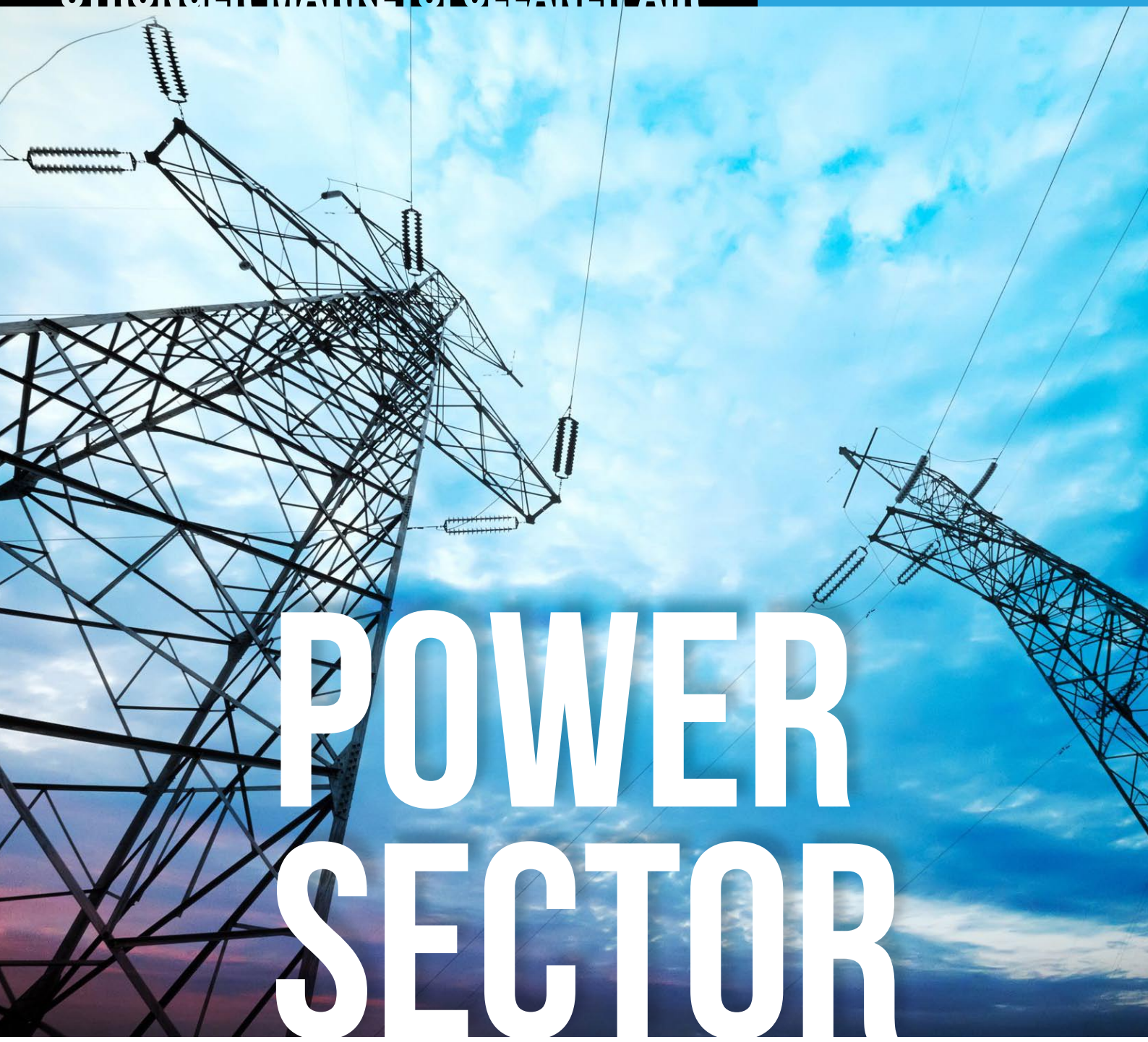
STRONGER MARKETS, CLEANER AIR

PAULSON DIALOGUE PAPERS



POWER SECTOR

Deepening Reform to Reduce Emissions, Improve Air Quality and Promote Economic Growth

September 2015

保尔森基金会
PAULSON INSTITUTE

The Opportunity: The power sector accounts for about half of China's annual coal consumption. Small changes in policy could have a big impact on cutting emissions.

About the Paulson Institute:

The Paulson Institute is a "think and do" tank that promotes environmental protection and sustainable development in the United States and China, while advancing bilateral economic relations and cross-border investment. Established in 2011 by Henry M. Paulson, Jr., the Institute is committed to the principle that today's most pressing economic and environmental challenges can be solved only if the United States and China work in complementary ways. The non-partisan institute is headquartered at the University of Chicago with staff in Beijing, San Francisco, New York and Washington D.C. The Institute focuses on research, programs, and advocacy that promote increased economic activity to spur job creation, smart urban growth and responsible environmental policies. Our Think Tank publishes papers on the most important macroeconomic issues facing China today, energy strategies, and issues in US-China economic relations. Learn more at www.paulsoninstitute.org

About the Series: *Stronger Markets, Cleaner Air*

This paper is one in a series produced in 2015 by the Paulson Institute's Climate Change and Air Quality Program aimed at policymakers and influencers in China. The series provides recommendations on how policymakers can harness market forces to reduce emissions of both conventional pollutants and greenhouse gases that contribute to climate change. The topics covered by the series include power sector reform, electric power demand response, carbon emissions trading and building energy disclosure.

Contact: media@paulsoninstitute.org
Design by Jonathan Tsao, Chinabeat Ltd.

Stronger Markets, Cleaner Air

POWER SECTOR

Deepening Reform to Reduce Emissions, Improve Air Quality and Promote Economic Growth

Co-Authors

Max Dupuy and Frederick Weston
Regulatory Assistance Project (RAP)

Anders Hove
Paulson Institute

Chinese Strategic Advisors

Kejun Jiang (姜克隽)	*Energy Research Institute, National Development and Reform Commission*
Zhongfu Tan (谭忠富)	*School of Management & Economics, North China Electric Power University*

External Reviewers

Michael Davidson	*Massachusetts Institute of Technology*
Kejun Jiang (姜克隽)	*Energy Research Institute, National Development and Reform Commission*
Manping Liu (刘满平)	*Pricing Monitoring Center, National Development and Reform Commission*
Mackay Miller	*U.S. National Renewable Energy Laboratory*
Kevin Porter	*Exeter Associates*
Wanxing Wang (王万兴)	*Energy Foundation*
Ryan Wiser	*Center for Resource Solutions*
Jiahai Yuan (袁家海)	*Northern Power University*

Those acknowledged as advisors and reviewers do not necessarily endorse the views expressed in the paper.

保尔森基金会
PAULSON INSTITUTE

Smart Grid: Power system dispatch based on emissions and efficiency would help increase integration of renewable energy into the grid.

CONTENTS

INTRODUCTION

The power sector alone accounts for about half of China's annual coal consumption.

The power sector alone accounts for about half of China's annual coal consumption. China's ambitious goals for air quality—along with related policies on coal consumption control, energy efficiency, renewable energy and carbon emissions—will necessitate changes in power sector policies, regulation, markets, and business models. The March 2015 "Deepening Reform of the Power Sector" policy document, also known as Document #9, issued under the joint authority of the State Council and the Central Committee of the Communist Party of China, reflects this need.[1] The document should enable the power sector to operate more efficiently with lower emissions. The document frames the challenges for power sector policy in terms of emissions reductions, energy efficiency and renewable energy, and is in line with the decision of the third plenum of the 18th Party Congress to enable market forces to play a "decisive role" in the allocation of resources. At its core, Document #9 calls for effective, market-based pricing for electricity, supported by government, trading platforms, trading markets, and trading mechanisms. It is an excellent starting point for decisions about how to develop and implement a path of reform for the power sector.[2]

Although this power sector reform process will largely take place at the national level, with a power sector reform path plotted for the country as a whole, there will continue to be an important role for regional pilots. The Beijing-Tianjin-Hebei (Jing-Jin-Ji) region, with its leading role in national air quality policy, can play an important part in power sector reform, and also reap early benefits.

The purpose of this brief paper is to provide a small menu of 3-4 suggestions to advance the goals of the "Deepening Reform" document. In particular, our goal is to outline ways in which a *small number of market-oriented reforms* could increase uptake of renewable energy and end-use energy efficiency. Because the paper focuses on market-oriented reforms, it does not address other issues, such as the need for more transmission investment embodied in the Energy Internet plan.

Notably, this paper does not attempt to review all of the causes of highly complex issues such as generation curtailment (a reduction in a specific generator's energy output from what it could have otherwise produced given available resources – see a list of definitions on page 9 for more explanation), shortage of flexible power generation, or present power sector pricing mechanisms. Other organizations, including the Energy Foundation, the National Center for Climate Change Strategy and International Cooperation (NCSC), Tsinghua University, North China Power University, and the Regulatory Assistance Project (RAP) have produced in-depth published and unpublished research on these topics.[3] Power sector reform is a highly technical topic and, where challenges exist, they will not be resolved by single solutions, but rather through reforms that work in tandem with other broad policies.

This paper draws on international experience and focuses on incentives to align the behavior of power sector firms—the grid companies in particular—with the government's emission reduction goals. We believe that China can benefit from lessons learned elsewhere while taking the country's unique circumstances into account.

