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Four Things You Should Know about China's Electricity System

By Fredrich Kahrl, Jim Williams, and Ding Jianhua

High-level dialogue on energy and climate between the United States and China has focused heavily on technology. Low carbon technologies are a necessary part of energy and climate solutions, but by themselves wind turbines, PV arrays, carbon capture facilities, and nuclear reactors are just equipment. Without policies to curb electricity demand growth, the benefits of even a massive build out of low carbon technologies will be limited. Without a regulatory system that fosters transparent, cost-reflective energy pricing, rising costs may doom new technologies before they can make it onto the grid, and opportunities for more prosaic solutions, such as expanding natural gas generation, may be missed. This brief highlights why an understanding of how China's electricity sector works is crucial in promoting effective clean energy collaboration. Why, for example, do highly polluting and inefficient power plants in China run just as much as efficient ones, even though efficient plants cost less to run? How can one province defy Chinese central government orders to shut down small coal power plants and become a "learn-from" model for other provinces in the process? Answering questions like these pinpoints China's challenges and areas where U.S. experience can help.

Coordination and collaboration between the United States and China—the world's largest energy consumers and greenhouse gas emitters—is critical to solving global energy and climate problems. Although the United States and China may be business competitors, both countries have an interest in seeing the other increase energy security while reducing the environmental and economic impacts of energy use.

In a climate and energy constrained world, electricity stands out as the most important area for energy cooperation between the United States and China. For both countries the electricity sector is the largest source of greenhouse gas emissions. The massive growth in electricity demand projected for China over the next two decades could roil global markets for coal, uranium, and natural gas, but could also open opportunities for collaboration in developing new energy technologies.

Despite the obvious importance of dialogue between the United States and China on electricity issues, our understanding of each other's electricity sectors is surprisingly inadequate. Promising new initiatives on technical cooperation in clean energy are likely to meet with limited success until the similarities and differences in engineering, economic, and political challenges facing each country's electricity sectors are better appreciated. With improved understanding, there is a large untapped potential for joint investigation and problem solving.

This research brief describes four themes that we think are essential for deepening U.S. understanding of the Chinese electricity sector:

-Growth in electricity demand, not technology, is the biggest challenge to China's energy and climate goals;
-Neither regulated nor market-based, China's electricity sector is in need of an institutional overhaul;
-Rising costs of electricity could cause China to lower its renewable energy sights; and,
-Natural gas is as important as renewables and nuclear power for China's transition to a low carbon electricity system.

1. Growth in Electricity Demand, Not Technology, is the Biggest Challenge to China's Energy and Climate Goals

China's clean energy and climate goals have been all over the headlines of late. On the energy front, China has set an ambitious goal of obtaining 15 percent of economy-wide final energy consumption from non-fossil alternative energy sources by 2020.[1] On the climate front, China aims to reduce the CO_2 intensity of its GDP to 40-45 percent below 2005 levels by 2020. But whether either of these goals is achievable will depend less on technological innovation and more on the ability to manage growth in electricity demand.

Separately from the alternative energy and CO_2 goals, the government has set ambitious targets for the electricity sector to build renewable, large hydroelectric, and nuclear power plants (Table 1). These targets represent most of the alternative energy that will be developed in China over the next decade, which links the success of the 15 percent alternative energy goal to the electricity sector's success in meeting its new capacity targets. But the alternative energy goal is not a fixed number – how much total energy China consumes determines how much alternative energy China needs to build to meet the goal. The same is true for China's CO_2 intensity goal, which has been an important feature of China's international negotiating position on climate.

Some numbers may help clarify how electricity demand affects China's likelihood of reaching its alternative energy and CO_2 intensity targets. The International Energy Agency (IEA) predicts that China's final energy consumption will reach 76 quadrillion Btu (quads) by 2020. In that case, reaching the 15 percent goal will require just over 11 quads of alternative energy.[2]

Table 1. Targeted and Existing Renewable Generation Capacity, and Required New Capacity to Meet Targets

Resource	Target Capacity 2020 (GW)	Energy Output Estimate 2020 (Quads)	Existing Capacity 2009 (GW)	Required New Capacity 2009-2020 (GW)
Hydropower	300	3.4	196	104
Wind	150	1.1	18	132
Biomass	30	0.6	1	29
Solar	20	0.1	0	20
Nuclear	86	2.3	9	77
TOTAL	**586**	**7.6**	**224**	**362**

