降：关停机组转移电量萎). See also Gao and Li, 2010 at 7350.

revenues are either too high (for efficient units) or too low (for less efficient units), relative to either a cost-of-service-based system or a competitive market.¹⁹

2.2 Dispatch Rules, Organizations, and Hierarchy

The rules and regulations currently governing electricity dispatch in China are stipulated in a 1993 State Council regulatory directive, *Grid Dispatch Regulations* (*Regulations* in this section), which was revised in 2011.²⁰ This document allocates authority and responsibility for dispatch, sets an organizational hierarchy, and specifies a basic process for and rules governing dispatch. Implementation instructions for the *Regulations* were provided in the then-Ministry of Electric Power's *Implementation Measures for Grid Dispatch Regulations*, which was released in 1994.²¹ The *Regulations* were motivated by the need for more formal dispatch organizations and rules following the pluralization of generation ownership that occurred over the 1980s, in particular as local governments began to finance and build generation within their jurisdictions.

Under the *Regulations*, “executive-level electricity departments” (电力行政管理部门 | dianli xingzheng guanli bumen), currently the National Energy Administration (NEA), have the authority to determine the responsibilities of dispatch organizations (DOs), their geographic scope, and their jurisdiction, or which DOs have control over which generators and transmission facilities. DOs are currently Power Dispatch and Communications Centers (电力调度通信中心 | Dianli Diaodu Tongxin Zhongxin) within the State Grid Corporation of China (SGCC) and provincial and regional grid companies, and variously named dispatch centers within prefecture- and county-level electricity supply companies.²² The titles “dispatch organization” and “dispatch center” are thus used interchangeably here.

The organizational hierarchy laid out in the *Regulations* is based on a principle of “unified dispatch and multi-level management” (统一调度、分级管理 | tongyi diaodu, fenji guanli). This principle sought a political compromise between the need for unified dispatch, following a diversification of generation ownership, and the prerogatives of local governments to manage local generation and loads. Multilevel management is based on a five-level hierarchy of DOs, each with a separate jurisdiction and function. Table 1 provides an overview of this hierarchy, showing the division of responsibilities for three key functions: supply-demand balancing (balancing), generator dispatch (dispatch), and load management. Although the DOs in Table 1 are functionally separate, with the exception of the China Southern Grid region, the regional and provincial grid companies to which regional and provincial dispatch organizations belong are subsidiaries of SGCC.

¹⁹ Kahr et al. 2013.

²⁰ State Council. (1993, revised 2011). Grid dispatch regulations 《电网调度管理条例》. No. 115.

²¹ Ministry of Electric Power. (1994). Implementation measures for grid dispatch regulations 《电网调度管理条例实施办法》. No. 3.

²² The current administrative system in China is based on a four-tier hierarchy at the provincial level: (1) provinces, (2) prefectures, (3) counties, and (4) townships.

Table 1. Overview of Dispatch Organization Hierarchy²³

Level	Host	Jurisdiction	Key Functions
National (NDO) 国调 guodiao	SGCC	<i>Voltage level:</i> >500 kV <i>Geographic:</i> Regional interties <i>Generators:</i> Large thermal or hydropower shipping across regions	Interregional balancing, interregional dispatch
Regional (RDO) 网调 wangdiao or 总调 zongdiao	Regional grid companies	<i>Voltage level:</i> 330–500 kV <i>Geographic:</i> Provincial interties <i>Generators:</i> Pumped hydro storage, regulation	Interprovincial balancing, interprovincial dispatch
Provincial (PDO) 省调 shengdiao or 中调 zhongdiao	Provincial grid companies	<i>Voltage level:</i> 220 kV (330–500 kV terminal substations) <i>Geographic:</i> Bulk provincial system <i>Generators:</i> Larger generators not controlled by RDO or NDO	Intra-provincial balancing, intra-provincial dispatch, coordinating load management
Prefecture (MDO) 地调 didiao or 市调 shidiao	Prefecture power supply organizations	<i>Voltage level:</i> ≤220 kV <i>Geographic:</i> Local system <i>Generators:</i> Smaller local generators	Prefecture load management
County (CDO) 县调 xiandiao	County power supply organizations	<i>Voltage level:</i> ≤110 kV <i>Geographic:</i> County system <i>Generators:</i> Any remaining generators	County load management

DOs that are lower in this hierarchy (e.g., county-level) are required to comply with instructions from those more senior in the hierarchy (e.g., provincial-level), with one exception. China Southern Power Grid Company's (CSG's) Dispatch Center, which is technically a regional dispatch organization (RDO), is not under the direct control of a national dispatch organization (NDO), or SGCC.²⁴ Unified dispatch is

²³ This table is based on information in the text as well as on Jiang, L., Chi, Y., Qin, H., et al. (2011). Wind energy in China. *IEEE Power & Energy Magazine*. 9:36–46.

²⁴ Dispatch centers for China's two independent provincial grid companies, the West Inner Mongolia Electric Power Corporation and the Shaanxi Regional Electric Power Group Corporation, are both provincial dispatch organizations within the dispatch hierarchy.

achieved through rules and procedures that institutionalize coordinated planning and real-time management among these organizations, described below.

The three principal actors within this five-level hierarchy are SGCC (the NDO), the RDOs, and provincial dispatch organizations (PDOs), which are responsible for scheduling and balancing most of the system. The division of labor among SGCC, RDOs, and PDOs is somewhat subtle, and easier to see from their interaction in the scheduling and dispatch process (see Section 2.5, Scheduling and Dispatch Processes). As a general principle, scheduling and balancing responsibilities among DOs are separated according to geography and voltage levels, with PDOs responsible for managing the 220-kV provincial grids and generators that are dispatched to meet within-province demand, and RDOs responsible for higher voltage (330–500 kV) provincial interconnections and generators that are dispatched across provinces. The NDO, SGCC’s dispatch center, has jurisdiction over regional grid interconnections and generators that are dispatched across regions.

Prefecture-level dispatch organizations (MDOs) and county-level dispatch organizations (CDOs) are responsible for implementing dispatch instructions from PDOs, monitoring frequency and voltage conditions in local grids, and managing local generators and load. MDOs control any generating units in their geographic area that are not under the control of a more senior DO, as well as lower voltage (<110 kV) sub-transmission and distribution substations and lines in their jurisdiction. CDOs typically control any remaining generating units that are in their jurisdiction, as well as substations less than 110 kV and distribution lines less than 35 kV.²⁵ MDOs and CDOs are responsible for demand planning within their jurisdictions (see Section 2.4, Annual Demand Planning), a process that is coordinated across the province by the PDOs.

Each level in the five-level hierarchy of dispatch organizations develops detailed dispatch rules and procedures, which are contained in *Operating Procedures for Dispatch* (调度规程 | Diaodu Guicheng). Topics covered in these *Procedures* include management responsibilities, procedures for frequency and voltage control and contingency management, and rules for equipment repair schedules and information exchange between dispatch organizations.

China’s five-level dispatch hierarchy evolved organically over time. Its administrative complexity stands in contrast to the shift toward centralized system operators and wider balancing areas seen internationally, reflecting economies of scale.²⁶ However, consolidating DOs has not been a focus of electricity sector reform discussions in China.

²⁵ Zhang, F. (2011, March). Operating procedures for local dispatch in Hunan: training notes (湖南地区电力调度规程培训讲).

²⁶ For a version of this argument, see: ISO/RTO Council. (2005). The value of independent regional grid operators, pp 19–23. Available at: http://www.nyiso.com/public/webdocs/media_room/press_releases/2005/isortowhitepaper_final11112005.pdf.

2.3 Annual Demand Planning

Demand planning in China dates back to the early 1970s, when the State Planning Commission's *Rules for Supply and Use of Electricity* required government agencies at all levels to establish departments responsible for planning, allocating, and managing electricity demand.²⁷ These early plans focused on allocating scarce electricity supply, and, in particular, “filling valleys and shaving peaks” (填谷削峰 | tiangu xiaofeng) by instituting a program of peak load shifting and “peak avoidance” (避峰 | bifeng) for large industrial users (non-continuous production), and through “rotating outage” (轮休 | lunxiu) programs for other urban users.²⁸ Unlike in North America, where utilities built new generation capacity (supply) to meet demand and fulfill their obligation to serve, in China the approach was to use demand planning to limit demand to match supply.

Although it has evolved over the course of three decades, to some extent this system of demand planning and rationing is still in place. The most significant changes to this system occurred in 2011 with the issuance of the NDRC's directive, *Measures for Orderly Electricity Use* (*Measures* in this section). The *Measures* attempted to better rationalize and standardize demand planning and load management, by establishing a formal planning process through which expected available generation capacity is allocated to municipalities and counties, a warning and response system for supply shortages, a process for shifting and curtailing load when conditions warrant, and a penalty system for violating load management directives.²⁹

To allocate available supply (generation capacity), provincial planning departments develop annual plans that give each municipality and county an “electricity use quota” (用电指标 | yongdian zhibiao), typically by quarter. These quotas are for a maximum not-to-be-exceeded peak load, including line losses. They are developed on the basis of expected available generation capacity (including net exports), economic metrics, and historical demand, although methods for allocation appear to vary by province and are not made public. Prefectures and counties are not permitted to exceed their quota, and can be penalized if they do.³⁰ Prefecture and county planning departments allocate these quotas internally among regions within their jurisdictions on the basis of an *Orderly Electricity Use Plan* (有序用电方案 | youxu yongdian fangan), as required by the NDRC's *Measures*, with allocation also done using

²⁷ The *Rules* stipulated that “electricity use should be managed, planned, rationed, and measured” (用电有人管, 使用有计划, 耗电有定额, 考核有制度供用电规则). See State Planning Commission. (1972). *Rules for supply and use of electricity* 《供用电规则》, cited from: Zhenfang, Z. (2006). *A history of the power sector in the People's Republic of China: Inner Mongolia*. Beijing: China Water and Power Press.

²⁸ “Peak avoidance” refers to the scheduling of load to avoid peak demand periods. “Revolving rationing” involves mandating weekly outages for certain customers.

²⁹ NDRC. (2011). *Measures for orderly electricity use* 《有序用电管理办法》. No. 832.

³⁰ For instance, Zhongshan Municipality's rules stipulate that townships that exceed their quota are first warned, and then may have their next quarter's quota reduced. See Zhongshan EIC. (2012). *Implementation and management measures for orderly electricity use* 《中山市有序用电管理实施办法》.

a combination of economic metrics and historical demand.³¹ The process of allocation, both among municipalities and counties and individual customers, is an important lever for implementing national and local industrial and environmental policy,³² although it also appears to be open to political influence.³³

Table 2. Four Kinds of Load Management Defined in the Measures for Orderly Electricity Use

Chinese pinyin	English	Description
错峰 cuofeng	Peak load shifting	Customers move load from one period to another; typically does not change total use
避峰 bifeng	Peak load avoidance	Customers reduce demand in peak period; typically reduces total use
限电 xiandian	Restricted use	Customers restrict use in specified periods
拉闸 lazha	Load curtailment	System operator curtails load

The *Measures* define four kinds of load management and lay out a sequence for managing load: (1) peak load shifting, (2) peak load avoidance, (3) restricted use, and (4) load curtailment (Table 2). Provincial and local planning agencies and local power supply companies manage peak load shifting and avoidance through a planning process and contracts with industrial firms. Planning agencies manage restricted use and load curtailment through an annual planning process that prioritizes loads for rationing.

For the purposes of triggering load management, the *Measures* also define “power shortages” (电力缺口 | dianli quekou) and “energy shortages” (电量缺口 | dianliang quekou). Power shortage (*PS*) is defined as

³¹ For instance, Zhongshan Municipality in Guangdong Province uses GDP, nominal industrial value added, and metered electricity load to allocate quarterly quotas. See Zhongshan EIC, 2012. Dongguan Municipality in Guangdong Province uses peak demand over some period in the previous quarter to allocate quarterly quotas, with non-firm industrial customers given the residual of the total quota minus demand from critical facilities, firm industrial customers, residential and commercial customers, and key government agencies. See Dongguan EIC. (2011). Notice on allocation quotas for the second quarter of 2011 for Dongguan Municipality 《关于下达东莞市二〇一一年第二季度电力分配指标的通知》, No. 132.

³² Article 12 of the *Measures for Orderly Electricity Use* explicitly notes that local annual Orderly Electricity Use Plans should be consistent with national industrial and environmental policies (编制有序用电方案应贯彻国家产业政策和节能环保政策).

³³ For instance, the city of Enping’s website describes the prodigious efforts of city officials to obtain a higher quota in 2011, including inviting higher-level officials for local inspections. See Enping Economic and Information Bureau. (2011, April 19). City EIB does everything in its power to obtain higher electricity quota. (市经信局千方百计争取增加我市网供电指标). Available at: <http://www.epei.gov.cn/jx/ShowInfo.asp?InfoID=712>.

$$PS = \text{peak load shifted} + \text{peak load avoided} + \text{use restricted} + \text{load curtailed}$$

where peak load shifted, peak load avoided, demand rationed, and load curtailed are measured at a single point in time (e.g., in MW). Energy shortages (ES) are defined as

$$ES = \text{peak load avoided} + \text{use restricted} + \text{load curtailed}$$

where these quantities are measured over a specified period of time (e.g., in MWh).