The experience with power sector policy and regulation around the world has been diverse. Different countries have taken different paths, and have experienced varied results. Policymakers, regulators, and utilities worldwide are adapting to the challenges of increasing renewable energy generation, promoting energy efficiency, and reducing emissions. While there are no international power sector reform models that perfectly fit China's situation, there is a wealth of practices and cases that China can adapt to suit its own unique conditions. The suggestions put forth in this paper focus on improved planning that works together with market- and incentive-based mechanisms to ensure that policy goals are met in a cost-effective and low-risk manner.

In summary, our suggestions are as follows:

- **Reform generation pricing to facilitate improved generator dispatch:** China's present power pricing system is designed to compensate generators for both fuel cost and capital cost, based on planned annual operating hours. This method of generator compensation is at the root of the problematic approach to generator dispatch seen in most provinces, which gives inadequate consideration of efficiency and emissions. As recognized in recent policy announcements, improved dispatch would reduce curtailment of renewables, emissions and energy use while saving money. We suggest a transition to a merit order approach for unit commitment and dispatch that incorporates emissions costs. To support this, we also recommend reform of generation pricing in a manner that breaks the link between planned operating hours and generators' recovery of fixed costs.
- **Create incentives for grid companies to better support integration of renewable energy resources:** Curtailment of renewable energy is a complicated issue with many causes and potential solutions. Realigning the incentives of grid companies to support renewables integration could be part of an effective package of solutions. It would provide more motivation to grid companies to consider all possibilities before curtailing variable generation and to be more innovative regarding efforts to increase power system flexibility. Our suggestion is to create an incentive mechanism that exposes the grid companies to some of the costs associated with curtailment. This makes sense because the grid companies are well positioned to take action to address integration issues and reduce curtailment, as they do in many other countries. This approach would work best in tandem with other measures such as improved transmission and resource planning, and wider balancing areas for dispatch.
- **Support end-use demand-side resources within the context of the new "transmission- and distribution-pricing" reform plan:** In 2014, the National Development and Reform Commission (NDRC) launched a pilot in Shenzhen that represents a new approach to regulation of grid

While there are no international power sector reform models that perfectly fit China's situation, there is a wealth of practices and cases that China can adapt to suit its own unique conditions.

We suggest a requirement to compare new coal-fired power plants with energy efficiency investments that could be embedded in the approval process for power plants.

companies in China. It opens the possibility of better aligning the behavior of grid companies toward energy efficiency. Now that the Shenzhen pilot is being extended nationally, it is important for policymakers to get the details right to support demand-side resources, including ensuring that grid companies can claim expenses associated with energy efficiency programs as allowed costs. Such incentives are likely to be included in the new grid company reform in West Inner Mongolia, for example.[4]

- **Launch a pilot that requires a comparison with energy efficiency resources as part of the coal plant approval process, as a simple first step toward integrated resource planning:** Experience in other countries shows that end-use energy efficiency—that is, the energy efficiency of energy use in households, businesses, industry, and agriculture—can be treated as a resource for the power sector in the same way that conventional power plants are. Energy efficiency is usually a much less expensive and much cleaner option. We suggest a requirement to compare new coal-fired power plants with energy efficiency investments that could be embedded in the approval process for power plants. This would represent a more comprehensive resource-planning process that includes energy efficiency explicitly and would help alleviate overbuilding of coal-fired generation.

Each of these **market- and incentive-based** measures would have the joint benefit of helping China address major problems with the power sector—particularly the challenge of cost-effectively meeting the government's ambitious targets for emissions, air quality and coal consumption control—while maintaining a low-cost and reliable supply of electricity for China's growing economy. We emphasize that these solutions would work in tandem with other actions and policies currently under consideration.

Overview of China's Power System

China has built the world's largest electricity sector in just a few decades. As of 2013, the country's grid had more than 770,000 kilometers of transmission infrastructure,[5] a quarter larger than that of the U.S.[6] In 1980, China had just 65 GW of generation capacity,[7] an amount which had grown to 1,273 GW by November 2014[8] (compared to 5,330 GW worldwide at 2011 year-end).[9] From 2010 to 2013, China added more than 80 GW of new generation capacity annually,[10] and capacity continues to grow rapidly.[11]

Wind and solar capacity are a key part of this growth. China's total installed renewable energy capacity in the power sector (including hydro) tripled between 2005 and 2013, to 380 GW. China now has more installed onshore wind capacity than any country in the world (105 GW as of June 2015, with a target of 200 GW by 2020). China is also investing heavily in solar photovoltaic (PV) generation capacity, reaching an estimated 28 GW by the end of 2014. Of this, 23.4 GW is from utility-scale PV and the remainder is from distributed PV installations. China's 12th Five Year Plan includes PV capacity goals of 35 GW by 2015 and 100 GW by 2020.[12] A new study by the Energy Research Institute of the NDRC shows that it should be both technically and economically feasible for renewable energy to satisfy more than 60% of China's energy consumption and more than 85% of electricity consumption by 2050.[13]

Before this year's "Deepening Reform" document, the last power sector policy document to be issued at the same level came from the State Council in 2002.[14] Among other measures, the 2002 document split grid companies from generation assets.[15] The 2002 reforms also envisaged creation of regional markets and market-based dispatch. Despite pilot efforts, however, regional markets were never implemented.[16]

China's power sector continues to be dominated by large state-owned companies. The country's grid is owned and operated primarily by the state-owned State Grid Corporation of China (which supplies power to 88% of China), while China Southern Grid, also state-owned, accounts for most of the remainder. A handful of large state-owned power generation companies are responsible for generating most electricity, including the so-called "big five" – China Datang Corporation, China Guodian Corporation, China Huadian Group, China Huaneng Group, and China Power Investment Corporation – that account for 47% of power capacity.[17]

Power pricing, which is handled by the NDRC, involves government-set generation tariffs, retail tariffs, and feed-in tariffs for certain renewable generators.[18] Some retail pricing policies in China are supportive of emissions reduction goals, including differential price policy for industrial consumers and tiered pricing for residential consumers. However, there is significant room to improve transparency of retail prices and to ensure that they better reflect power system costs, including the societal costs of emissions.

BY THE NUMBERS

770,000 km of transmission infrastructure
a quarter larger than that of the U.S.

1,273 GW of generation capacity
more than **80 GW** of new generation capacity annually from 2010-2013

380 GW of renewable energy capacity
most onshore wind capacity installed in the world

State Grid Corporation supplies power to **88%** of China

2. CHINA'S 2015 "DEEPENING REFORM" DOCUMENT

Document #9 calls for effective, market-based pricing for electricity, supported by government, trading platforms, trading markets, and trading mechanisms.

The State Council issued the "Deepening Reform of the Power Sector" document, also known as *Document #9*, in late March 2015. At its core, *Document #9* calls for effective, market-based pricing for electricity, supported by government, trading platforms, trading markets, and trading mechanisms. The document provides several principles that state that power-sector policy should be guided by:

- The need for reliability;
- Increased use of market mechanisms;
- Protection of residential and agricultural consumers;
- Energy savings, emissions reductions, and increased use of renewable and distributed generation; and
- Better governance and regulation, including better planning and strengthened capacity in terms of regulatory agencies and approaches.

The "Deepening Reform of the Power Sector" document also addresses a number of important specific policy issues, including:

- **Grid company reform:** The document extends the "transmission and distribution pricing" regulatory approach used in the recent Shenzhen grid company pilot (launched in November 2014) to cover the entire country. The policy subjects the grid companies to an "allowed revenue" regulatory regime, which should increase transparency and controls costs. Judging by the experience in other countries with this type of "revenue regulation," the new policy may also have benefits for end-use energy efficiency and distributed renewables. In particular, depending on the details of implementation, this type of regulation should decouple grid company revenues from energy sales growth, which should change the way that grid companies regard measures that reduce energy sales. In short, energy savings and distributed renewables may no longer cut into grid company profits.[19]
- **Direct access and retail competition:** The document emphasizes expansion of current provincial-level pilot programs that allow large users to bypass the grid companies and negotiate prices directly with generators. The document requires that both demand-side and supply-side parties be screened, with participation limited to those demonstrating good performance in terms of energy efficiency and compliance with environmental regulations.
- **Demand-side management:** The document calls for better demand-side management and end-use energy efficiency, although financing of energy efficiency is not directly addressed.

- **Improved generator dispatch:** The document recognizes the need to improve dispatch, a significant source of inefficiency and curtailment of renewables.[20]
- **Renewables integration:** In addition to dispatch reform, the document discusses other challenges with renewables integration, including the need for new mechanisms for ancillary service provision and improved inter-provincial, and cross-regional power trading mechanisms.
- **Distributed generation:** The document emphasizes the development of new mechanisms for distributed generation. It aims to remove market access barriers and allow distributed generation to participate in power trading mechanisms that may be developed.
- **Power sector planning:** The document stresses the need to revamp power sector planning and includes the declaration that "power planning should take full account of environmental carrying capacity."

In summary, the "Deepening Reform of the Power Sector" document is a broad roadmap for reforming the power sector. Since the document was released, several other supporting regulations have been issued. In general, these reforms point towards China gradually developing solutions to some of the country's most pressing power sector problems, including those related to power system dispatch, planning, demand response, and renewable integration.

