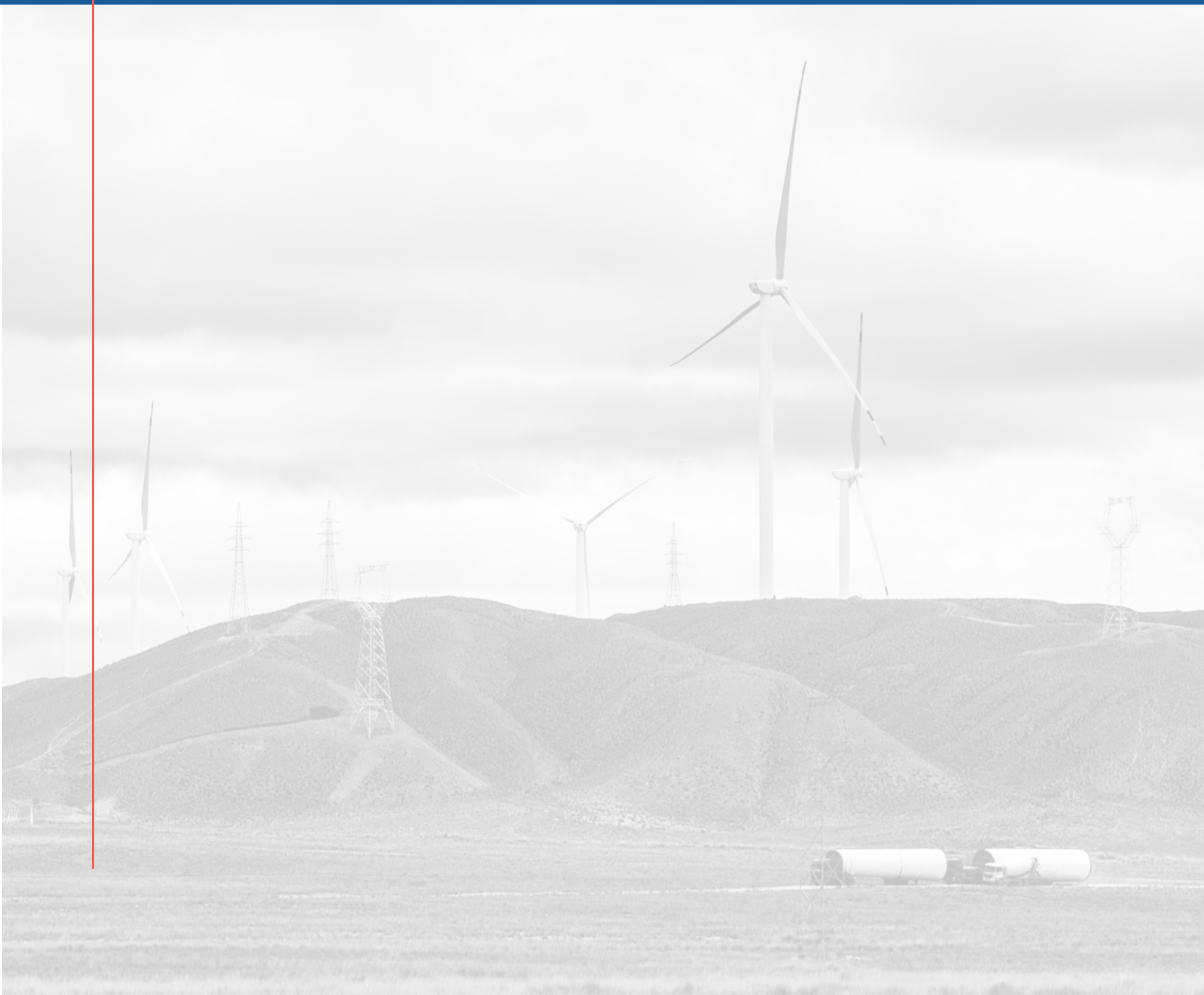
MAY 2021

REGULATORY ASSISTANCE PROJECT

Road Map for Power Sector Transition and Coal Generation Retirement in Northwest China

Policy and Regulatory Strategies



Introduction[1]

China's central government has outlined ambitious goals that imply substantial changes for the power sector, including carbon peaking and carbon neutrality goals, and increasingly stringent air quality standards. At the same time, the government has ongoing objectives to reduce power system costs and maintain reliability. To meet all these goals, the country's power sector will need to transition from a coal-dominated generation mix to a more carefully targeted mix of non-fossil resources. This transition will require continued policy reform focused on advancing environmental objectives while improving operational and investment efficiency.

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To meet China's ambitious new climate and energy goals (see the text box on the next page), it is clear the power sector will need to change dramatically. Fortunately, the cost of constructing wind and solar generation and storage capacity has fallen significantly in recent years. However, to take full advantage of the cost reductions, ensure an optimal mix of resources, motivate rational coal retirement and promote efficient power system operation, there is much to be done in power sector reform and related energy policy areas. Many countries are struggling with broadly similar challenges of policy reform to support decarbonization, although each faces particular problems and barriers.

In this power sector transition, Northwest China faces similar challenges to other parts of the country and other parts of the world. It also has unique opportunities and challenges. The Northwest has abundant renewable energy resource potential and a longstanding tradition of regional cooperation in the electricity sector. It also has significant overcapacity in coal generation and is the pilot region for a new national coal asset restructuring effort, led by the State-owned Assets Supervision and Administration Commission (SASAC). The region also has had high levels of wind, solar and hydro curtailment, although curtailment levels have decreased in recent years. Finally, the region has economic development challenges that set it apart from the coastal provinces that have been the leaders of power sector reform to date.

Given excellent wind and solar resource potential, the Northwest has the opportunity to greatly expand net exports of non-fossil-fuel generation to the rest of China. Indeed, for these reasons, it is possible that the central government will eventually give the region more ambitious targets for renewable energy for 2030, so it is worthwhile thinking ahead and laying the groundwork. In any case, meeting the Northwest region's goals for power sector transition and taking advantage of cost-effective opportunities to export renewable energy to other regions will require renewed progress with power sector reform and related policy efforts, including those of SASAC — all on a coordinated basis across the region. This report recommends policy and

[1] This paper benefited from comments from and discussion with a group of expert reviewers in China.

The power sector and China's emissions goals

Recently, China's government announced a dramatic set of new emissions and energy goals. In September 2020, the government announced that China will meet its carbon peaking goal before 2030 and be carbon neutral by 2060. Then, in December, a statement targeted an increase in the share of non-fossil fuels in primary energy consumption to 25% by 2030, up from a previous commitment of 20%. According to a "policy recommendations" scenario released in October 2020 by Tsinghua University's Institute of Climate Change and Sustainable Development, this 25% non-fossil target will mean a 3.5% decline in total primary coal consumption between 2020 and 2030 and likely also a decline in coal use in China's electricity sector over that period.[2] In February 2021, the National Energy Administration issued a draft national policy providing more detail on the 25% goal, including a target for increasing the share of renewables in electricity generation to 40% by 2030, from 28% in 2019.[3, 4] Meanwhile, government officials are in the process of setting air quality improvement goals for 2025 under the 14th Five-Year Plan. Recent five-year plans have been successively more stringent in terms of air quality goals, and it is reasonable to expect that the 14th Five-Year Plan will continue that trend.[5]

regulatory strategies to support the power sector transition in Northwest China. These recommendations focus on three main areas: (1) taking a regional approach to grid operations to improve efficiency; (2) coordinating coal retirement initiatives across the central and regional levels; and (3) ensuring that planning processes are transparent, consistent and grounded in science. We offer practical next steps for power sector reform and related policy initiatives. The report draws on international experience as well as the reform experience in other parts of China.[6]

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[2] He, J. (2020, October 12). *Launch of the outcome of the research on China's long-term low-carbon development strategy and pathway* [Presentation], Section 8. Institute of Climate Change and Sustainable Development, Tsinghua University. https://www.efchina.org/Attachments/Program-Update-Attachments/programupdate-lceg-20201015/Public-Launch-of-Outcomes-China-s-Low-carbon-Development-Strategies-and-Transition-Pathways-ICCSD.pdf. Under the "policy recommendations" scenario, total primary energy consumption rises to around 6,000 metric tons carbon equivalent (Mtce) in 2030, from about 5,000 Mtce in 2020, with non-fossil energy accounting for 70% of the increase. Under the scenario, coal falls from 57% of energy consumption in 2020 to 45% in 2030, implying that total coal energy use will fall from approximately 2,800 Mtce in 2020 to 2,700 Mtce in 2030.

[3] Xie, E. (2021, February 10). Climate change: China's energy regulator proposes target of 40 per cent renewables by 2030. *South China Morning Post.* https://www.scmp.com/news/china/science/article/3121362/climate-change-chinas-energy-regulator-proposes-target-40-cent; and 北极星储能网. (2021, February 10). 能源局可再生能源消纳目标征意见！2030年全国统一消纳责任权重40%. http://chuneng.bjx.com.cn/news/20210210/1135946.shtml

[4] Whether the 2030 goals represent the best trajectory to meet China's 2060 goal will be a subject of ongoing cost-benefit research. Recent research examines the case of China, assuming a plausible rate of continued cost declines for wind and solar and evaluating a 2030 scenario with a 60% renewable energy target. The research finds significant cost savings of a 60% target over a lower renewables target, in light of inexpensive wind and solar. The expected net benefits of an expanded renewable energy target for 2030 are even larger when considering the social benefits associated with improved air quality. Lin, J., & He, G. (2021). *China can benefit from a more ambitious 2030 solar and wind target.* China Dialogue. https://chinadialogue.net/en/energy/china-can-benefit-from-a-more-ambitious-2030-solar-and-wind-target/. Meanwhile, another research team recently constructed a related scenario for meeting a below 2 degree goal. This scenario includes a 73% share of renewable energy in electricity generation by 2035. Energy Research Institute of Academy of Macroeconomic Research & China National Renewable Energy Centre. (2020). *China renewable energy outlook 2019.* https://www.ea-energianalyse.dk/en/publications/china-renewable-energy-outlook-2019/

[5] In addition to carbon emissions goals, the 14th Five-Year Plan will likely also include more stringent air quality standards throughout the country. In 2017, provinces in the Northwest region were required to begin meeting more stringent targets for reductions in fine particulate matter concentrations. "Optimizing and adjusting energy structure" (优化调整 能源结构), which aims to increase the share of non-emitting non-fossil-fuel generation, was a key component in some provinces' 2017 air quality plans and will likely become more important with electrification in the transportation, building and industrial sectors.

[6] For a discussion of power sector reform options in China's Southern Grid region, see Dupuy, M., Kahrl, F., & Wang, X. (2020). *'Energy revolution' and power sector reform: Insights on challenges in the China Southern Grid Region from a comparative international perspective.* Regulatory Assistance Project. https://www.raponline.org/knowledge-center/energy-revolution-power-sector-reform-insights-challenges-china-southern-grid-region-from-comparative-international-perspective/. The report was also published in Southern Grid Company's *Energy Observer.*

Report Organization

The report has two main sections:

- **Background: Key Issues in the Northwest** provides an overview of key context for power sector transition in Northwest China, including (1) rapid growth in renewable energy and challenges with integration; (2) overcapacity in coal generation and restructuring of coal generation ownership; and (3) initial development of electricity markets.
- **Policy and Regulatory Strategies for Power Sector Transition** recommends several approaches for Northwest China. These are organized as follows:

Operational Issues: Moving Toward Regional Economic Dispatch
Recommendation 1: Maintain and improve priority dispatch for renewables by empowering the regional grid company to adjust provincial hydropower and coal schedules.
Recommendation 2: Consider implementing time-differentiated on-grid prices.
Recommendation 3: Promote flexibility in delivering energy contracted under medium- and long-term (MLT) contracts, within the portfolios of individual generation companies.
Recommendation 4: Reallocate MLT contract payments on an ex-post basis to support efficient dispatch.
Recommendation 5: Continue to develop spot markets, with the goal of forming a regional spot market, perhaps with inspiration from U.S. regional transmission organizations.
Coal Asset Retirement Policy: Coordinating the Role of SASAC in Promoting Efficient Generator Behavior and Renewable Energy Integration
Recommendation 6: Harmonize SASAC coal restructuring efforts with broader power sector reform efforts.
Planning for Energy Transition: Encouraging Rational Investment and Retirement Decisions
Recommendation 7: Rationalize the process for identifying specific coal generation units for retirement.
Recommendation 8: Determine new resource investment mix based on least-cost planning.
Recommendation 9: Implement a rigorous regularly updated analysis of near-term system reliability (reserve margin study) for the region.
Recommendation 10: Improve wholesale pricing and operational models for energy storage.