Although there are no national rules for how different prefecture- and county-level organizations manage peak load shifting and avoidance, provincial planning agencies have generally laid out high-level responsibilities in their respective *Implementation Measures for Demand-Side Management*.³⁴ Practices differ among provinces, with government agencies more directly involved in planning in some areas and less involved in others.³⁵ In general, though, peak load shifting and avoidance plans (错峰避峰方案 | cuofeng bifeng fangan) are developed at a prefecture or county level and aggregated and approved at a provincial level. These plans typically lay out a strategy for peak load shifting and avoidance based on different levels of power shortage. Table 3 shows an example plan, from Qingyuan County in Zhejiang Province, which includes 3 MW (1 company) of peak load avoidance and 10.1 MW (25 companies) of peak load shifting for high-voltage industrial customers, as well as some restrictions on and notices to other customers.

When peak load shifting and avoidance are insufficient to ensure reliability, grid companies begin to implement rationing plans, based on emergency response procedures and a “demand rationing order table” (限电序位表 | xiandian xuwei biao). The development of this table was first mandated in the 1993 version of the *Grid Dispatch Regulations*.³⁶ Table 4 shows an example of one such table, for Henan Province’s Nanyang County in 2012.

³⁴ These implementation measures are generally called Provincial Electricity Demand-Side Management Implementation Measures (省电力需求侧管理实施办法).

³⁵ For instance, the Hubei provincial government created a demand-side management working group under the province’s Economic Commission that is responsible for planning load shifting and avoidance; in Inner Mongolia, planning was delegated to grid companies, to be approved by the provincial EIC. See Hubei Economic Commission and Price Bureau. (2005). Hubei provincial implementation measures for demand-side management 《湖北省电力需求侧管理实施办法》; Inner Mongolia Autonomous Region Government. (2012). Inner Mongolia implementation measures for demand-side management 《内蒙古自治区电力需求侧管理实施办法》.

³⁶ Both the *Grid Dispatch Regulations* and *Implementation Measures for Grid Dispatch Regulations* directed grid management departments (电网管理机构 | dianwang guanli jigou) to create an “accident and over-planned electricity use curtailment table” (事故及超计划用电的限电序位表 | shigu ji chao jihua yongdian de xiandian xuwei biao) that would be approved by the appropriate level of government and implemented by the appropriate DO. These tables are often referred to as “demand curtailment and rationing order tables” (拉闸限电序位表) as well.

Table 3. Peak Load Shifting and Avoidance Plan for Qingyuan County, Zhejiang Province for 2011³⁷

Level	Power Shortage	Incremental Measures
A	1 MW	1. Institute peak avoidance for large energy users (total peak avoidance = 3 MW, one company) 2. Shut off all advertisements with neon lights or light cases; shut off one side of street lighting, to the extent it does not affect visibility 3. Turn off all customers who have outstanding bills
B	A + 1 MW	4. Government offices, hotels, entertainment businesses control air conditioners above 26°C in summer and heating below 20°C in winter
C	B + 2 MW	5. Shift peak loads for some higher-voltage (≥ 350 kV) customers (shifted load = 1 MW, two companies) 6. Encourage residential customers to conserve energy, keeping air conditioners above 26°C in summer and heating below 20°C in winter
D	C + 1 MW	7. Shift peak loads for more higher-voltage (≥ 350 kV) customers (shifted load = 1 MW, four companies) 8. Curtail customers who have not implemented load shifting as directed
E	D + 2 MW	9. Shift peak loads for more higher voltage (≥ 350 kV) customers (shifted load = 2 MW, three companies)
F	E + 1.25 MW	10. Shift peak loads for more higher voltage (≥ 350 kV) customers (shifted load = 1.25 MW, five companies)
G	F + 3.2 MW	11. Shift peak loads for more higher voltage (≥ 350 kV) customers (shifted load = 3.2 MW, six companies)
H	G + 1.65 MW	12. Shift peak loads for more higher voltage (≥ 350 kV) customers (shifted load = 1.65 MW, five companies)

³⁷ Qingyuan County Government Office. (2011). Notice on Qingyuan County's 2011 Orderly Electricity Use Plan 《关于印发庆元县 2011 年有序用电预案的通知》.

Table 4. Demand Rationing Plan for Nanyang Municipality, Henan Province, 2012³⁸

Level	Power Shortage	Level/Color	Incremental Measures
IV	<10 percent	Normal (一般)	1. Restrict load for illegal projects, firms that fall in the “retire” (淘汰 taotai) and “restricted” (限制 xianzhi) differential price categories, or firms that are more energy-intensive than national minimum standards 2. Limit production from other energy- or emissions-intensive firms
III	10 to 15 percent	Somewhat Severe (较重)	3. Implement weekly or rotating outages 4. Large users implement “peak avoidance production” (错峰生产 bifeng shengchan)
II	15 to 20 percent	Severe (严重)	5. Limit production by calcium carbide, iron alloy, aluminum, steel, cement, and other energy-intensive firms, while maintaining supply for residential customers and key agencies 6. Implement two-day-a-week peak load avoidance for mining, equipment manufacturing, and pharmaceutical firms
I	>20 percent	Very Severe (特别严重)	7. Curtail iron alloy, non-metal minerals, and fire-resistant material producers; limit production by municipal aluminum steel and cement producers and all sub-municipal-level industrial and chemical producers 8. Under extreme circumstances, curtail all industrial load that does not affect social stability or residential customers

Local rationing plans typically distinguish priority and non-priority customers and as many as three kinds of load: (1) critical facilities (e.g., street lights) and “priority use” (保用 | bao yong) industrial customers; (2) residential and commercial customers and key government agencies; and (3) non-priority industrial customers.³⁹ The first two categories are given priority over the third. Industrial customers that are

³⁸ Nanyang Municipal Government. (2012). Nanyang Municipality Orderly Electricity Use Plan for summer and winter peaks. 《南阳市 2012 年迎峰度冬有序用电方案 有序用电方案》.

³⁹ These three categories are from Dongguan Municipality. Zhongshan Municipality only has priority and non-priority categories, with the former including military facilities, television and post, transportation, key public places, hospitals, schools,

included in the priority use category typically include firms for which continuous production is a matter of public safety (e.g., chemical plants), and in some cases firms that have met energy efficiency targets and national and local champion firms (龙头企业 | longtou qiye).⁴⁰ Industrial customers that are not included in the priority use category are required to ration before all other customers.

For non-priority use customers, demand rationing is typically tied to “electricity supply contracts” (供电合同 | gong yong dian hetong) with local supply companies. Contracts between electricity providers and non-residential customers, which have been required since the 1995 *Electricity Law*,⁴¹ specify a maximum quantity of power (MW) and annual energy (MWh) for each customer. Because industrial customers constitute more than 80 percent of electricity demand in China,⁴² fixed-quantity contracts allow local planning agencies to plan and control demand with some degree of confidence. Customers who exceed the quantities in their contracts pay a significantly higher price for electricity consumed in excess of contracted amounts and are first in line for rationing. If customers are required to restrict use, as per the rationing order table, and do not, they can have their power cut off for a specified period of time.

As a final step in the demand planning process, RDOs and PDOs develop seasonal load management plans on the basis of provincial and local load allocation plans and local plans for peak load shifting, avoidance, rationing, and curtailment. Most of the actual planning is carried out by PDOs, with RDOs responsible for aggregation and coordination. RDOs’ and PDOs’ seasonal management plans focus on peak balancing and forced outage preparedness, and strategies for managing load in peak demand months.⁴³

In China, and unlike in Organization for Economic Co-operation and Development (OECD) countries, administrative demand rationing is the norm rather than an extraordinary measure reserved for emergency conditions. The amount of peak demand shifted, avoided, restricted, and curtailed (“power shortages,” described above) in China is substantial — in 2011, for instance, the NDRC estimated total

water and energy providers, irrigation, residential users, fish producers, and refrigeration facilities. See Zhongshan EIC, 2012; Dongguan EIC, 2011.

⁴⁰ For instance, the Dongguan Municipal Government prioritizes champion firms and includes evaluation against energy efficiency targets as part of its assessment of which firms to offer priority use. See Dongguan EIC, 2011.

⁴¹ Article 17 of the Electricity Law 《电力法》 stipulates that electricity providers and customers should sign electricity supply contracts that specify rights and responsibilities.

⁴² In 2012, industrial customers accounted for 73 percent of total demand; heavy industrial customers accounted for 60 percent. Data are from: China Electricity Council. (2013). Table of basic electricity statistics for 2012. (2012 年电力统计基本数据一览表). Available at: <http://www.cec.org.cn/guihuayutongji/tongjixinxi/niandushuju/2013-11-07/111737.html>. Accessed January 2014.

⁴³ See, for instance: China Southern Power Grid Company. (undated). Grid operating procedures 《中国南方电网调度管理规程》.

nationwide power shortage to be 30 GW, and demand rationing occurred in multiple provinces throughout the year.⁴⁴

2.4 Annual Generator Output Planning

Provincial planning agencies, typically provincial Economy and Information Commissions (EICs, 经济信息委员会 | Jingji Xinxin Weiyuanhui),⁴⁵ are responsible for planning annual generator output. For provinces that do not use energy efficient dispatch, each year provincial agencies develop an annual generator output plan (年度发电量计划 | niandu fadianliang jihua), which is based on a recommended plan drafted by the PDO and approved by the provincial grid company. The plan is typically drawn up in October and finalized and distributed in December. Annual and monthly output totals from this plan are included in annual contracts for generators.

Annual output plans are intended to guarantee operating hours for generators, subject to system constraints, and are not intended to be “guiding” targets. For instance, the Hunan EIC’s 2013 *Implementation Measures for Annual Generation Plans* (年度发电量计划管理办法 | Niandu Fadianliang Jihua Guanli Banfa) states that thermal generator output is only allowed to deviate from the annual plan in response to changes in hydropower output and load conditions.⁴⁶ When these changes occur, adjustments are made on the basis of target completion rates, which are defined as

$$\text{Target completion rate} = \frac{\text{Actual annual generation} + \text{Annual lost generation}}{\text{Annual generation target}}$$

where “annual lost generation” is generation lost because of forced outages, forced output reductions, coal shortages, and poor coal quality. Generators in Hunan that have not yet met their annual targets are given priority in allocating any additional need for thermal generation. Nationally, as a general principle, SERC’s 2003 *Temporary Measures for Transparent, Fair, and Just Electricity Dispatch* requires that adjustments to generators’ annual contracts be made on the basis of fairness.⁴⁷

Approaches to determining operating hours for generators vary among provinces. For instance, in Shanghai, planning agencies use a formula to allocate hours across different resources. “Base output” (基数电量 | jishu dianliang) is calculated for renewable energy and “efficient resource use” (综合利用 | zonghe liyong) units on the basis of resource availability, for combined heat and power on the basis of heat output, and for natural gas using 2,500 fully-loaded operating hours. Average operating hours for

⁴⁴ See: NDRC. (undated). Status of orderly electricity use in 2011 (2011 年全国有序用电情况). Available at: http://www.sdpc.gov.cn/jjxsfx/t20120117_456725.htm.

⁴⁵ EICs are provincial planning agencies of relatively recent vintage that were often reorganized from former Economic and Trade Commissions (经济贸易委员会 | Jingji Maoyi Weiyuanhui) and parts of provincial Development and Reform Commissions (发展和改革委员会 | Fazhan he Gaige Weiyuanhui). In some provinces, multiple planning agencies co-exist.

⁴⁶ Hunan Economy and Information Commission. (2013). Management measures for compiling annual generator output plans for the Hunan grid 《湖南电网年度发电量计划编制管理办法》.