The following sections attempt to build upon the progress represented by the "Deepening Reform" document by making suggestions in four broad areas: incentive mechanisms to reduce curtailment of renewable energy, prioritizing the development of "energy efficiency power plants" over new coal plants, incentive mechanisms for investments in energy efficiency, and adjusting compensation for generator capital costs to speed reform of dispatch. These suggestions are *not intended to be comprehensive*. For example, issues such as transmission bottlenecks, local over-building of generation capacity in certain regions, and renewable curtailment necessitated by wintertime demands for coal-fired heating are not discussed here. Rather, this paper is intended to build upon the spirit of "Deepening Reform" by focusing on a few examples of how market mechanisms could help incentivize market participants to favor efficiency and clean energy.

The document stresses the need to revamp power sector planning and includes the declaration that "power planning should take full account of environmental carrying capacity."

3. IMPROVING EFFICIENCY OF POWER SYSTEM OPERATIONS THROUGH GENERATOR PRICING REFORM

One of the most important aspects of the "Deepening Reform" document is its call to use markets to improve power system dispatch based on emissions and efficiency.

One of the most important aspects of the "Deepening Reform" document is its call to use markets to improve power system dispatch based on emissions and efficiency. Most power systems in other countries operate according to *economic dispatch*, based on a *merit order* of available resources that is updated throughout the day (see definitions on page 9). This approach seeks to use resources that are available to the grid in a way that minimizes operating costs, including fuel costs, operations and maintenance (O&M) costs and also ideally the societal costs of emissions. China's present approach to power sector operations is much different in that it centers on an annual planning process that sets annual hours for thermal generators. This approach distorts investment decisions, hampers integration of renewable energy and increases costs and emissions. (Beginning in 2007, five provinces piloted an alternative dispatch approach known as energy efficient dispatch, although this was never expanded to cover the entire country.[21])

China's approach to power sector operations can be traced, in large part, to the approach to compensating generators. Prices for generators are set administratively on a per-kWh basis, based on a planned number of annual hours for each coal-fired generation unit. If coal units run less than their planned time they may not earn sufficient revenue to cover their fixed costs. Renewable energy has very low variable costs and should be dispatched before coal, but policies to try to promote this approach to dispatch have run into resistance from coal generators because of the tariff design for coal generators. This paper's suggestions center on creating a business model for thermal generators to reduce hours of operation while still being compensated for maintaining capacity for times when it is needed to balance the grid.

The approach to dispatch is rooted in China's current compensation mechanisms for thermal power generation. This compensation is based on a fixed tariff per kWh generated. The tariff is designed to compensate generators for both fuel cost and capital cost, based on an annual plan for operating hours.[22] This approach, while effective at ensuring generator availability and operations, also creates strong incentives for generators to oppose reductions in operating hours that might come from dispatch reform, because they would lose not only the revenue for covering operating expenses for those hours but also revenues intended to cover capital costs.

"Deepening Reform" and associated documents indicate a strong push to reform dispatch, but have not fully addressed the root problem of generation pricing. There are different avenues to reforming generation pricing. The key is to break the link between meeting planned operating hours and the recovery of capital costs. In other words, it is important to create a business model that rewards efficient operation of the overall system—that is, one in which

thermal generation resources operate more or less frequently, depending on their efficiency, but are compensated for keeping their capacity available to be called on as needed (whether for energy, balancing, or other ancillary services). Such a model would reduce opposition to improved dispatch that reduces generating hours for less efficient and higher-emitting resources in favor of more efficient and cleaner resources.

Two-part pricing is one potential near-term approach for China. The current benchmark tariff for thermal generators could be broken into a two-part price, with separate prices and payments for: (1) capacity (fixed costs), tied to generator availability, and (2) energy (variable costs), tied to generator output. This could be implemented relatively easily in China without much change to current power sector procedures, and could eventually evolve into a wholesale market. Zhejiang province recently announced a two-part pricing mechanism for gas-fired generation.

Definitions

System operations	The process, managed by system operators (which in China are located within the grid companies), of turning on and off ("committing") and dispatching generating units to meet demand, subject to transmission and reliability constraints.
Merit order	Ranking available sources of electricity generation (or other resources, such as demand response), iterated on an hourly or sub-hourly time-scale, and based on ascending order of variable cost. Ideally this ranking also includes the cost of emissions; see also 'environmental dispatch', below. A merit order does not necessarily require a bid-based wholesale power market.
Economic dispatch	The operation of generation facilities (or other resources, such as demand response) according to the merit order (see above) to produce energy at the lowest cost to reliably serve consumers, recognizing any operational limits of generation and transmission facilities.[23] Under economic dispatch, generators with the lowest variable costs are the first ones to be brought online to meet demand, and the plants with the highest variable costs are the last to be brought online. Dispatching generation in this way minimizes the cost of producing electricity.
Environmental dispatch	Form of economic dispatch that accounts for the environmental characteristics of generation in addition to fuel and other marginal costs. Environmental dispatch can be implemented by taking into account the marginal environmental cost of electricity production for various pollutants, including both air and water emissions.
Curtailment	A reduction in a specific generator's energy output from what it could otherwise produce given available resources.[24] Intermittent wind and solar generation in China often face curtailment by the grid operator. Since State Grid does not compensate wind and solar developers for curtailment, wind and solar projects and experience a direct reduction in revenue. Generally, curtailment is caused by a lack of flexibility in the power system. Some options for increasing flexibility include reforming dispatch, widening balancing areas, reducing transmission congestion, adding new transmission lines, faster scheduling and dispatch, demand response, energy storage, and adding more flexible generation assets, among other approaches.
Wholesale power market	Wholesale power markets refer to the purchase or sale of electricity, ancillary services, and generation capacity in the bulk power system, which comprises the interconnected resources at the high-voltage level—generation, transmission, and interties to neighboring systems.[25] China currently lacks a wholesale power market.

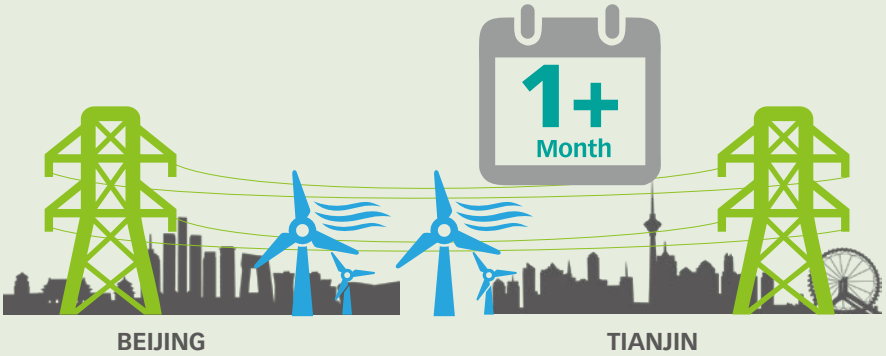
4. INTEGRATING MORE RENEWABLE ENERGY RESOURCES INTO THE POWER SYSTEM

In the past few years, China has invested in large amounts of renewable energy resources, and it has ambitious targets for continued expansion. But China has struggled with the challenge of integrating variable generation resources into the power system–and there has been significant waste of wind energy and, increasingly, of solar energy.

Although China has more wind power capacity than any other single country, it trails the U.S. in terms of wind energy generated.[26] A significant proportion of wind energy is wasted—or"curtailed."[27] The amount of wind energy curtailed in 2013 alone could power both the cities of Beijing and Tianjin combined for well over a month.[28] (Curtailment of hydroelectric resources has also been a problem.[29])

The amount of wind energy curtailed in 2013 alone could power both the cities of Beijing and Tianjin combined for well over a month.

China's wind curtailment rate peaked at 16% in 2012, falling to 11% in 2013 and 8% in 2014 (although there may be some reason to view the 2014 data with skepticism, given that 2014 appears to have been a low-wind year overall).[30] In the first part of 2015, wind curtailment reportedly reached 18%.[31] The national trend can be deceptive because curtailment rate trends are inconsistent across provinces—some locations are seeing worsening curtailment while others are seeing improvement.[32] Integrating growing amounts of renewable energy resources will be a major challenge in many parts of the world for years (or decades) to come, as renewable energy resources become a more prominent source of power. However, China's wind curtailment is already relatively severe. In the U.S., most wind-rich regions have curtailment rates below 4%, and some have curtailment lower than 1%.[33] Italy and Denmark are in the range of 1-2%.[34]



A significant proportion of wind energy in China is wasted—or "curtailed." The wind energy curtailed in 2013 alone could power both the cities of Beijing and Tianjin combined for well over a month.

There is also reason to be concerned about curtailment of solar generation in China as the country rapidly adds solar capacity. For example, Gansu, a province that already has problems with curtailment of wind energy, is now also seeing significant curtailment of solar energy as it expands solar capacity. [35] Between the third quarter of 2013 and the same quarter in 2014, Gansu solar plant capacity factors fell from around 19% to 14%, with solar plant operators reporting severe curtailment rates throughout the province.[36]

The overarching problem, particularly given that China's renewable capacity will likely continue to rise rapidly over the next 10 years, is the lack of flexibility in the power system to support renewables. New investments will be needed, including in transmission, flexible generation, and demand response.

