DECARBONIZING THE POWER SECTOR IN THE U.S. AND CHINA

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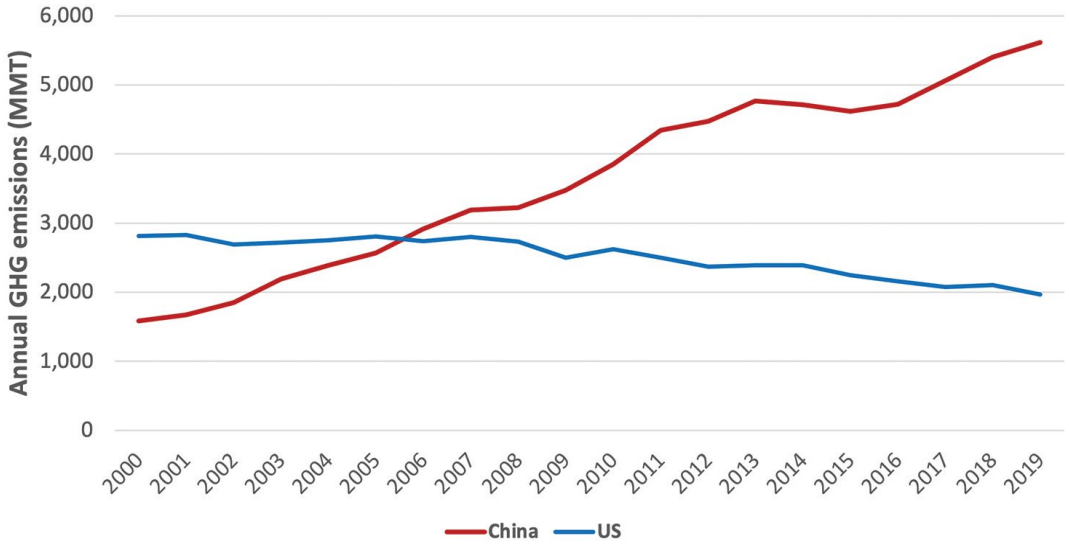
KEY ISSUES AND TRENDS

Together, the United States' and Chinese power systems emitted 5,780 million metric tons of carbon dioxide equivalent (CO_2e) in 2020, about 36% of the two countries' and 17% of the world's annual carbon emissions (International Energy Agency 2022). Consensus is growing among the scientific community that majority renewables-based electricity systems exceeding 80% carbon-free can be operated reliably and at low cost, without developing new technologies (Abhyankar et al. 2022; MacDonald et al. 2016; Novacheck, Brinkman, and Porro 2018; NREL 2012; Phadke et al. 2020). The U.S. and China face similar physical and policy challenges to transform their power sectors, despite different economic and institutional conditions. The transition to a renewables-based electricity system is also essential for decarbonizing end-uses – such as transportation and heating of buildings – through electrification.

The Nationally Determined Contributions (NDC) of both countries under the United Nations Framework Convention on Climate Change include significant power sector commitments.

Figure 1 | U.S. and China Electricity Sector Greenhouse Gas Emissions, 2000-2019.



Data source: Climate Watch (https://www.climatewatchdata.org/ghg-emissions?end_year=2019&regions=CHN%2CUSA&sectors=electricity-heat&start_year=1990)

However, given that neither country's NDC pledges for 2030 are sufficient to support a 1.5 degrees C pathway, and given the centrality of the power sector to decarbonization efforts, both must consider redoubling efforts to reduce power sector emissions. The good news is that well-understood and feasible policy pathways, applicable to both countries, can improve reliability and help reduce costs while accelerating the power sector transformation.

The U.S. recently committed to reducing economy-wide net greenhouse gas emissions by 50% below 2005 levels by 2030, a zero-carbon power sector by 2035 and a net-zero emissions economy by no later than 2050. The U.S. electricity sector must reduce emissions approximately 80% below 2005 levels by 2030 in order to meet the 2030 national target (Abhyankar et al. 2021; Larsen et al. 2021; Larson et al. 2021). While the U.S. electricity sector has substantially reduced emissions from its peak in 2005, and is currently 40% carbon-free, reaching 80% carbon-free in 2030 and 100% in 2035 would represent a dramatic acceleration of clean energy deployment and fossil retirement. Sector experts widely agree that meeting these targets is possible, would markedly improve public health, create new jobs, and even potentially reduce consumer electricity costs (Abhyankar et al. 2022). However, doing so will require additional policy, including new federal regulation and sub-national action.