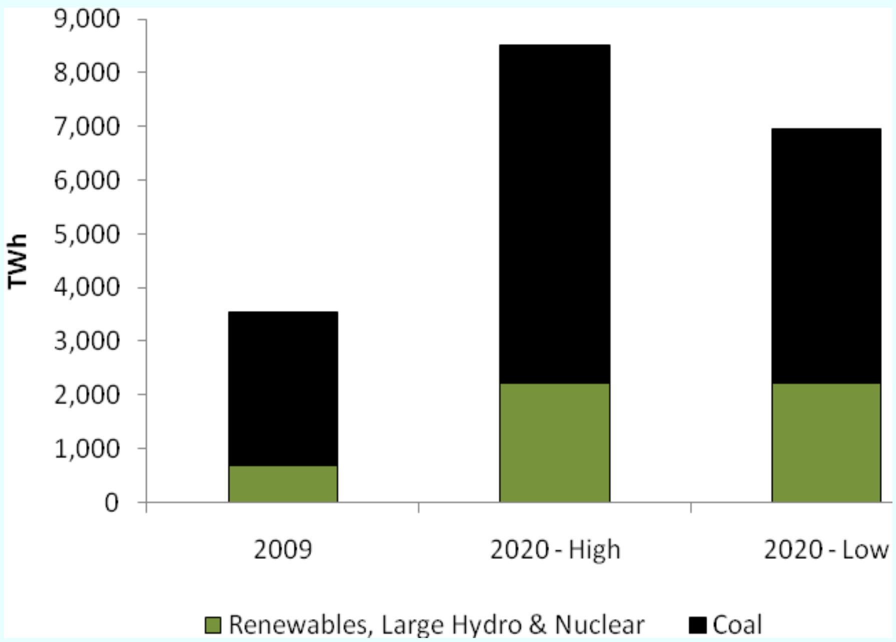
Sources and Notes: Hydropower, wind, biomass, and solar targets are from Martinot (2010); nuclear targets are from Chai and Zhang (2010). Existing capacity is from CEC (2010).

If the power sector were to meet its aggressive targets for renewable, hydro and nuclear power, that would provide 7.6 quads of end use energy, but still leave nearly 4 quads of the alternative energy goal to be met by other sectors, which is probably unachievable. On the other hand, if China's final energy consumption could be reduced by (for example) 15 percent below the 76 quad level, to 65 quads, this would leave only 2 quads of the goal to be met by other sectors. Reducing electricity demand, in short, makes the alternative energy goal easier to achieve.

Similarly, high demand growth for electricity could erode the CO_2 benefits of a massive increase in alternative energy. For instance, in its "high" scenario China's State Grid Economic Research Institute (SGERI) projects China would need to generate 8,510 terawatt hours (1 TWh is 1 billion kWh) by 2020 to meet demand. The renewable, large hydro, and nuclear build-out in Table 1 would generate around 2,200 TWh, representing the upper limit of what could be achieved by the power sector.[3] If the difference had to be made up with coal, then in the high demand scenario coal would end up accounting for 74 percent of China's generation mix in 2020, down only slightly from 78 percent in 2009 and more than doubling China's coal generation in 2009, despite the large investment in alternative energy. (See Figure 1).

But if the amount of electricity needed was more in line with SGERI's "low" forecast of 6,947 TWh, the coal share would fall to 68 percent.[4] While 6 percentage points may not seem like a lot, this would be equivalent to more than 1.5 billion metric tons of CO_2 reductions annually, or more than half of all CO_2 emissions from China's electricity sector in 2007.[5]

Figure 1. Coal-Fired and Alternative Generation Under High and Low Demand Growth Forecasts (Assuming Targets for Renewables, Large Hydropower, and Nuclear Power are Met)



Sources and Notes: See endnotes 3-4 for the sources and assumptions for this figure.
Data for 2009 are from the China Electricity Council (2010). For simplicity this figure ignores 132 TWh of generation (3.6 percent of total) from oil, natural gas, waste, cogeneration, and geothermal in 2009 and for the sake of illustration assumes that they are small in 2020.

The electricity sector is a key player in reducing energy demand growth. China is in the process of electrifying, meaning that an ever-larger share of the energy it consumes is in the form of electricity. Since 1990 the electricity share has more than tripled, and is expected to nearly quintuple by 2020, as households and industry alike use more electricity-consuming equipment.[6] Improvements in end use efficiency and a reduction in the share of heavy industry in the Chinese economy could significantly reduce growth in electricity demand, which would improve China's chances for success in meeting its energy and climate goals.

