中国电力圆桌
POWER SECTOR ROUNDTABLE

Policy Brief

Renewable Energy Integration:
US Experience and Recommendations for China

Power Sector Roundtable Working Group

November 2017

Power Sector Roundtable (PSR)

NRDC launched the Power Sector Roundtable (PSR) in 2015, aiming at addressing climate change and supporting China's efforts in power sector low-carbon transition. PSR provides an open platform for dialogues within a diverse group of policymakers, industry experts, researchers, and NGO representatives. As the current round of Chinese power sector reform involves a wide spectrum of stakeholders representing a multitude of perspectives and interests, the Power Sector Roundtable was designed from its inception as a forum and an ongoing channel for discussion of critical and contentious reform issues. These exchanges and analyses will inform policymakers with an on-the-ground picture of the effects of the reform across industrial sectors, and in turn, support policy implementation.

Power Sector Roundtable Working Group

NRDC

The Natural Resources Defense Council (NRDC) is an international nonprofit environmental organization with more than 3 million members and online supporters. Since 1970, our lawyers, scientists, and other environmental specialists have worked to protect the world's natural resources, public health, and the environment. NRDC works in countries and regions including the United States, China, India, Canada, Mexico, Chile, Costa Rica, and the European Union.

RAP®

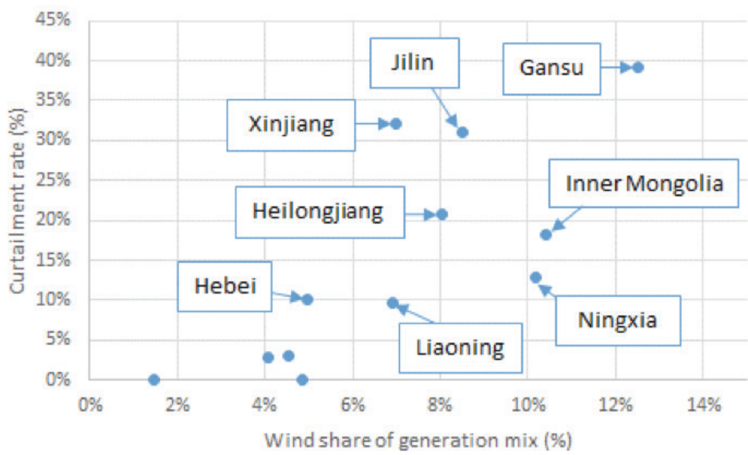
The Regulatory Assistance Project (RAP)® is an independent, non-partisan, non-governmental organization dedicated to accelerating the transition to a clean, reliable, and efficient energy future. We help energy and air quality regulators and NGOs navigate the complexities of power sector policy, regulation, and markets and develop innovative and practical solutions designed to meet local conditions. We focus on the world's four largest power markets: China, Europe, India, and the United States. Visit our website at www.raponline.org to learn more about our work.

1 Introduction

Countries around the world are facing challenges in integrating rising amounts of renewable energy into their electricity systems. Given that wind and solar generation varies with weather conditions, a major challenge is increasing the flexibility of electricity systems in order to make the most economic use of these resources.

Unfortunately, curtailment of renewable energy has reached very high levels in China and is threatening to become a bottleneck to further renewable energy development (Figure 1). This is a complex problem, with many different sources, including inefficient dispatch, difficulties in coordinating the electricity and heating sectors, and insufficient transmission capacity.

Figure 1. Wind curtailment rates as a function of wind penetration by province in China, 2015[1]



The 13th Five-Year Plan recognizes the importance of the problem and sets a goal of reducing curtailment to below 5% by 2020. The National Development and Reform Commission (NDRC) and National Energy Administration (NEA) have issued a string of policies to promote renewable energy integration and have launched several related pilots in provinces with high curtailment. Together, these policies and pilots comprise an overlapping set of measures—of which some have moved ahead, while others have yet to be fleshed out and implemented. Particular measures include guaranteed minimum generation hours for renewable energy, promoting electric heating and other electric loads that could help absorb renewable energy, and implementation of an "ancillary services market" in the Northeast grid region under which wind generators pay coal generators to reduce their generation.

1 Wind curtailment data for China are from the National Energy Administration (NEA), "Development of the Wind Industry, 2015" (2015年风电产业发展情况), http://www.nea.gov.cn/2016-02/02/c_135066586.htm. Generation data in "wind share of generation mix" are from a variety of online sources; generation data for Ningxia and Hebei were estimated.