More specifically, reasons for this lack of flexibility include:

- Concentration of wind capacity in the northern and western regions of China, meaning a high amount of variable renewable energy relative to local power demand.
- Heavy reliance on coal-fired plants, inadequate planning processes, and inefficient dispatch.[37] Coal-fired plants can be particularly inflexible, requiring significant time to start up and ramp output, in addition to wear and tear caused by cycling operations (adjusting output up and down over short time-frames). Coal plants can be operated more flexibly, but doing so increases their costs.[38]
- Lack of mechanisms in China to plan for and compensate generators for providing flexibility and ancillary services.
- China's approach to dispatch. A merit order approach would make much greater use of low- and zero-marginal cost resources (e.g., wind and solar) and dispatch the thermal generators according to their relative efficiencies (i.e., heat rates).
- Dispatch and power system balancing are handled primarily by provinces, with poor interconnections between provinces. Dispatch and power system balancing would be easier with more regional (i.e., multi-provincial) dispatch and system balancing.
- Institutional barriers to interprovincial trading of electricity.[39]
- The significant expansion of combined heat and power (CHP) generation – which cannot be turned off – in the northeast over the past decade. During the winter, dispatch centers (the system operator) use CHP units to meet heating demand, and because CHP units cannot readily be turned off during heating season, these plants are unable to be operated flexibly in response to changes in electricity demand and wind output.

The flexibility challenge is not just a technical one, but also institutional. System operations can enhance flexibility that is already in the system but currently not being used. In all countries, the system operator determines when to curtail non-dispatchable generation, and in China the system operator is not independent, but rather a part of the grid company. However, there may be additional measures that the grid companies could take to reduce curtailment in a cost-effective manner. Several policy directives (and China's renewable

Windfall: Power sector reform and increased grid flexibility would significantly decrease the amount of wind power that is wasted each year.

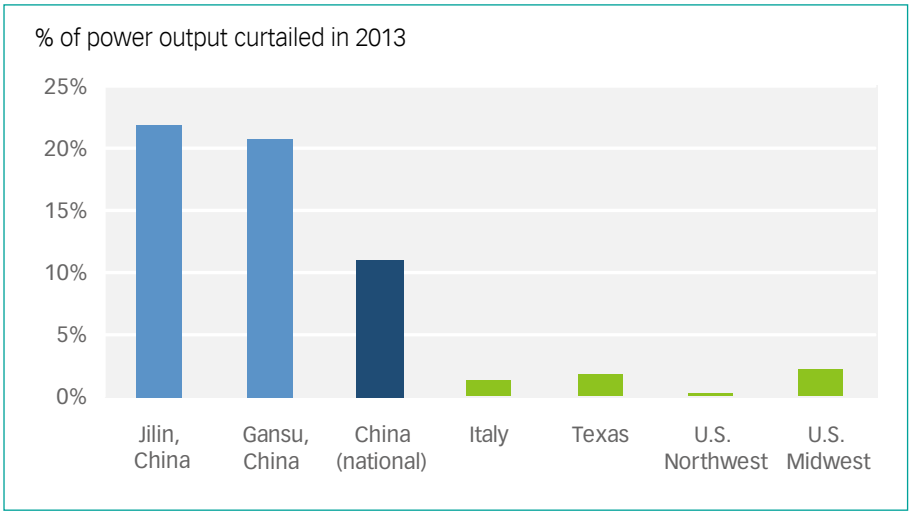
The overarching problem, particularly given that China's renewable capacity will likely continue to rise rapidly over the next 10 years, is the lack of flexibility in the power system to support renewables.

energy law) require that renewable energy generation should be given priority dispatch over other generation sources.[40] In addition, in March 2015, NDRC and National Energy Administration (NEA) issued a policy guidance document that re-emphasized the need for priority dispatch for renewable energy.[41]

As noted, the technical challenges of renewable integration are well understood by renewable energy experts in China. It is a multi-faceted problem that does not yield easily to single solutions. The key is to put together a policy package that will comprehensively address renewable energy integration and reduce curtailment. A full discussion of these issues is beyond the scope of this paper,[43] but it is clear that the grid companies will play a major role in resolving the problem. Realigning the incentives of the grid companies to support renewables integration would provide clear motivation to grid companies to consider all possibilities before curtailing variable generation and to be more supportive—and innovative—regarding efforts to increase power system flexibility. Exposing the grid company at least partially to curtailment costs makes sense because they are well positioned to take action to address integration issues and reduce curtailment.

International examples can also inform shared compensation mechanisms. In several countries (and jurisdictions within countries), grid companies (or system operators) pay compensation to wind and solar generators when the generation is curtailed. This is a rising trend in the U.S., where the compensation arrangements are increasingly specified in detailed agreements between renewable energy generators and utilities.[44] (However, not all grid operators compensate for renewable energy curtailment; Texas and Hawaii do not, for example.[45]) There are many variations on these cost-sharing arrangements, but there is a general emphasis on compensating generators for curtailment due to factors that are under control (or open to influence) of the grid company and system operator, including curtailments due to congestion, balancing purposes, and routine maintenance of the grid.

CHINA WIND CURTAILMENT RATES IN INTERNATIONAL COMPARISON



Note: Jilin, Gansu and China wind curtailment rates from 2013, Italy from 2012, U.S. from 2013.
Source: Paulson Institute, based on data from NREL (Italy, U.S.) and CNREC[42]

COMPENSATION FOR CURTAILED ENERGY IN THE U.S.

Utility or grid operator	Compensation provided	Limits Specified in Contracts	Reasons for Compensation	Limits to Compensation
AESO	No			
APS	Yes	√		Limited annually, do not pay if directed by other transmission operators
BPA	Some			
CAISO	Varies	√	Some contracts for renewable energy brought online before sufficient transmission include compensation	No compensation for reliability caused or issues with interconnection studies
ERCOT	No			
HECO, HELCO	No			
ISO New England	No			
MISO	Yes	√	Wind generators eligible for MISO's make-whole payments, off-taker contracts may specify	
NV Energy	Yes	√	Compensated for non-emergency situations or those unrelated to reliability	Not compensated under specific scenarios
PJM	Yes		If wind curtailed below economic base point	No compensation if wind not providing required data or not following PJM dispatch signals
PSCO	Yes	√	Balancing purposes	Transmission causes beyond control, limited annually
Salt River Project	Yes		Take-or-pay contracts	
SMUD	Yes		If CAISO curtails due to oversupply, SMUD compensates	
SPP	Yes	√	Congestion-based curtailment has been compensated	No compensation for reliability-based curtailment.
Tucson Electric Power	Yes	√	For reasons under TEP's control	No compensation for curtailment by others

Source: U.S. National Renewable Energy Laboratory, 2014

In many European countries, compensation for curtailment is specified in government policy or legislation. Some jurisdictions, including Ireland, Italy, and Romania, compensate generators for the market value of curtailed energy. In other countries, renewable energy generators receive only a fraction of the value of curtailed energy, ranging from 15% to 50%.[46] Legislation in Portugal requires wind producers to be compensated, but only for losses that exceed 50 hours at full capacity.[47]

Currently, in China, the grid companies do not bear any of the costs of curtailment. Changing this so that grid companies pay for *part* of curtailment costs—even if it is only a fraction, or only under certain circumstances under grid company control, possibly determined by a third party—could better align grid company incentives toward greater facilitation of renewable energy resources. Although in some countries or jurisdictions there is full (or near full) compensation to the generator for curtailment, we do not advocate that

generators in China should be compensated for 100% of curtailed energy. Instead, we believe generators should continue to bear some of the costs associated with curtailment. This will help provide an incentive to investors and plant owners to locate new renewable generation capacity in areas where transmission is adequate and curtailment is less likely. Indeed, compensation for curtailed energy may work best in situations with a robust approval process for wind and solar plants.

We do not advocate that generators in China should be compensated for 100% of curtailed energy. Instead, we believe generators should continue to bear some of the costs associated with curtailment.

Because of the technical complexity of generation curtailment, partial compensation for curtailed energy is not a cure-all for renewable integration problems—nor is it necessarily the most important solution. A number of Chinese organizations and government entities have researched the curtailment problem and reached a variety of conclusions about steps that are needed to reduce curtailment. These include: major increases in transmission capacity from areas with high renewable energy (including the development of ultra-high voltage transmission lines as envisioned in State Grid's plan for a Global Energy Internet), restrictions on new renewable energy capacity in areas with insufficient local power demand or transmission capability, increased regional power trading, larger energy balancing areas, shorter generation dispatch times (such as 15-minute or 5-minute scheduling, as practiced in some areas of the U.S.), improved renewable energy weather forecasting, more demand response, and greater attention to distributed energy versus utility-scale renewable energy. Nevertheless, we suggest that sharing of curtailment costs can be an effective way to align incentives with the search for solutions in these and other areas.

5. BOLSTER THE SHENZHEN PILOT TO SUPPORT END-USE ENERGY EFFICIENCY

China's grid companies, which rank on the list of the largest firms in the world, play a central role in the power sector and thus have a large role to play in transforming the sector. The "Deepening Reform" document signals a new approach to regulation of grid companies, including national implementation of a method that is close to what is called revenue regulation in the United States. Careful design of this grid company regulatory reform will be essential for ensuring that the power sector plays its role in meeting the government's goals for air quality, energy efficiency, and renewables.

The importance of grid company incentives to energy efficiency programs has also been seen in many other countries. In the United States and elsewhere, utility regulators see an important part of their task as designing and implementing mechanisms to align the behavior of profit-seeking utilities with social and environmental goals of policymakers. In particular, the U.S. now has decades of history with regulatory incentive mechanisms that shift utilities toward a business model that includes significant investment in end-use energy efficiency.