U.S. efforts at the federal and sub-national levels are evolving. Twenty-one states plus the District of Columbia and Puerto Rico, representing one-third of electric generation, have set goals for 100% clean electricity, although many of these are 2050 goals, not 2035 as in the U.S. national commitment.[1] 39 of the 41 largest utilities in the U.S. have made public commitments to hit net zero emissions by midcentury (Esposito and Jeffrey 2022). The U.S. passed a major infrastructure bill in 2021 which includes funding for end-use energy efficiency and transmission projects (along with provisions to support transmission siting authorization) that will support renewable project development and renewable energy integration. In August 2022, the U.S. passed into law a historic package of federal policies to support economy-wide decarbonization.[2] The package includes financial incentives for wind, solar, energy efficiency, energy storage, and electrification of transportation, buildings, and other end-uses. The U.S. Department of Energy estimates that the package will reduce economy-wide emissions to 40% below 2005 levels by 2030. With additional contributions from state-level policy, the U.S. economy-wide 2030 NDC target (50-52% below 2005 levels in 2030) will be within reach.[3]

In September 2020, the Chinese government updated its NDC targets to peak carbon emissions before 2030 and achieve carbon neutrality before 2060 (known as the dual carbon pledges). The government also set a target for about 25% of total energy consumption to be met by non-fossil fuels by 2030 and a 2030 power sector target to surpass 1,200 gigawatts (GW) total wind and solar power capacity (People's Republic of China 2021). Meanwhile, according to the 14th Five-Year Plan, non-fossil power generation will reach 39% of total power generation in 2025. While it appears the rapid pace of wind and solar investment means China is on a path to exceed the 2030 wind and solar capacity target, continuing power sector reform will be needed to support integration of large amounts of new renewable energy into the grid and to meet the longer-term decarbonization goal.

OPPORTUNITIES AND CHALLENGES

To get the most out of the clean energy opportunities and meet decarbonization goals, policymakers in the U.S., China, and around the world are considering a broadly similar set of power sector issues, centered on ensuring a reliable grid with high levels of wind and solar generation. Fortunately, this challenge is manageable. With a well-designed policy, market, and regulatory framework one can expect a very reliable power sector, even at very high penetrations of wind and solar generation. A growing body of international experience – including from the U.S. and China – bears this out. Here we summarize several key aspects of the common opportunities and challenges faced by both countries.

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1 For a list of these states see Clean Energy States Alliance. https://www.cesa.org/projects/100-clean-energy-collaborative/

2 The package is part of the Inflation Reduction Act of 2022. For a summary, see https://www.democrats.senate.gov/imo/media/doc/summary_of_the_energy_security_and_climate_change_investments_in_the_inflation_reduction_act_of_2022.pdf

3 US Department of Energy, "The Inflation Reduction Act Drives Significant Emissions Reductions and Positions America to Reach Our Climate Goals," August 2022. https://www.energy.gov/sites/default/files/2022-08/8.18%20InflationReductionAct_Factsheet_Final.pdf.

Reliability challenges

Both the U.S. and China have struggled recently with regional power sector reliability. In both countries, some stakeholders argue trade-offs exist between an electric power system based on clean energy and other goals such as power sector reliability and energy security. These arguments pose a threat to the pace of the energy transition. However, evidence indicates that power sector reforms, such as those recommended below, can improve power sector reliability while accelerating the clean energy transition, at low (or even reduced) cost (Abhyankar et al. 2022; Energy Research Institute 2022; Geocaris 2022).

In 2020-2021, the two largest U.S. states, California and Texas, faced extreme weather conditions and experienced rolling power outages. In California, extreme regional heat and wildfire threats affected the reliability of the regional fossil fleet, transmission system, and wind output, forcing rolling outages. In Texas, extreme cold shut down significant gas capacity and led to extended outages during life-threatening weather conditions. In 2022, the national grid reliability authority warned that extreme heat would threaten summer reliability for most of the U.S. grid, citing faster-than-expected coal retirements and a failure to quickly replace that capacity (NERC 2022). While no such outages occurred in 2022, there were several close calls in regions with high shares of renewable energy.