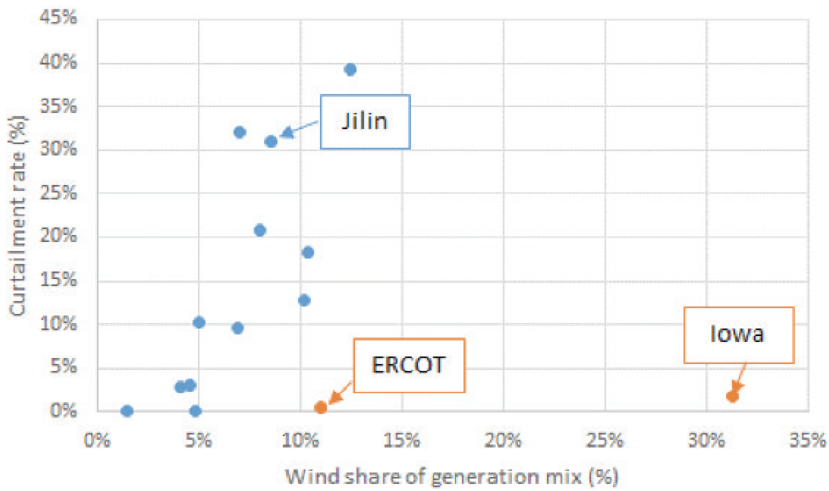
Improving flexibility and reducing curtailment requires innovation in regulation, market design, planning, and incentives. As efforts in China evolve, the efforts of other countries to struggle with similar challenges will continue to provide a valuable reference. As with the other papers in this series, here we provide an overview of international developments—with a focus on US experience, given the need to keep this discussion brief—and then briefly set out some implications and questions for China.

2 US Experience with Renewable Integration

Many US states have aggressive goals for renewable energy. Rising penetrations of wind and solar generation in these states have required changes in market designs, system operations, and regulation. Areas that have historically operated as separate control areas are also now exploring strategies for better coordinating their operations, to deal with wind and solar variability and uncertainty.

In the US, the longstanding "economic" approach to dispatch—where resources with low operational costs are dispatched before resources with higher costs—has been a major ingredient in maintaining low levels of curtailment. This is because variable renewable generation (VRG: wind, solar, and run-of-river hydropower) has near zero operational costs, and thus is dispatched first. For instance, economic dispatch of wind in Texas (ERCOT) and Colorado (Xcel Energy) has helped to keep curtailment to less than 5%, despite limited interconnections with neighboring states and wind penetrations that are on par with Gansu Province. Coordination of increasingly sophisticated wind and solar forecasting with power system dispatch has also been an important part of the picture.

Figure 2. Wind curtailment relative to wind penetration in China's twelve largest wind producing provinces, Texas (ERCOT) and Iowa, 2015[2]



2 China data as in Figure 1. Curtailment data are from US Department of Energy (2016). 2015 Wind Technologies Market Report. Retrieved from: https://emp.lbl.gov/sites/all/files/2015-windtechreport.final_.pdf. Penetration data are from ERCOT (2016). Energy use in ERCOT region grows 2.2 percent in 2015. Retrieved from: http://www.ercot.com/news/releases/show/86617. Iowa wind penetration is from Iowa Utilities Board (undated). Wind-powered Electricity Generation in Iowa. Retrieved from: https://iub.iowa.gov/wind-powered-electricity-generation.

An important consideration for policymakers and regulators is how to balance two broad ways to increase system flexibility: (1) changes in regulation and market design, and (2) investing in new flexible resources, such as gas-fired generation or energy storage. An emerging consensus in the US is that increasing the flexibility in existing systems will be less expensive than investing in new resources that increase flexibility, although certainly investment in new resources has played a significant role to date. Table 1 provides examples of measures to increase existing system flexibility, and new resources that increase system flexibility.

Table 1. Examples of measures for increasing existing system flexibility and new resources that increase system flexibility.

Increasing flexibility of existing system	Adding new resources to boost flexibility
• Revisions to grid codes, operating processes, regulations, market designs • Encouraging portfolio diversity in VRG and spatial diversity in the location of VRG • Changes in retail tariffs to promote demand-side flexibility • Expanded balancing areas	• Energy storage • New transmission • New, more flexible generation

Looking more closely at increasing the flexibility of the existing system, we can identify three topics that have been particularly important:

- Congestion management.
- Regional balancing.
- Flexibility incentives.