A core function of U.S. regulatory agencies is to establish mechanisms and procedures to:

- Allow the utility an opportunity to earn sufficient (but no more than sufficient) revenue;
- Establish consumer prices that provide that allowed revenue;
- Align the behavior of the utilities with public policy objectives, including investment in end-use energy efficiency.

The third item has become particularly important in the U.S.[48] Beginning in the late 1980s, various states made changes to the traditional approach in order to remedy these incentives to resist energy efficiency. This became particularly important as states began to develop utility-delivered energy efficiency programs (similar to the obligations on grid companies in China to invest in end-use energy efficiency). Broadly speaking, these states now employ two types of mechanisms, sometimes both at once. First, decoupling mechanisms break the link between profits and energy sales.[49] But decoupling only removes disincentives toward energy efficiency; it does not motivate the utility to invest in energy efficiency as a resource. This is where the second type of incentive mechanism comes in: specifically, financial incentives to encourage utilities to invest in end-use energy efficiency. Some state regulatory commissions have implemented mechanisms that provide financial rewards when the utility meets specified targets for promoting end-use energy efficiency.[50]

In November 2014, the NDRC launched a "transmission and distribution pricing" pilot in Shenzhen that for the first time in China makes strides toward decoupling grid company profits from energy sales while opening

China's grid companies, which rank on the list of the largest firms in the world, play a central role in the power sector and thus have a large role to play in transforming the sector.

the possibility for aligning the behavior of the grid companies toward energy efficiency.[51] Implementation of these grid company regulatory reforms is very important, given that the "Deepening Reform" document has signaled that the Shenzhen pilot will be gradually extended to the rest of the country. So far, pilot provinces include Inner Mongolia, Anhui, Hubei, Ningxia, Yunnan, and Guizhou.

When rolling out the Shenzhen pilot for national implementation, we suggest Chinese authorities should be sure to recognize and reinforce how the pilot creates incentives for the grid companies to support end-use energy efficiency. (Such demand-side management incentives are likely to be included in the new West Inner Mongolia grid company reform pilot.[52]) There are at least two ways in which the pilot might make it more attractive for the grid company to implement end-use energy efficiency:

- Because the Shenzhen grid company will receive a capped level of revenue over a three-year regulatory period, which will not vary based on the amount of electricity it sells, reduced sales resulting from demand-side management and energy efficiency programs will not affect the grid company's financial position (an effect similar to decoupling in the United States); and
- The Shenzhen grid company should, in principle, be able to claim expenses associated with energy efficiency programs as allowed costs. However, in practice, it is not clear whether this is being approved.

There is much valuable experience from U.S. states about best practices and possible pitfalls that will be useful as the new approach to grid company regulation is expanded to other parts of China.

Test case: In November 2014, Shenzhen (pictured here) became the first pilot city to test the decoupling of grid company profits from energy sales. This will open the possibility for aligning the behavior of grid companies toward more energy efficient practices.

6. A FIRST STEP TOWARD INTEGRATED RESOURCE PLANNING: PILOT A NEW APPROVAL PROCESS FOR NEW COAL-FIRED POWER PLANTS

In recent years, China's coal-fired capacity has continued to grow rapidly, with 36 GW added in 2014.[53] While coal expansion has slowed from peak years, this growth in coal-fired capacity appears to be inconsistent with China's goals for emission reduction and cost-effective development of the power sector, particularly given slowing demand for electricity and rapid expansion in renewable energy resources. The continuing expansion in coal-fired generation can be partly attributed to inadequate planning processes and investment approval procedures that are not sufficiently connected with planning.[54]

In the best examples from other countries, planning works to identify resource needs to satisfy demand for energy services while meeting emissions goals. The main idea is to coordinate plans for transmission resources, demand-side resources, and conventional supply-side resources in order to maintain reliability while minimizing costs, risks, and environmental damage. Comparing the costs and benefits of these different resource choices on an equal basis identifies opportunities for cost- and emission-savings. In particular, end-use energy efficiency is typically a plentiful and inexpensive resource that can effectively displace the need for new power plants. This is important even in places with a liberalized market approach. Market mechanisms can help guide capital to needed investments in the power sector, but these markets need to be well-designed and regulated to support policy objectives. In addition, even in a liberalized market context, some resource investments, including transmission resources and demand-side resources, may not be subject to market mechanisms, yet these investments need to be coordinated with investments that are subject to market mechanisms.

End-use energy efficiency can be a resource for the power sector in the same way that power plants are. Energy efficiency is usually a much less expensive and much cleaner option. There is much experience in other countries with investing in energy efficiency in order to displace the need for new power plants, new transmission and distribution infrastructure. Some places, such as California, have gone as far as to declare energy efficiency the "priority resource" for the power sector and require that electric utility resource procurement plans include all "cost-effective, reliable, and feasible" energy efficiency.[55]

China has some of the elements for such an approach. The 1995 Electricity Law states that "planning … shall reflect … coordinated development of power sources and power networks, increasing economic benefits, and being conducive to environmental protection.[56]" The "Deepening Reform" document recognizes the need for a major revamp of power sector planning,

End-use energy efficiency can be a resource for the power sector in the same way that power plants are. Energy efficiency is usually a much less expensive and much cleaner option.

and the other recent official announcements indicate that the 13th Five-Year Plan is taking up the task.[57] In addition, Chinese government agencies and researchers have made strides in developing the concept of the "efficiency power plant" (EPP)—that is, the idea of bundling end-use energy efficiency investments in a way that would help power sector planners to directly compare energy efficiency resources with conventional power plants. However, in practice, planning processes are fragmented and China lacks an adequate framework for comparing the costs and benefits of various supply-side, demand-side, and transmission resources. A closely related problem is that approval of investments doesn't necessarily follow either policy guidelines or the planning processes that do exist. Power sector firms appear to be able to sometimes gain approval for investments that may not be in line with those policy objectives.[58]

In recent decades, the energy intensity of China's economy—measured as energy consumed per unit of GDP—has fallen considerably, although there is undoubtedly significant room for continued reductions. The decline in energy intensity has been driven, in part, by improvements in end-use efficiency. In turn, the improvements in energy efficiency have resulted in part from policies specifically designed to promote energy efficiency investments in heavy industry and other sectors, as well as tightening energy efficiency standards for buildings, transportation, and other areas of the economy.

Despite these policy successes, energy efficiency policy does not yet play an effective role in the power sector, and energy efficiency is still not fully acknowledged as a power sector resource.

Despite these policy successes, energy efficiency policy does not yet play an effective role in the power sector, and energy efficiency is still not fully acknowledged as a power sector resource.

Our medium-term suggestion for China is to gradually develop a comprehensive and coordinated resource planning process for the power sector that would directly compare demand-side resources (including EPPs), supply-side resources, and transmission resources in an integrated manner. This planning process should include consideration of environmental costs associated with each resource. There are useful examples of this kind of planning in leading states in the U.S., where state regulators have evolved useful methods and sophisticated techniques that compare and identify a desired mix of resources—often called integrated resource planning or IRP.[59] In these states, the utility works with regulators to develop a multi-year electric utility plan for meeting annual demand for energy services through a least-cost combination of supply-side, demand-side, and transmission resources. This approach has led to increased investment in end-use efficiency by recognizing the value of energy efficiency and supporting investments in energy efficiency as a resource.

In the leading state-level examples in the U.S., IRP has developed over many years as planners and policymakers have developed the necessary analytical tools and institutional capacity.[60] We expect that Chinese authorities could

draw on this experience and move much more quickly. Nevertheless, we offer a rudimentary first step toward IRP that we believe could contribute to alleviating the bias toward investment in coal-fired generation, mitigating the current tendency to overbuild coal capacity, and unlocking more of the potential of energy efficiency as a resource for the power sector. It involves modifying the coal-plant approval process by imposing a requirement to compare the cost-effectiveness of a proposed coal-fired plant versus a proposed (or default) portfolio of efficiency projects, with an assessment of the emissions and coal savings from the efficiency investment relative to the coal plant. This comparison would take into account:

- Heat rate or grams of coal per kWh (EPPs burn zero grams per kWh saved);
- Emissions in grams of sulfur dioxides, nitrogen oxides, and carbon dioxide per kWh (EPP emissions are zero per kWh saved); and
- Cost on a levelized per-kWh basis.

The levelized cost for an EPP can be estimated from existing energy efficiency investments in China, and the results of the analysis will likely show that EPPs are typically around a third of the cost of a coal-fired plant.[61] Under this practice, coal-fired power plants could not receive approval unless they could exceed the performance of alternative EPP in all three categories. We suggest piloting this in a province or region that is attempting to implement strict limits on expansion of coal-fired capacity.

This suggestion is intended to illustrate a simple first step toward a more comprehensive resource planning process. The journey toward fully-integrated resource planning may take years and it is necessary to start with a logical first step. Our suggestion would effectively bolster existing policies for coal control and the restriction on new coal-fired power plants. Moreover, it would provide impetus for strengthening policies to fund and "build" any EPPs needed to take the place of coal-fired power plants. This could be achieved by expanding the existing requirement on grid companies, in place since 2011, to invest in end-use energy efficiency.[62]

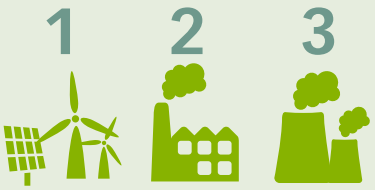
In recent decades, the energy intensity of China's economy—measured as energy consumed per unit of GDP—has fallen considerably, although there is undoubtedly significant room for continued reductions.