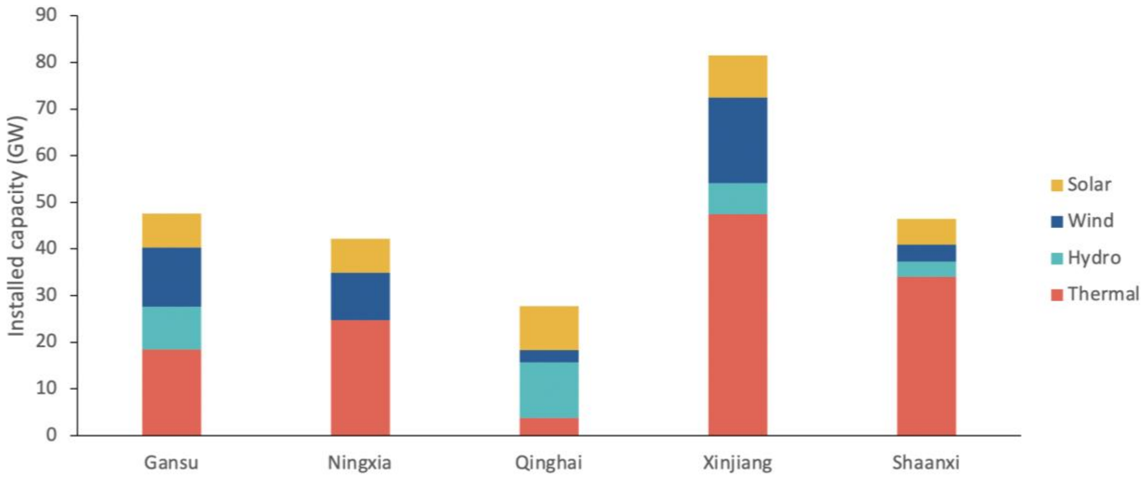
Background: Key Issues in the Northwest

Several interrelated trends and factors are shaping power sector transition in the Northwest. These include rapid growth in renewable energy, overcapacity in coal generation, restructuring of coal generation ownership, the development of electricity markets, and national carbon emissions and air quality goals.

Rapid Growth in Renewable Energy and Ongoing Integration Challenges

In the 2010s, wind and solar generation in the Northwest grew rapidly, shifting the region from a reliance on coal and, to a lesser extent, hydropower to a more diverse generation mix. Wind and solar generation now account for more than 40% of total generation capacity in Gansu, Ningxia and Qinghai and more than 30% of generation capacity in Xinjiang and Shaanxi (Figure 1).[7]

Figure 1. Estimated installed capacity in the Northwest's five provinces, 2020

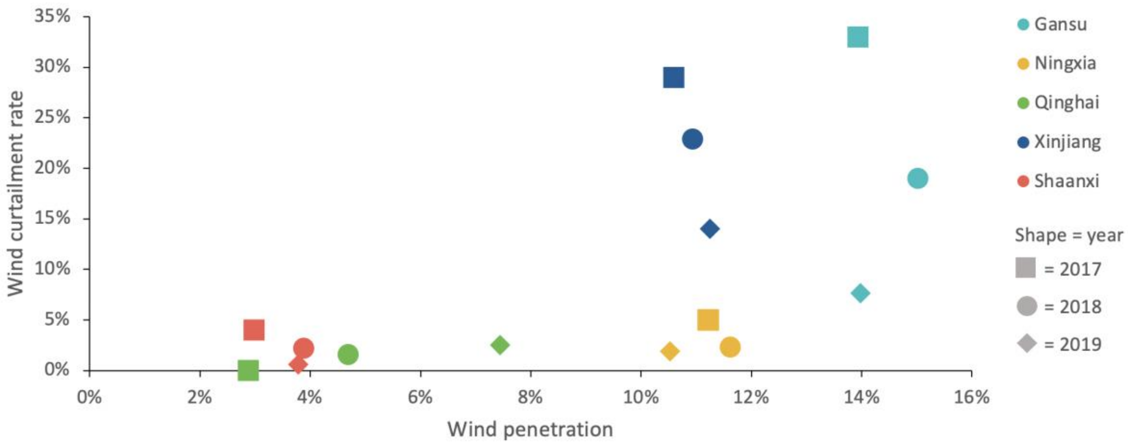


Sources: Published data from provincial governments, grid companies and China Electricity Council

[7] As of the time of this writing, provincial data for 2020 was not yet available from NEA. Accordingly, this figure shows RAP estimates, based on published data from provincial governments, grid companies and China Electricity Council. 甘肃省工业和信息化厅.（2021年1月8日）. 2020年12月全省电力生产运行情况. http://gxt.gansu.gov.cn/meiridongtai/bumendongtai/20210108/11341424226e7444b97.htm; 腾讯网. (2021年2月26日). 这组数据告诉你宁夏电力发展有多“牛”. https://new.qq.com/omn/20210226/20210226A0CFKR00.html; 北极星售电网. (2020年12月18日). 陕西电力现货市场建设方案征求意见稿：2022年开展陕西电力现货市场结算试运行. 陕西省发改. https://shoudian.bjx.com.cn/html/20201218/1123353.shtml; 国际能源网. (2021年1月23日). 预计“绿电”交易规模25-30亿千瓦时！陕西省发布2021年新能源发电企业参与市场化交易实施方案. https://www.in-en.com/article/html/energy-2300723.shtml; 央广网. (2021年1月7日). 青海新能源装机占比超六成，光伏成为第一大电源. http://news.cnr.cn/native/city/20210107/t20210107_525385768.shtml; 中国电力网. (2021年1月5日). 新疆电网总装机容量突破1亿千瓦，规模位居西北第一.科技日报. http://chinapower.com.cn/xw/gnxw/20210105/42013.html

Rapid growth in solar and wind generation led to operational strain on the region's electricity system, high rates of solar and wind curtailment in some provinces and the need for integration solutions. Wind curtailment rates in Gansu and Xinjiang were 33% and 29%, respectively, in 2017 (see Figure 2[8]). Solar curtailment rates in Gansu and Xinjiang peaked at 20% and 22%, respectively, in 2017.[9]

Figure 2. Wind curtailment rates as a function of wind penetration in the Northwest, 2017-2019



Sources: National Bureau of Statistics. (n.d.). *Output of Industrial Products.* National Energy Administration: (2018, February). *Wind power Grid-Connected Operation in 2017; (2019, January). Grid-Connected Operation of Wind Power in 2018; and (2020, February). Grid-Connected Operation of Wind Power in 2019*

Over the last three years, the Northwest Energy Bureau and provincial government agencies have implemented a number of policies that have contributed to reduced wind, hydro and solar curtailment. These include provincial, regional and interregional electricity transaction mechanisms. These improvements have been motivated, in part, by the central government's targets and high-level strategies for limiting wind and solar curtailment.[10]

At a provincial level, mechanisms to reduce wind and solar curtailment have included the establishment of "ancillary service" deep ramping markets (调峰辅助服务市场) and

[8] Wind penetration here is wind generation divided by total generation. Total generation data are from National Bureau of Statistics. (n.d.). *Output of industrial products*. China Data Online. https://www.china-data-online.com/ (subscription only). Wind curtailment data are from the National Energy Administration: (2018, February). *Wind power grid-connected operation in 2017* (2017年风电并网运行情况). http://www.nea.gov.cn/2018-02/01/c_136942234.htm; (2019, January). *Grid-connected operation of wind power in 2018*. (2018年风电并网运行情况). http://www.nea.gov.cn/2019-01/28/c_137780779.htm; and (2020, February). *Grid-connected operation of wind power in 2019* (2019年风电并网运行情况). http://www.nea.gov.cn/2020-02/28/c_138827910.htm. At the time of this writing, data for 2020 had not been released.

[9] Data are from the National Energy Administration: (2020, February). *Grid-connected operation of photovoltaic generation in 2019* (2019年光伏发电并网运行情况). http://www.nea.gov.cn/2020-02/28/c_138827923.htm; (2019, January). *Introduction to the grid-connected operation of renewable energy in 2018* (2018年可再生能源并网运行情况介绍). http://www.nea.gov.cn/2019-01/28/c_137780519.htm; and (2018, January). *In 2017, 53.06 million kilowatts of new photovoltaic power generation installed capacity ranked first in renewable energy* (2017年光伏发电新增装机5306万千瓦). http://www.nea.gov.cn/2018-01/24/c_136920159.htm

[10] National Development and Reform Commission and National Energy Administration. (2018). *Action plan for clean energy integration 2018-2020* (国家发展改革委 国家能源局关于印发《清洁能源消纳行动计划（2018-2020年）. https://www.ndrc.gov.cn/xxgk/zcfb/ghxwj/201812/t20181204_960958.html

"energy substitution transactions" (电能替代交易).[11] At an interprovincial and interregional level, mechanisms have included a regional deep ramping market that complements provincial deep ramping markets, generation rights trading for renewable energy, banking arrangements (省间互济协议) between provinces, and interprovincial transactions for surplus renewable generation (跨区域省间富余可再生能源电力现货交易) facilitated by State Grid and the Beijing Power Exchange Center.[12]

Due, in part, to these efforts, Ningxia maintained low levels of curtailment over 2017-2019 despite having relatively high wind penetration. Wind and solar curtailment in Gansu and Xinjiang fell significantly from 2017 to 2019, though the two provinces still have the highest levels of wind curtailment in China. Meanwhile, solar curtailment in Xinjiang and Qinghai exceeded 7% in 2019.[13] High levels of curtailment in these provinces indicate the ongoing challenge the region faces in managing curtailment.

In short, the successful efforts in the region to bring down curtailment represent important progress. However, there is a big mountain to climb: Decarbonization means there is a need for continued improvement in power sector policies, planning and market mechanisms to support ongoing increases in renewable energy penetration without uneconomic levels of curtailment. In particular, continued work toward implementation of economic dispatch throughout the region will be important for addressing the challenge of rapid continued increases in wind and solar penetration rates (see recommendations 1 through 5). Regional economic dispatch will be particularly important to support higher levels of wind and solar resources. As we will discuss in those recommendation sections, it is not just a matter of changing the approach to dispatch but also changing the way that generators and other resources are compensated, so there are adequate business models to support a rational mix of resources under the new approach to dispatch.

[11] The deep ramping markets established in the Northwest and other regions are market mechanisms unique to China. They allow for thermal generators to be compensated to reduce output below a designated minimum generation level (which, unlike in other countries, is referred to as an ancillary service), typically around 50% of nameplate capacity. These markets have been effective as a mechanism to help reduce curtailment of wind and solar generation, although there will likely be limits to this approach as wind and solar penetration continues to increase. In energy substitution transactions, industrial facilities with cogeneration or other behind-the-meter generation can negotiate to purchase renewable generation rather than using their own.

[12] Banking arrangements are nonmonetary agreements to share energy on a seasonal basis, typically between regions that are rich in hydropower resources and those that have abundant coal or natural gas resources. In 2020, Qinghai and Shaanxi signed a banking agreement for 2020-2022, under which Shaanxi would export 3.2 to 3.5 TWh per year of energy to Qinghai during the winter, and Qinghai would export between 0.5 and 2 TWh to Shaanxi during its summer peak. See Qinghai Ribao. (2020). Qinghai and Shaanxi provinces signed a medium- to long-term mutual framework agreement for energy exchange (青陕两省签订中长期电能互济框架协议). *Qinghai Daily*. https://m.yunnan.cn/system/2020/07/08/030777127.shtml

[13] Full annual data for 2020 were not available at the time of writing. An announcement from NEA indicates that wind curtailment fell to 10% in Xinjiang and 6% in Gansu in 2020. Meanwhile, solar curtailment fell to 5% in Xinjiang and 2% in Gansu in 2020. See National Energy Administration. (2021, January 21). *Transcript of the online press conference of the National Energy Administration in the first quarter of 2021* (国家能源局2021年一季度网上新闻发布会文字实录). http://www.nea.gov.cn/2021-01/30/c_139708580.htm. For Qinghai, cumulative monthly data for 2020 indicate that solar curtailment rose to 8% in 2020. The monthly data are from China New Energy Absorption Monitoring and Alert Center (全国新能源消纳监测预警中心). (2021, February). *National new energy absorption assessment analysis for Q4 2020* (2020年四季度全国新能源电力消纳评估分析). https://news.bjx.com.cn/html/20210207/1135111.shtml

Overcapacity in Coal Generation and Restructuring of Ownership

Driven by rapid growth in generation capacity of various types and lower than expected demand growth, utilization rates for coal units have declined steadily in most of the region's provinces since 2010. Coal generation in four of the region's five provinces had annual operating hours of less than 4,600 hours per year (53% capacity factor) in 2019.[14] Declining operating hours contributed to aggregate losses for coal generators.[15] Coal generators under central-government-owned enterprises saw losses in 15 provinces in 2018, with loss-making generators concentrated in the Northeast, Southwest and Northwest regions. Looking in more detail at the Northwest, centrally owned coal generators in four of the Northwest's five provinces reported net losses totaling 5.3 billion yuan (U.S. $800 million) in 2018.[16]

In response, SASAC announced plans in November 2019 to restructure ownership of central-government-owned coal generation across the Northwest, transferring coal assets to one central government company in each province (一省一企).[17] SASAC's policy also called for rapid retirement of unneeded coal generation assets in the Northwest, stating that "coal power capacity will drop by a quarter to a third" (煤电产能压降四分之一至三分之一) by 2021.[18] The statement also calls for significant increases to annual operating hours for remaining centrally owned coal generators and for increases in operating efficiency at remaining coal generation facilities.[19]

Overall, the SASAC plan is an important step forward and represents a major advancement not only in efforts to rationalize the finances of state-owned generation companies but also toward meeting China's goals for carbon peaking and neutrality. The recommendations below discuss various possible refinements to the SASAC approach, how to avoid possible pitfalls, and how it might be better coordinated with other aspects of power sector policy in the region.