⁴⁷ SERC. (2003). Temporary measures for transparent, fair, and just electricity dispatch 《关于促进电力调度公开、公平、公正的暂行办法》, No. 46.

coal units are then calculated as the difference between an energy forecast and the sum of base outputs, divided by total coal capacity.⁴⁸ In Hunan, planning agencies use a set of criteria to determine operating hours, ranging from generator efficiency to corporate social responsibility.⁴⁹

For provinces that use energy efficient dispatch, provincial planning agencies develop annual and quarterly “dispatch order tables” (排序表 | paixu biao), which create an ordered ranking of generating units for dispatch, on the basis of which PDOs create an annual unit commitment plan. The dispatch order in these tables, specified in the multiagency *Pilot Measures for Implementing Energy Efficient Dispatch*, is:⁵⁰

1. Non-dispatchable renewable generation
2. Dispatchable renewable generation, including large hydropower
3. Nuclear power
4. Cogeneration units, where electricity is the byproduct
5. Demonstration projects and units under national dispatch control
6. Cogeneration units, where heat is the byproduct
7. Coal gangue, washed coal, and other efficient resource use units authorized by environmental protection agencies at a provincial level or higher, and approved by the NDRC and local planning agencies
8. Natural gas and gasified coal
9. Coal, including coal cogeneration units that are generating only electricity and integrated resource use units that are using conventional coal
10. Oil-fired units

As an illustration, Figure 2 shows Guangdong Province’s ordered ranking, aggregated by technology type, for 2013. Within technology categories (e.g., coal, natural gas), units are ranked in order of ascending heat rates, and, if ties exist, in order of ascending emissions rates. Initially, heat rates were based on manufacturer specifications, but increasingly provinces are moving toward monitored and measured heat rates.⁵¹

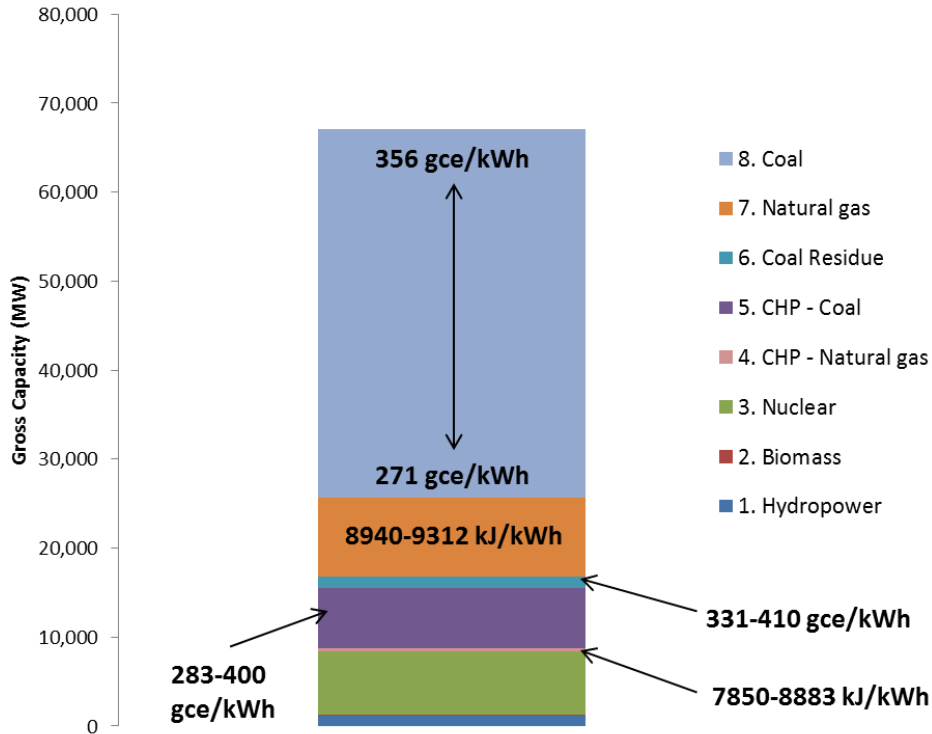
⁴⁸ Shanghai Municipal Development and Reform Commission. (2011). Shanghai municipal management measures for annual operating hour planning 《上海市年度发电量计划管理办法（试行）》，No. 32.

⁴⁹ Hunan Economy and Information Commission. Management measures for compiling annual generator output plans for the Hunan grid.

⁵⁰ NDRC. (2007). State Environmental Protection Administration (SEPA), SERC, National Energy Working Group, Pilot measures for implementing energy efficient dispatch 《节能发电调度办法实施细则（试行）》，No. 523.

⁵¹ For instance, in Guangdong Province’s dispatch order table, units of the same capacity that had installed heat rate monitoring equipment were given dispatch priority over those that had not. See Guangdong DRC and EIC. (2013, January 11). Announcement of Base 2013 Energy Efficient Dispatch Table for Guangdong Province 《关于 2013 年广东省节能发电调度发电机组基础排序表公示的通知》.

Figure 2. Energy Efficient Dispatch Order for Guangdong Province, 2013 (Showing the range of heat rates by technology type (coal-fired technologies in gce/kWh, gas-fired technologies in kJ/kWh))⁵²



Notes: Energy units are as reported. For reference, 1 gce/kWh is equivalent to 29.3 kJ/kWh. The thermal efficiencies of the coal units above thus range from 35-45%, gas units from 39-40%, coal residue units from 30-37%, CHP coal from 31-43%, and CHP gas from 41-46%.

Under current law, grid companies are required to give renewable energy priority in dispatch and, by extension, in output planning. Priority dispatch in China takes two forms. First, SERC's 2007 *Regulatory Measures for Grid Companies' Full Purchase of Renewable Energy* requires grid companies to purchase all renewable energy, regardless of dispatch system, subject to grid security constraints.⁵³ Second, in provinces that use energy efficient dispatch, non-fossil fuel resources are prioritized in dispatch order, similar to priority dispatch policies found in Europe.⁵⁴ Purchase requirements have not been successful,

⁵² "Coal" here does not include units smaller than 300 MW, or coal units larger than 300 MW that have not installed functioning real-time heat rate monitoring equipment. Guangdong DRC and EIC. (2013). Base 2013 Energy Efficient Dispatch Table for Guangdong Province (2013 年度广东省节能发电调度发电机组基础排序表).

⁵³ SERC. (2007). Regulatory measures for the full purchase of renewable energy 《电网企业全额收购可再生能源电量监管办法》, No. 25.

⁵⁴ The only discernible difference between energy efficient dispatch, as currently formulated and practiced in China, and priority dispatch, is in the interpretation of the term "grid security constraints." In China, the interpretation of this term remains relatively ambiguous. In the European Union, the interpretation of security constraints is formally described in Article 16 of Directive 2009/28/EC.

as the high level of wind curtailment indicates. The effect of priority dispatch under the energy efficient dispatch system is not yet clear, as it has largely been implemented in provinces that do not have high penetrations of wind or solar energy. As an alternative, the NEA has proposed a national system of provincial quotas for renewable energy, imposed on provincial grid companies.⁵⁵

Generator output planning, and its link to investment cost recovery for thermal generators, creates a conflict between renewable and thermal generators. For wind and solar energy, output is inherently variable and growth in output may exceed growth in demand, reducing output for other generators. As long as fixed cost recovery for thermal generators, and the idea of ‘fairness’ in adjusting their annual contracts, is tied to output, this conflict is not easily reconcilable.

2.5 Hydropower, Solar, and Wind Output Planning and Forecasting

Relative to thermal generators, hydropower, solar, and wind power output is highly dependent on climate and weather conditions. The availability of reservoir hydroelectric generators is additionally dependent on how reservoir water is allocated to competing uses, such as irrigation, recreation, and ecosystems, which also varies over time. Integrating variable hydropower, solar, and wind resources into output planning and scheduling processes thus requires accurate forecasts and, for hydropower generation, coordination and allocation rules that are followed across organizations responsible for managing water resources.

a. 2.5.1 Hydropower Forecasting and Reservoir Management

Hydropower resources are classified into reservoir systems, where energy output can be controlled by regulating the amount of water that passes through the turbines, and run-of-river (ROR) systems, where energy output depends on river flow and cannot be controlled. In China, reservoir systems are typically dispatched at a provincial level or above. ROR systems are often small- to medium-sized dams, owned by local governments, and are typically dispatched by MDOs or CDOs.

For both reservoir and ROR hydropower, output forecasting is decentralized to individual hydropower plants, and forecasts are then provided to DOs and planning agencies for output planning and scheduling purposes. This process of hydropower output planning varies among provinces and regions. For instance, in Fujian Province, hydropower output planning is more centralized, with the provincial Economic and Trade Commission (ETC, 经济贸易委员会 | Jingji Maoyi Weiyuanhui) responsible for managing and overseeing hydropower dispatch.⁵⁶ In Guangdong Province, by contrast, hydropower

⁵⁵ Under the NEA’s current (September 2014) proposal, *Measures for Evaluating Renewable Electricity Quota Compliance* 《可再生能源电力配额考核办法（试行）》，quotas would be implemented as procurement requirements on provincial grid companies, with provincial governments responsible for meeting these quotas.

⁵⁶ Fujian Provincial People’s Government. (2011). Notice on strengthening the operations and management of hydropower plants 《福建省人民政府办公厅关于加强水电站运行管理的通知》，No. 146.

plants under PDO jurisdiction submit annual, monthly, weekly, and daily recommended output plans, which the PDO then aggregates and adjusts as needed into a single plan (Table 5).⁵⁷

b. 2.5.2 Wind and Solar Forecasting

Forecasts for wind power are included in the day-ahead planning and scheduling process. Wind forecasting is primarily decentralized to a facility level, consistent with the approach for hydropower. According to the NEA's 2012 *Implementation Rules for Coordinating Wind Power Forecasts and Grid Operations* (Rules in this section), wind plants are required to create a short-term, three-day-ahead forecast, as well as an ultra-short-term, four-hour-ahead forecast, both at 15-minute intervals.⁵⁸ The wind plant is required to automatically submit the following information to a DO: a day-ahead forecast of wind output and expected online capacity, the four-hour-ahead forecast, online capacity every 15 minutes, and real-time wind measurements every 5 minutes. DOs are also required to create wind forecasting systems for their jurisdictions as a complement to wind plant forecasts.

Individual wind plants and provincial DOs are required to maintain forecast errors of below 20 percent, with non-compliance defined as at least three months within a six-month period where forecast errors are in excess of this target. For wind plants that meet this target, grid companies are not permitted to use forecast errors in determining their output, for instance, by curtailing wind plants in order of forecast error. Wind plants that do not meet the target are given at most three months to reduce forecast error. Those that still do not are not given access to priority dispatch. DOs that are not able to meet the forecast error target are also given at most three months to comply.⁵⁹

Based on day-ahead wind forecasts, and taking into account load forecasts and generator and grid conditions, the DO decides how much wind output it can accommodate. The DO is then required to send a day-ahead schedule to the wind plant, which it adjusts in real time based on changing conditions. The NEA's *Rules* identify three typical constraints under which a DO may curtail wind output: (1) system security constraints; (2) insufficient load following capacity; and (3) system emergencies.⁶⁰ If the DO curtails wind output, it must provide the amount of output curtailed, the reason for curtailment, and the situation under which curtailment occurred.⁶¹ Grid companies are currently not required to compensate wind plants for curtailed energy. The *Rules* do not specify which level of DO has responsibility for wind forecasting, output planning, curtailment, and reporting on curtailment. Consistent with the multilevel management approach to dispatch, SGCC is reportedly responsible for wind plants that are dispatched

⁵⁷ Based on the Fujian Electric Power Company's 2008 Operating Procedures for Dispatch, Fujian appears to have also had a more decentralized process similar to Guangdong's, but then switched to more centralized planning and oversight in 2011. See Fujian Electric Power Company. (2008). Fujian provincial operating procedures for dispatch 《福建省电力系统调度规程》.

⁵⁸ See National Energy Administration. (2012). Implementation rules for coordinating wind power forecasts and grid operations (trial) 《风电功率预报与电网协调运行实施细则（试行）》，No. 12. According to Article 8 of the Rules, wind plants can outsource their forecasts to specialized forecasting organizations.

⁵⁹ National Energy Administration. (2012). Evaluation measures for wind power forecasts 《风电功率预报考核办法》，No. 208.

⁶⁰ Importantly, the *Rules* do not limit curtailment to situations in which these constraints are present.

⁶¹ This language is provided in Article 24 of these *Rules*. Interestingly, PDO Operating Rules for Dispatch often include a detailed discussion on their right to curtail, but omit discussion of the National Energy Administration's reporting requirements.

across regions, RDOs are responsible for wind plants that are dispatched across provincial boundaries, MDOs are responsible for any wind plants under municipal jurisdiction, and PDOs are responsible for the remainder, which in most cases constitutes the bulk of wind plants.⁶²

Wind forecasting is a significant hurdle to more effective integration of wind power in China. Forecast errors in China tend to be high, and grid companies do not appear to trust the forecasts.⁶³ Grid companies have insufficient economic incentives to reduce forecast error, as they are not penalized for curtailment. As a result, DOs do not currently use wind forecasts in unit commitment decisions. This can lead to too much coal generation online relative to that which is needed to ensure reliability, and subsequently to wind curtailment because of operating constraints on coal units.

The Standardization Administration's 2012 *Technical Requirements for Connecting Photovoltaic Power Station to Power System*, which went into effect in June 2013, also requires larger (>10 MW) solar plants to be equipped with forecasting equipment, and to submit short-term and ultra-short-term forecasts for the same time intervals as wind plants.⁶⁴ This *Technical Requirements for Connecting Photovoltaic Power Station to Power System* also requires solar plants to maintain a short-term (within three-day) and ultra-short-term (within four-hour) mean absolute forecast error of less than 15 percent and 10 percent, respectively.

c. 2.5.3 Scheduling and Dispatch Processes

Annual generator output plans and dispatch order tables form the basis for daily, monthly, and in some cases annual and weekly generator schedules, referred to as “generator dispatch plans” (发电调度计划 | fadian diaodu jihua), that are developed by the PDOs and RDOs. Finalized generator dispatch plans, in turn, are based on year-ahead, month-ahead, and day-ahead “grid operating plans” (电网运行方式 | dianwang yunxing fangshi) that incorporate transmission system elements and security constraints and are drawn up by PDOs, RDOs, and SGCC. DOs in some regions are also required to develop week-ahead grid operating plans.

In developing dispatch and operating plans, each DO focuses on the generation and transmission facilities under its jurisdiction, consistent with the principle of unified dispatch and multilevel management. Most planning is done by PDOs, with RDOs playing a coordinating role. In particular, SGCC and RDOs develop interregional and interprovincial power exchange plans, which are typically fixed, and PDOs develop generator schedules and dispatch plans to meet residual demand. RDOs and PDOs then adjust and finalize these plans, with the RDO producing a final regional plan. PDOs are typically only able to make temporary changes to the final regional operating plan with permission from the RDO.⁶⁵ The

⁶² See Jiang et al. Wind energy in China, p 45.

⁶³ Based on communications with power sector experts in China in 2013.

⁶⁴ Standardization Administration of the People's Republic of China. Technical requirements for connecting photovoltaic power station to power system 《光伏发电站接入电力系统技术规定》, GB/T 19964-2012, 2012.