7. CONCLUSIONS

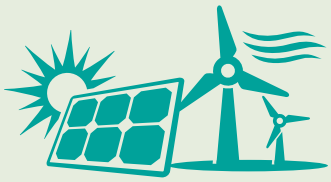
The question at hand is whether the broad principles set out in the policy announcement will be backed up and made workable by well-designed regulations and effective implementation.

The March 2015 "Deepening Reform" document issued by the Central Committee of the Communist Party and the State Council sets the stage for the power sector to be remolded in a way that will support emissions and air quality objectives, while continuing to support China's economic development. The question at hand is whether the broad principles set out in the policy announcement will be backed up and made workable by well-designed regulations and effective implementation. This paper has offered four main suggestions that are opportunities for *quick wins*—that is, measures that can be implemented feasibly and speedily in the context of China's current power sector structure. The majority of the suggestions relate to incentives and price signals for power sector companies. These fit well with the emphasis in the "Deepening Reform" document on market mechanisms, and they are in line with international experience in recent decades.

Four power sector quick wins to support emissions and air quality objectives



Reform generation pricing to facilitate improved generator dispatch.



Create incentives for grid companies to better support integration of renewable energy resources.

Support end-use demand-side resources within the context of the new "transmission and distribution pricing" reform plan.

As a first step toward integrated resource planning, require that a comparison with energy efficiency resources be included in the coal plant approval process.

All four of these suggestions touch on some of the major lessons from international experience with power sector policy and regulation: power sector planning and enforcement need to work together with well-designed market mechanisms and regulatory incentives in order to achieve policy goals for emissions and reliability.

ABOUT THE AUTHORS

Max Dupuy

Based in Beijing since 2009, Max Dupuy leads projects in the areas of power sector policy and regulation at the Regulatory Assistance Project (RAP). He has served as an author, public speaker, and expert for the press on international developments in power sector regulation, energy efficiency, emissions trading, and other topics. He specializes in comparative analysis of energy policy, and has particular experience with China's energy institutions and challenges.

Before joining RAP, Mr. Dupuy served at the New Zealand Treasury in Wellington, leading economic research projects and developing policy advice on electricity markets, transmission regulation, and capital efficiency.

Mr. Dupuy's work in energy policy is complemented by a background in financial sector regulation and macroeconomic policy. He worked as an economist at the U.S. Treasury in Washington, D.C. for six years, advising the Secretary of the Treasury and other senior officials. His time at the U.S. Treasury included successive periods as the economist responsible for developing policy advice on issues concerning India, Indonesia, and China. He also worked in economic research in the Federal Reserve System.

Frederick Weston

Rick Weston directs RAP's China Program. He advises central governmental and provincial decision-makers on power sector issues, among them governance and regulation, system operations, wholesale and retail pricing, end-use energy efficiency and long-term planning, renewables, air quality management, and low-carbon policies, including emissions trading schemes and multi-pollutant strategies. More recently Mr. Weston has been assisting RAP's European Program primarily in Poland and Germany.

Mr. Weston joined RAP in 1999 after eleven years as an economist and hearing officer with the Vermont Public Service Board, the state's utility regulator. His work stretched over a wide variety of matters, including the design and implementation of integrated least-cost plans, power purchases, rate-setting and rate design, competition in local telecommunications service, and the creation of Efficiency Vermont, the nation's first "energy efficiency utility." In the mid-1990s, he was co-chair of the National Association of Regulatory Utility Commissioners' (NARUC) staff subcommittee to the Committee on Energy Conservation (now Energy Resources and the Environment). He also served as co-chair of NARUC's Staff Subcommittee on Electric Industry Restructuring.

Before joining the Public Service Board, Mr. Weston was an energy and economic consultant for clients in the U.S. and Middle East, and was employed with the American International Group in Saudi Arabia from 1981 to 1984.

Anders Hove

Anders Hove is Associate Director of Research at the Paulson Institute. He guides the Institute's research work related to China air quality and climate change, developing insights related to policy, market and technology solutions. He also provides research support for other Institute programs. Hove has more than 15 years of public and private sector experience related to energy policy and markets, including nine years on Wall Street and four years in China. He began his career as an energy policy analyst with the Rand Corporation in Washington, DC, then performed equity research in the electric utilities and oil services sectors with Deutsche Bank AG and Jefferies and Co. Hove has both a Master of Science and a Bachelor of Science in Political Science from MIT, and he is a Chartered Financial Analyst.

ACKNOWLEDGEMENTS

The Paulson Institute is grateful for the support of many esteemed individuals and organizations for their insights and contributions to this paper.

We extend a special thanks to the co-authors for their significant contributions over many months. We also thank our strategic advisors who offered valuable recommendations on paper content and our advocacy approach during the roundtable and in follow-up discussions. We express our gratitude to the external reviewers who offered feedback on content and tone of the paper.

Also, to seek broad insights from a diverse group of stakeholders and experts, Paulson Institute held the *Stronger Markets, Cleaner Air Power Sector Dialogue* in early June to refine a draft version of this policy paper and its suggestions to the Chinese government. With the support of the Chinese Enterprise Management Science Foundation and the China Enterprise Confederation, around thirty experts from business, government, academia, business and social organizations provided their inputs via a moderated roundtable discussion. We express our sincere gratitude to the organizations listed below for their contributions.

- AVIC International Renewable Energy
- Beijing Development and Reform Commission (DRC)
- China Enterprise Management Science Foundation (CEMSF)
- China Power Investment Corporation (CPI)
- Chinese Academy of Sciences (CAS)
- Chinese Academy of Social Sciences (CASS)
- Development Research Center, State Council P.R. China (DRC)
- Energy Foundation (EF)
- Energy Review
- Hebei Demand-Side Management Center
- Institute for Industrial Productivity (IIP)
- Ministry of Industry and Information Technology (MIIT)
- Ministry of Science & Technology (MOST)
- NDRC, Energy Research Institute (ERI)
- North China Electric Power University
- Natural Resources Defense Council (NRDC)
- Pricing Monitoring Center, NDRC
- Regulatory Assistance Project (RAP)
- State-owned Assets Supervision and Administration Commission (SASAC)
- Society of Automotive Engineers China (SAE-China)
- State Grid Energy Research Institute

Finally, we would also like to thank Elle Carberry, Chelsea Eakin, Dinda Elliott, Lini Fu (付莉霓), Kate Gordon, Hortense Halle-Yang, Cindy Jiang (姜新燕), Lily Lou (娄雪莲) and Amy Wan (万婧) of the Paulson Institute. We extend a special thanks to Yuanping Yin (尹援平), Feifei Wang (王菲菲) and Wu Yu (于武) of the Chinese Enterprise Management Science Foundation and China Enterprise Confederation, as well as Chi Hu (胡迟) of the State-owned Assets Supervision and Administration Commission of the State Council (SASAC). We would also like to thank David Crossley, Christopher James and David Moskovitz of the Regulatory Assistance Project, Fredrich Kahrl of Energy and Environmental Economic, Inc., as well as Mahesh Dushakaran of IBM for reviewing early drafts of this document.

Those acknowledged do not necessarily endorse the views expressed in the paper.

REFERENCES

1. “关于进一步深化电力体制改革的若干意见” [Deepening Reform of the Power Sector],” China State Council, Document #9, March 21, 2015, accessed at http://www.ne21.com/news/show-64821.html.

2. Supporting announcements on renewables integration, demand-side management, grid company regulation, and cross-provincial trading of renewables have already appeared, with more expected in the coming months.

3. For a broad view of power sector reform challenges in China, as well as detailed discussion of a full range of policy recommendations, see “Low-Carbon Power Sector Regulation: Options for China,” Consultant’s Report Commissioned by the World Bank, Regulatory Assistance Project, Draft Final, February 2015, accessed at www.raponline.org/document/download/id/7582. See also “Next steps -Recommendations for Power Sector Policy in China,” Regulatory Assistance Project, 2013, accessed at http://www.raponline.org/document/download/id/6869. For discussion of China’s challenges from the perspective of developments in other countries, see RAP, “Low-Carbon Power Sector Regulation: International Experience from Brazil, Europe, and the United States,” Consultant’s Report Commissioned by the World Bank, Regulatory Assistance Project, 2014, accessed at http://raponline.org/document/download/id/7432.

4. “国家发展改革委关于内蒙古西部电网; 输配电价改革试点方案的批复,” National Development and Reform Commission, 2015, accessed at http://bgt.ndrc.gov.cn/zcfb/201506/t20150615_696101.html.

5. “Corporate Social Responsibility Report 2013,” State Grid Corporation of China, 2014, accessed at http://www.sgcc.com.cn/images/ywlm/socialresponsiility/brief/2014/10/23/2FE46B3DA8D748AF3A0F1854CD73F75D.pdf.

6. Herman K. Trabish, “Texas and Inner Mongolia Need Transmission to Integrate Wind,” Greentech Media, February 19, 2013, accessed at http://www.greentechmedia.com/articles/read/Texas-and-Inner-Mongolia-Need-Transmission-to-Integrate-Wind.

7. “China,” U.S. Department of Energy, Energy Information Administration, 2013, accessed at http://www.eia.gov/countries/country-data.cfm?fips=ch#elec.

8. “2014年1-10月份电力统计数据一览表,” China Electricity Council, November 20, 2014, accessed at http://www.cec.org.cn/guihuayutongji/tongjxinxi/yuedushuju/2014-11-20/130211.html.