2.1 Congestion Management

Congestion can be defined as the condition in which generation plus export capability in a part of the transmission system exceeds load. When congestion occurs, the system operator must ensure that the transmission system is not overloaded (i.e., frequency is maintained), and thus typically takes action to curtail certain generators. There are many ways that the system operator can go about this at any given moment, and the challenge is to ensure that management of congestion is done in the most efficient and least cost manner. To put this a different way, management of congestion should be done in a way that is "economic."

In any country, there are several general reasons why non-economic management of VRG-related congestion might occur, including:

• Inadequate software and controls—system operators may not have sufficient visibility or control over the system to dispatch it in an economic manner.[3]

• Poor quality (or poor use of) VRG forecasts—unanticipated levels of VRG will mean that system operators do not have the most economic generation online to respond to VRG.

3 This is generally not a problem in the US. Most system operators (except for some smaller balancing areas) have implemented adequate technology: security constrained unit commitment and economic dispatch (SCUC/SCED) software and energy management systems (EMS).

• Conflicts of interest—in cases where system operators also own (or are affiliated with) generation assets, the system operator may prefer to dispatch its own generation rather than dispatching other, more cost-effective generation.

• Market rules—rules governing bidding and scheduling may allow generators to be dispatched uneconomically in some situations.

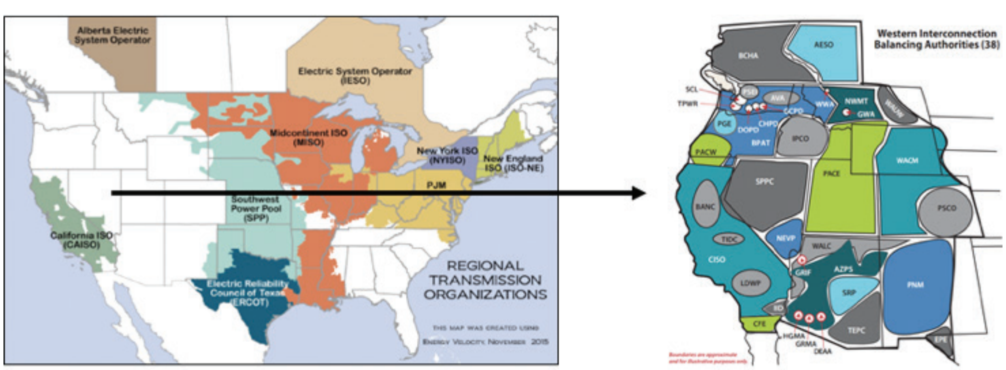
In the US, the Federal Energy Regulatory Commission's (FERC's) "open access" regulations are the main regulatory framework governing congestion management, and are largely focused on the third and fourth items from the above list.[4] FERC's regulations require transmission owners (which may be utilities that possess both generation and transmission assets) to provide all generators, regardless of ownership, with access to the transmission system on an equal footing.

Some parts of the US have implemented a system of dispatch based on real-time ("spot") markets with locational marginal prices (LMPs), which feature different prices for different locations ("nodes") on the grid.[5] Without nodal dispatch, system operators are forced to choose which generators to re-dispatch when transmission lines become congested, such as during periods of high wind generation and low loads in one part of the system. With nodal dispatch, these re-dispatch decisions are made automatically using security-constrained economic dispatch software. Reducing the need for manual re-dispatch during congestion events enables VRG to be dispatched more economically.

2.2 Regional Balancing

The Western US has more than 35 balancing areas, many of which are relatively small. In each of these balancing areas, system operators have traditionally balanced their systems independently. Higher VRG penetrations in the Western region have spurred efforts at better coordination in order to take advantage of the way in which the variability of VRG tends to even out over larger geographic areas.

Figure 3. Formation of the Western Energy Imbalance Market



4 See FERC Orders 888, 889, 890, 2000.
5 These regions are known as ISO/RTO regions. For more discussion, see the article in this series on wholesale electricity markets.

This reform has included:

• The Western Energy Imbalance Market (EIM), a real-time balancing mechanism featuring competitive bidding created by the California Independent System Operator (CAISO) and PacifiCorp. (See Figure 3.) The EIM, which became operational in 2014, will cover at least nine utilities in the Western region by 2019. It is an intra-hour balancing market, which means that it does not affect utility day-ahead or hour-ahead schedules.