China's new demand-side management (DSM) rule, which requires grid companies to meet 0.3 percent of sales (kWh) and load (kW) from energy efficiency, is a small but important step toward a greater emphasis on demand-side efficiency in electricity sector planning.[7] But much more is needed. To make a

meaningful dent in energy demand growth, China will need to give energy efficiency an even higher priority than expanding energy supply in its planning and investment decisions.

2. Neither Regulated nor Market-based, China's Electricity Sector is in Need of an Institutional Overhaul

For the last 20 years, China's electricity sector has had one foot in its planned economy past, and one foot in transition. Moving out of the planned economy and setting up an independent regulatory system is a crucial step for China's electricity sector, with implications for the success of China's energy and climate policies.

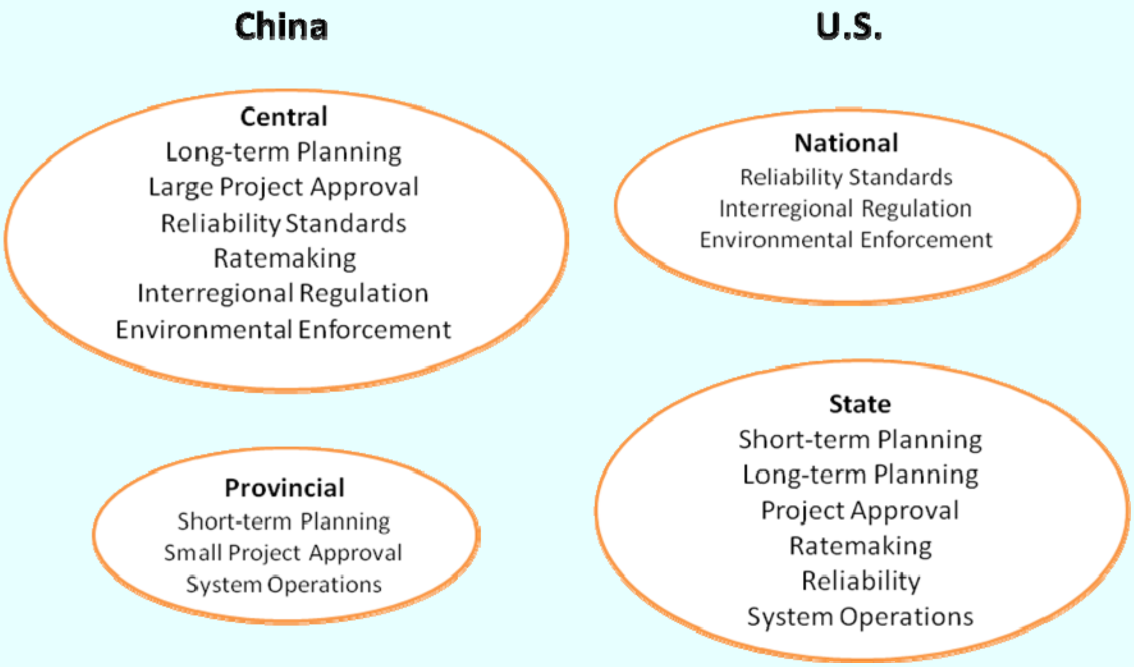
Historically a natural monopoly, in Western countries the electricity industry developed around a regulated investor-owned utility model that provided guaranteed returns in exchange for strong oversight. In the United States this oversight is carried out at the state level by public utilities commissions (PUCs), whose authority is superseded by the Federal Energy Regulatory Commission (FERC) only in interstate issues.

This cost-of-service model never took hold in China. During the planned economy and even into the 1980s, China's electricity sector was owned, planned, financed, and operated by government agencies. In the late 1990s, the government formally corporatized the sector, creating the State Power Corporation (SPC). In the early 2000s, with deregulation en vogue worldwide, China "unbundled" the SPC, separating the generation, transmission and distribution businesses and creating a national regulator, the State Electricity Regulatory Commission (SERC). However, despite these changes, China's electricity sector remains fundamentally government owned and operated, but only lightly regulated. Indeed, China deregulated its electricity sector without it having ever been regulated in the first place.