In 2021, China experienced a series of power crises affecting large parts of the country and many millions of consumers experienced power outages. The summer of 2022 has brought a major heatwave, severe drought, significantly reduced hydroelectric generation, and renewed power reliability problems, particularly in the central part of the country.

Control and Retirement of Coal-fired Generation Capacity

Coal power is among the most emissions-intensive power sources and is responsible for a majority of U.S. and China power sector emissions. The April 2022 Intergovernmental Panel on Climate Change report finds that "limiting global warming to 2 degrees C or below requires a rapid shift away from unabated coal consumption.... This will require cancellation of new coal power projects and accelerated retirement of existing coal plants." (IPCC 2022). Coal also creates large public health costs through air and water pollution.

Fortunately, it is increasingly clear that new coal power is not needed for affordable, reliable power. Internationally, well-designed markets and planning mechanisms no longer identify new coal generation capacity as the best solution to meet power system needs, for several reasons. First, in the U.S., China, and many other countries, the levelized cost of solar and wind generation is now near or below the fuel cost of coal-fired and gas-fired power plants, meaning that it can be less expensive to construct new solar and wind generators than it is to operate existing thermal plants (IRENA 2022). This renewable energy cost advantage has been strengthened by coal price increases seen by many countries in 2021 and 2022. Second, compared to hydro, demand response, energy storage, and gas-fired generation, coal power is relatively ill-equipped to provide the rapid changes in output to complement low-cost wind and solar generation (Lin et al. 2022; Lu et al. 2019).

The U.S. has made significant progress reducing coal generation and retiring coal-fired power plants in the last decade. Since peaking in 2007, coal generation is down 55%. Ending unabated coal power by 2030 is within reach, although additional national and subnational action will likely be necessary to eliminate many of the last unabated coal plants. Coal mining and coal power remain culturally, economically, and politically important in some parts of the U.S. Furthermore, insulation from the full social (e.g., health) costs of coal, along with stranded asset concerns, have led some utilities to delay coal retirements. The opportunity to develop lower-cost clean energy portfolios locally to replace retiring coal is virtually ubiquitous in the U.S. (Gimon, Myers, and O'Boyle 2021) The Infrastructure Investment and Jobs Act of 2021 and Inflation Reduction Act of 2022 provide grants and incentives to coal-dependent communities to invest in clean energy manufacturing, and provide the utility industry with low-cost financing to transition from coal to clean infrastructure.

In China, many of these factors are also relevant. A well-designed "scientific" set of market and planning mechanisms, such as those currently being pursued under the banner of power sector reform, will likely identify better and lower-cost solutions than new fossil-fired generation capacity to support a power grid with increasing amounts of renewables. These reformed mechanisms will also likely reject the proposition to "cut and replace" old coal plants with new more efficient coal plants. Replacing old coal power plants with cleaner and more flexible resources, including demand response and energy storage, will likely be lower-cost and better for reliability.

Regional integration

When optimizing demand and supply on the grid in real time and when planning new transmission and new resources, widening the geographic operational balancing area is beneficial. This regional approach can be an effective and low-cost way to boost system reliability and support integration of wind and solar generation (IRENA 2019). Real-time economic dispatch across broad regions directs dispatchable fossil resources, which incur costs by purchasing and burning fuel, to adjust output based on the availability of complementary sources of zero-marginal-cost wind and solar energy, reducing cost and increasing the share of renewable energy in the generation mix. Unifying this dispatch function over a wide geographic area leverages the diversity of wind and solar output, increasing reliability contributions from wind and solar, reducing renewable integration costs, and reducing the need for fossil reserves. Both the U.S. and China have made significant progress in this regard, but there are more opportunities to leverage the benefits of regional integration.