The central government's share of coal asset ownership and the amount of coal generation to be transferred in each province under the SASAC plan varies across provinces in the Northwest. In Gansu and Shaanxi, for instance, the central government generating companies were majority owners in about 55% to 60% of total coal generation capacity in each province before restructuring, according to publicly available data.[20]

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14 Data are from Sinolink Securities. (2020). 西北煤电合并方案出台，提升回报保供应. http://pdf.dfcfw.com/pdf/H3_AP202005251380197092_1.pdf

15 A substantial increase in coal prices in 2017 has also contributed to financial losses of coal generators.

16 The December 2019 SASAC policy was circulated in media reports. See 中国碳交易网. (2019, November 29). 重磅！国资委发布《中央企业煤电资源区域整合试点方案》全文. http://www.tanjiaoyi.com/article-29645-1.html

17 中国碳交易网, 2019. We use an exchange rate of 6.56 yuan to $1.

18 It is not clear from the SASAC document whether this is referring to a "quarter to a third" of all regional coal generation capacity, including coal generation units owned by provincial companies, or whether it means a "quarter to a third" of coal generation capacity owned by central-state-owned enterprises will be retired. In any case, this is a substantial amount of coal retirement.

19 中国碳交易网, 2019.

20 All calculations are based on data from Global Energy Monitor. (n.d.). *Global coal plant tracker*. https://endcoal.org/tracker/

Because these ownership statistics are only for coal generation, they provide a limited picture of industry concentration. The centrally owned generating companies are also major investors in wind, solar and other types of generation capacity. Nevertheless, coal asset restructuring raises concerns about the competitiveness of electricity markets in Gansu and the region as a whole. With higher concentration of ownership, these markets may suffer from insufficient competition and market power. In Gansu, for instance, assuming 25% of Huaneng's generation is retired, it would still be a majority owner in about 45% of provincial coal generation after restructuring. Coal generation accounts for about 40% and 60% of Gansu's total installed capacity and generation, respectively, and thus, measured against total capacity and generation, Huaneng's ownership share might not seem unduly high.[21] Such a high share of coal generation ownership could, however, give Huaneng significant market power during resource-scarce hours and in transmission-constrained zones. Higher concentration of ownership and market power could raise system costs, increase curtailment of wind and solar generation, decrease reliability and act as a barrier to meeting emissions reduction goals. Several of the recommendations in the subsequent section discuss regulatory mechanisms to deal with consolidated ownership and market power to ensure outcomes that are economically efficient and aligned with environmental and emissions goals.

Even as it creates challenges for competition, however, the implementation of SASAC's plan to rapidly retire unneeded coal generation assets will be a major step forward.

Development of Wholesale and Retail Electricity Markets

The Northwest already has a foundation in electricity market development that can be built upon to help meet policy goals. As early as 2013, Ningxia and Gansu had already begun pilots to allow industrial customers to procure their own electricity through direct access transactions (直接交易). These pilots grew into stable markets, and the region's other provinces also developed direct access markets. By the release of Document 9 in 2015, a significant fraction of electricity consumption in the Northwest was already market based. After 2017, provinces built on these existing markets as they developed rules for medium- and long-term contracting, which created more formal annual and monthly platforms for bilateral and auction-based electricity trading. Unlike in other regions, renewable energy generation has actively participated in MLT markets in the Northwest.

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[21] Data for Gansu are from Global Energy Monitor, n.d. Assuming 55% ownership in provincial coal generation and a small amount of hydro (about 160 MW), wind (about 1,250 MW) and solar (roughly 200 MW), Huaneng's contribution to an energy-weighted Herfindahl-Hirschman Index would be on the order of 1,225 (assuming 35% of energy is generated from facilities that are majority-owned by Huaneng). This would likely put Gansu on the lower side of "moderate concentration." However, provincial Herfindahl-Hirschman Index analysis does not identify the market power that can arise in smaller parts of the provincial grid due to fluctuating constraints. Huaneng non-coal generation data are from 中国华能集团有限公司. (2016). 华能甘肃能源开发有限公司. https://www.victortunggal.com/n31529/n31563/n1551866/c39809080/content.html

In 2019, Gansu was selected as one of eight provinces to design and pilot a spot market for electricity. As in the other seven provinces, Gansu's pilot includes day-ahead and real-time (15-minute) energy markets. Gansu's spot market completed a five-month trial operation and settlement (结算试运行), in preparation for regular operation. In late January 2021, the trial operation of Gansu's market was put on temporary hold.[22] An official statement of problems and next steps for the Gansu market has yet to be released, but spot market design and implementation still appear to be an area of strong interest for central government and regional policymakers. In March 2021, the National Development and Reform Commission (NDRC) announced five new provincial-level spot market pilots and indicated that Xinjiang, Qinghai and Shaanxi are each in earlier stages of developing separate provincial spot markets.[23]

Continued development of wholesale market mechanisms and ultimately a unified regional spot market (see Recommendation 5) will help to improve dispatch efficiency, reduce costs and renewable curtailment, and provide price signals to help guide investment and retirement decisions across the Northwest.

In sum, the key issues outlined in this section — the development of electricity markets, overcapacity and restructuring in coal generation, and growth in renewable generation — will continue to be an important context for Northwest China's power sector transition over the next decade.

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[22] 中国能源报. (2021, January 25). 屡遭叫停，电力现货试点怎么了？http://paper.people.com.cn/zgnyb/html/2021-01/25/content_2031407.htm

[23] 北极星售电网. (2021, March 17). 第二批5个省级电力现货市场试点公布. http://shoudian.bjx.com.cn/html/20210317/1142342.shtml

Policy and Regulatory Strategies for Power Sector Transition

In this section, we offer details regarding practical recommendations to facilitate the Northwest region's power sector transition. This discussion offers concrete next steps based on international experience but tailored to conditions and realities in the Northwest region, including the context discussed in the previous section. Our discussion is organized according to three main areas of policy discussion.

1. Operational issues: Moving toward regional economic dispatch. This section focuses on the challenges of improving the efficiency of the regional power system's hour-by-hour operation. The discussion focuses on unlocking the benefits associated with a more regional approach to generator scheduling and dispatch. Such a regional approach will promote greater reliability, reduce emissions and facilitate integration of renewable energy.
2. Coal retirement policy: Coordinating the role of SASAC. SASAC's role as a major policymaking voice in the coal retirement discussion is a key issue for the region. Coordinating SASAC's initiatives with those of central and regional agencies concerned with power sector reform will be an important aspect of regional policymaking. SASAC's role is related to operational issues and planning reform, but because its role is so important, we discuss related recommendations in a standalone section.
3. Planning reform: Encouraging rational investment and retirement decisions. Improving planning processes is essential for smoothing and optimizing the power sector transition. Without transparent, consistent and scientific planning approaches, it will be difficult to maintain the ambitious transition path implied by the new national goals for emissions.

Moving Toward Regional Economic Dispatch

Regionally coordinated economic dispatch — or, more simply, regional economic dispatch — refers to operation of the regional power system in a way that minimizes its short-run operating costs, ideally including the social costs of emissions. Regional economic dispatch will facilitate exports from provinces that have lower marginal cost generation to provinces that have higher marginal cost generation, as long as adequate transmission capacity is available.

As the Northwest region's energy mix increasingly shifts toward solar and wind generation, continuing to move toward regional economic dispatch will be important for cost-effectively integrating these resources. Regional economic dispatch would allow wind and solar generation to be balanced across a larger footprint, thus reducing the overall variability and uncertainty associated with these resources and taking advantage of diversity in loads and other generation resources. This would help to reduce curtailment across the Northwest.

Improving the efficiency of dispatch has been a longstanding objective of policymakers in the Northwest and around the country. Substantial progress has been made, including through the implementation of the regional deep ramping market. A number of barriers to more efficient regional dispatch remain, however, including unresolved problems with generator compensation and the inflexible physical approach to MLT contracting.[24] In this section, we offer suggestions on steps to deal with those issues.

Recommendation 1: Maintain and improve priority dispatch for renewables by empowering the regional grid company to adjust provincial hydropower and coal schedules.

Hydropower, solar and wind have very low operating costs. From a societal perspective, maximizing the utilization of these types of generation (i.e., keeping curtailment at rational or economic levels) will minimize electricity generation costs, reduce emissions and maximize return on investment for the electricity sector as a whole. However, given the existing structure of generator compensation in the Northwest, companies that own large amounts of coal generation have an incentive to operate their coal generation as much as possible, even if that requires curtailing hydro, solar or wind generation owned by the same company. SASAC's target for central-government-owned coal generators to increase operating hours may exacerbate these incentives (see Recommendation 6).

China's 2005 Renewable Energy Law established priority dispatch for renewable energy to create dispatch space for renewable generation relative to incumbent coal generation. Priority dispatch is broadly consistent with the ultimate goal of economic dispatch, which is an important underlying principle of the power sector reform launched in 2015 by the central government. (Under economic dispatch, renewable generation will tend to be dispatched first, given its near-zero operating cost.)

Governments and grid companies in the Northwest have taken various steps to support priority dispatch of renewable generation. These steps include changes in solar and wind forecasting; reforms to unit commitment and dispatch; participation by nonthermal resources in MLT markets; and the development of other market mechanisms that enable renewable generation to displace coal generation.[25] In addition, Gansu province has committed to allowing nonthermal generation to participate in its spot market, which should help facilitate real-time economic dispatch of all resources. Continued high levels of renewables curtailment in the region suggest, however, that the region as a whole still appears to be falling short on its implementation of priority dispatch.

One challenge for priority dispatch is the province-centric nature of energy dispatch in the Northwest, meaning that provincial dispatch centers have limited ability to balance renewable and hydro generation resources over a larger geographic footprint. That is, provincial dispatch centers each handle dispatch within each province, but there is insufficient attention to optimizing dispatch regionally. Balancing over a larger footprint can unlock substantial benefits and ease the challenge of wind and solar integration, because these resources' variability tends to even out over larger areas.

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[24] Historically, dispatch centers have deviated from economic dispatch to satisfy monthly or annual allocations of operating hours to individual thermal generation units. These allocations have been made under annual generation output planning or (increasingly) competition between generators for monthly or annual amounts of operating hours in the form of MLT contracts. A key aspect of reform across the country will be transitioning the MLT contracts to a "financial" contract approach. For more discussion of these issues, see Dupuy et al., 2020. See also Dupuy, M. (2019). *Comments on National Energy Administration's 'Advancing Electricity Spot Market Implementation.'* Regulatory Assistance Project. https://www.raponline.org/knowledge-center/comments-on-national-energy-administrations-advancing-electricity-spot-market-implementation/

[25] Allowing nonthermal resources to participate in MLT markets may have reduced curtailment by enabling nonthermal generators to underprice thermal generators, thereby shifting generation from the latter to the former.