⁶⁵ For instance, Article 5.4.6 of China Southern Power Grid Company's *Operating and Management Procedures for Dispatch* states that PDO staff must apply to make changes in daily operating plans, and have agreement from China Southern Grid staff

example used below, which describes a day-ahead plan for the China Southern Grid region, provides an illustrative view of this interaction between RDOs and PDOs, although the process through which generators are scheduled and dispatched varies among grid regions and even among provincial grids, particularly between provinces that do and do not use energy efficient dispatch.

Figure 3 shows a high-level overview of the next-day generator scheduling and energy efficient dispatch process between China Southern Power Grid Company's Dispatch Center (CSG-DC), an RDO, and the PDOs under its jurisdiction. First, PDOs develop inputs for their next-day generator dispatch plans, including a 15-minute load forecast and a unit commitment plan based on the dispatch order table.⁶⁶ CSG-DC provides PDOs with an initial next-day plan for interprovincial power exchange. On the basis of CSG-DC's plan, PDOs use their inputs to develop a 15-minute generator dispatch plan, in some cases minimizing heat rates for coal generators subject to generator constraints.⁶⁷ CSG-DC then evaluates the energy savings potential of these plans, using a modeled baseline.⁶⁸

CSG-DC also assesses PDO generator dispatch plans to determine if further energy saving opportunities exist among provinces. If the heat rate for the marginal generator in one province (Unit A) is higher than the next available generator in another province (Unit B), accounting for line losses and other constraints, CSG-DC will adjust its interprovincial power exchange plan to include Unit B. CSG-DC then sends this adjusted plan back to Guangdong Power Grid Corporation's Dispatch Center (GPG-DC) and other PDOs, who adjust their generator dispatch plans as necessary, in this case turning off Unit A. With regional and provincial plans finalized, both CSG-DC and the PDOs conduct security analysis to ensure that security constraints are met. The final result of this scheduling and dispatch process is a consistent, balanced, 15-minute schedule for each generator, for each province as a whole, and for the interties.

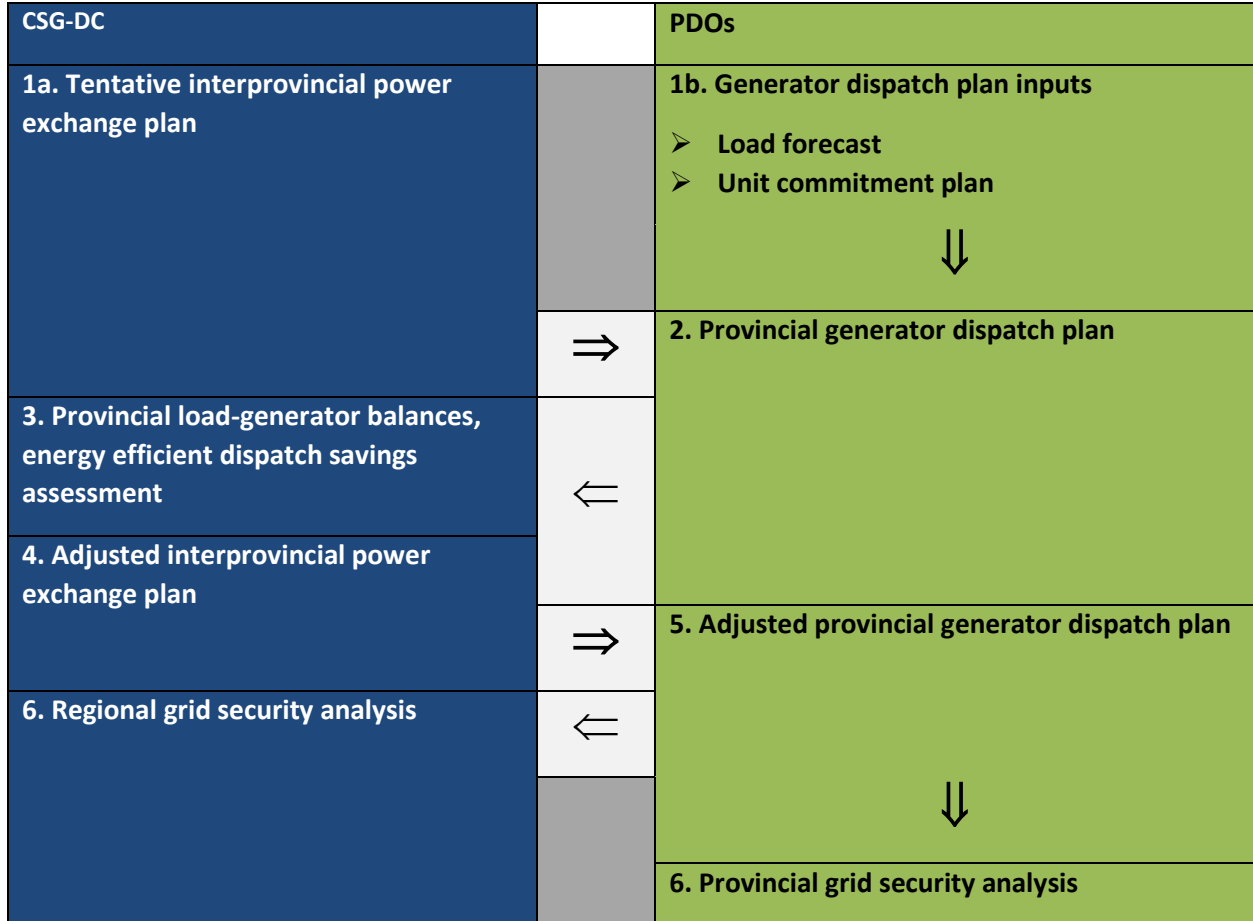
to do so. See China Southern Power Grid Company. (undated). Operating and management procedures for dispatch 《中国南方电网电力调度管理规程》.

⁶⁶ This unit commitment plan is developed by stacking generators according to the dispatch order table, until the last generator added to the stack is larger than peak provincial demand minus net exports. See He, C., Liang, S., Song, X., & Ding, J. (2012). The thinking, practice and effect of energy-conservation power generation scheduling in China Southern Power Grid (南方电网节能发电调度计划编制思路、实践及效果). *Southern Power System Technology*. 6: 60.

⁶⁷ When the aggregate provincial coal input-output curve is convex, PDOs minimize provincial heat rates by calculating system lambda values for coal units and adjusting coal generator output values iteratively to account for generator and transmission constraints. For a more detailed description, see He et al, 2012, p 60. For more on this approach, see: Wood, A. J., & Wollenberg, B. F. (1984). *Power generation operation and control*. New Jersey: John Wiley & Sons. pp 30–34.

⁶⁸ More specifically, the baseline is based on a simple model that seeks to minimize the deviation between individual generator load factors and the system load factor over a given period. See He et al, 2012, p 60.

Figure 3. Next-Day Generator Scheduling and Energy Efficient Dispatch Process Between CSG-DC And PDOs Under its Jurisdiction⁶⁹



The combination of unbundled ownership of generation and the grid and the multilevel dispatch management structure requires a significant amount of coordination among the DOs (Table 5) — no one organization has visibility over all equipment or the entire process. Throughout this process, a significant amount of information is passed between DOs, and between generators and the DOs that control them, including resource and load forecasts, maintenance planning, and output planning for renewables and non-PDO generators.

⁶⁹ Figure and text are based on He et al, 2012, p 58.

Table 5. Schedule of Seasonal and Year-Ahead, Month-Ahead, and Day-Ahead Interactions Between CSG-DC, GPG-DC, and MDOs Under GPG-DC Jurisdiction⁷⁰

Schedule (Before)	Correspondence		Contents of Correspondence
	Sending Organization	Receiving Organization	
Seasonal and Year-Ahead			
April 15	CSG-DC hydro generators	CSG-DC	Inflow forecast for this year’s rainy season and reservoir plans for flood management
September 30	CSG-DC generators	CSG-DC	Proposed next-year maintenance schedule
October 1	GPG-DC generators	GPG-DC	Proposed next-year maintenance schedule
October 15	GPG-DC hydro generators	GPG-DC	Next-year monthly inflow forecast and recommended reservoir operation plan
October 20	MDOs	GPG-DC	Next-year annual load forecast, including high and low load and energy by month
October 31	GPG-DC	CSG-DC	Next-year annual load forecast, including high and low load and energy by month
Month-Ahead			
20th of each month	GPG-DC generators	GPG-DC	Next-month maintenance schedule
22nd of each month	MDOs	GPG-DC	Next-month load forecast, including high and low load and energy in each half-month
23rd of each month	GPG-DC	CSG-DC	Next-month load forecast, including high and low load and energy in each half-month

⁷⁰ These tables are based on: Guangdong Power Grid Company. (2012). Operating procedures for power system dispatch (revised) 《广东电力系统调度规程（修订）》；China Southern Power Grid Company. (undated). Operating and management procedures for dispatch 《中国南方电网电力调度管理规程》.

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Schedule (Before)	Correspondence		Contents of Correspondence
	Sending Organization	Receiving Organization	
	CSG-DC generators	CSG-DC	Next-month maintenance schedule
5 days before month end	GPG-DC hydro generators	GPG-DC	Next-month inflow forecast and recommended reservoir operation plan
3 days before month end	CSG-DC hydro generators	CSG-DC	Next-month inflow forecast and recommended reservoir operation plan
Month end	CSG-DC / GPG-DC	Generators	Adjust repair schedules as needed, send to generators
Week-Ahead			
Wednesday morning	MDOs	GPG-DC	Next-week load forecast, including high and low load and energy by day
Thursday morning	GPG-DC	CSG-DC	Next week load forecast, including high and low load and energy by day
Thursday before 12	GPG-DC hydro generators	GPG-DC	Daily reservoir inflow forecast, recommendations on reservoir operation plans
Day-Ahead			
08:30	CSG-DC hydro generators	CSG-DC	Next-day hourly reservoir inflow forecast, next- week weather forecast
10:00	GPG-DC hydro generators	GPG-DC	Next-day reservoir inflow forecast, recommendations on power output and total energy
14:00	CSG-DC	GPG-DC	Tentative next-day schedule for interprovincial power flows
	GPG-DC	MDOs	Total next-day output schedule for generators under MDO jurisdiction
16:00	MDOs	GPG-DC	Next-day 15-minute load forecast

Schedule (Before)	Correspondence		Contents of Correspondence
	Sending Organization	Receiving Organization	
17:00	GPG-DC	CSG-DC	Next-day 15-minute load forecast, as well as other provincial inputs needed for regional grid operating plan
	MDOs	MDO generators	Output schedule for generators under its jurisdiction, based on total output schedule from PDO
17:30	CSG-DC	GPG-DC	Final regional next-day grid operating plan
	GPG-DC	RDO/MDO	Final provincial next-day grid operating plan
22:00	GPG-DC	GPG-DC generators	Output schedule to generators under its jurisdiction
4-hour-ahead and 15-minutes-ahead	Wind and solar generators	Relevant DOs	Wind and solar output forecast
Unspecified	Relevant DOs	Wind and solar generators	Next-day output schedule

In day-ahead and real-time, PDOs balance demand and available supply through a combination of adjusting generator output and managing local loads. Grid companies in China have an obligation to make good faith efforts to meet demand but do not have an obligation to serve, which effectively makes demand rationing and load curtailment a key part of dispatch. Loads are typically managed according to an alert system and process that incorporates the demand planning process described in Section 4.2. When prefectures have or are about to exceed their quotas, PDOs first implement the load shifting programs developed by local electric power supply companies. When these programs are no longer effective in keeping local loads below their allocated quotas, PDOs ration and, if necessary, curtail load on the basis of the priority order rationing tables. Figure 4 shows an example of the alert system and short-term load management process used by the GPG-DC.

Figure 4. Alert System and Load Management Process Used by GPG-DC⁷¹

GREEN	Prefecture is below quota; MDOs run thermal and hydropower plants in their jurisdiction using output plans provided by the GPG-DC
WHITE	Prefecture is below quota; MDOs need to run thermal plants at full capacity and adjust hydro output based on operating conditions
YELLOW	Prefecture is or will soon be above quota (scarcity conditions); implement “white” and begin to implement voluntary and mandatory load shifting programs to keep load under quotas
RED	Prefecture is or will soon be above quota (scarcity conditions); implement “white” and “yellow” and begin to curtail load in areas that are in excess of their quota to keep load under quotas

d. 2.5.4 Challenges for Integrating Renewable Energy

Integrating high penetrations of variable renewable generation at a reasonable cost requires loads or other generation resources that are able to respond on intraday timescales to changes in renewable output. Greater intraday flexibility in loads and resources in turn requires more flexible and efficient planning, scheduling, and dispatch processes.

In China, current approaches to managing dispatch, planning generator output, rationing demand, and scheduling and dispatching generators were designed for a previous era in which neither loads nor generation resources were particularly variable, and are not consistent with the needs of power systems that have high penetrations of variable generation. More specifically, five features of current practices create challenges for integrating renewable generation:

1. **Output planning for thermal generators:** In provinces that do not use energy efficient dispatch, annual generation output planning requires dispatch organizations to maintain operating hours for coal units even when use of existing, low-variable-cost hydropower, wind, and solar generation would reduce system costs.⁷² This creates an obvious conflict of incentives with renewable energy goals.

⁷¹ This figure is based on: Guangdong Power Grid Company, 2012, Article 8.3.