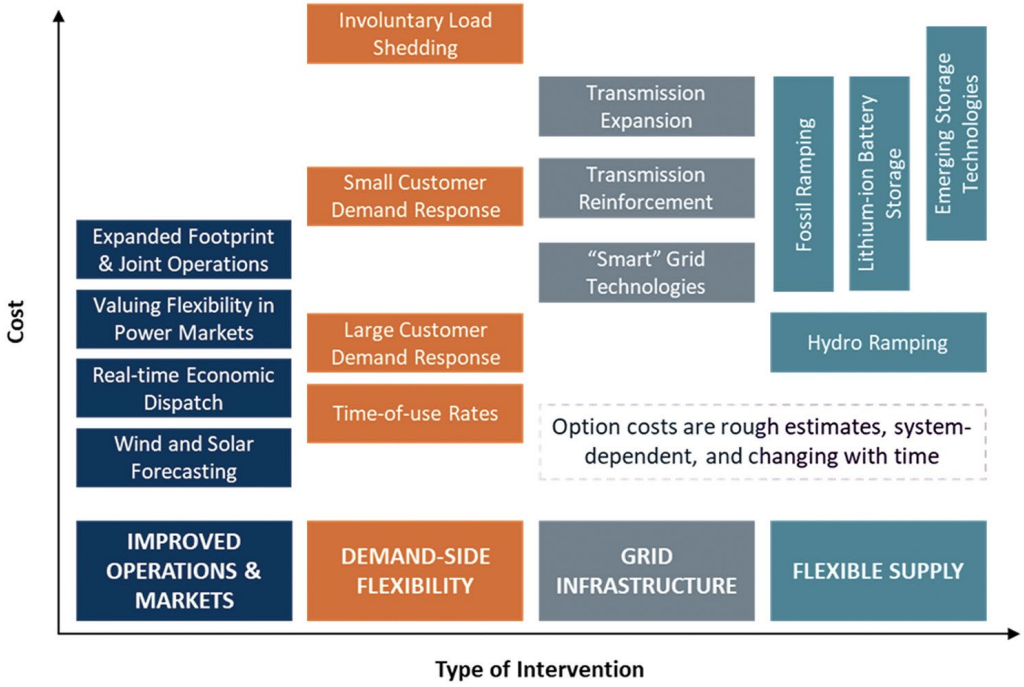
Regional transmission organizations (RTOs) in the U.S. feature competitive markets and economic dispatch of electricity in real-time over large geographic areas and demonstrate a substantial track record of regional coordination. About two-thirds of the U.S. are served by these markets. The southeast and western parts of the U.S. currently lack RTOs, although the western U.S. has been gradually moving in this direction and has established interim regional market mechanisms. The Southeast has lagged behind, although nascent efforts are afoot in that region to increase regional coordination. Regions with RTOs have seen substantial benefits, including reduced consumer costs and reduced emissions. In these markets, renewable energy investment and low gas prices have contributed to competitive pressure on coal power, prompting rapid coal retirements. However, increasing renewable energy investment has tested the ability of RTOs and states to adequately plan and site new transmission to integrate the 1,000 GW of clean energy resources that have applied to interconnect to the grid.

China's power system has made impressive strides in absorbing fast-growing amounts of wind and solar energy. As in the U.S. and other countries, however, much work remains to be done to ensure that the grid can integrate much higher shares of variable renewable generation. Large investments in the country's transmission network have helped link large geographic areas and balance variable supply and demand across great distances. Policymakers in China have also introduced new policies including markets to help ensure that this modern grid network is operated efficiently. The January 2022 policy on a "National Unified Electricity Market System" is a very important step forward, although opportunities remain to improve this vision and ensure successful implementation.

System flexibility

With growing amounts of wind and solar generation, maintaining reliability requires managing increased variability at various time scales. Wind and solar generation increase variability due to dependence on weather patterns, and they need resources able to adjust output to compensate for this variability – a trait known as "flexibility." This includes short-term (seconds, minutes, and hours) to long-term (e.g., weeks) fluctuations in supply and demand. Managing this variability requires identifying, constructing, and orchestrating a cost-effective portfolio of resources with the right characteristics to support a clean energy grid. In turn, this requires a well-designed set of policies – and associated market mechanisms, planning processes, and regulations. (See figure 2.)