An approach that builds upon recent efforts to encourage more efficient interprovincial dispatch would be to empower the Northwest Power Grid dispatch center to take a more active role in rationalizing the operational decisions that are currently determined independently, on a province-by-province basis. That is, in order to facilitate regional optimization of wind, solar and hydropower, the Northwest Power Grid dispatch center would be empowered — by a policy statement from the National Energy Administration (NEA) if necessary — to adjust provincial hydropower and coal schedules. Most of the thermal commitment and dispatch decisions under provincial dispatch (省调), as well as the setting of initial hydropower and coal schedules, would still be the purview of provincial dispatch centers.

Under this regional optimization, the Northwest Power Grid would be responsible for week-ahead, day-ahead and real-time forecasting of regional wind and solar generation, either directly or by aggregating provincial forecasts. Beginning multiple days ahead of the operating day, the Northwest Power Grid would assemble:

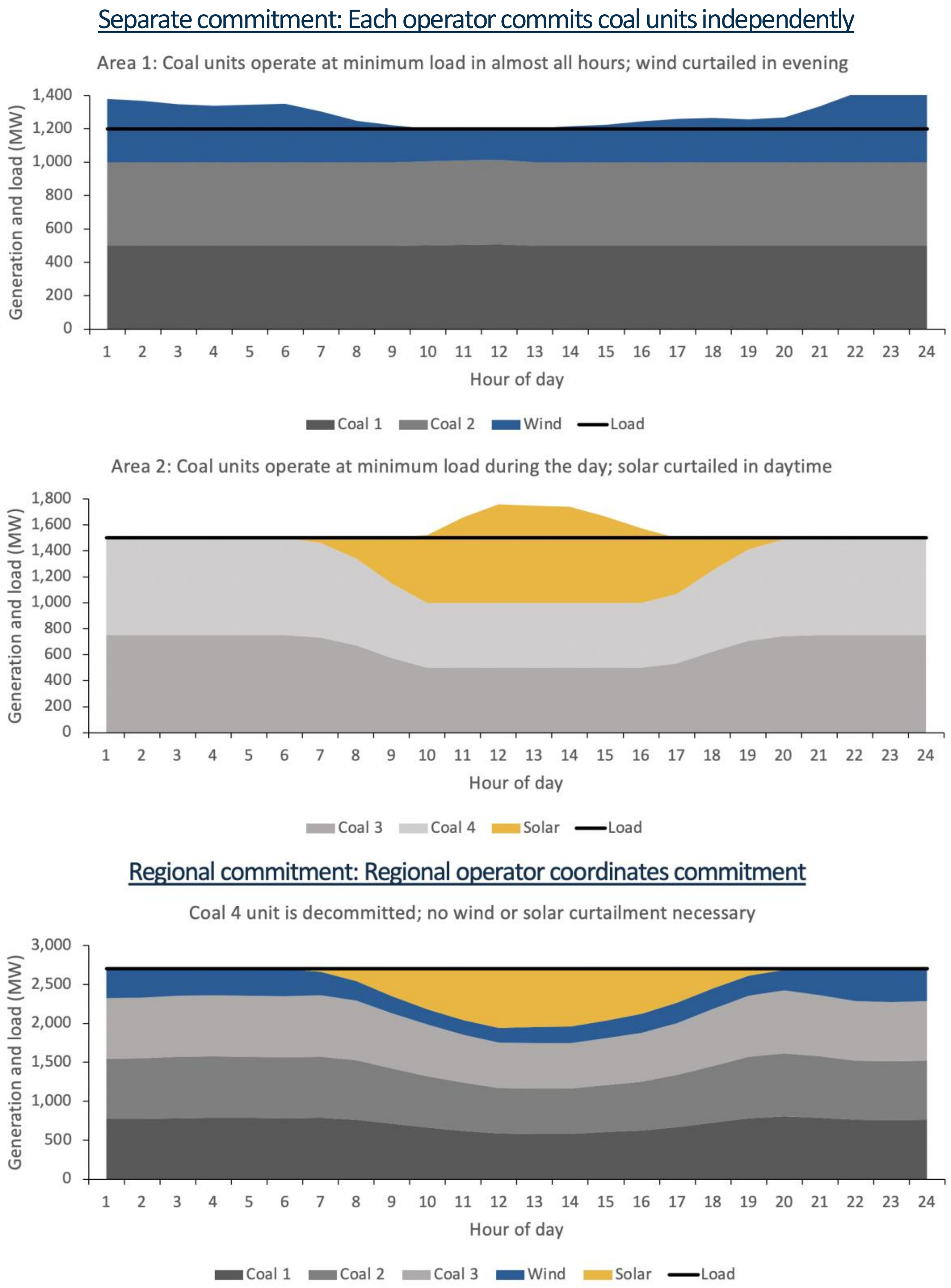
- Hourly (or, even better, 15-minute) forecasts for wind and solar.
- Daily and hourly hydropower budgets and constraints.
- Load forecasts.
- Actual provincial schedules for hydro and thermal generators.
- Preferred hydro and thermal schedules and generator constraints from provincial dispatch centers.

The Northwest Power Grid would adjust the provincial hourly hydropower and thermal schedules using an algorithm that maximizes forecasted regional wind and solar generation and minimizes the evening ramp for coal units, subject to generator and transmission constraints. Thermal generation schedules could be adjusted up or down on a pro rata basis across provinces. The Northwest Power Grid would then adjust schedules for the day and for each time interval in the day up until real-time dispatch.

The main effect would likely be on day-ahead commitment of coal units, allowing some units to be shut down day-ahead — for example, in response to a high wind generation forecast. Day-ahead decommitment of coal units would reduce fuel costs for the region as a whole by reducing the need for some coal generators to run at minimum load. Given the Northwest's comparatively small hydropower resources, the impact of regional optimization on hydropower dispatch would likely be relatively small. With increases in solar penetration, it would shift hydro generation into the evenings, minimizing the evening ramping required for coal generation.

Figure 3 on the next page provides a simple illustration of how regionally coordinated scheduling of coal units can create additional space for renewable generation. In this illustration, there are two geographic areas, each of which has two 1,000 MW coal units. Area 1 has 1,000 MW of wind. Area 2 has 1,500 MW of solar generation. In the first two panels ("separate commitment"), each region commits its coal units separately, requiring them to be run at minimum load during parts of the day and resulting in 3,400 MWh wind and solar curtailment. In the third panel ("regional commitment"), coal unit 4 is decommitted and no curtailment is needed. As a whole, the region saves 3,400 MWh (6%) in coal fuel costs.

Figure 3. Illustration of benefits of regionally coordinated scheduling of coal generation



This approach would likely create income transfers among generators, which could be addressed through ex-post adjustments to contracts — that is, modifications to previously contracted compensation (Recommendation 4). Regional optimization could be an initial step toward the more efficient use of generation resources called for in SASAC's restructuring plan.

Recommendation 2: Consider implementing time-differentiated on-grid prices.

How generators and other resources get paid affects their behavior. Ideally, generators and other resources on the grid are rewarded for providing services during the hours when the services are most needed — that is, rewarded for operating in line with regional priority dispatch and economic dispatch. In most of the Northwest, however, the structure of generator compensation leaves generators without a viable business model under priority dispatch or full economic dispatch. This is because generator compensation is still heavily dependent on MLT contracts and administratively set on-grid prices (per kWh). Under this framework, despite the progress with the deep ramping market and other mechanisms, generator compensation does not reflect fluctuating grid conditions and system needs. A unified regional spot market that is well designed and competitive can be regarded as an ideal end point for such a reform. Under such a spot market, regional nodal prices would fluctuate, sending efficient signals for regional optimization (see Recommendation 5). However, implementation of a well-designed regional spot market is not easy and is likely to take time.

An administratively implemented time-differentiated on-grid price can be an additional incremental step that helps rationalize generator compensation and eases regional implementation of priority dispatch, as discussed under Recommendation 1. Such an on-grid price could be implemented on a regional basis ahead of an eventual integrated spot market.

As with time-of-use retail prices, which have been in place for some time for various classes of customers in the Northwest, a time-differentiated on-grid price would require identification of well-defined daily time periods with prices based on calculation of system costs (e.g., lower costs during the evening, higher costs during the day). These could be further differentiated by season.

Such a time-differentiated price would give better incentive (assuming the price is based on a detailed assessment of system cost) for various resources, including remaining coal generators, hydro generators and storage resources, to play more efficient regional roles, as envisaged in Figure 3. In this way, the time-differentiated price would complement the regional deep ramping market. It would also help dampen the interest of remaining coal generators in maximizing annual operating hours. Instead, these coal generators would earn additional revenue by operating in the hours when they are most needed. MLT contracts would be negotiated with reference to this time-varying on-grid price (i.e., the time-varying price would be incorporated into the catalog).[26]

Such a time-varying on-grid price with preset periods could be an improvement on the current approach, but it would be inefficient relative to a well-designed spot market with well-formed scarcity prices that vary according to grid conditions. Accordingly, we emphasize in Recommendation 5 that an integrated spot market should remain an ultimate goal for the region.

[26] Our understanding is that the time-of-use retail prices are authorized in the “catalog price” policy already, but the key here would be to expose generators to peak/off-peak period compensation structure.

Recommendation 3: Promote flexibility in delivering energy contracted under MLT contracts, within the portfolios of individual generation companies.

For decades, dispatch centers in the Northwest and elsewhere in China scheduled (committed) coal power plants according to annual operating hour plans, with all coal units receiving a similar number of operating hours. This meant that more and less efficient power plants would be operated the same number of hours, leading to higher than necessary fuel costs. The creation and expansion of direct access and later MLT markets likely helped to improve efficiency by allowing more efficient, lower-cost coal units to be contracted and scheduled more often than less efficient, higher cost ones.

At present, dispatch centers schedule and dispatch individual coal units so that each unit gets its monthly and annual contracted amounts. This practice can lead to deviations from economic dispatch, resulting in higher costs and emissions. It can lead to uneconomic curtailment of renewable generation (for example, if a given month has stronger than expected wind generation or a given year has higher than expected hydropower). In addition, inefficiencies in the MLT market itself — for instance, if units with higher operating costs are able to beat lower-cost units in competition for contracts — will compound these problems and lead to higher than necessary costs.

Ideally, dispatch centers should avoid making operational decisions with reference to MLT contracts. Internationally, the power sectors of many countries feature financial contracting. This includes contracts for difference in which contract participants agree to make up the difference between a contracted spot market price in a future period and the spot market price that actually emerges in that period. An important aspect of financial contracting is that the contracts do not directly affect short-term operational (dispatch) decisions; that is, the system operator dispatches according to economic dispatch principles, and the system operator is typically not even aware of the existence of most long-term contracts. However, given that spot markets do not yet exist in much of the Northwest, we offer here several more immediate steps that can be taken to alleviate barriers to economic dispatch associated with MLT contracting.

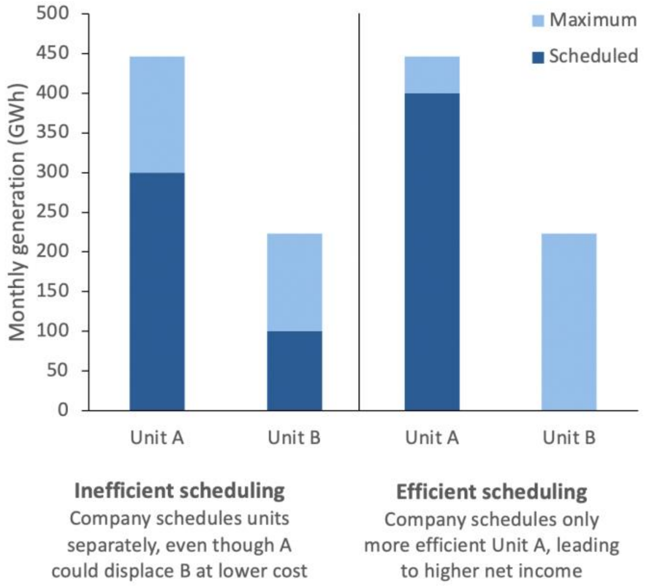
A step that could provide additional flexibility and improve efficiency in coal dispatch would be to allow coal generation companies to economically schedule coal units within their portfolios. Under this proposal, if a particular coal generation unit has signed a MLT contract, another generation unit owned by the same parent company could operate to meet the contracted obligation, in cases where such a switch improves the efficiency of system dispatch.

As a simple illustration, consider a generation company with a portfolio that has an efficient 600 MW coal unit (Unit A) and a less efficient 300 MW coal unit (Unit B). In the month of July, the maximum that each unit could generate is 446 GWh and 223 GWh, respectively.[27] The company has MLT contracts for 300 GWh for Unit A and 100 GWh for Unit B. Scheduling Unit A for 400 GWh instead (see Figure 4 on the next page) would help the company reduce its operating costs and increase its profits, while meeting its contractual obligations. It would also move dispatch closer to economic dispatch, meaning system cost savings and emission reductions.