⁷² Consider a situation in which a DO curtails a wind plant rather than backing down a coal unit. Without a renewable procurement quota on the grid company, the incremental cost to the system (in yuan/MWh) is the variable unit cost of the coal unit, minus any variable unit cost of the wind plant (effectively 0 yuan/MWh). With a quota in place, the incremental system

2. **Administrative demand planning and rationing:** The current approach to load management was designed to administratively restrain demand levels below a fixed quantity of supply, and not to respond to changes in supply over the course of a day, as would be required to use demand response as a resource for balancing variable generation.
3. **Fixed schedules for interregional and interprovincial power exchange:** As described further in Section 4, allowing SGCC and the RDOs to fix schedules for interregional and interprovincial generation in advance of PDO schedules overly constrains dispatch, potentially leading to wind curtailment when out-of-province generators can be more cost-effectively backed down.
4. **Lack of optimized, economic dispatch:** In all provinces, DOs currently do not optimize dispatch across generating types (e.g., across coal, gas, and hydropower units), which means that some units might be running out of merit and are not maximizing their value to the system.⁷³ This lack of system-wide, marginal-cost-based dispatch means that there is little basis for economically rationalizing curtailment of variable renewable generation. Moreover, provinces that do not use energy efficient dispatch have an ad hoc approach to dispatch, providing policymakers with little visibility on optimal electricity sector policies and planners with little visibility on optimal choices for new generation.
5. **Lack of system visibility:** The multilevel approach to dispatch management means that no one DO has visibility over all generators and transmission facilities within an entire control area, which slows response during emergency conditions.

cost must also include the cost to the utility of procuring additional resources to meet the quota, such as additional renewable generation or a renewable energy credit.

⁷³ For instance, under energy efficient dispatch, natural gas units will be dispatched before coal units for baseload, even though the least-cost and emissions solution may be to use natural gas units for load following.

3. Ancillary Services

Even before the separation of grid companies and generators in 2002, there was a de facto separation of generation and grid services in China that resulted from a liberalization of generation investment in the mid-1980s. This separation led to a need to more clearly define and, after the formal separation of generation and grid companies in 2002, compensate, ancillary services. The focus here is on the development of operating reserve categories.

3.1 Ancillary Service Definitions

SERC established the first, and still current, formal definition of ancillary services in China in its 2006 *Temporary Measures for Ancillary Services Management for Interconnected Generators*.⁷⁴ These definitions, which were intended to provide a basis for fairly compensating generators, classified ancillary services into “basic” (uncompensated) and “compensated” services (Table 6). This paper focuses on two of these services — operating reserves and load following — whose definitions and rules predate the SERC *Temporary Measures*.

Table 6. Ancillary Service Definitions

Service Category	Chinese pinyin	Services
Basic ancillary services	基本辅助服务 jiben fuzhu fuwu	Generator frequency response “Basic” load following “Basic” reactive power support
Compensated ancillary services	有偿辅助服务 you chang fuzhu fuwu	Automated generator control Compensated load following Compensated reserves Compensated reactive power support Black-start capability

⁷⁴ SERC. (2006). Temporary measures for ancillary services management for interconnected generators 《并网发电厂辅助服务管理暂行办法》, No. 43.

3.2 Operating Reserves: Definitions and Rules

The 1993 *Grid Dispatch Regulations* explicitly required grid companies to hold some capacity in reserve. The 1994 *Implementation Measures* specified three categories of reserves and, for each category, reasonable reserve levels: “load” reserves (负荷备用容量 | fuhe beiyong rongliang), more commonly known as regulation (or regulating) reserves elsewhere, which address short-term fluctuations in load and load forecast error and should be two percent to five percent of “peak generator load”;⁷⁵ contingency reserves (事故备用容量 | shigu beiyong rongliang), which respond to equipment failure and should be approximately ten percent of peak generator load, but not less than the largest unit in the regional grid; and maintenance reserves (检修备用容量 | jiangxiu beiyong rongliang), which are held to cover units undergoing routine maintenance, and should be 8 percent to 15 percent of peak generator load. The sum of these three reserves, according to the Implementation Measures, should not be less than 20 percent of peak generator load.⁷⁶

Over time, the definition of these categories has evolved and become more precise, although in many regions ancillary service definitions retain some amount of ambiguity. For instance, the Guangdong Power Grid Company’s 2012 *Operating Procedures for Power System Dispatch* lists only load and contingency reserves in its definition of reserves, and is closer to the definition of “operating reserves” typically used in North America. Load reserves should “normally” be no less than two percent of regional system peak load. Contingency reserves should “normally” be between 8 percent and 12 percent of system peak, should be able to respond within a “specified period of time,” and “at least some” of these reserves should be able to provide frequency response.⁷⁷

The most precise definition of operating reserves arose from SERC’s efforts to rationalize reserve levels in the Northwest Grid region (see Section 4.3, *Efforts to Rationalize Operating Reserve Levels*). In regulatory documents accompanying these efforts, SERC classified operating reserves into spinning and “emergency” (应急备用 | yingji beiyong) reserves. Spinning reserves, which can be load bearing or non-load bearing, include load and contingency reserves. Emergency reserves are non-spinning, but can respond within ten minutes to a dispatch signal and maintain output for two hours. Load control reserves that provide emergency services should be able to be controlled within ten minutes. SERC’s definitions do not include a requirement for replenishing reserves within specified time frames.⁷⁸ To our knowledge, neither SERC (now NEA) nor SGCC has raised the question of whether different types of operating reserves may be needed at higher penetrations of wind and solar energy.

⁷⁵ Peak generator load (最大发电负荷 | zuida fadian fuhe) is defined as peak system demand + exports – imports.

⁷⁶ Ministry of Electric Power. Implementation measures for grid dispatch regulations, Article 23.

⁷⁷ See Guangdong Power Grid Corporation. Operating procedures. p 67.

⁷⁸ SERC Northwest Region Department. (2012). Northwest Grid reserve capacity measures (pilot) 《西北电网备用容量监管办法（试行）》，p 4.

Required operating reserve levels for each province are determined by RDOs, as part of the planning and scheduling process described above, accounting for transmission constraints. This allows for sharing of contingency reserves across the region. If a PDO determines that available reserves are insufficient to meet provincial needs, it can request additional reserves from the RDO if sufficient reserves are available in the region. If additional reserves are not available in the region, operations staff is authorized to take unspecified emergency measures to restore reserve levels.⁷⁹

Automatic generation control (AGC) equipment, which allows dispatchers to remotely control generator output, is now widely required on thermal and dispatchable hydropower units in China. SERC's 2006 *Management Rules for Generator Interconnection and Operation* stipulated that regional grid companies should set minimum requirements for the amount of AGC-equipped generating capacity in each province under its jurisdiction.⁸⁰ These requirements vary by region. For instance, in Guangdong Province, all thermal units above 200 MW and all dispatchable hydropower and pumped storage units above 40 MW must have AGC installed in order to connect to the grid.⁸¹ In Fujian Province, all thermal units above 100 MW and all hydropower units above 50 MW must have AGC.⁸²

All generating units are obligated to provide basic ancillary services; basic load following requirements, for instance, are allocated to generators as part of the generator output planning process or implicitly through dispatch order tables. SERC's *Management Rules for Generator Interconnection and Operation* stipulate that grid companies should allocate ancillary services requirements to generators so that, adjusted over the course of a year, equivalent kinds of generation technologies in the same grid have the same ancillary services requirements.⁸³

3.3 Load Following Reserve: Rationale and Rules

Although it has never formally been considered a “reserve” in China, RDO Operating Procedures for Dispatch have historically stipulated that sufficient “load following reserves” (调峰备用 | tiaofeng beiyong) should be kept on hand,⁸⁴ and load following is formally considered to be an ancillary service.⁸⁵ The rationale for considering load following as a reserve and ancillary service is in keeping with constraints imposed by the high share of coal generation on many provincial power systems, and the need for coal units to participate in load following. Because coal units have longer startup–shutdown

⁷⁹ See, for example: Guangdong Power Grid Corporation. Operating procedures, Section 8.4.3, 67–88.

⁸⁰ SERC. (2006). Management rules for generator interconnection and operation 《发电厂并网运行管理规定》, No. 42, Article 13.

⁸¹ Ibid, Section 5.3.3, 21–22.

⁸² Fujian Electric Power Company. (2008). Fujian Provincial operating procedures for dispatch, Section 3.2.4. This document is from 2008, and these rules may have been since revised.

⁸³ SERC, 2006, Article 20.

⁸⁴ See, for instance: East China Grid Company. (undated). East China Grid operating procedures for dispatch. 《华中电网调度规程》, p 17.

⁸⁵ See, for instance, SERC. (2006). Management rules for ancillary services for interconnected generators 《并网发电厂辅助服务管理暂行办法》, No. 43.

periods than hydropower or natural gas units, at least some of these units must be kept running and ramped down in the evening when demand falls. There is a technical limit to how low coal units can be ramped down as a percent of their rated capacity (a minimum output constraint), which is typically higher for coal units than for hydropower and natural gas units.

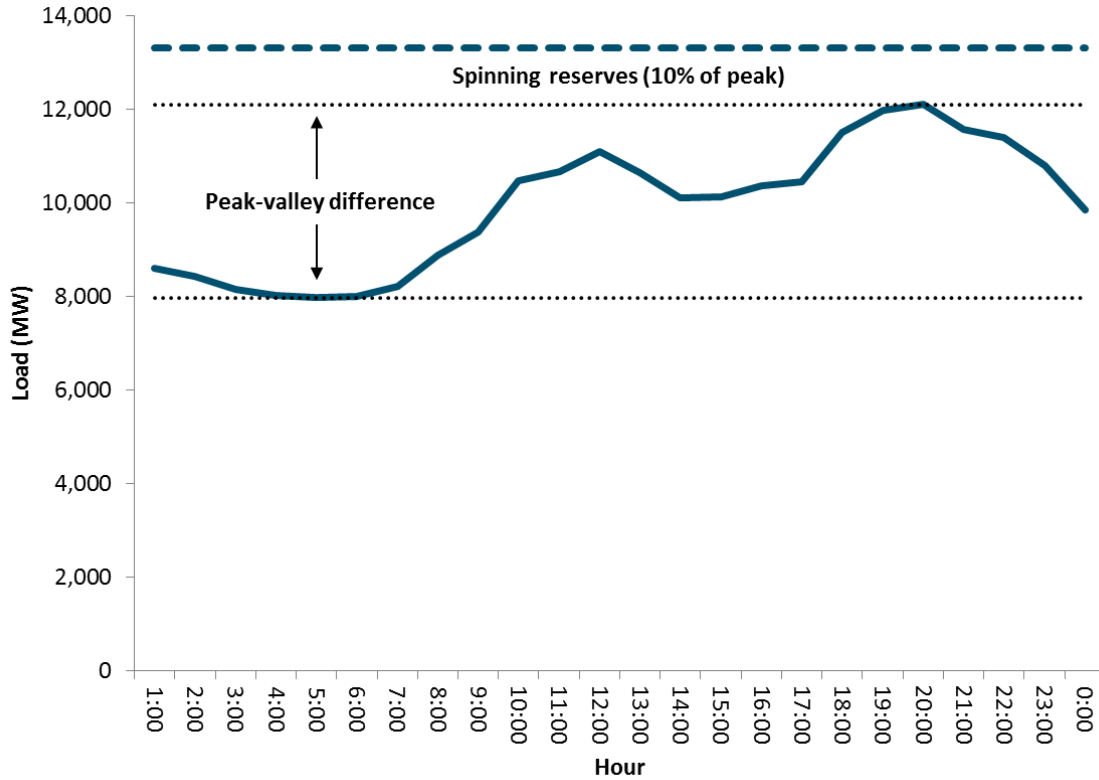
As a result of the need to use coal units to follow load, two metrics have emerged in China that are not typically used elsewhere: (1) “peak–valley difference” (峰谷差 | feng gu cha), which is the difference between daily system peak and daily minimum load; and (2) “deep ramp” (深度调峰 | shendu tiaofeng), which describes the need to, in certain cases, ramp coal generators down to very low output levels during evening hours. Particularly in provinces that have high heat loads and must-run generation, using coal generators to follow load results in low load factors — actual output divided by rated capacity and the number of hours that the unit is online — for conventional coal units. In 2011, for instance, average load factors for conventional coal units in Inner Mongolia, Heilongjiang, and Hainan were 58 percent, 65 percent, and 65 percent, respectively.⁸⁶

Figure 5 illustrates this notion with a typical daily load shape for Guangxi Province (2009). For illustrative purposes, suppose that this already includes transmission and distribution losses. Assuming, hypothetically, that other generation resources are not available, enough coal generation would need to be online to meet daily peak demand and losses (~12,100 MW) plus a spinning reserve margin (~121 MW). In the evening, these coal units would need to be ramped down to approximately 8000 MW, or on average around 60 percent of their rated capacity ($= 8000 / [12100 + 121]$).⁸⁷ The peak–valley difference is thus an indicator of ramping requirements for coal units, which in some provinces can impose constraints on system operations.

⁸⁶ SERC, 2012.

⁸⁷ This example assumes that all spinning reserves are provided through units that are already carrying some load, but spinning reserves could also be provided by generators that are synchronized to the system but not carrying any load.