Figure 2 | Intervention Policies and Relative Cost



Source: Energy Innovation, adapted from *NREL Flexibility in 21st Century Power Systems*

The U.S. has significantly improved grid flexibility. Economic dispatch and improved forecasting have become widespread best practices, with more opportunities to increase interregional transmission and take advantage of regional diversity, particularly between the three major interconnections in the West, East, and Texas (ESIG 2022). Demand response is another major opportunity for improvement. U.S. demand response participation has remained mostly stagnant despite widespread advanced meter deployment, widely available time-of-use pricing, and rules allowing demand response to participate in wholesale generation markets. Federal-state coordination remains problematic. Existing gas and hydro capacity have supported renewable energy integration, and battery storage is quickly becoming an economic option to increase system flexibility. However, much work remains to unlock the full potential of various low-cost sources of flexibility including demand response (Dupuy and Linvill 2019).

In China, the power system has become increasingly flexible and policymakers have been laying the foundation for further improvements, but implementation challenges remain. The effort to design and implement spot electricity markets will be very important for flexibility. If designed well, these markets will help send better signals on the supply- and demand-side about the value of flexibility across time and location. In addition, recent national policy statements regarding time-of-use pricing, virtual power plants, and demand response open the possibility for greatly improved power system flexibility, if implementation of these broad statements proceeds well at the provincial and local levels. China is a world-leader in uptake of electrification, particularly in transportation – presenting a major opportunity to unlock the flexibility they can provide. In addition, the Chinese government has announced ambitious goals for pumped hydro projects and retrofit of existing coal plants for more flexible operation.

End-use energy efficiency

Improvements in consumer energy efficiency (EE) is another important ingredient for a low-cost, speedy, and reliable energy transition. Both the U.S. and China have decades of experience in this area. There is overlap with several other papers in this series, including those on transportation, buildings, and industry. We echo the EE discussion in this paper because international experience

demonstrates the importance of integrating EE policy with power sector policy in order to identify and exploit ways in which EE can displace expensive and dirty power resources and mitigate the grid impacts of rapid electrification (Crossley 2014).

In the U.S., energy efficiency policy is mostly a state and local issue, although federal policies provide some financial support. Local building codes drive efficiency in new buildings, while a mix of federal and state policy dictates appliance efficiency standards. Public investment in efficiency partly takes place through state-regulated electric utility programs, but state experience in this regard is mixed.

Leading states like California and Massachusetts have implemented energy efficiency resource standards and utility incentives, which use financial incentives and consumer education programs to drive measurable savings (Berg, Cooper, and DiMascio 2022). These programs are typically accompanied by revenue decoupling, a practice to reduce the negative impact of energy savings on utilities' financial health (Lazar 2016). Some states require integrated planning practices in which traditional power sector resource investments are compared against alternative energy efficiency investments. In other states, little policy exists to support efficiency investments. There are huge opportunities for state public utility regulators, state legislators, and federal funding to unlock greater efficiency at the state and local level and ensure that efficiency investments are integrated with power sector planning.

In China, the 2021 carbon action plan committed to "give first priority to the conservation of energy." This is a very important pledge with potential to boost reliability by managing demand growth, improve energy security by reducing energy imports, and reduce system costs and emissions. However, the policy is largely silent on how to integrate this conservation pledge with ongoing power sector reform efforts. China also has a significant demand-side management policy that requires grid companies to meet targets for investing in end-use energy savings. Although the targets under this policy are small as a percentage of electricity sales (0.3%), the great size of the Chinese power sector means that this is likely the largest utility energy savings obligation in the world in terms of volume of annual energy savings.

RECOMMENDATIONS FOR THE U.S.

The U.S. federal-state legal system splits authority to regulate the electricity sector between the federal and state government. Federal policy is a key lever, and recent progress on federal spending priorities will significantly bolster the economics of clean energy, invest in emerging clean energy technologies, and increase the pace of deployment. Further action from states implementing these policies, as well as federal agencies, will be crucial to realizing the potential of federal clean energy subsidies to reduce emissions and meet U.S. climate goals.