[27] Operating at full capacity 24 hours a day for 31 days.

Given the shared ownership structures of many power plants in Northwest China, this portfolio-based approach to dispatching coal units would require revenue-sharing agreements among shareholders of individual power plants. For instance, in the above example if Unit B is 60% owned by the majority owner for Unit A and 40% owned by another company, the majority owner would develop a mechanism to ensure that minority shareholders in Unit B are held harmless by the decision to run Unit A instead of Unit B.

Figure 4. Illustration of flexible contract scheduling



Encouraging companies to think in a more integrated fashion (and less as individual generation units with separate decision-making processes) and have more flexibility in the scheduling of coal generation within their portfolios would have the added benefit of acclimating generating companies to contracting, scheduling generation and managing a portfolio of generation and energy storage resources in a spot market environment.

Recommendation 4: Reallocate MLT contract payments on an ex-post basis to support efficient dispatch.

Deepening priority dispatch of renewable energy and hydropower, for instance through regional optimization of these resources (Recommendation 1), will likely lead to transfers of generation (monthly or annual MWh) and income from thermal generators with MLT contracts to renewable and hydropower generators. For instance, in an unexpectedly high hydro year or in a year with a large solar expansion, economic dispatch of these resources should reduce thermal generation, even if thermal generators have MLT contracts that exceed what would be needed from them under economic dispatch. These kinds of transfers have historically been an obstacle to dispatch reform in China.

In well-designed spot markets, higher than expected hydropower or new renewable generation would displace incumbent thermal generation in the dispatch stack because of their lower marginal cost. Incumbent thermal generators would not be compensated for lost generation or lower spot market prices associated with changes in dispatch. In the near term, however, before electricity spot markets are operational in the Northwest, dispatch reforms may require additional mechanisms to address income transfers among generators.

One potential approach to addressing income transfers among generators would be through a revenue-sharing mechanism that reallocates generator compensation on an ex-post basis. This mechanism would allow thermal generators whose generation is less than their MLT-contracted amounts to earn a share of the increased income for renewable and hydro generators. This mechanism could be implemented on an administratively determined basis (50-50 split, for instance) or through additional monthly auctions. The auction approach recognizes that coal generators save on fuel costs by not operating, and thus in an auction, coal generators could bid on the amount of reduction in their contract payments, similar to the MLT price difference (价差) format. This mechanism is similar to generation rights trading, except that dispatch determines trades rather than vice versa.

For instance, consider a case where total coal generation under MLT contract generates 100 GWh less than its monthly contracted amount so the system can absorb an additional 100 GWh of hydro, solar and wind generation. The power exchanges would collect payments from the MLT customers, as per their contracts. The exchanges, working with the Northwest Power Grid, would then use the revenue-sharing mechanism to address any discrepancies between contracted generation and metered generation. If hydro, solar and wind generation would have earned 30 million yuan[28] as a result of additional dispatch, a 50-50 sharing mechanism would allocate 15 million yuan to thermal generators and 15 million to hydro, solar and wind generators.

Recommendation 5: Continue to develop spot markets, with the goal of forming a regional spot market, perhaps with inspiration from U.S. regional transmission organizations.

The development of a regional spot market for electricity, building on the Gansu pilot, could help to address several of the Northwest region's challenges: renewable generation siting and integration, energy storage valuation and dispatch, efficient operation of cogeneration, limits on exports, overcapacity, and coal retirements. The Northwest's long history of regionally coordinated operations provides a foundation for a regional electricity market.

The development of a regional spot market is likely to take time, so it may be helpful to begin considering the key elements and roles and responsibilities in a regional market. Recently, RAP prepared some suggestions for the Southern Grid region[29] — which is slated to become the first regional spot market in China — in which we drew on experience from the regional transmission organizations (RTOs) in the United States.[30] As explained in more detail in the Southern Grid report, we suggest that the Northwest should consider establishing its regional spot market with characteristics of a U.S.-style RTO, which would include the following features:

- A single regional system operator (dispatch center) and a single regional market operator (both of which could be part of the Northwest Power Grid Company or could be housed separately) overseeing a unified regional market with day-ahead and real-time markets for energy and ancillary services.

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[28] Based on 100 GWh at 300 yuan/MWh.

[29] See Dupuy et al., 2020.

[30] The spot markets under development in several Chinese provinces are roughly analogous to the independent system operator (ISO) and regional transmission organization (RTO) markets that cover about two-thirds of the United States, except that most of the ISOs/RTOs are regional in nature, with footprints covering multiple U.S. states. Because the terms "ISO" and "RTO" are nearly synonymous in the U.S., we will simply refer to RTOs in the text of this paper when describing these U.S. ISO/RTO markets as a category. For additional information on ISO/RTO markets, see Hurlbut, D., Zhou, E., Porter, K., & Arent, D. (2015). *'Renewables-friendly' grid development strategies: Experience in the United States, potential lessons for China.* (NREL/TP-6A20-64940). National Renewable Energy Laboratory. https://www.nrel.gov/docs/fy16osti/64940.pdf (available in Chinese at https://www.nrel.gov/docs/fy16osti/66729.pdf). See also Federal Energy Regulatory Commission. (2015). *Energy primer: A handbook of energy market basics.* https://www.ferc.gov/market- oversight/guide/energy-primer.pdf

- Detailed RTO rules based on the principle of regional economic dispatch (ideally with emissions cost internalized) and the principle of a level playing field for all resources, including demand response and other distributed resources.
- Strong mechanisms for monitoring and mitigating the exercise of market power, including a structure for collection of information on generator operating costs. This will be particularly important for the Northwest given the high concentration of generation ownership in the wake of the SASAC restructuring.
- A financial approach to contracting. The dispatch center would no longer monitor or attempt to dispatch according to MLT contracts.
- A unified regional set of rules for allocating regional transmission costs.[31]
- A unified regional transmission planning process.

It would be very useful for Gansu, as the leading spot market pilot in the region, to carefully consider these points in the design of its markets. Market power mitigation and operational cost collection will be essential from the beginning in Gansu, given generation ownership concentration and transmission constraints there. We also suggest strong coordination among neighboring regional electricity markets, including coordination on market designs and processes and coordination in market operations.

Coordinating the Role of SASAC in Promoting Efficient Generator Behavior and Renewable Energy Integration

Recommendation 6: Harmonize SASAC coal restructuring efforts with broader power sector reform efforts.

SASAC policy can potentially help or hinder meeting high priority national goals. There is good reason for SASAC to become even more closely involved in power sector reform efforts and to support NDRC and NEA efforts to advance power sector reform — particularly reform of generator compensation. Implementation of well-designed compensation mechanisms for generators that reward efficient behavior is an area of clear intersection of interests for SASAC, NDRC and NEA. In other words, in addition to improving the financial health of the enterprises under its authority, SASAC could work with NDRC and NEA on the important work of reforming the market and policy mechanisms that influence generator compensation and behavior. An important goal of this joint reform effort would be to ensure that generators profit from behavior that is efficient and that supports national objectives for emissions reduction, cost reduction and reliability in the power sector. SASAC could work with NDRC and NEA on promoting the power sector reform initiatives suggested in this paper, including economic dispatch (see Recommendation 1) and implementation of well-designed spot markets (Recommendation 5).

In addition, SASAC's metrics (考核) and objectives are important shapers of the behavior of the generation enterprises under its authority — and ideally these metrics

[31] An RTO-style approach would involve recognizing regional transmission as beneficial to the region as a whole. Transmission costs could then be allocated to all provincial grid companies (and ultimately to all demand) in the RTO region on a monthly or annual basis based on peak demand (as opposed to the per-kWh basis that is now common for cross-provincial transactions in China). This would help ensure that transmission charges do not obscure the relative operating costs of different generation resources located in different provinces. For more discussion, see Dupuy et al., 2020.

and objectives should be harmonized with power sector reform. One of SASAC's stated objectives in the December 2019 announcement is to "significantly increase the average number of operational hours for generators" (平均设备利用小时明显上升). Unfortunately, this goal clashes with important power sector reform objectives to improve generator dispatch, increase grid flexibility and reduce curtailment of variable renewable energy. This is because the goal is at odds with the idea that each resource on the grid should produce only when it is most efficient to do so. In short, if SASAC uses operating hours as a metric for evaluating individual enterprises or individual generation units, this may slow power sector reform, undermine the objective of economic dispatch and hinder reductions in cost and emissions.

Another way to look at the problem is that annual generator operating hours are gradually losing usefulness as a proxy for generator profitability or generator contribution to economic value added. Indeed, if power sector reform is well implemented, then remaining coal generators will maximize profits by being compensated for operating in relatively rare high-value periods — those minutes and hours when wind and solar generation is low and demand is high — and by providing services such as ramping to meet changes in demand and variable renewable output. In this reformed power sector, generator profitability and output maximization will no longer be consistent. Instead, coal generators will maximize profit by pursuing a business model in which each generator operates only when it is needed.

We suggest that SASAC review all its metrics for state-owned generators to help motivate economically efficient behavior and support the government's stated power sector reform objectives, including those for clean energy. We have several specific suggestions, some of which SASAC can do on its own and some of which may need to be done in conjunction with NDRC and NEA.

- Remove any SASAC metric or objective that evaluates individual generators based on annual number of full-load hours. Maximization of coal generator load hours is not in line with economic dispatch and other principles of power sector reform. Generation plant managers should be given incentives to operate in line with economic dispatch and to support integration of variable renewable energy.

- Recognize that, given incomplete power sector reform, generator profitability is not fully in line with efficient and low-emissions operation. In other words, generators that are profitable within the current power sector policy and market framework are not necessarily operating efficiently. Once power sector reform and carbon trading are well implemented, generator profitability will be better aligned with efficient and flexible operations. Indeed, internationally, the gold standard for electricity market design is to give generators incentive to operate efficiently and in line with policy objectives. Power sector reform is, however, a gradual process. Current reform efforts in the Northwest (and elsewhere in the country) are far from complete. This means that generator profitability, for the time being, is still an imperfect way to measure whether generators are operating efficiently and cleanly.

- Until power sector reform is fully implemented — a process that may take many years — SASAC could design and implement metrics for generation enterprises other than profitability. Doing this would help incentivize policy goals such as emissions reductions. We suggest SASAC consider implementing the following:
    - A metric for generator compliance with existing emissions standards for coal units. In 2015, the Ministry of Ecology and Environment (MEE) issued a standard that required all coal units to meet "super low" emissions standards for sulfur dioxide (SO_2), nitrogen oxides (NO_X) and particulate matter by 2020.[32] Coal generators have subsequently made significant investments in pollution control equipment, but some reports indicate there may be problems of inaccurate reporting of results.[33] Establishing additional SASAC metrics for these emissions, if they do not already exist, could contribute to better generator compliance.
    - A metric for the carbon intensity and overall carbon emissions of each generation company's resource portfolio in the Northwest region to support the national 2030 and 2060 carbon goals, as well as the regional 2030 goals for renewable energy.

Planning for Energy Transition: Encouraging Rational Investment and Retirement Decisions

As SASAC implements its restructuring plan and the Northwest transitions to non-fossil-fuel generation resources in line with carbon reduction and renewable energy goals, a scientific, transparent approach to reliability planning will help ensure that coal generation retirements do not reduce reliability, while ensuring a least-cost resource mix.

The reductions in coal generation capacity that these goals imply are likely to meet objections from coal industry stakeholders. These stakeholders may raise questions about the path of coal retirements in coming years and decades and the nature of the replacement mix of resources. In particular, there is likely to be recurring debate about reliability concerns, especially in times when system resources appear to be getting tight. Transparent and detailed planning processes can help resolve these debates and ensure a rational approach to new coal generation investment.

Recommendation 7: Rationalize the process for identifying specific coal generation units for retirement.

A coordinated regional effort on coal capacity retirement involving SASAC, NDRC and NEA would help smooth the path to the 2030 goals. In 2021, SASAC plans to retire a large amount of central-government-owned coal generation in the Northwest, and this

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[32] According to the MEE policy, retrofittable (具备改造条件) units should meet emissions standards of 10, 35 and 50 mg per cubic meter for particulate matter, SO_2 and NO_X. See Ministry of Environment and Ecology. (2015, December). *Workplan for implementing super low emission standards for coal-fired power plants* (全面实施燃煤电厂超低排放和节能改造工作方案). http://www.mee.gov.cn/gkml/hbb/bwj/201512/t20151215_319170.htm. Meeting these standards, which are comparable to those for natural gas units, requires pollution removal efficiencies that are much higher than what has been commercially available in, for instance, the United States.