9. “International Energy Statistics: Total Electricity Installed Capacity (Million Kilowatts),” U.S. Department of Energy, Energy Information Administration, accessed December 6, 2014, at http://www.eia.gov/cfapps/ipdbproject/IEDIndex3.cfm?tid=2&pid=2&aid=7.

10. “Newly installed power generation capacity China 2010-2013,” Statistica, 2014, accessed at http://www.statista.com/statistics/302301/china-power-generation-installed-capacity-added/.

11. The nature and extent of capacity additions in coming years will depend, in part, on the course of the reforms discussed in this paper. The following offers some references regarding some recent projections and government targets. “Rise in China's coal-fired capacity in 2014, 2015 may not boost thermal coal prices: UBS,” Platts, May 20, 2014, accessed at http://www.platts.com/latest-news/coal/singapore/rise-in-chinas-coal-fired-capacity-in-2014-2015-21573872; “China unveils energy strategy, targets for 2020,” Xinhua, November 19, 2014, accessed at http://news.xinhuanet.com/english/china/2014-11/19/c_133801014.htm; “CEC publishes the Demand/Supply Analysis and Forecast of China Power Industry 2014,” China Electricity Council, 2014, accessed at http://english.cec.org.cn/No.105.1534.htm.”

12. China’s total installed capacity of renewable energy in the power sector tripled between 2005 and 2013, to 380 GW (including hydro). China now has the most installed onshore wind capacity of any country in the world. In addition, China is very close to meeting its target of 100 GW of grid-connected wind capacity by 2015, and has a 2020 target of 200 GW. China is also investing heavily in installed solar photovoltaic (PV) generation capacity, with an estimated 28 GW at the end of 2014. Of this, 23.4 GW is from utility-scale PV and the remainder is from distributed PV installations. China has PV capacity goals of 35 GW by 2015 and 100 GW by 2020. “国务院办公厅关于印发能源发展战略行动计划 (2014-2020年) 的通知” [State Council Office Issues Energy Strategy Action Plan], Document #31, China State Council, November 19, 2014, accessed at http://www.gov.cn/zhengce/content/2014-11/19/content_9222.htm; “GWEC Global Wind Statistics 2014,” Global Wind Energy Council, February 10, 2015, accessed at http://www.gwec.net/wp-content/uploads/2015/02/GWEC_GlobalWindStats2014_FINAL_10.2.2015.pdf; “China installed wind power capacity hits 7 pct. of total in 2014,” Reuters, February 12, 2015, accessed at http://www.reuters.com/article/2015/02/12/china-power-windpower-idUSL4N0VM3XJ20150212; Vincent Shaw, “China: PV installed capacity grows to almost 30 GW in 2014,” PV Magazine, February 16, 2014, accessed at http://www.pv-magazine.com/news/details/beitrag/china--pv-installed-capacity-grows-to-almost-30-gw-in-2014_100018231/#axzz3XLh8NZIA.

13. “China 2050 High Renewable Energy Penetration Scenario and Roadmap Study,” Energy Research Institute of the National Development and Reform Commission, April 2015, accessed at http://www.efchina.org/Attachments/Report/report-20150420/China-2050-High-Renewable-Energy-Penetration-Scenario-and-Roadmap-Study-Executive-Summary.pdf(English); Chinese version available at http://www.efchina.org/Attachments/Report/report-20150420/中国2050高比例可再生能源发展情景暨途径研究-摘要报告.pdf

14. “Program for Electricity System Reform” (国发2002, 5号), China State Council, 2002.

15. Hongliang Yang, “Overview of the Chinese Electricity Industry and its Current Uses,” Electric Power Research Group, February 2006, accessed at http://www.eprg.group.cam.ac.uk/wp-content/uploads/2014/01/eprg0517.pdf, page 32.

16. Frederich Kahrl and Wang Xuan, “Integrating Renewables into Power Systems in China: A Technical Primer: Power System Operations,” Regulatory Assistance Project, December 2014, accessed at http://www.raponline.org/document/download/id/7459.

17. “State Grid Corporation of China Profile,” Zpryme Smart Grid Insights, March 2012, accessed at http://cdm.unfccc.int/filestorage/m/n/ZLAKFVJ73GYIM5SP4XOECT0BW9HR62.pdf/Attachment-2_State%20Grid%20Corporation%20of%20China%20Profile.pdf?t=Z0x8bmc1eWh0fDA_YmlH8ZADvdU7SP9MHO2Z. “[State Grid] supplies power to 88% of China…” Michael Davidson, “China's Electricity Sector at a Glance: 2013,” The Energy Collective, February 3, 2014, accessed at http://theenergycollective.com/michael-davidson/335271/china-s-electricity-sector-glance-2013.

18. Dexter Roberts, “China's Economic Policy Factory: The NDRC,” Business Week, June 20, 2013, accessed at http://www.businessweek.com/articles/2013-06-20/chinas-economic-policy-factory-the-ndrc.

19. “NDRC launches power transmission & distribution price pilot reform in Shenzhen,” Xinhua, November 6, 2014, accessed at http://en.xinhua08.com/a/20141106/1408477.shtml.

20. Also in March, the NDRC and NEA issued a “guidance” document with much more detail on dispatch and renewable integration issues: “发展改革委、能源局关于改善电力运行调节促进清洁能源多发满发的指导意见” National Development and Reform Commission and National Energy Agency, March 23, 2015, accessed at http://www.gov.cn/xinwen/2015-03/23/content_2837637.htm. For an overview and commentary, see http://www.raponline.org/featured-work/chinese-government-releases-major-policy-guidance-on-renewable-integration-and-related.

21. For more detail, see Frederich Kahrl and Wang Xuan, “Integrating Renewables into Power Systems in China: A Technical Primer: Power System Operations,” Regulatory Assistance Project, December 2014, accessed at http://www.raponline.org/document/download/id/7459.

22. “Recommendations for Power Sector Policy in China,” Regulatory Assistance Project, October 2013, accessed at http://www.raponline.org/document/download/id/6869.

23. “Economic Dispatch: Concepts, Practices and Issues,” U.S. Federal Energy Regulatory Commission, November 13, 2005, accessed at http://www.ferc.gov/eventcalendar/Files/20051110172953-FERC%20Staff%20Presentation.pdf.

24. Lori Bird, Jaquelin Cochran, and Xi Wang, “Wind and Solar Energy Curtailment: Experience and Practices in the United States,” U.S. National Renewable Energy Laboratory, NREL/TP-6A20-60983, 2014, http://www.nrel.gov/docs/fy14osti/60983.pdf.

25. Adapted from “Glossary,” U.S. Department of Energy, Energy Information Administration, accessed December 16, 2014 at http://www.eia.gov/tools/glossary/index.cfm?id=W; and Jaquelin Cochran et al., “Market Evolution: Wholesale Electricity Market Design for 21st Century Power Systems,” National Renewable Energy Laboratory (NREL), NREL/TP-6A20-57477, October 2013, accessed at http://www.nrel.gov/docs/fy14osti/57477.pdf.

26. “New analysis: U.S. is world’s number one wind energy producer, leading China and Germany,” American Wind Energy Council, November 11, 2014, accessed at http://www.awea.org/MediaCenter/pressrelease.aspx?ItemNumber=6965.

27. A related problem is ensuring timely connection of renewable energy resources to the grid, although discussion of that problem is beyond the scope of this paper.

28. Paulson Institute calculation. Curtailment of 16 TWh in 2013 (China), while Beijing consumed 87 TWh in 2012 and Tianjin 72 TWh, yielding an average combined monthly rate of about 13 TWh. "China Statistical Yearbook 2013," China Bureau of Statistics, 2013, accessed at http://www.stats.gov.cn/tjsj/ndsj/2013/indexch.htm. See table 8-14, "分地区电力消费量." China curtailment figures accessed at http://www.cnrec.org.cn/hd/2014-02-25-412.html.

29. David Stanway, "Dam waste: planning chaos drains China's hydro ambitions,"Reuters, June 6, 2015, accessed at http://www.reuters.com/article/2015/06/07/china-renewables-hydropower-idUSL3N0YB3UB20150607.

30. Brian Publicover, "In depth: China wind on the up," Recharge News, October 1, 2014, accessed at http://www.rechargenews.com/wind/1378299/IN-DEPTH-China-wind-on-the-up. For 2013 full year statistics, see "国家能源局召开风电产业监测沟通会," China National Renewable Energy Centre, February 25, 2014, accessed at http://www.cnrec.org.cn/hd/2014-02-25-412.html; "国家能源局关于做好2014年风电并网消纳工作的通知," National Energy Administration, Number 138, April 14, 2015, accessed at http://zfxxgk.nea.gov.cn/auto87/201404/t20140414_1787.htm; "国家能源局发文促风电并网消纳," Xinhua, April 7, 2014, accessed at http://news.xinhuanet.com/2015-04/07/c_1114890358.htm.

31. "2015年第一季度中国弃风弃光大调查," We Energy, June 23, 2015, accessed at http://mp.weixin.qq.com.

32. Brian Publicover, "In depth: China wind on the up," Recharge News, October 1, 2014, accessed at http://www.rechargenews.com/wind/1378299/IN-DEPTH-China-wind-on-the-up. For 2013 full year statistics, see "国家能源局召开风电产业监测沟通会," China National Renewable Energy Centre, February 25, 2014, accessed at http://www.cnrec.org.cn/hd/2014-02-25-412.html.