Accelerate transmission capacity expansion

The U.S. currently has more than 1,000 GW of proposed clean energy projects which have applied to interconnect to the grid, roughly enough to meet its 2030 decarbonization goals. This number, which has skyrocketed in recent years, is driven by economics and consumer interest in wind, solar, and batteries. As this interconnection queue grew, transmission interconnection processes have become more complex, and now take four years on average. U.S. grid operators must find a way to sort through the queue to prioritize the most viable projects, while reforming planning processes to increase needed transmission capacity. This profoundly includes offshore wind, a newly economic resource for the U.S. The Federal Energy Regulatory Commission (FERC) has embarked on rulemakings to achieve this potential.

US federal electricity regulators and utilities and RTOs should:

- Pass new regulations requiring regional transmission plans and cost allocation rules that increase access to the grid for economic clean energy projects.

- Clarify the intention to reduce interconnection queue times and develop criteria for fast-tracking projects with sufficient transmission capacity.

Increasing regional integration and improving markets

Recent extreme weather events including extreme heat have tested the resilience of the U.S. electricity system. As the grid becomes more dependent on weather conditions to produce electricity, more linkages and coordination over broader geographies is crucial to improving reliability at a low cost. This takes two forms.

First, Western and Southeastern states still have fragmented management of the transmission system and power plants, similar to provincial-level approach to system operation in China, but often at an even smaller geographic scale. As a result, states and utilities are not able to take advantage of reliability and cost benefits of cheaper energy in neighboring states.

Second, even in areas with regional transmission coordination, interregional capacity would help improve reliability, access low-cost renewable energy, and ride through severe weather. A National Renewable Energy Laboratory study indicates increasing interconnection between the three national grids would yield dramatic net benefits and increase resilience (Bloom et al. 2022).

To improve reliability and resilience in a high-renewables future:

- At state and federal levels, develop resource adequacy metrics and market products that recognize and preserve the reliability value of portfolios including renewables, storage, demand, and dispatchable capacity.
- Western and Southeastern States, under FERC guidance, should join unified RTOs with unified spot markets and shared reliability obligations.
- The U.S. Department of Energy should study the feasibility of a national "macrogrid," linking key renewable resource regions and quantifying the benefits, including resilience.
- DOE should designate high-voltage interconnections between regions as National Interest Electric Transmission Corridors, unlocking authority to finance and site these vital lines.
- FERC should create greater requirements to study and plan new interregional lines.

Updating state utility planning processes

U.S. states retain significant authority under existing law to determine their own electricity resources. It is common practice for regulated utilities to propose, and regulators approve, 15 to 20-year resource plans and update them periodically. Many of these processes are out of date, or are controlled by utilities with a vested interest in maintaining the status quo. New subsidies for clean energy resources mean utilities and their consumers will need to update these planning processes, integrating up-to-date technology costs as well as using modern tools to assess the reliability needs of high-renewable electricity systems. Unless these processes evolve, states will be too slow to adopt economic wind, solar, and storage resources, leaving cost savings on the table and threatening the U.S. ability to meet its climate goals.

U.S. utilities and their regulators should:

- Open new rulemakings to assess the economics of clean energy through competitive bidding, and plan for a faster electricity transition.
- Develop new clean energy goals (and require associated procurement) that align with national and international standards for climate mitigation, such as 80 percent carbon-free electricity by 2030.
- Coordinate planning processes with regional activities to plan for and expand transmission capacity.

- Adopt state-of-the-art modeling tools that accurately model electricity systems with high levels of storage, wind, and solar.
- Link utility profitability to performance on cost and clean energy adoption.

Fossil retirements and community transition

While coal fired power plants are declining in the U.S., they are still a key reliability resource and an economic contributor to local economies. New clean energy resources and greater system flexibility can replace the reliability services coal provides, and these same solutions can revitalize coal-dependent communities. For example, the transmission capacity left by retired coal facilities can help fast-track local clean energy development. Examples of good policy underway include recent funding under the federal Infrastructure Investment and Jobs Act of 2021 providing grants and tax credits to locate clean energy manufacturing in coal-dependent communities, and the establishment of a "Just Transition Office" in the state of Colorado.