[33] Karplus, V., Zhang, S., & Almond, D. (2018). Quantifying coal power plant responses to tighter SO_2 emissions standards in China. *Proceedings of the National Academy of Sciences*, *115*, 7004-7009. https://www.pnas.org/content/pnas/115/27/7004.full.pdf

needs to dovetail with the broader efforts to implement a sustained reduction in coal capacity in future years. It would be best to focus the retirements on older, smaller, less-efficient coal generators, expanding on previous smaller scale efforts to retire capacity, but looking across the region as a whole instead of considering units on a province-by-province basis.

NDRC and NEA have extensive experience with developing and implementing national retirement plans for outdated (落后) coal units, including the policy to "replace small units with big units" (上大压小) that was launched in the 11th Five-Year Plan and continued in the 13th Five-Year Plan.[34] Although these efforts were limited in comparison to the capacity reductions needed in the Northwest, the experience gained in the previous efforts will be very useful.[35] The administrative, metric-based approach (i.e., metrics based on average heat rate, age, and compliance with SO_2, NO_X and particulate emissions control regulation) used in these plans can be the basis for the 2021 SASAC goals as well as an ongoing rolling process that continues to retire coal capacity, in line with 2030 and 2060 goals. This ongoing process could be conducted by a special committee with representatives from SASAC, NDRC and NEA and provincial government officials.[36]

Eventually, the administrative retirement system could move to a more market-based system, based on a well-developed carbon trading market and a well-functioning regional spot market. However, as experience in other countries shows, effective design and implementation of these market mechanisms can take many years.

These new market forces can increasingly drive retirement of existing coal units. In the new electricity markets, generation companies would assess the "going-forward" cost of existing coal units — that is, the costs that generators need to cover to remain in commercial operation (see the text box on the next page). The generation companies would then compare this with expected electricity market revenues. Whenever the company finds that future costs of individual existing coal units are projected to exceed market revenues, the company would voluntarily retire the unit, improving the company's overall financial picture.

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[34] As part of the 2007 *Opinions on Accelerating the Closure of Small Thermal Units* (关于加快关停小火电机组若干意见) and 2017 *Opinions on Promoting Structural Reforms in Supply and Reducing the Risk of Coal Generation Overcapacity* (关于推进供给侧结构性改革 防范化解煤电产能过剩风险的意见), respectively.

[35] NEA also has a "coal generation plan risk warning system" (煤电规划建设风险预警), but this is designed as a regulatory framework for managing or limiting coal investments, not for managing large-scale reductions in coal capacity. Moreover, it has had problems even with managing investment in a rational fashion. It does not explicitly consider long-term asset risk, and the assumptions used in calculating its metrics are in some cases untransparent. See Yue, L., Kahrl, F., & Dupuy, M. (2019). *Strategies for China to reduce the risk of new coal power plant investments.* Regulatory Assistance Project. https://www.raponline.org/knowledge-center/strategies-china-reduce-risk-new-coal-power-plant-investments/. In addition, at times, NEA's system has sent (and still sends) signals that conflict with other elements of national policy. NEA's 2020-2023 warning system doesn't prohibit Shaanxi (except for areas designated in the Blue Sky Action Plan) or Xinjiang from building more coal generation. See National Energy Administration. (2020, February). *Notice on 2023 coal generation plan risk warning* (关于发布2023年煤电规划建设风险预警的通知). http://www.nea.gov.cn/2020-02/26/c_138820419.htm

[36] A recent study identified coal units most suitable for immediate retirement in each province, based on several metrics, including efficiency and environmental performance. See Cui, R., Hultman, N., Jiang, K., McJeon, H., Yu, S., Cui, D., Edwards, M., Sen, A., Song, S., Bowman, C., Clarke, L., Kang, J., Yang, F., Yuan, J., & Zhang, W. (2020). *A high ambition coal phaseout in China: Feasible strategies through a comprehensive plant-by-plant assessment.* Center for Global Sustainability. https://cgs.umd.edu/sites/default/files/2020-01/1.13.2020_AHighAmbitionCoalPhaseoutInChina_EN_fullreport%20.pdf

Going-forward costs and retirement decisions in electricity markets

Going-forward costs typically include both all variable costs and fixed costs that must be paid for the unit to remain in commercial operation. Variable costs include fuel costs, emissions costs (for example, cap-and-trade permit costs), and operations and maintenance (O&M) costs that change depending on the level of the generator's output. Fixed costs do not depend on a generator's level of output. For existing generation, going-forward fixed costs would include fixed maintenance costs (including equipment upgrades), fixed tax payments, insurance payments, some labor costs, and any rent payments for land under the plant, but would not include sunk investment costs.

In a well-designed and well-regulated market framework, the owner will compare a unit's forecast market revenues with its forecast costs over some period to determine whether the unit should remain in commercial operation. If costs exceed revenues, the owner will likely retire the unit. For instance, if a coal unit has forecast average market revenues of 500 yuan/kW-year but has costs of 550 yuan/kW-year for the next few years, the owner may decide to retire the unit.

The new national carbon trading system will be an important part of this more market-oriented coal retirement framework. Ideally, the carbon trading system will develop into a cap-and-trade mechanism with an absolute annual emissions cap. In this case, the MEE would determine the total allowable carbon dioxide (CO_2) emissions (ideally from not just the electricity sector but the economy as a whole) for each year during a planning period and allow flexible compliance through allowance (permit) trading. In comparison to the administrative retirement approach described above, this would, at least in theory, lead to more efficient identification of coal units for retirement. Generating companies would have more autonomy and flexibility regarding coal generation retirement decisions, rather than having retirement decisions mandated by government agencies. In this more market-based environment, CO_2 allowance pricing would influence coal generation retirement decisions. Even small increases in CO_2 prices can significantly increase the costs of coal generation and have strong implications for coal capacity retirement. For instance, each increase of 100 yuan per ton of CO_2 in allowance costs will increase coal generation costs by around 225 to 250 yuan per MWh.[37]

Recommendation 8: Determine new resource investment mix based on least-cost planning.

The previous recommendation discussed identifying specific coal generation units for retirement. This leaves the question of rationalizing investment decisions so that investors choose the right mix of new clean energy resources. An important part of power sector transition in the Northwest will be planning for and investing in the region's future mix of generation and energy storage resources. Because power sector transition away from reliance on coal generation will entail a fundamental shift in the Northwest's generation mix, a careful planning process will be needed to underpin and assess the mix of new resources as the transition unfolds. One aspect of this will be planning for the challenge of integrating large amounts of variable renewable energy and unlocking the potential value of distributed energy resources (including demand

[37] Assuming an emissions factor of 0.9 ton CO_2/MWh and a net efficiency of 35% to 40%.

response). Similar efforts to improve planning approaches to face these challenges are also underway in Europe, India and the United States.

The five-year plan process in China has long played an important role in establishing national industrial and environmental policy and providing high-level guidance for the amount and type of investment and retirement. Meanwhile, central and provincial governments also issued separate resource-specific policies and regulations, including a feed-in tariff, a renewable energy quota, an emissions trading scheme, development plans for energy storage, energy savings policies and so on. The challenge will be to continue to improve the five-year plan process and to coordinate between that process and the resource-specific policies and regulations. Fortunately, NEA's 2016 planning policy sets out some integrative principles that serve as an excellent basis for these tasks.[38] Bolstering the five-year plan process with advanced planning models — that is, state-of-the-art models for load forecasting, reliability evaluation and least-cost capacity expansion — would be very useful.[39]

In particular, an improved five-year plan process should seek to rigorously address the following questions:

- Portfolio optimization: What are the amounts and locations of non-fossil-fuel generation and different kinds (technologies and durations) of energy storage and demand response that will cost the least and maintain high levels of system reliability? What is the overall least-cost portfolio of resources on a regional level, considering not just generation resource options but also storage, demand response and energy savings investments?
- Large-scale versus distributed resources: What should the balance be between generation and energy storage investments by generation companies interconnected to the high voltage transmission (i.e., large-scale resources) and investments by customers interconnected to the distribution system (distributed resources)?
- Transmission investment: How should transmission investments be decided, particularly given the substitutability between energy storage and transmission?

It would be useful to establish a regional five-year plan that would include targets for non-fossil-fuel generation, storage and demand-side management for provincial governments. NDRC and NEA could regularly evaluate directional compliance with these targets, to ensure that investments are approximately consistent with plans. This process would ideally include evaluation and updating of plans at the midpoint

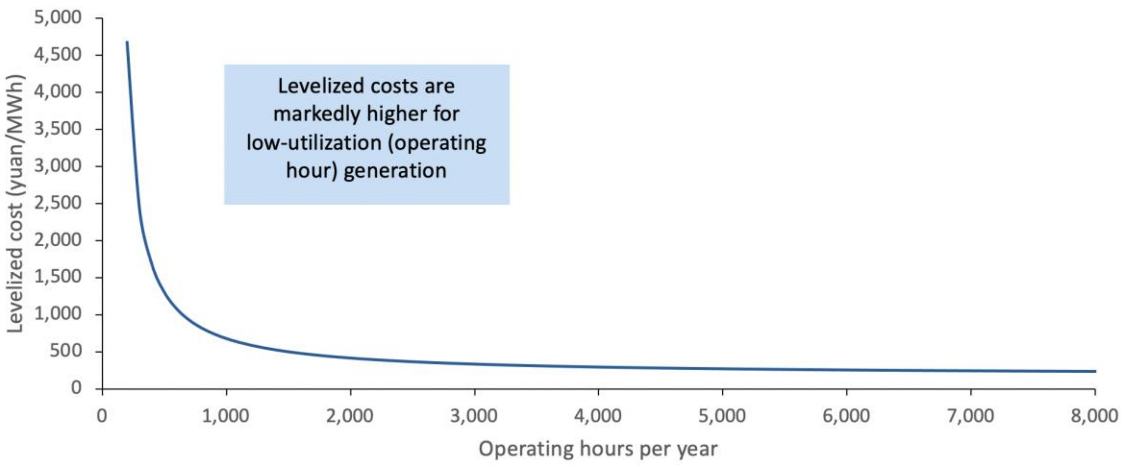
[38] National Energy Administration. (2016). *Notice of the National Energy Administration on issuing the "Measure for the Administration of Electric Power Planning" Guong Electric Power* (No. 139). http://zfxxgk.nea.gov.cn/auto84/201606/t20160606_2258.htm. For discussion, see Dupuy, M., & Wang, X. (2016). *Excess coal generation capacity and renewables curtailment in China: Getting with the plan*. Regulatory Assistance Project. https://www.raponline.org/blog/excess-coal-generation-capacity-and-renewables-curtailment-in-china-getting-with-the-plan/

[39] For more discussion of these topics in international and U.S. context, see Ringkjøb, H.-K., Haugan, P. M., & Solbrekke, I. M. (2018). A review of modelling tools for energy and electricity systems with large shares of variable renewables. *Renewable and Sustainable Energy Reviews, 96*, 440-459. https://doi.org/10.1016/j.rser.2018.08.002; Kahrl, F., Mills, A., Lavin, L., Ryan, N., Olsen, A., & Schwartz, L. (2016). *The future of electricity resource planning* (LBNL-1006269). Lawrence Berkeley National Laboratory. https://eta-publications.lbl.gov/sites/default/files/lbnl-1006269.pdf; Fisher, J., Santen, N. R., Luckow, P., de Sisternes, F., Levin, T., & Botterud, A. (2016). *A guide to clean power plan modeling tools.* Synapse Energy Economics. https://www.synapse-energy.com/sites/default/files/Guide-to-Clean-Power-Plan-Modeling-Tools.pdf; and California Public Utilities Commission. (2014). *Collaborative review of planning models.* https://www.cpuc.ca.gov/WorkArea/DownloadAsset.aspx?id=6626

of the five-year plan period, to adapt to changes in forecasts, technologies and technology costs.

Proposals for new coal capacity to fill resource adequacy needs are likely to come up in recurring fashion. In addition, it is likely that coal industry interests will continue to propose new coal generation as the best option to meet the need for flexible resources that can support variable renewable generation. Accordingly, the type of planning process described in this section would likely judge investments in new coal generation to fill resource adequacy needs as relatively expensive — that is, expensive relative to other options that might include a mix of variable renewables, storage resources, demand response and targeted energy savings measures — even without considering full emissions costs. In addition, as has recently been the case in the Northwest, additional investments in coal generation would likely continue to depress operating hours for all coal generation, which means that new coal units would have low effective annual operating hours and high levelized energy costs (yuan/MWh).[40] Figure 5 illustrates the nonlinear increase in levelized costs (including fixed costs) for coal generation at lower annual operating hours.