33. Lori Bird, Jaquelin Cochran, and Xi Wang, "Wind and Solar Energy Curtailment: Experience and Practices in the United States," U.S. National Renewable Energy Laboratory, NREL/TP-6A20-60983, 2014, http://www.nrel.gov/docs/fy14osti/60983.pdf. See graph on page 3.

34. Debra Lew, et al., "Wind and Solar Curtailment," National Renewable Energy Laboratory (NREL), Conference Paper, NREL/CP-5500-60245, September 2013, accessed at http://www.nrel.gov/docs/fy13osti/60245.pdf. See respective sections on Denmark and Italy.

35. In 2013, Gansu's curtailment rate was double that of the national average. "能源局监管甘肃可再生能源全省弃风率超20%," NDB, July 21, 2014, accessed at http://www.nbd.com.cn/articles/2014-07-21/850063.html.

36. "2014年第三季度重点地区光伏电站利用小时数浅析," BJX, December 15, 2014, accessed at http://guangfu.bjx.com.cn/news/20141215/573182.shtml.

37. Another issue has been the significant expansion of combined heat and power (CHP) generation in the northeast over the past decade. During the winter, dispatch centers (the system operator) operate CHP units to meet heating demand, and they are thus unable to be operated more flexibly in response to changes in electricity demand and wind output.

38. Jaquelin Cochran, Debra Lew, and Nikhil Kumar, "Flexible Coal," U.S. National Renewable Energy Laboratory, 2014, accessed at http://www.nrel.gov/docs/fy14osti/60575.pdf.

39. Kat Cheung, "Integration of Renewables Status and challenges in China," International Energy Agency, 2011, accessed at http://www.iea.org/publications/freepublications/publication/Integration_of_Renewables.pdf.

40. China's renewable energy law also includes a provision that renewable energy resources should be given 'priority dispatch' over other generation sources. In 2014, the NDRC also required grid companies to prioritize renewable energy in dispatch.

41. "发展改革委、能源局关于改善电力运行调节促进清洁能源多发满发的指导意见" [NDRC, NEA: Improving Power Operations, Adjusting Incentives for Clean Energy Production Guiding Opinion], China National Development and Reform Commission, March 23, 2015, accessed at http://www.gov.cn/xinwen/2015-03/23/content_2837637.htm.

42. Guo Qiaoxiong, "国家能源局召开风电产业监测沟通会," China National Renewable Energy Centre, February 25, 2014, accessed at http://www.cnrec.org.cn/hd/2014-02-25-412.html.

43. For a broader set of recommendations on renewable energy integration in China, see RAP's forthcoming paper for World Bank and RAP (2013) Next Steps.

44. L. Bird et al., "Wind and Solar Energy Curtailment: Experience and Practices in the United States," U.S. National Renewable Energy Laboratory, NREL Report No. TP-6A20-60983, 2014, accessed at http://www.nrel.gov/docs/fy14osti/60983.pdf.

45. Lori Bird, Jaquelin Cochran, and Xi Wang, "Wind and Solar Energy Curtailment: Experience and Practices in the United States," U.S. National Renewable Energy Laboratory, NREL/TP-6A20-60983, 2014, http://www.nrel.gov/docs/fy14osti/60983.pdf.

46. L. Bird et al., "Wind and Solar Energy Curtailment: Experience and Practices in the United States," U.S. National Renewable Energy Laboratory, NREL Report No. TP-6A20-60983, 2014, accessed at http://www.nrel.gov/docs/fy14osti/60983.pdf.

47. Debra Lew, et al., "Wind and Solar Curtailment," National Renewable Energy Laboratory (NREL), Conference Paper, NREL/CP-5500-60245, September 2013, accessed at http://www.nrel.gov/docs/fy13osti/60245.pdf. See respective sections on Denmark and Italy.

48. Herman K. Trabish, "Can performance-based ratemaking save utilities?" Utility Dive, April 17, 2014, accessed at http://www.utilitydive.com/news/can-performance-based-ratemaking-save-utilities/252683/.

49. "Revenue Regulation and Decoupling: A Guide to Theory and Application," Regulatory Assistance Project, 2011, accessed at www.raponline.org/document/download/id/902.

50. Max Dupuy, "Low-Carbon Power Sector Regulation: International Experience from Brazil, Europe, and the United States" Regulatory Assistance Project, December 2014, accessed at http://raponline.org/document/download/id/7432.

51. "NDRC launches power transmission & distribution price pilot reform in Shenzhen," Xinhua, November 6, 2014, accessed at http://en.xinhua08.com/a/20141106/1408477.shtml; David Crossley, Wang Xuan, and Helen He, "China Opens the Door for New Utility Business Model and More Energy Efficiency," Regulatory Assistance Project, November 12, 2014, accessed at http://www.raponline.org/featured-work/china-opens-the-door-for-new-utility-business-model-and-more-energy.

52. In a June 2015 announcement regarding transmission and distribution pricing for the grid company in western Inner Mongolia, the NDRC called for formulation of an incentive mechanism to reward the grid company for exceeding targets for various performance metrics, including demand-side management. See http://www.ne21.com/news/show-67462.html

53. "中电联: 中国电力工业现状与展望," Changzhou Research Institute, March 18, 2015, accessed at http://www.cari.com.cn/CariWeb/newsinfo.aspx?NewsID=1734.

54. See also "Next steps -Recommendations for Power Sector Policy in China", Regulatory Assistance Project, 2013, accessed at http://www.raponline.org/document/download/id/6869. For discussion of China's challenges from the perspective of developments in other countries, see Max Dupuy, "Low-Carbon Power Sector Regulation: International Experience from Brazil, Europe, and the United States" Regulatory Assistance Project, December 2014, accessed at http://raponline.org/document/download/id/7432.

55. "California Long-Term Energy Efficiency Strategic Plan," California Public Utilities Commission, September 2008, accessed at http://www.cpuc.ca.gov/NR/rdonlyres/D4321448-208C-48F9-9F62-1BBB14A8D717/0/EEStrategicPlan.pdf. In addition, California has implemented a energy resource "loading order" policy to guide energy resource decisions. The purpose of the loading order is to reduce electricity demand by increasing energy efficiency and demand response, and to meet new generation needs first with renewable and distributed generation resources, and second with clean fossil-fuel generation. The loading order policy was codified by statute in 2005.

56. "电力发展规划，应当体现合理利用能源、电源与电网配套发展、提高经济效益和有利于环境保护的原则" [Power Development Planning: Principles for Appropriately Using Energy, Power and the Grid System; Raising Economic Efficiency; and Benefiting Environmental Protection], National Energy Agency, January 4, 2012, accessed at http://www.nea.gov.cn/2012-01/04/c_131262818.htm.

57. "国家能源局关于推进简政放权放管结合优化服务的实施意见国能法改[2015]199号," National Energy Agency, June 5, 2015, accessed at http://zfxxgk.nea.gov.cn/auto81/201506/t20150610_1936.htm.

58. Wang Zuo, "10家新能源公司涉"未批先建"被点名," People.Cn, November 19, 2014, accessed at http://energy.people.com.cn/n/2014/1120/c71661-26059388.html.

59. Max Dupuy, "Low-Carbon Power Sector Regulation: International Experience from Brazil, Europe, and the United States" Regulatory Assistance Project, December 2014, accessed at http://raponline.org/document/download/id/7432; Rachel Wilson and Bruce Biewald, "Best Practices in Electric Utility Integrated Resource Planning," Regulatory Assistance Project, June 2013, accessed at http://www.raponline.org/document/download/id/6608.

60. For more discussion of IRP, see Chapter 2 of "Low-Carbon Power Sector Regulation: Options for China," Consultant's Report Commissioned by the World Bank, Regulatory Assistance Project, Draft Final, February 2015, accessed at www.raponline.org/document/download/id/7582. See also http://www.sgeri.sgcc.com.cn/html/sgeri/col1080000045/2013-07/08/20130708145951065319786_1.html, which provides a more theoretical view.

61. Mao Xianqiang and Hu Tao, "Co-control of CO2 and Local Air Pollutants in the Electric Power Industry of China," Wilson Center, March 14, 2012 accessed at http://www.wilsoncenter.org/sites/default/files/Mao%20Xianqiang%20-Co-Control-03142012.pdf, "New Report Finds Energy Efficiency is America's Cheapest Energy Resource," American Council for an Energy Efficient Economy (ACEEE), 2014, accessed at http://aceee.org/press/2014/03/new-report-finds-energy-efficiency-a; Megan A. Billingsley et al., "Program Administrator Cost of Saved Energy for Utility Customer-Funded Energy Efficiency Programs in the United States," Energy Technology Area, March 2014, accessed at http://eetd.lbl.gov/news/article/57600/program-administrator-cost-of-s; Rebecca Schultz, "Energy Efficiency Power Plants: A Policy Option for Climate-friendly Air Quality Management in China," Regulatory Assistance Project, November 2009, accessed at http://www.raponline.org/document/download/id/265.

62. "关于印发《电力需求侧管理办法》的通知" [Demand Side Management Measures], Document #2643 , National Development and Reform Commission, November 4, 2010, accessed at http://www.ndrc.gov.cn/fzgggz/jjyx/dzxqcgl/201011/t20101116_381342.html; David Crossley, "Energy Efficiency as a Resource for the Power Sector in China," Regulatory Assistance Project, August 2014, accessed at www.raponline.org/document/download/id/7259.


保尔森基金会
PAULSON INSTITUTE