To revitalize coal communities with clean energy development, federal and state governments should:

- Authorize state public utilities commissions to create ratepayer-backed bonds that securitize and retire uneconomic coal and gas units, relieving utility customers of the obligation to pay high costs of capital, while making utilities whole for their reasonable investments. Provide federal financing for the same.
- Provide stopgap funding to supplement the tax base provided by retired coal infrastructure and consider setting up a state just transition office.
- Provide economic opportunity for coal-dependent communities through clean energy investment, job training, and stopgap funding for public services.

Prioritizing Energy Efficiency and Demand Response

Energy efficiency and demand response are among the lowest cost zero-carbon resources available to society to meet future energy needs. While efficiency in the U.S. economy has continuously improved, the U.S. building stock remains rife with potential low-cost opportunities for efficiency. State and local governments control the rules governing building construction and energy pricing.

To leverage the vast potential of efficiency to meet climate goals, state and local governments should:

- Update local and state-wide building codes to international best practices, including rules that require rooftop solar on new buildings.
- Develop programs like green banks or utility financing to help low-income customers finance efficiency improvements and access distributed energy.
- Require utilities include efficiency measures in planning. Develop utility-led efficiency incentive programs to invest in cost-effective efficiency measures.
- Utilities should offer time-of-use and critical peak pricing programs to reward consumers for shifting demand and contributing to system reliability. Rates should encourage consumers to pair distributed solar with storage to benefit the grid.

RECOMMENDATIONS FOR CHINA

Following China's landmark dual carbon pledges, the government in late 2021 issued the first documents under the "1+N" framework for decarbonization. These initial documents include high-level directives for the power sector, including requirements to "speed up the

development of the new electric power system" with "optimized clean energy generation" (China NDRC 2021a, 2021b). The recommendations in this section offer practical ways to follow through on these statements and build on China's rapid renewable energy investment – while containing costs and accelerating progress toward the dual carbon targets.

Refinement and implementation of the "National Unified Electricity Market System"

The January 2022 statement from the National Development and Reform Commission (NDRC) and National Energy Administration (NEA) on a "National Unified Electricity Market System (Document 118)" is a very important step forward toward regional and national integration of the power sector (China NDRC 2022).

To build on Document 118, it would be valuable to:

- Put spot markets first. Focus on development of unified national (or at least multi-provincial) spot markets as opposed to the longer-term and interim markets that have been piloted in China and that are discussed in Document 118. Spot markets should be designed to send rational time- and location-varying signals to support system flexibility. The design of the national or regional spot markets should emphasize practicality and need not be as complex as the pilot provincial-level spot markets.[4] Meanwhile, the medium-and-long term contract market, which in current form is a barrier to system flexibility, should be transformed into a financial market that has a primary function of allowing market participants to hedge the spot price.
- Be cautious about implementing a "generation capacity cost recovery mechanism" that would "guarantee electric resource fixed cost recovery", as countenanced in Document 118. Only resources that are needed for reliability (as identified in a scientific planning process) and that meet policy criteria (including air quality standards) should be allowed to recover any fixed costs. It is important to avoid offering capacity payments to excess coal power resources and to avoid promising capacity payments for new coal power.

Transparent power sector planning to support reliability during the transition

To complement the five-year plan process, various organizations in China, including the grid companies and research institutions, carry out detailed power sector planning, but these are not sufficiently transparent nor sufficiently coordinated to support a reliable, efficient, and competitive marketized power system with high penetrations of renewable energy. We recommend updating NEA's 2016 planning regulation[5] to create an official planning framework with three closely interlinked and transparent planning processes, each with published reports, reviewed and approved by NEA, and online data releases:

- A seasonal planning process to assess and manage near-term risks and support reliability. This would have a rolling one-year time horizon and twice-yearly reports. Such a process would have been very valuable in managing measures to mitigate the 2021 power crises as well as assessing the lessons of those crises.
- A medium-term least-cost resource planning process that improves on the existing five-year planning process. This would identify the least-cost mix of new resources needed to meet power sector needs (and the resources that should retire), given decarbonization and other policy objectives. It would have a rolling time horizon of five to ten years, with yearly reports.