Figure 5. Levelized cost for illustrative coal unit with different annual operating hours



Note: This assumes variable costs of 175 yuan/MWh and fixed costs of 450 yuan/kW-year.

Internationally, coal has not been a cost-effective solution for low-utilization (low capacity factor) generation because it has relatively high fixed costs.[41] Historically, in the United States peak demand has often been supplied by demand response and single cycle combustion turbines, which have relatively low capital costs. In some states, battery storage is now becoming a cost-effective alternative to combustion turbines, and this trend will continue if battery cost continues to fall. Energy efficiency investments aimed at reducing peak demand can also be highly cost-effective.

As a longer-term goal, it would be ideal to implement a more refined resource planning process under the regional spot market structure in a way that reflects market pricing.

[40] Under economic dispatch, newer, more efficient units will be dispatched before existing units, meaning that they will have relatively high annual operating hours. However, if demand growth is limited to peak hours, energy margins for new coal generators will likely be low in most hours. This means that the net cost (fixed cost minus annual energy margins, in yuan/kW-year) of these units will be similar to what it would be if these units only operated a small number of operating hours.

[41] See, for instance, Masters, G. M. (2013). *Renewable and efficient electric power systems* (2nd ed.). John Wiley & Sons.

In Recommendation 5, we suggested the Northwest's eventual regional spot market should take the form of a U.S.-style RTO. Under such an RTO structure, regional market pricing and RTO planning will play key roles in guiding investments. RTO planning includes both resource adequacy planning and transmission planning. RTO planning aims to ensure that, even as investment decision-making becomes decentralized, wholesale markets can maintain reliable electricity supply, are workably competitive and have economically efficient levels of transmission congestion.

In a market investment paradigm, generators would make investments based on an evaluation of the net market value of new resources (see the text box), incorporating long-term forecasts of regional spot market pricing. For state-owned companies, these evaluations would be part of their due diligence for bank loans and their project proposals (项目建议书).

Illustration of market-based resource evaluation

A generation company is considering an investment in a 50 MW battery facility. The facility has an annualized installed cost (including financing) of 800 yuan/kW-year. The company acquires a 20-year forecast of hourly energy and ancillary service market prices from a consulting firm.

Using an internal model, the company dispatches the proposed battery facility against market prices to determine its benefits (net revenues) to the company. If the annualized present value of net revenues over 20 years exceeds 800 yuan/kW-year, the investment's projected benefits will exceed its expected costs.

The outcome of this analysis is the projected net market value (benefits minus costs, including emissions costs) of the investment. Because the value and cost of different kinds of resource investments may be very different, this approach enables an apples-to-apples comparison of different kinds of resources. For instance, say that the generation company is comparing an investment in the battery facility versus a 600 yuan/kW-year combustion turbine. If the battery facility has expected net revenues (annualized present value) of 1,000 yuan/kW-year while the combustion turbine has expected net revenues of 500 yuan/kW-year, the company should invest in the battery (200 yuan/kW-year net market value) rather than the combustion turbine (-100 yuan/kW-year), even though the combustion turbine has lower costs.

Allowing market pricing to play a more important role in guiding resource investment decisions would not necessarily replace five-year planning. Long-term resource planning could still help to set longer-term expectations for banks, electricity suppliers and electricity buyers. The main goals of using market pricing to guide investment would be to allow generation investments to be more responsive to changes in technology costs and power system costs, to reduce the administrative challenges of coordinating between resource plans and project approval, and to encourage innovation by providing generating companies with more flexibility in developing resource portfolios.

Recommendation 9: Implement a rigorous regularly updated analysis of near-term system reliability (a reserve margin study) for the region.

As the power sector undergoes rapid and dramatic transition, policymakers and stakeholders are likely to have ongoing questions and concerns about maintaining reliability. There is a history of difficulty and contention in China and other countries with managing periods of system "tightness" and "looseness," which can become headline news. In addition, there is the challenge of coordinating detailed decisions about these topics among various policymakers — with NEA, SASAC and regional officials all playing important roles.

Implementation of a rigorous ongoing process for reliability planning for the region, of the variety seen in parts of the U.S. and other countries, can be of great help in answering these questions and ensuring that the transition proceeds without reliability problems. The purpose of system reliability planning is to make a near-term assessment of whether a power system has adequate resources — generation, storage and demand-side resources (including demand response) — to reliably meet peak electricity demand.[42] The analysis considers important variables: weather; unplanned generator outages; the annual or hourly variability of hydro, wind and solar generation; and the uncertainty of wind and solar generation. Reliability planning is often based on median weather years and average outage events, though climate change is challenging the logic behind these assumptions.

Internationally and in China, power system operators and planners have often used rules of thumb to assess reliability. As power systems grow increasingly complex, however, with more diverse generation resources and loads, rules of thumb are becoming less meaningful for assessing reliability. For instance, annual operating hours (capacity factors) for thermal generators are not a good proxy for reliability in systems with large seasonal variations in resources (hydro, wind, solar) and demand (e.g., winter or summer peaks), as some units will need to run at low capacity factors due to these variations. According to our understanding, this is a major consideration in NEA's coal generation plan risk warning system (煤电规划建设风险预警). The most effective approach to assessing power system reliability, however, is through rigorous reliability studies.

In North America, system reliability planning is centered on reserve margin studies. These typically include annual and subannual analysis and public reports on three topics: (1) estimates of current reserve margins, (2) forecast reserve margins and (3) the setting of target reserve levels based on a reliability target.[43] For utilities and other generation owners, reliability planning through these reserve margin studies provides a basis for mothballing or retiring generation. Even in parts of the United States, Canada and other countries with well-developed electricity markets, this type of reliability planning is very important. Figure 6[44] on the next page provides an illustration of regular forecasts of reserve margins for Alberta's electricity market.[45] The details and methods of reserve margin planning studies in North America continue

[42] Reliability planning covers both the adequacy and security of supply. The focus in this section is on adequacy.

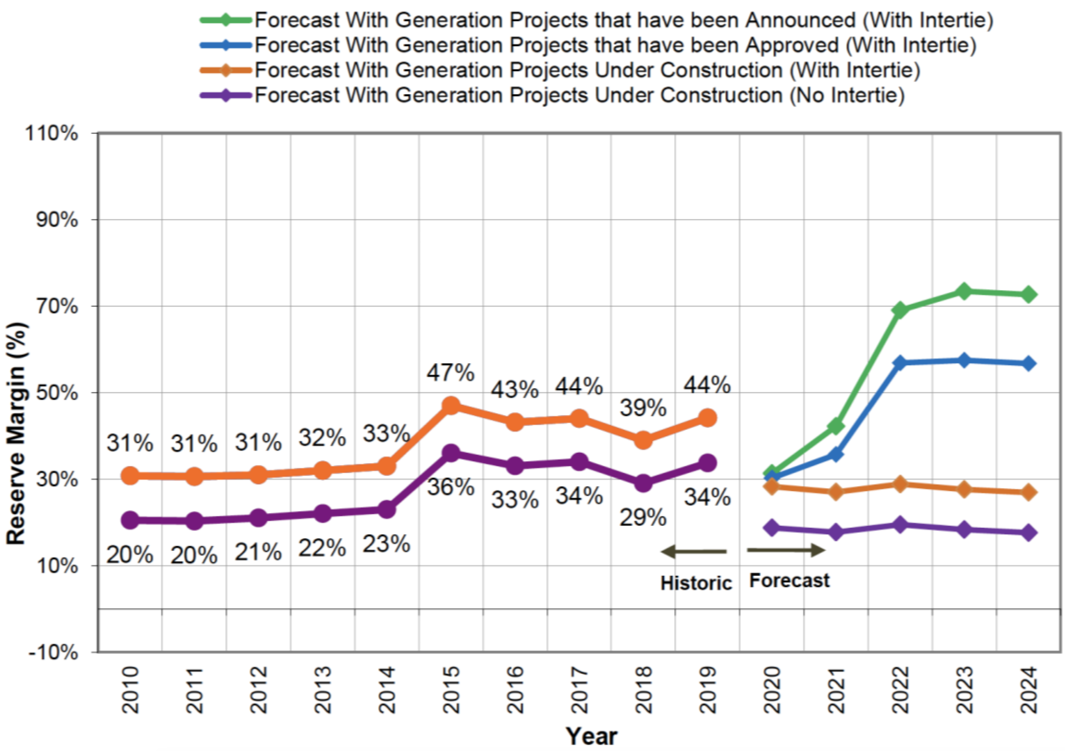
[43] This reliability target could be a loss-of-load expectation target but could also include other metrics.

[44] Alberta Electric System Operator. (2020, November). *Long term adequacy report.* https://www.aeso.ca/download/listedfiles/2020-11-LTA-Final.pdf. For other AESO reports and associated information on AESO reliability studies, see https://www.aeso.ca/market/market-and-system-reporting/long-term-adequacy-metrics/.

[45] Alberta has had high reserve margins beginning in 2015, signaling the need to mothball or retire generation capacity. Alberta has relatively limited interconnection with other provinces in Canada, which partly explains why its reserve margins are higher than those commonly found in other parts of North America.

to evolve, including as problems and unintended biases become apparent from time to time.[46]

Figure 6. Forecast reserve margin for the Alberta Interconnected Electric System, 2010-2024



Source: Alberta Electric System Operator. (2020, November). *Long Term Adequacy Report*

Again, NEA's 2016 planning regulation provides a good overarching framework within which to implement such a process.[47] Such an ongoing study would help build consensus among policymakers and stakeholders about the difficult process of retiring large amounts of coal generation and would help allay recurring fears about reliability and periods of tightness. To put this another way, the periodic reliability studies, if done well, would indicate when problems might be emerging and allow policymakers to adjust regulations and market rules to rapidly deal with the problems. In this way reliability planning would be very useful to help support the regional transition toward the 2030 and 2060 goals.

Northwest China's electricity system has several features that complicate reliability planning and evaluation, including a large amount of cogeneration; a high share of exports and generation of high voltage direct current that is used only for export; a hydro-heavy province (Qinghai); a rapidly growing share of intermittent solar and wind generation; and significant regional load and resource diversity. A rigorous

[46] The February 2021 energy crisis in the Electric Reliability Council of Texas (ERCOT) region has led to considerable public discussion of ERCOT's resource adequacy planning process. At the time of this writing, it is too early to draw strong conclusions about that crisis, and it appears that problems with the electric system resource adequacy planning process were not a key aspect of the crisis. Nevertheless, detailed analysis of the crisis may show that ERCOT's resource adequacy planning had some problematic assumptions that contributed to underestimation of risks. In particular, the planning process may have failed to take into account the possibility of more extreme winter storms in light of climate change. See Dupuy, M. (2021). *Some preliminary thoughts on the energy crisis in Texas, USA* (对美国得克萨斯州能源危机的一些初步想法). Regulatory Assistance Project. https://www.raponline.org/blog/some-early-observations-on-the-texas-energy-crisis/ (in Chinese)

[47] National Energy Administration, 2016. For discussion, see Dupuy & Wang, 2016.

reserve margin study can help address these complexities. To capture regional load resource diversity and incorporate transmission constraints, the Northwest Power Grid may be best suited to leading this study. In North America, annual and seasonal reliability studies are made publicly available, typically along with detailed data needed to verify the results. The reports are subject to review and comment by regulators, stakeholders and independent market monitors.[48] We suggest this kind of approach would also be valuable in the Northwest.

The Northwest Power Grid's reserve margin study could include annual reporting of historical reserve margins, an annual forecast of future reserve margins (e.g., for the next five years), and a target reserve margin based on reliability metrics and a loss-of-load probability study. As part of its analysis, the reserve margin study would identify the amount of coal generation needed to meet the target reserve margin. SASAC, generation companies and grid companies could use this information to verify the amount of existing excess coal generation capacity that can be retired in any given year without reducing reliability. Should the study indicate reliability concerns in coming years, there would be time to take responsive action, such as expanding demand-side management programs.

The reserve margin study would also be an important foundation for the continued development of wholesale electricity markets. Policymakers who are making ongoing decisions about outlining and refining electricity market designs would likely find the periodic reserve margin studies very useful in ensuring that the electricity market designs are producing the desired results. In the North American context, reserve margin studies often shed light on how changes in market rules affect reserve margins and reliability.[49]

The Northwest region reserve margin study can incorporate two elements that would help to reduce the costs of maintaining reliability: (1) a regional perspective that accounts for regional load diversity benefits, and (2) rigorous accounting for the contribution of hydro, solar, wind, energy storage and demand-side resources to reliability.