Figure 5. Illustration of Peak–Valley Difference and Spinning Reserves for Guangxi Province, Typical Daily Load In January 2009⁸⁸



Growing penetration of wind power in some provinces has increased the need for deep ramps by coal-fired generators through: (1) reducing minimum net load (load minus non-dispatchable generation) because a higher share of wind output occurs at night, further reducing the need for coal generation at night; and (2) increasing, or at least not reducing, spinning reserve requirements.⁸⁹ As a result, the amount of coal generation online remains constant or even increases, while the valley in the peak–valley difference decreases, further reducing load factors. High penetrations of solar energy will lead to a similar problem, to the extent that they reduce afternoon net load to much lower levels.

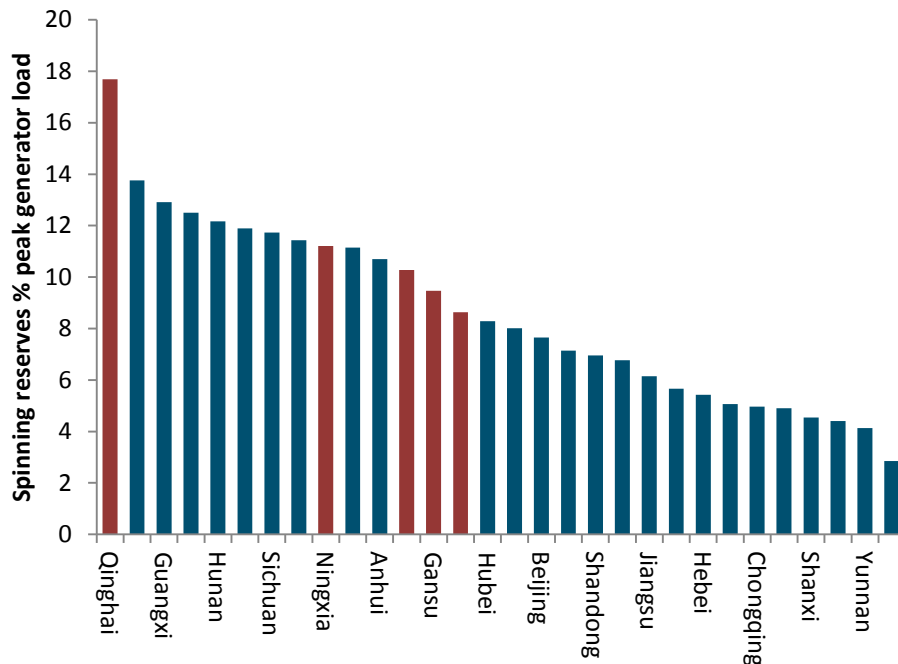
⁸⁸ Note that the “peak” in this figure is arbitrarily chosen to be peak load, but could also be peak generator output, in which case the peak–valley difference would include the spinning reserve margin.

⁸⁹ In the Northwest region, for instance, DOs reportedly used increased penetration of wind energy as a justification for increasing spinning reserve levels. See Fu, Y. (2012, November 19). Capacity reserves “eaten” by renewables (可再生能源并网被“吃掉”的备用容量). *China Energy News*.

3.4 Efforts to Rationalize Operating Reserve Levels

As a result of differences in operating conditions and ambiguity in rules governing reserve requirements, in the late 2000s and early 2010s there was a large variation in operating reserve levels among different provinces, with a nearly 15 percentage-point difference between provinces with the highest (Qinghai Autonomous Region, ~18 percent) and lowest (Henan, ~3 percent) ratios of average monthly spinning reserves to peak (Figure 6).⁹⁰ SERC began a multiyear investigation into the causes behind high operating reserve levels in 2007, focusing on the Northwest Grid (shown in red in Figure 6).

Figure 6. Spinning Reserve Levels by Province, 2011⁹¹



SERC's investigation found two important drivers behind high operating reserve levels in the Northwest Grid that it felt were unjustified: (1) DOs were "over-increasing" reserves to respond to higher wind penetration and transmission contingency concerns related to higher power exports from the region; and (2) generators were attempting to avoid being shut down, so that they could meet their annual operating hour targets.⁹² In the latter case, increasing the amount of provincial generation capacity

⁹⁰ SERC argued that spinning reserve levels in the Western Inner Mongolia Power Grid were even higher than in Qinghai, at around 25 percent of peak. SERC did not specify whether "reserve ratio" (备用率 | beiyong lu) is being measured relative to peak generation or load. Data are from SERC, 2012, p 4.

⁹¹ SERC, 2012, p 4.

⁹² Fu, 2012.

online relative to peak demand, without increasing net exports, necessarily increases spinning reserve capacity.⁹³

To address what it assessed to be overly high spinning reserve levels in the Northwest, SERC developed a set of regulatory rules for operating reserves in the region, *Measures for Regulating Operating Reserves in the Northwest Grid*, which it released in 2012. These rules stipulate that spinning reserve capacity in the Northwest Grid region must not be less than:

- Five percent of peak generator output (load + line losses) in the regional grid;
- The largest generator in the regional grid;
- The maximum output for the largest wind plant “cluster” in the regional grid, in which cluster is defined as a concentrated geographic area with similar resource profiles, high output coincidence, and close proximity (electrical length) to where units connect to the grid;
- The maximum output for the largest solar plant “cluster” in the regional grid;
- The amount of power imports reduced by tripping the largest DC transmission path; and
- The maximum output at a generator or generators that are interconnected through a single transmission line to another regional grid.⁹⁴

SERC noted that spinning reserves for each province in the region should, in principle, not be higher than ten percent of peak generator load. To exceed this level to address concerns related to intermittent renewable energy or transmission contingencies, the RDO would be required to report each case to SERC’s regional office.

In its *Regulatory Measures*, SERC also developed a rule for allocating reserves across the five provinces in the region. Under normal conditions, this rule states that provincial reserves should be allocated according to the formula

$$\text{Province A's SRC} = \frac{\text{Regional SRC}}{\text{Regional PGL}} \times \text{Province A's PGL}$$

where SRC is spinning reserve capacity and PGL is peak generator load. Spinning reserves are to be allocated to generators under RDO direct control on the same basis.

In the event that a PDO deems its spinning reserves to be insufficient, it can apply in writing to the Northwest RDO for assistance from other provinces before 12 pm on the day before. If other provinces do not have sufficient capacity available, the PDO can take one of two actions to restore reserve levels

⁹³ The total amount of provincial generation capacity online (PGCO) is the province’s peak generator load (peak demand + net exports) plus its spinning reserve capacity (SRC), or $PGCO = \text{peak demand} + \text{net exports} + \text{SRC}$.

If provincial generation capacity online increases without an increase in net exports, SRC increases, as does the ratio between SRC, which has increased, and peak generator load, which has not changed.

⁹⁴ SERC Northwest Department. (2012). Measures for regulating operating reserves in the Northwest Grid (pilot) 《西北电网备用容量监管办法（试行）》，No. 148, p 4.

at least one hour before peak generator load: (1) activate emergency reserves, or (2) apply to the RDO for reserve support from another region.

SERC's *Regulatory Measures* require that emergency reserves are determined by the RDO. However, for provinces that are not reliant on interconnections with other provinces to meet their spinning reserve requirements, PDOs have the authority to determine their own emergency reserve levels.⁹⁵

SERC tasked the Northwest Grid's RDO with implementing these regulatory rules across the regional grid's five provinces, to be overseen by SERC's Northwest Department. Although the *Regulatory Measures* stipulated a clear division of responsibility between the RDO and PDOs for rule violations, the document does not provide clear provisions for enforcement.⁹⁶ Nevertheless, spinning reserve levels in the Northwest Grid did fall in the latter half of 2012.⁹⁷ SERC's *Regulatory Measures* appear to be a "one-off" regulatory intervention, rather than a foundation for a framework that will be mandated in other grid regions.

A subsequent (2014) NDRC policy document, *Guidance on Strengthening and Improving the Management of Generator Operations*, attempts to provide a broader solution to the problem of excess operating reserves by establishing three conditions under which DOs can de-commit coal units.⁹⁸ These are: (1) if forecasted operating reserves are higher than a specified level above forecasted load or below reserve requirements, with specific levels to be decided by NEA and local planning agencies; (2) if the forecasted average load factor for coal units to meet their planned output targets for the remainder of the year falls below a certain level, which is specified by provinces but, as a guiding principle, is lower than 70 percent in thermal-dominant systems or 60 percent in hydro-dominant systems; or (3) if, because of congestion or other transmission constraints, the load factor for any power plant falls below 65 percent.

3.5 Challenges for Integrating Renewable Energy

Generally, the two most important operational challenges to integrating variable renewable generation into existing power systems are: (1) minimum net load constraints, in which wind and solar generator output must be curtailed because output from dispatchable generation cannot be ramped down any further (e.g., due to generator constraints); and (2) forecasting and positioning the grid for large net load ramps from variable generators, typically in response to a weather event such as a storm or front, requiring dispatchable generators to be operated more frequently and at a wider range of operations.

⁹⁵ Ibid., p 6.

⁹⁶ Article 17 of the *Regulatory Measures* states that violators will be "punished according to relevant laws and regulations" (依照相关法律法规进行处理), but does not clarify either the kinds or levels of penalties.

⁹⁷ SERC's Northwest Department reports that spinning reserve levels fell significantly in the latter half of 2012, although it concedes that some of this decline was attributable to higher than average hydro conditions. See SERC Northwest Department. (2013). Northwest Grid electricity regulatory report 《西北区域电力监管报告》, pp 30–31.

⁹⁸ NRDC. (2014). Guidance on strengthening and improving the management of generator operations 《加强和改进发电运行调节管理的指导意见》.

These challenges have two potentially conflicting implications for the provision of ancillary services. First, generators providing ancillary services need to be as flexible as possible (e.g., have shorter shut-down times, lower minimum load constraints) to reduce system minimum net load constraints. Second, sufficient operating reserve capacity must be available to accommodate upward and downward ramps.

Addressing these constraints requires formal rules that stipulate and clarify system and generator requirements for ancillary service provision, and a more optimized approach to committing and using generators to provide spinning reserves. The absence of these today in China has created two main challenges for integrating renewable generation:

1. **Ambiguous ancillary service definitions, lack of alignment with system needs:** With the exception of the Northwest Grid region, local rules for ancillary services are still often ambiguous in their requirements for generators, suggesting that RDOs and PDOs are not basing ancillary services rules on a rigorous understanding of ancillary service needs for maintaining system reliability. In regions where wind penetration is high, higher-than-needed reserve levels can lead to lower load factors for coal units than would otherwise be necessary.
2. **Lack of optimized unit commitment and dispatch for spinning reserves:** In addition to a lack of precise definitions and rules, the lack of an optimized unit commitment on shorter timescales (e.g., day-ahead) means that some coal units are left running when they could be shut down without compromising system reliability. Moreover, because provision of operating reserves is not optimized across coal units, units providing reserves may not be the most economically well positioned to do so, relative to system and generator constraints. As a result, wind and solar energy may need to be uneconomically curtailed to meet technical constraints for coal generators that could have been removed with optimized unit commitment and dispatch.

4. Interregional and Interprovincial Power Exchange and Dispatch

In China, a significant amount of power — just over 13 percent of total generation in 2011 — flows across provincial boundaries.⁹⁹ Interregional and interprovincial power exchange grew significantly over the late 2000s — by 25 percent and 7 percent per year, respectively, between 2006 and 2011.¹⁰⁰ This growth was the result of concerted efforts by government agencies to encourage: (1) provinces in the resource-rich west to export power to load centers in the east; (2) provinces with excess generation capacity to export to those with shortages; (3) better use of existing transmission capacity; and (4) greater regional sharing of spinning and emergency reserves. Here we focus on the regulatory framework for and kinds of interregional and interprovincial power exchange.

4.1 Regulatory Framework for Cross-Border Power Exchange

The regulatory framework for cross-border power exchange in China began to take shape in the early 2000s. In July 2003, SERC released its *Provisional Rules for Interregional and Interprovincial Optimized Dispatch* (“Provisional Rules” or “Rules” in this section),¹⁰¹ which sought to lay the groundwork for power exchange both between and within grid regions. The NDRC followed this in 2005 with *Guidelines for Accelerating Interregional Power Exchange* (“Guidelines” in this section),¹⁰² which provided a more detailed framework for interregional exchange.

SERC’s *Provisional Rules* define two kinds of interregional and interprovincial power exchange: (1) “annual power exchange” (年度交易 | niandu jiaoyi), which is to be integrated into the annual generator scheduling and dispatch process; and (2) “short-term power exchange” (短期交易 | duanqi jiaoyi), which is to occur outside of the annual planning process, be negotiated bilaterally between individual parties, and be carried out on a monthly, daily, and real-time basis. The terms of both annual and short-term exchange are to be written in contracts, with separately priced transmission charges. Although most annual power exchange was expected to be arranged through government plans, the

⁹⁹ This includes power flows within and between regional grids. Interregional and interprovincial power data are from SERC, 2012, p 23. Total generation data are from China Electricity Council (CEC), Table of basic electricity statistics for 2012.

¹⁰⁰ More rapid growth in interregional power exchange meant that its share in total cross-boundary power exchange increased, from 25 percent in 2006 to 43 percent in 2011. Data for 2011 are from: SERC, 2012, p 23. Data for 2006 are from: SERC. (2008). 2007 Annual electric power regulatory report (电力监管年度报告 (2007)), p 13.

¹⁰¹ SERC. (2003). Provisional rules for interregional and interprovincial optimized dispatch 《跨区跨省电力优化调度暂行规则》, No. 20.