[4] To start, the dispatch and trading centers could be tasked with 1) implementing a single unified economic dispatch procedure for each multi-province region; and 2) creating a spot market energy price based on estimated system marginal cost. In a "step-by-step" fashion while ensuring stability, this could be refined into a more competitive system over time as regions become confident with regional market operations.

[5] The 2016 framework can be found here: http://www.gov.cn/gongbao/content/2016/content_5145577.htm

- A long-term transmission system planning process to examine different long-run pathways for the clean energy transition. The rolling time horizon would be twenty years or more, with reports every two years.

We suggest considering emerging planning practices in the European Union (EU), where the European Association for the Cooperation of Transmission System Operators serves as a continent-wide planning authority and has been developing a set of transparent processes with different timeframes, to better support a clean energy grid (ENTSO-e 2021).

Policies to support low-cost system flexibility

China's "1+N" framework calls for "the construction and operation of a new power system...[with] improved comprehensive flexibility." The market and planning reforms mentioned above will help optimize the resources to provide flexibility. Similarly, they will help avoid costly, polluting, and inefficient options, including unneeded new coal power capacity. Additional policy and regulatory mechanisms will be needed to support low-cost flexibility, including the following:

- In 2021, NDRC issued a requirement for national time-of-use retail electricity pricing.[6] Provincial governments have been making good progress implementing this requirement but it would be valuable to refine those efforts and make sure they are comprehensive. This includes ensuring that all system costs, including transmission and distribution costs, are reflected in the design of TOU rates.
- The government's carbon action plan commits to supporting "virtual power plants" (VPPs), which are aggregations of distributed and demand-side resources. It would be worthwhile to issue national policy measures to ensure VPPs can participate fairly and fully in the new spot electricity markets in a way that identifies and compensates these resources for the full value of various services that they can provide to the system. Some of these policies are now being investigated in the pilot provincial spot markets.

Integrating the pledge to "give first priority to the conservation of energy" with power sector reform

China's conservation pledge is very important for the decarbonization effort, and parallels the EU, which issued a landmark "efficiency first" principle in 2015. In the EU, this has been useful in focusing attention on the promise of EE as a low-cost resource to boost power system reliability, improve energy security by reducing energy imports, and reducing emissions.[7] However, in the EU, much work is needed to implement these policies and ensure efficiency is truly the priority resource in the power sector.

We offer the following recommendations for China with the idea of ensuring China's conservation pledge is well integrated with China's power sector reform.

- Create detailed rules requiring grid companies to evaluate and invest in energy conservation and other demand side resources as "non-wires alternatives". Alternatively, and perhaps better in line with China's virtual power plant policy, this concept could be framed as "virtual transmission and distribution assets".
- Under the ongoing effort to eliminate coal as a fuel in buildings, emphasize electrification while ending coal-to-gas conversion. This will free up expensive gas supplies for more valuable uses, including in hard-to-electrify segments of industry.
- Expand the target, under the NDRC's 2010 demand-side management policy, for grid company annual energy savings.[8]

[6] https://zfxxgk.ndrc.gov.cn/web/iteminfo.jsp?id=18212

[7] https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficiency-targets-directive-and-rules/energy-efficiency-first-principle_en

[8] China National Development and Reform Commission. (2010). *Guidance on Electricity Demand-side Management Regulations No. 2643.*

OPPORTUNITIES FOR COLLABORATION

Given that the U.S. and China are grappling with technical and policy challenges that have similar themes, the two nations can continue collaboration on a number of areas, including:

- Mutual learning on power sector reform, including markets, planning, pricing, operations, demand-side integration, and other topics. This can include meetings between officials, grid operators, and other relevant stakeholders. For example, increased interactions between NEA (and its regional regulatory bureaus) and US agencies such as FERC would be productive.
- Jointly coordinated deployment goals and clean energy targets for clean energy resources, targeting 80 percent carbon-free electricity in each country as soon as feasible, recognizing common but differentiated responsibilities.
- Technology knowledge exchange, including on demand response, transmission, hydrogen, and vehicle-to-grid integration.
- Scientific exchange to understand the impacts of climate change on grid reliability and resilience, and jointly develop policy, analytical, and technological solutions.

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