Load diversity benefits are the cost savings that result from planning for reliability around a regional coincident peak (CP) demand rather than the sum of provincial noncoincident peak (NCP) demands. The regional CP will almost always be smaller than the sum of NCPs, allowing the system to hold fewer resources to meet a reliability target. In the Northwest, the main load diversity benefit is between Shaanxi, which is summer peaking, and the four other provinces, which are winter peaking. We estimate that the regional load diversity benefit was approximately 4 GW in 2019, which would

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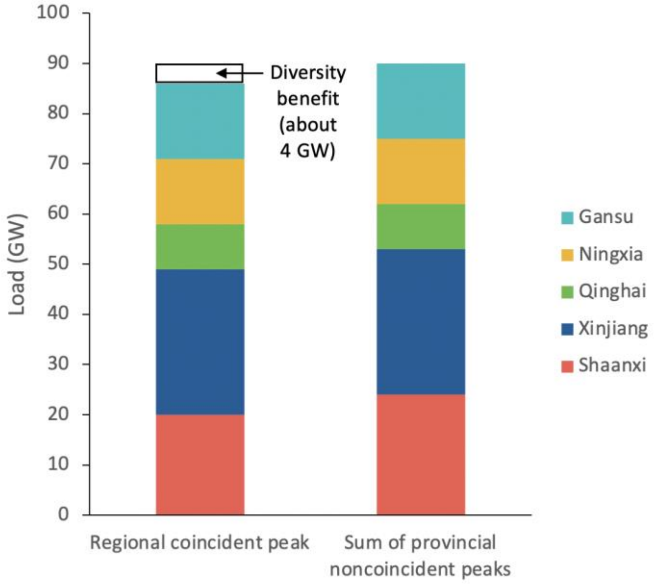
[48] For example, reports and data regarding the resource adequacy studies for the main grid in Texas are available from the Electric Reliability Council of Texas (http://www.ercot.com/gridinfo/resource).

[49] For example, a recent reserve margin report for the ERCOT grid in Texas quantifies how recent changes to the details of a specific market mechanism known as the operating reserve demand curve affect the forecast reserve margin. See Carden, K., & Dombrowsky, A. K. (2021, January 1). *Estimation of the market equilibrium and economically optimal reserve margins for the ERCOT region for 2024: Final.* Electric Reliability Council of Texas. http://www.ercot.com/content/wcm/lists/219844/2020_ERCOT_Reserve_Margin_Study_Report_FINAL_1-15-2021.pdf. Related versions and documents are available at http://www.ercot.com/gridinfo/resource.

translate into a cost savings of around 2 billion yuan ($300 million) a year (Figure 7).[50]

Achieving these benefits requires mechanisms to facilitate resource sharing among provinces, such as regional sharing of operating reserves and real-time balancing energy facilitated by the Northwest Power Grid. Ultimately, we suggest that the design and implementation of these sharing mechanisms can be an important aspect of implementing a regional spot market.[51]

Figure 7. Illustration of the diversity benefit in the Northwest in 2019



Hydro, energy storage and demand response are energy-limited resources, whereas solar and wind are both capacity limited and energy limited. This means that the contribution of these resources to power system reliability will be probabilistic and will decline with penetration, but it will not be zero. Failure to account for the reliability contribution of these resources will lead to excess capacity and higher costs and is likely contributing to the current overcapacity in coal generation in the region.

In the United States, capacity credits for solar and wind generation have often been calculated using capacity factors during peak demand periods, but system operators are increasingly using an effective load carrying capability (ELCC) methodology to calculate them.[52] Planners and system operators are also increasingly using an ELCC methodology to calculate the capacity credit of energy storage.[53] Ensuring that the reliability contribution of storage is accurately calculated is becoming

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50 This is an estimate, based on typical provincial load shapes. National Development and Reform Commission. (2019). *Notice on the signing of mid- and long-term power contracts in 2020 (No. 1982)* (国家发改委关于做好2020 年电力中长期合同签订工作的通知). https://www.ndrc.gov.cn/xxgk/zcfb/tz/201912/t20191230_1216857.html; and National Development and Reform Commission. (n.d.). *Typical power load curve of each provincial power grid* (各省级电网典型电力负荷曲线). https://www.ndrc.gov.cn/xxgk/zcfb/tz/201912/P020191230336066090861.pdf. The cost savings estimate assumes an annualized capacity cost of around 450 yuan/kW-year.

51 We suggest that the model of a U.S. regional transmission organization is a good approach for such a spot market. According to this model, a Northwest Grid RTO would include a unified regional set of rules for allocating regional transmission costs, a unified regional transmission planning process, a single regional system operator and a single regional market operator (though these need not necessarily be part of the same organization) overseeing a unified regional market. For discussion of the RTO model in the Southern Grid context, see Dupuy et al., 2020.

52 For an applied example, see Midcontinent Independent System Operator. (2019, December). *Planning year 2020 wind & solar capacity credit.* https://cdn.misoenergy.org/2020%20Wind%20&%20Solar%20Capacity%20Credit%20Report408144.pdf. See also Milligan, M., & Porter, K. (2008). *Determining the capacity value of wind: An updated survey of methods and Implementation* (NREL/CP-500-43433). National Renewable Energy Laboratory. https://www.nrel.gov/docs/fy08osti/43433.pdf; and Madaeni, S. H., Sioshansi, R., & Denholm, P. (2012). *Comparison of capacity value methods for photovoltaics in the Western United States*. National Renewable Energy Laboratory. https://www.nrel.gov/docs/fy12osti/54704.pdf

53 Examples include the New York Independent System Operator and the California Public Utilities Commission. For an overview see PJM. (2020). *ELCC rules at other ISO-RTOs.* https://www.pjm.com/-/media/committees-groups/task-forces/ccstf/2020/20200407/20200407-item-05-elcc-at-otherisortos.ashx

increasingly important as storage becomes the marginal capacity resource in parts of the United States.

Recommendation 10: Improve wholesale pricing and operational models for energy storage.

Although much of the focus on deploying electricity storage has been to support renewable integration, the most important nearer-term value for storage — internationally, in China and in the Northwest — is likely to be avoiding the need for new thermal generation. In the near term, developing a tariff and operational model will be important for enabling business models for storage as a capacity resource in the Northwest. In the longer term, regional electricity spot markets could help to coordinate storage investments and dispatch.

In the Northwest, energy storage can already participate in deep ramping markets. This provides incentives for co-locating storage with generation, which may limit its value to the electricity system. The Northwest Energy Regulation Bureau and industry participants are exploring models for encouraging standalone energy storage that can provide a broader range of values to the electricity system.[54]

With current institutions, the three questions for standalone storage in the Northwest are:

1. How would it be compensated?
2. How would it be operated to maximize its value?
3. How would its costs be recovered?

In the near term, a benchmark on-grid tariff (标杆电价) for storage resources could address the first question, with different operational models (question 2) depending on tariff design (see Table 1). A benchmark tariff that declines over time would also provide incentives for continued innovation and cost reductions in storage technologies.

Table 1. Potential approaches to energy storage tariffs and operational models

Storage tariff	Unit
Capacity cost-based	yuan/kW-year
Energy cost-based	yuan/MWh
Time-differentiated	yuan/MWh

For the capacity cost-based and energy cost-based tariff approaches, the grid company would have the flexibility to operate storage facilities to ensure bulk system reliability and minimize its costs. Ensuring that grid company incentives for storage operation are aligned with *system* benefits would likely require strengthening targets, such as the dual targets for provincial renewable curtailment and renewable consumption levels (双降双升), which could include improved targets for reliability, fuel cost and

[54] The focus here is on energy storage connected in front of the customer meter and treated as a bulk system resource or grid-side (网侧) storage. Battery and thermal storage can also be located at the customer side (用户侧) and incentivized through retail or wholesale tariffs, but that is not an area of focus here.

curtailment. Strengthened targets would give the grid companies additional incentive to charge and discharge storage to provide system benefits.[55]

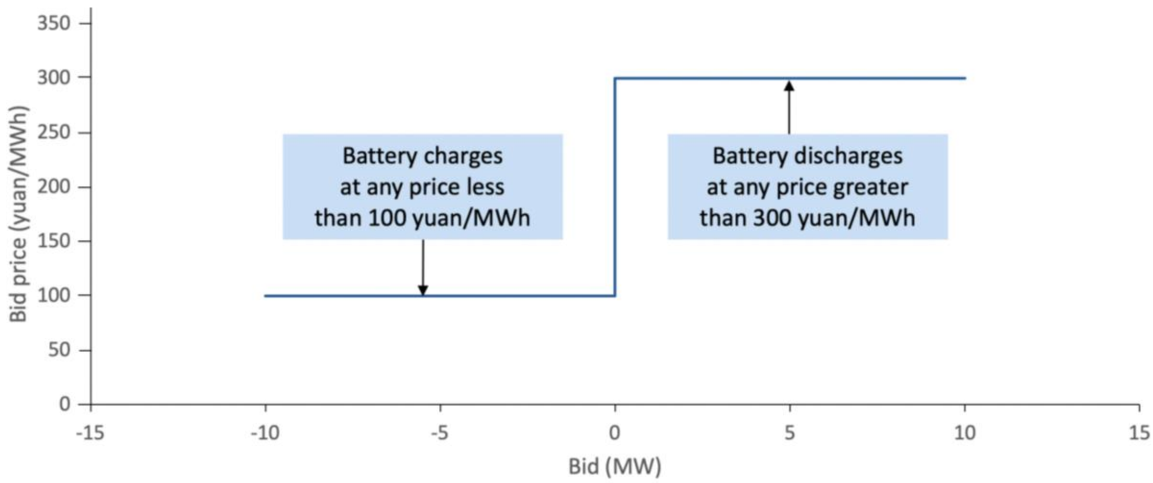
The time-differentiated tariff (as discussed under Recommendation 2) reduces potential incentive issues for grid company operation of storage but requires well-defined time periods that reasonably match with system costs (e.g., lower costs during the evening, higher costs during the day). Storage owners would be paid the net between charge and discharge prices, accounting for losses. Without well-defined cost periods and if there is a mismatch between tariff prices and system costs, grid company operation of storage could increase system costs.

From an asset owner perspective, the main difference between the capacity cost-based and the energy cost-based and time-differentiated tariffs is in their risks. A capacity cost-based tariff (yuan/kW-year) may lead to more operation and faster degradation than anticipated. An energy cost-based tariff or time-differentiated tariff may not allow the owner to recover costs if the storage facility is operated less than anticipated.

The costs of energy storage compensated through tariffs (question 3) are not directly recoverable from industrial and large commercial customers. Retailers and direct access customers do not have an incentive to sign contracts for storage, and these customers pay for energy through MLT contracts. Because of the reliability benefits of storage, there is a rationale that storage tariff payments should be recovered from all customers. This suggests allowing grid companies to recover storage tariff charges through their transmission tariffs.

In the longer term, spot markets can address the incentive issues associated with trying to maximize the system benefits of storage. Storage bids into day-ahead and real-time energy and ancillary services markets using a bid curve that extends from negative MW (charging, load) to positive MW (discharging, generator); see Figure 8. In U.S. electricity markets, co-optimization of energy and reserves in day-ahead and real-time markets has helped to make efficient use of storage resources by ensuring that storage owners are agnostic between participating in energy markets and reserve markets.

Figure 8. Illustrative energy bid curve for storage facility



[55] A key system benefit for storage is cost arbitrage, which is ultimately fuel cost arbitrage. Grid companies, however, have no incentive to reduce fuel costs because they do not actually see them. Because MLT contact imbalances are settled monthly based on a uniform price, grid companies have no arbitrage opportunities in MLT markets. The main incentives for grid company operation of storage will be arbitraging interprovincial price differences and in reducing its costs from serving customers that do not have MLT contracts.

Concluding Observations

Policymakers around the world are setting new targets for decarbonization and considering the detailed policy and regulatory changes that will be necessary to meet these goals. This paper discussed how this decision-making is playing out in China's Northwest region and provided a set of recommendations based on international experience, arranged around three central themes: power sector operational issues, coal asset retirement and reform to planning processes. Implementing reform in these areas is not an easy task, and so this paper has provided concrete proposals for immediate next steps as well as suggestions regarding ideal policies for the longer term. As policymakers in the Northwest region move forward in these areas, much will be gained from continuing to share international knowledge on these topics.

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