• Joint Dispatch Service (JDS), a real-time balancing mechanism based on reported costs created by the Public Service Company (PSCo) of Colorado. JDS currently covers three utilities, including PSCo. It is also an intra-hour balancing mechanism, and only affects generator operations within the hour.

The EIM is essentially an extension of the CAISO's existing real-time market software to neighboring balancing areas. Thus, it is complex and already reflects much of CAISO's decades-long accumulated experience with real-time markets. The JDS, on the other hand, is more basic and accessible.

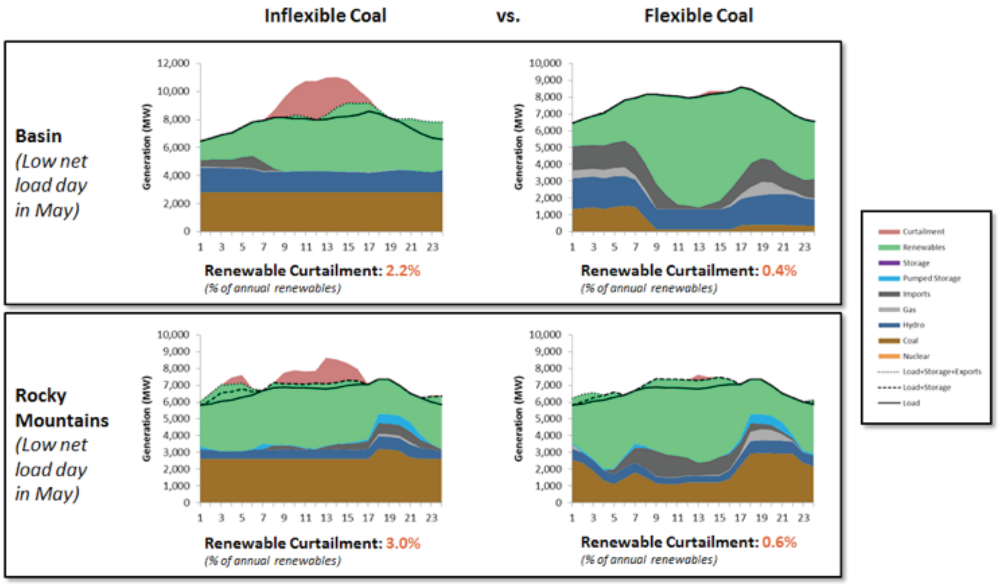
Under JDS, utilities submit heat rate curves, fuel prices, and variable operations and maintenance (O&M) costs for each generation unit. This information is submitted to a web portal and directly into PSCo's optimization software, so that PSCo does not see the information submitted by utilities. Each utility submits a balanced schedule to PSCo before the hour. PSCo then conducts a security constrained least-cost dispatch of all eligible generation in real-time. Prices for the deviation between scheduled and actual generation are settled based on the marginal system cost calculated from PSCo's real-time optimization.

2.3 Flexibility Incentives

Policymakers in various parts of the US have introduced new incentive mechanisms to encourage more flexible operation of thermal generation units and more demand-side flexibility. Historically, coal-fired generation units acted as baseload generation in the US. That is, system operators dispatched the electricity system to keep the output of these coal units relatively constant over time. Before the appearance of significant amounts of VRG capacity and before the fall in natural gas fuel prices, this made some degree of economic sense: coal units tended to be the resources with the lowest operational cost. However, rising VRG penetrations will require more ramping, low minimum generation levels, and potentially more startups and shutdowns for coal-fired units still in operation. Greater flexibility in coal units can help to economically reduce VRG curtailment.

Figure 4 illustrates the benefits of increased coal unit flexibility for VRG curtailment, based on an assessment of the Western Electricity Coordinating Council region. The figure shows dispatch for an illustrative day (which in this case is in May and features low load). Two sub-regions (Basin and Rocky Mountains) are represented. In the left-hand side, coal units are assumed to be inflexible (specifically, to have high minimum generation limits). This results in substantial VRG curtailment (red shaded area). In the right-hand side, coal units have lower minimum generation units, which results in absorption of more VRG.