¹⁰² NDRC. (2005). Guidelines for accelerating interregional power exchange 《关于促进跨地区电能交易的指导意见》, No. 292.

Provisional Rules create space for bilaterally negotiated annual and short-term contracts between exporting and importing balancing areas.¹⁰³ The *Rules* stipulate that generators meeting technology and environmental standards can participate in cross-border power exchange either by directly interacting with the importing province's grid company or through facilitation by the grid company in their own province.

Shortly after SERC released its *Provisional Rules*, it announced plans to create regional power market pilots in the East and Northeast grids.¹⁰⁴ Assuming that the pilots would lead to detailed regulations on interprovincial exchange, the 2005 *Guidelines* focused on establishing responsibilities, rules, and processes for interregional exchange. Consistent with the *Provisional Rules*, the *Guidelines* allow generators to participate in regional exchange either directly or through grid companies in their own region or province. Hydropower and large, efficient thermal units are to be given priority to enter into contracts for cross-border exchange, whereas inefficient, high-emissions thermal power plants are to be excluded.¹⁰⁵

The *Guidelines* clarify two kinds of interregional exchange: (1) “planned exchange” (计划交易 | jihua jiaoyi), which covers any interregional exchange planned according to expected supply and demand conditions; and (2) “temporary exchange” (临时交易 | linshi jiaoyi hetong), which covers imbalance energy and other short-term exchange between regional grid companies not covered under longer-term planning. Planned exchange contracts can be for energy or capacity, with the latter covered under a “capacity exchange contract” (容量交易合同 | rongliang jiaoyi hetong).

Contracts are to include, at a minimum: energy transfer amounts by period; transmission capacity needs; export, transmission, and import prices; transmission gateways, for allocating transmission losses; compensation for transmission losses; payment conditions; contract modification terms; and contract enforcement terms. Planned exchange contracts can be long- or short-term. Long-term contracts are defined as those longer than one year in duration; short-term contracts are defined as seasonal or monthly contracts. Daily and real-time exchange between RDOs is covered under agreements rather than contracts.

¹⁰³ Article 16 of the *Provisional Rules* stipulates that: “For annual power exchange not arranged by government agencies, the exporting and importing parties should negotiate [prices] based on market conditions and principles of improving energy exchange and resource use efficiency” (国家没有规定的, 由送、受双方根据市场供求情况, 按照有利于电能交易和资源充分利用的原则协商确定).

¹⁰⁴ These announcements were accompanied by two regulatory documents: SERC. (2003). Regulatory opinions on creating a regional electricity market in the Northeast Region 《关于建立东北区域电力市场的意见》, No. 15; and SERC. (2003). Notice on developing a pilot electricity market in the Eastern Region 《关于开展华东电力市场试点工作的通知》, No. 13.

¹⁰⁵ The *Guidelines* (Article 40) do not provide specific standards for what constitutes a “large, efficient, environmentally friendly thermal unit” (高效、环保的大型火电机组) or an “inefficient, high emissions generating unit” (高污染、高能耗发电机组). In RDO implementation documents, large, efficient, environmentally friendly thermal units are typically classified as coal units that are 300 MW or larger and are equipped with flue gas desulfurization units. See, for instance: SERC. (2010). Interregional and interprovincial power trading rules for the Central Grid 《华中区域跨区跨省（市）电能交易办法》.

To facilitate a more precise mapping between actors and their revenues and costs, the *Guidelines* define three stakeholders: (1) “exporting entities” (送电方 | song dian fang), including both the individual generators and the provincial grid company that organizes them; (2) “transmission entities” (输电方 | shu dian fang), including CSG, SGCC, and the regional grid companies under SGCC; and (3) “importing entities” (受电方 | shou dian fang), including the receiving regional or provincial grid company.

Although the pilot regional markets were ultimately not successful,¹⁰⁶ the regulatory framework provided by these two rules laid the groundwork for the rapid increase in both interregional and interprovincial power exchange over the 2000s. Government-planned exchange (计划形成的交易 | jihua xingcheng de jiaoyi) and market-based exchange (具有市场化特征的交易 | juyou shichanghua tezheng de jiaoyi) both emerged under this framework, although the former constituted the lion’s share (89 percent) of total exchange in 2011 (Table 7). The remainder of this section examines these two forms of exchange in greater detail and the conflicts within and between them, and attempts to reconcile these conflicts.

¹⁰⁶ The Northeast pilot had been abandoned by 2006, having only experienced a brief actual operational pilot period. Dai Junliang, SERC staff who was the final author on the *Regulatory Opinion*, reported in an interview that the key reason for the failure of the pilots was the political difficulty of finding a mutually acceptable solution for linking wholesale generation and retail prices, and for addressing cross-provincial settlement issues for generators and grid companies. At the time of the pilots, retail prices in China were (and still are) fixed. With fixed retail rates, it was not obvious how to allocate any cost savings. Additionally, coal prices had been partially deregulated and rose significantly during the period of preparatory work for the pilots, which created the added challenge of how to allocate cost increases. To deal with revenue imbalances, SERC proposed the equivalent of a centralized deferral account, in which surplus or losses would be maintained and passed through to ratepayers every six months. In principle NDRC agreed to this proposal, but stakeholders could not agree as to how the account should be initially funded. A larger obstacle arose from disagreements over cost allocation between provinces. Government agencies in net exporting provinces (Heilongjiang and Jilin) wanted the net importing province (Liaoning) to increase retail prices to pay for higher coal (fuel) costs. Government agencies in Liaoning disagreed, because, they argued, the Liaoning market was allowing generators in Heilongjiang, Jilin, and Eastern Inner Mongolia to increase their net revenues. SERC spent a significant amount of effort attempting to achieve consensus among stakeholders, but no decisions were ultimately made and provinces in the Northeast region returned to annual generator output planning. See Xiaobo, S. (2013, June 8). Pilot electricity market reforms in the Northeast (东北区域电力市场改革试验). *Energy*. Available at: <http://finance.sina.com.cn/leadership/mroll/20130708/141916049734.shtml>.

Table 7. Interprovincial Power Exchange, by Category¹⁰⁷

Category		Examples	Volume (TWh)
Planned Exchange	<i>Central government mandated or approved</i>	• Three Gorges (18,200-MW hydro, Hubei-to-Eastern, Central, Southern Grid) • Ezhouba (2715-MW hydro, Sichuan-to-Central, Eastern Grids) • Ertan (3300-MW hydro, Sichuan-to-Chongqing) • Lijiaxia (2000-MW hydro, Qinghai-to-Eastern regions) • Yangcheng (1200-MW coal, Shanxi-to-Jiangsu) • Jinjie (3600-MW coal, Shaanxi-to-North Grid) • Fugu (3600-MW coal, Shaanxi-to-North Grid) • Western Inner Mongolia-to-East • Wandian-to-East (Anhui-to-Eastern Grid) • Yimu HVDC line (Eastern Inner Mongolia-to-Northeast Grid) • Power plants directly dispatched by specific RDOs	358.8
	<i>Provincial government facilitated</i>	Power exchange within China Southern Grid region	81.9
	<i>Grid company planned</i>	High-voltage interregional exchange Eastern Ningxia-to-Shandong Power plants directly dispatched by specific RDOs Power exchange between SGCC and CSG	109.3
Market Exchange		Exports from the Northeast Grid Transactions between Northwest and Central Grids Transactions within the Eastern, Central, and Northeastern Grids Lijiaxia non-planned power exports Non-planned Southern Grid transactions	74.1
Total			621.3

¹⁰⁷ SERC, 2012, p 24.

4.2 Government Planned Exchange

Planned exchange consists of electricity volumes that are mandated or approved by the central government, initiated between provincial governments, or planned by grid companies. The first category includes three kinds of exchange: (1) large national hydropower projects (e.g., Three Gorges) and large mine-mouth coal facilities (e.g., Jinjie) that export to other regional grids; (2) interregional bulk power exchange programs, including the Western Inner Mongolia-to-East (蒙西东送 | Mengxi Dongsong), Wan-to-East (皖电东送 | Wandian Dongsong), and the Yimu 500-kV high voltage DC (HVDC) transmission line connecting Eastern Inner Mongolia with load centers in the Northeast Grid; and (3) plants directly dispatched by the Central China, Northeast China, and Eastern China Power Grid Companies. The second category covers planned power exchange within the China Southern Grid region, primarily from hydropower and coal units in Yunnan and Guizhou Provinces to load centers in Guangdong and, to a lesser extent, Guangxi Provinces. The third category is self-explanatory.

For central government mandated or approved exchange, power is often allocated first to grid regions and subsequently to provinces within that region. For instance, power from the Sanxia (Three Gorges) Dam is allocated to the Eastern Grid, Central Grid, and Guangdong Province as part of a long-term allocation plan, and is allocated to provinces within the Eastern and Central Grids as part of five-year planning processes.¹⁰⁸ In the China Southern Grid region, interprovincial transfers are allocated according to an annual plan. In both cases, these allocations are then converted into contracts with provincial grid companies, with prices and volumes determined or approved by the NDRC or provincial government agencies. The third type of planned exchange in Table 7 primarily involves high-voltage AC and DC power exchange planned directly by SGCC or RDOs, and to a lesser extent power exchange between SGCC and CSG. The latter is negotiated bilaterally, according to SERC guidelines.¹⁰⁹

4.3 Market-Based Exchange

Subsequent to the 2005 *Guidelines*, in 2006, provincial, regional, and national grid companies set up Grid Power Exchange Centers, independent from their dispatch centers, to manage market-based interregional and interprovincial market exchange. These centers were tasked with establishing

¹⁰⁸ Regional allocations for Sanxia power are based on long-term plans from the former State Planning Commission and its successor the NDRC, initially for the period 2003 to 2010. Before the transmission line connecting Sanxia to Guangdong was completed in 2004, Sanxia power was allocated 50/50 between the Eastern and Central Grids. After the Guangdong line was completed, this allocation scheme was revised. Currently, during the rainy season power is allocated 50/50 between Guangdong and the Eastern Grid, up to transmission limits, and to the Central Grid once transmission limits to the other two regions are reached. During the dry season, allocation to Guangdong, Eastern Grid, and Central Grid is 16 percent, 32 percent, and 52 percent, respectively. Within the Eastern Grid, Sanxia power is then allocated to individual provinces as part of the five-year planning process: in the 12th Five-Year Plan, Shanghai was allocated 40 percent, Jiangsu 28 percent, Zhejiang 23 percent, and Anhui 9 percent. This description is based on: Jiangsu Provincial Energy Administration. (2011). Research report on power imports to Jiangsu during the 12th Five-Year Plan (江苏“十二五”区外来电调研报告).

¹⁰⁹ These guidelines are stipulated in: SERC. (2012). *SERC notice on issues with transactions between State Grid Corporation of China and China Southern Grid Company* 《国家电监会关于国网与南网电能交易有关问题的通知》, No. 129.

platforms for interprovincial and interregional market-based exchange. For SGCC's Power Exchange Center, this platform covers exchange over the ultra-high-voltage, bulk transmission system.

The goal of these market mechanisms was, in part, to make regional power systems more flexible and economically efficient in the face of changing supply and demand conditions. For instance, provinces that had to curtail hydropower or operate thermal units at low capacity factors because of excess supply could export to provinces that were capacity constrained. Market mechanisms were designed not to influence provincial generator output planning.¹¹⁰

Two main types of trading mechanisms have emerged under these platforms: (1) centralized auctions with price ceilings (挂牌交易 | guapai jiaoyi), in which total quantity and a price ceiling or a fixed price are set by Exchange Centers and generators bid supply (MW or MWh) into the market, at a price below the ceiling in cases in which prices are not fixed; and (2) centralized matchmaking markets, described earlier (Section 2.1, Historical Overview), in which the Exchange Centers match supply and demand at different quantity and price bids. The most common trading mechanism has been the ceiling-price auction, in many cases with a fixed price rather than a price ceiling.¹¹¹ For these auctions, prices given to generators are generally lower than those they receive for planned output.

Market platforms were created at both the regional and provincial level, with auctions initiated and facilitated by grid companies at both levels. Ningxia's 2008 *Measures for Interprovincial and Interregional Ceiling-Price Auctions* illustrates a design and process for a provincial trading platform. First, based on its assessment of "market conditions," at "unspecified intervals" the Ningxia Grid Power Exchange Center announces an auction, providing generators with information on total quantity for export, a price (fixed, in this case), required transmission loss compensation, time, and other terms five days in advance. Generators then submit sealed bids, which are opened and awarded in front of all bidders. If total bids exceed the total amount auctioned, bidders quantity bids are weighted by environmental criteria.¹¹²

SERC's 2010 *Interregional and Interprovincial Power Trading Rules for the Central Grid* illustrates a design and process for a regional trading platform. The Central Grid Exchange Center uses a centralized ceiling-price auction (fixed prices) for interregional provincial exports, and a centralized matchmaking market for interprovincial exchange. Both trading platforms are typically monthly and annual, with "temporary exchange" as needed. In both cases, the Central Grid Exchange Center issues a call for bids, and generators respond by bidding quantities (ceiling-price auction) or prices and quantities

¹¹⁰ In principle, there are two ways to achieve this: (1) to count exports toward planned output, which is the approach used in the Central Grid; and (2) not count exports toward planned output, in the expectation that prices for exported power will be at or close to individual generators' marginal costs.

¹¹¹ For instance, the Central Grid and Ningxia Province ceiling-price auctions described later in the paper are both fixed-price auctions.

¹¹² The *Measures* list three weights: (1) 600-MW units with flue gas desulfurization (FGD) systems are given a weight of 1.1; (2) 300-MW units with FGD are given a weight of 1.0; (3) 300-MW units without FGD are given a weight of 0.9. Ningxia's *Measures* do not specify how the amount of power to be exported is to be determined. See Ningxia Autonomous Region EIC. (2008). *Measures for interprovincial and interregional fixed-price auctions* 《宁夏电网跨区跨省电能挂牌交易办法（试行）》.

(matchmaking market) into the market. Provincial grid companies sign agreements with winning bidders, and regional grid companies sign contracts with provincial grid companies, to supply power.

To address problems of wind curtailment, in 2012 the Inner Mongolia EIC, SERC's Northeast Department, and the Northeast China Power Grid Company collaboratively developed a market-based "wind-thermal substitution trading mechanism" (风火替代交易机制 | feng huo tidai jiaoyi jizhi), whereby wind generators can purchase additional generating rights from thermal generators at bilaterally negotiated prices.¹¹³ Under SERC's regulations governing these arrangements, trades within the same grid region, within the same parent company, and negotiated under long-term contracts were to be given priority. As of 2014, one such trade had taken place. Notably, this mechanism addresses an interrelated planning and pricing problem – too much new wind generation online relative to demand growth, and no other mechanism for generators to recover fixed costs – rather than an operational problem per se.

4.4 Conflicts Within and Between Planned and Market Exchange

The regulatory framework for cross-border power exchange was intended to address two problems: (1) spatial disparities between energy resources and load centers, as most of China's coal and wind resources are in the north of the country, most of its hydropower resources are in the south, and load centers are along the coast; and (2) mismatches in supply and demand on longer (e.g., annual) and shorter (e.g., daily) timescales, with generating capacity shortfalls and surpluses occurring in some provinces even when available transmission transfer capability would be sufficient to support trade. The strategies for addressing these two problems, however, have historically come into conflict.

The strategy for addressing the first problem was to build large generating facilities for exporting from resource-rich provinces to resource-poor ones. Thus, a significant amount of cross-border power exchange is concentrated in a small number of hydropower, coal, and nuclear power plants, most of which were built during the 2000s. As Table 8 shows, the 10 largest exporting power plants accounted for nearly 60 percent of SGCC's cross-border exchange in 2011; the top three accounted for nearly one-third.

¹¹³ 《蒙东地区风火替代交易暂行办法》

Table 8. Largest Ten Exporting Power Plants in SGCC Region in 2011¹¹⁴

Power Plant		Type	Year(s) Online	Total Exchange (TWh)	Percent of SGCC Total
Sanxia	三峡	Hydropower	2003–2009	77.3	19%
Tuoketuo	托克托	Coal	2003–2007	27.9	7%
Qinshan	秦山	Nuclear	1994	24.2	6%
Yangcheng	阳城	Coal	2001–2002	15.8	4%
Jinjie	锦界	Coal	2006–2008	15.4	4%
Tianwan	田湾	Nuclear	2007	15.0	4%
Ertan	二滩	Hydropower	1999	14.3	4%
Shangdu	上都	Coal	2006–2007	14.2	4%
Daihai	岱海	Coal	2005–2006	14.1	4%
Laxiwa	拉西瓦	Hydropower	2009–	9.0	2%
Total above				227.3	57%
Total SGCC				399.9	

The majority of the power plants that were built to address the load-resource distribution problem fall under the “planned exchange” category in Table 7, with their output typically planned by the NDRC and converted into long-term contracts with importing provinces that are intended to recover generator costs, but are not a means to negotiate supply and demand. These plants are scheduled and dispatched directly by SGCC or the RDOs and have dispatch priority through the process described in Section 2.6 (Scheduling and Dispatch Processes). As Tables 6 and 7 suggest, power plants built to address spatial load-resource imbalances account for the majority of cross-border power exchange.

Planned output and priority dispatch of exporting power plants has, in some cases, created conflicts of interest. Despite reforms in 2002 that officially divested the State Power Corporation (中国电力公司 | Zhongguo Dianli Gongsi) of most of its generation assets and intended to separate ownership of generation and grid assets, the RDOs maintained ownership over a significant amount of hydropower

¹¹⁴ SGCC. SGCC 2011 power exchange annual report (国家电网公司 2011 年电力市场交易年报). Available at: <http://210.77.176.122/images/dlijnb/2012/02/10/0B495D021DCDF5C022BEE9DF3DAE0A1E.pdf>.

capacity over the 2000s, nominally for regional load balancing purposes. Toward the end of the 2000s, SGCC began to expand its direct ownership of generation assets, transferring assets from RDOs to SGCC¹¹⁵ and investing in new mine-mouth coal plants (e.g., Jinjie and Fugu in Table 7) and pumped hydro stations,¹¹⁶ arguing that these new investments were necessary for regional frequency regulation and load following support.¹¹⁷ All of SGCC's thermal generation assets were transferred to the Shenhua Group Corporation in 2012.¹¹⁸

The solution to the second problem (supply-demand imbalances) has been to promote market mechanisms that allow for more flexible power exchange between provinces and regions. However, in a number of cases conflicts have emerged between the rigid nature of central government-planned generator output and the flexibility needed to adjust to changing supply and demand conditions. For instance, SERC staff describe a situation (undated) in which Hubei Province was exporting power from the Sanxia Dam to Jiangxi Province under its long-term contract, but was itself experiencing power shortages. In response, Jiangxi's grid company organized within-province thermal generators to export to Hubei to cover Hubei's power shortage, using a ceiling-price auction. The net physical result was simply a reduction in power flow from Hubei to Jiangxi, which effectively meant that Hubei bought back some of its contracted exports to Jiangxi. Because Jiangxi's grid company used a ceiling-price auction to set the price for exports to Hubei, however, the net financial result was to lower generating costs in Jiangxi. Because of China's wholesale and retail pricing structure, in which the prices grid companies

¹¹⁵ At the end of the 2000s, RDOs had majority ownership, and presumably dispatch control, over a large number of hydropower facilities. In the early 2010s, however, some of these assets appear to have been transferred to SGCC. For instance, by the end of 2009 the Northeast China Power Grid Company (东北电网有限公司) owned and managed more than 4 GW of hydropower units. In 2011, the 1-GW Fengman Hydropower Station (丰满水电站), the 2-GW Baishan Hydropower Plant (白山发电厂), and the 510-MW Songhe River Hydropower Plant (松江河发电厂) were transferred to the State Grid Xin Yuan Company (国网新源控股有限公司), a subsidiary of SGCC. See State Grid Xin Yuan Company. Organizational chart (组织机构). Available at: http://www.sgxy.sgcc.com.cn/html/sgxy/col1060000024/column_1060000024_1.html. Accessed January 23, 2014. The Northeast China Power Grid Company's website lists only the 400-MW Yunfeng Hydropower Plant (云峰发电厂) and the 340-MW Taiping Bay Hydropower Plant (太平湾发电厂), which straddle the China-North Korea border and provide power to both countries, as being under its direct management. See: Northeast China Grid Power Company. Organizational chart (组织机构). Available at: <http://www.ne.sgcc.com.cn/dbdwww/gsis/zjig/>. Accessed January 23, 2014.

¹¹⁶ SGCC reportedly created a subsidiary in 2008, the State Grid Energy Development Corporation (国网能源开发有限公司), to invest in "coal-power bases" (煤电基地 | mei dian jidi) in Shaanxi, Inner Mongolia, Ningxia, Xinjiang, and Heilongjiang. A second subsidiary, the State Grid Xinyuan Company (国网新源控股有限公司), reportedly owns 4.5 GW of conventional hydropower and 9.7 GW of pumped hydropower, with the vast majority of the latter having been completed after 2009. SGCC also continues to own a small amount of wind capacity through its ownership stake in Luneng Group (鲁能集团). Capacity holdings for State Grid Xinyuan Company are from: State Grid Xinyuan Company. Organizational chart (组织机构). Available at: http://www.sgxy.sgcc.com.cn/html/sgxy/col1060000024/column_1060000024_1.html. Accessed February 6, 2014.

¹¹⁷ In an interview with *Wangyi Caijing*, a State Grid representative argued that the State Grid Energy Development Corporation's assets were for load following and frequency regulation, and thus were not relevant to the "generator-grid unbundling" policy ("国家电网内部人士对网易财经表示...国网能源所属的发电资产以前主要是承担电网内部调峰调频作用, 根本不在“厂网分开”的范围内"). See: Ruimin, Z. (2012, July 18). Shenhua absorbs state grid energy development company, 60 GW of capacity makes it larger than China Power Investment Corporation (神华接手国网能源 装机 6000 万赶超中电投). *Wangyi Caijing*. Available at: <http://money.163.com/12/0618/09/84988UFV0025402B.html>.

¹¹⁸ Ruimin, 2012.

receive are the residual between the retail prices and an average generation procurement price, this decrease in generating costs increased profits for the Jiangxi grid company.¹¹⁹

To address these and other problems,¹²⁰ SERC issued two regulatory documents, *Regulatory Opinions on Interprovincial and Interregional Power Exchange* in 2011 and *Basic Rules for Interprovincial and Interregional Power Exchange (Pilot)* in 2012.¹²¹ In these documents, SERC clarified, inter alia, that: long-term contracts can be transferrable or re-purchasable, if the buyer and seller can reach an agreement; generators, not grid companies, should be the principal suppliers in most cross-border market exchange; and market mechanisms should either be centralized matchmaking markets or bilaterally negotiated deals between a buyer (e.g., provincial grid company) and a generator.

4.5 Challenges for Integrating Renewable Energy

There is a growing body of research and analysis that suggests that cost-effectively integrating higher penetrations of wind and solar generation will require larger balancing areas (BAs) or, at a minimum, greater coordination among BA authorities.¹²² By aggregating wind and solar profiles and diversifying the generation resource mix, larger BAs decrease wind and solar variability, reduce forecast error, and improve system operators' ability to respond to unanticipated changes in demand (e.g., owing to weather conditions) and supply (e.g., owing to generator-forced outages or unforeseen changes in wind or solar output).

In China, the current approach to coordinating dispatch across BAs is primarily through the system of multilevel management, in which SGCC and the RDOs schedule and dispatch planned output from dispatchable generators across provinces. Market-based cross-border exchange, which in principle provides flexibility to PDOs, is currently designed for addressing imbalances on day-ahead or longer timescales. Four main features of this system of BA coordination create challenges for integrating renewable generation:

- **Lack of mechanisms for more extensive interprovincial dispatch of renewable generation:** The current approach to scheduling and dispatch only enables significant interprovincial exports of renewable generation when that generation is under RDO jurisdiction. Without a more

¹¹⁹ Chang, J., & Yu, D. (2010). Some thoughts on more flexible mechanisms for long-term contracts for interprovincial energy exchange (对跨省(区)长期电能交易合同“灵活”调整机制的几点思考). SERC White Paper.

¹²⁰ For a discussion of “other” problems, see, for instance: Hoping for a unified market platform for interprovincial and interregional transactions (跨省区电能交易期待统一市场平台). (2012, December 23) *China Energy News*.

¹²¹ SERC. (2011). Regulatory opinions on interprovincial and interregional power exchange 《关于跨省跨区电能交易监管工作的意见》. No. 36; SERC. (2012). Basic rules for interprovincial and interregional power exchange (pilot) 《跨省跨区电能交易基本规则(试行)》, No. 151.

¹²² See, for instance: GE Energy. (2010, May). Western Wind and Solar Integration Study. Prepared for the U.S. National Renewable Energy Laboratory. Available at: <http://www.nrel.gov/docs/fy10osti/47434.pdf>; Energy and Environmental Economics. (2013, March). PacifiCorp-CAISO energy imbalance market benefits. Available at: <http://www.caiso.com/Documents/PacifiCorp-ISOEnergyImbalanceMarketBenefits.pdf>.

integrated regional dispatch, grid regions will not see the diversity benefits of renewable resource aggregation.

- **Lack of flexibility under current market-based trading platforms:** Even if SERC's *Basic Rules for Interprovincial and Interregional Power Exchange* are effective in making long-term contracts more flexible, these platforms are not currently designed to address supply-demand imbalances on the intraday timescales that are relevant to wind and solar generation.
- **Lack of more formal, regular, centralized exchange platforms:** The current market trading platforms evolved, to a large extent, organically around grid companies' existing incentive structures. Creating a trading system to address intraday provincial imbalances would most likely require a more formal, regular, and centralized trading platform. This trading platform need not necessarily be a regional market with an independent system operator and centralized dispatch, but it must be institutionalized with clear rules, be available daily, and be sufficiently centralized to allow generators in neighboring provinces to respond to daily variation in supply.
- **Conflicts of interest between regional system optimization and grid company interests:** Even if SERC's *Basic Rules* effectively address grid company abuses under the current system, it will be difficult to ensure that SGCC and regional grid company interests are aligned with the goals of reducing regional power system costs and emissions and improving reliability as long as (1) grid companies have an ownership stake in and priority dispatch rights over generators that they dispatch; and (2) costs (and cost savings) are not more transparently and rationally allocated among generators, grid companies, and ratepayers. Conflicts of interest will likely limit the amount of renewable generation that can be cost-effectively brought online, as well as its ability to contribute to air quality and CO₂ reduction goals.