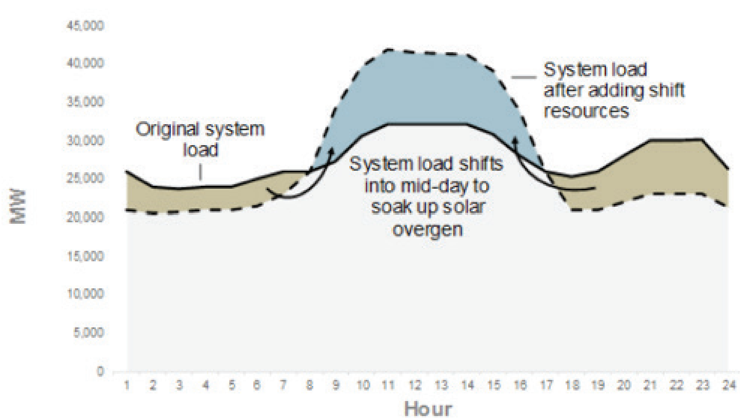
Figure 4. Illustration of inflexible and flexible coal operation[6]



More flexible operation of coal units often requires retrofits, increases operational costs, and reduces generator lifetimes. Thus, encouraging coal units to operate more flexibly requires providing adequate incentives to generators or utilities.

Demand-side flexibility has evolved from programs that were originally intended for “emergency” situations. In recent years, new demand response (load shifting) programs have been implemented to better support VRG. (Figure 5.)

Figure 5. Illustration of load shifting to support VRG integration in California[7]



6 E3. (2016b). Western Interconnection Flexibility Assessment, 2016. Retrieved from: https://www.wecc.biz/Administrative/E3_WECC_WIEB_FlexAssessment_2016-01-27.pdf

7 Lawrence Berkeley National Laboratory. (2016). Final Report on Phase 2 Results: 2015 California Demand Response Potential Study. Retrieved from: http://www.cpuc.ca.gov/WorkArea/DownloadAsset.aspx?id=6442451541

There has been significant discussion in the US about designing incentive mechanisms to encourage demand-side resources to shift net loads (electric vehicles, energy storage, and distributed generation) to follow VRG throughout the course of the day. How best to provide these incentives is a matter of ongoing debate. One proposal in New York and Hawaii is an opt-in “full value tariff” that tracks changes in system marginal cost, but still allows for fixed cost recovery of embedded costs for transmission and distribution infrastructure. During periods of high VRG output, marginal costs (and thus retail prices) will be low, encouraging consumption. During periods of low output, marginal costs and retail prices will be higher, encouraging reductions in load or increases in generation by DG providers.

3 Conclusions and Questions for Further Research and Discussion

• Renewable energy curtailment in China is an urgent and complex problem, requiring solutions in planning, policy, market design, regulation, operations (dispatch), and resource flexibility. All of these have a role to play in increasing system flexibility in order to support higher penetrations of VRG.

• In the US, there is an emerging consensus that the existing power system can be made substantially more flexible at reasonably low cost. These low-cost solutions include wider balancing areas, policies and pricing to promote demand-side flexibility, and incentives for existing conventional generators to operate more flexibly. New investments in transmission, storage, and flexible gas-fired generation can also be helpful for integrating renewable energy—but are typically less cost effective.

• The same is likely to be the case in China. Determining where and how to best increase the flexibility of China's existing electricity systems is a critical area of inquiry.

• Improved dispatch and better short-term wholesale pricing mechanisms are among the reforms that can be highly beneficial in China. Indeed, these have been part of the Document #9 effort—although consensus on a sufficiently detailed path forward has yet to emerge. The effort to design electricity markets will need to be done very carefully, with a focus on promoting flexibility in support of VRG.

• More specifically, we suggest careful consideration of the following questions as China moves ahead with power sector reform and the implementation of new electricity markets:

o When and how should dispatch centers begin to use economic dispatch software (SCUC/SCED) and controls that reflect the underlying system costs? How can this best be phased in, given efforts to phase out the annual generation output planning system?

o How best to improve (and make better use of) VRG forecasting?

o How can the spot market be designed to economically reduce curtailment?

• The Northeast ancillary services market could provide a useful model for how to encourage coal generators to increase operational flexibility in China.

o Are the incentives provided through the market sufficient to encourage meaningful reductions in coal generators' minimum generation levels?

• There is significant potential to increase demand-side flexibility in China, but current retail tariff structures and incentives are missing.

o Could time-differentiated rates do more to help to provide those incentives?

o Are additional incentives needed?

Recycled paper.

中国电力圆桌
POWER SECTOR ROUNDTABLE

Natural Resources Protection Association
Taikang finance building, No. 38, East sanhuan North Road,
Chaoyang District, China, 1706
P.C. :100026
Tel. :+86-10-5927 0688
www.nrdc.cn