Efforts at independent regulation of the electricity sector in China have run into two primary roadblocks. First, SERC does not have the powers or authority to be an effective regulator. SERC was never given approval, planning, or ratemaking powers. Key decision-making powers for the electricity sector are instead concentrated in the National Development and Reform Commission (NDRC), China's chief planning agency. National state-owned enterprises in China's electricity sector, and in particular the State Grid Corporation, are often more powerful than SERC, which, because China lacks an independent judiciary, leaves SERC with few direct options for enforcing the rules.

Second, beginning in the 1980s, China's electricity sector has grown ever-more decentralized, with provincial governments increasingly in control of generation assets and provincial grids.[8] China's national regulatory system is mismatched with the electricity sector's provincial character, and forms a sharp contrast with the more state-based regulatory systems in the United States (Figure 2). China's national-provincial incongruity has created frequent conflict between the central government and provincial governments and acts as an obstacle to the implementation of national policies.

Figure 2. Level of Decision-Making Authority in the Chinese and U.S. Electricity Sectors



China's efforts to shut down small, inefficient power plants illustrate how central-provincial tensions can thwart national policy. Facing a surplus in generating capacity during the Asian financial crisis of the late 1990s, China's central government slowed power plant approvals and began requiring provincial governments to shut down small, inefficient, and highly polluting power plants. Shandong Province, however, had only recently faced electricity shortages and decided to risk disobeying Beijing. Between 2000 and 2003, Shandong built 5 GW of small, coal-fired power plants. As the Chinese economy began to pick up in 2003 and demand for electricity surged, other provinces found themselves without enough generating capacity. Shandong, however, had capacity to spare. By 2005, Shandong had become China's largest industrial province, and other provinces were sending teams to "study" the Shandong model.[9]

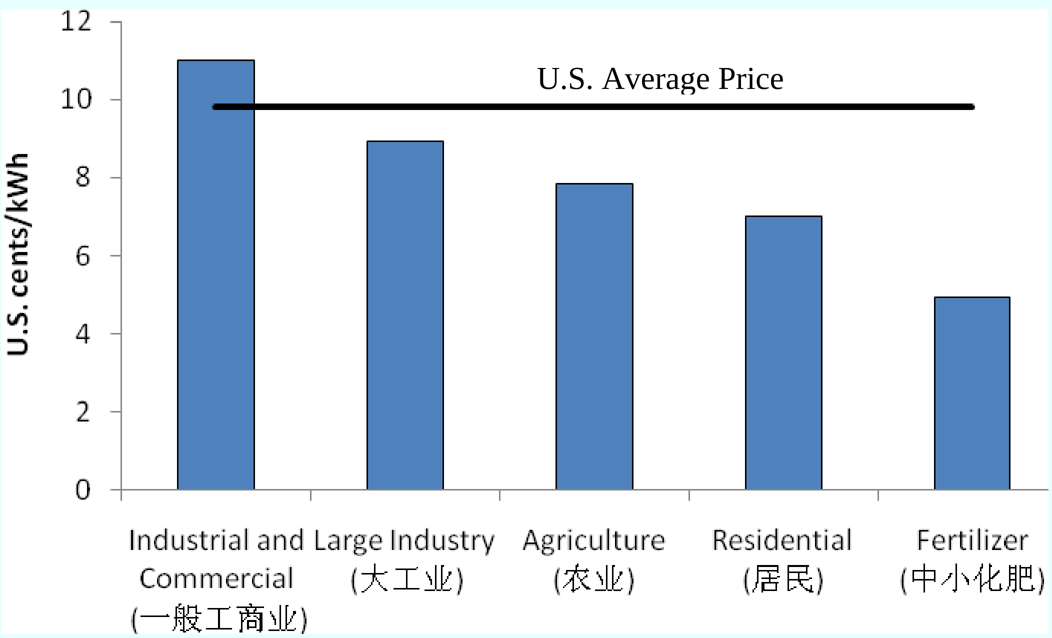
The consequence of these institutional shortcomings is an electricity sector with powerful, entrenched monopolies, tension between different levels of government, a strong reliance on negotiated settlements rather than rule-based decisions, and a lack of regulatory oversight and transparency. Within these confines, government agencies have only a limited space in which to operate. In particular, they lack the ability and tools to make trade-offs among competing interests, which rising costs and new environmental mandates are making more common.

3. Rising Costs Could Cause China to Lower its Renewable Energy Sights

Renewable energy is still costly relative to coal. Because electricity prices in China are regulated but not transparent, rising costs that result from the high costs of renewables have the potential to alienate both producers and consumers. Making prices more rule-based and transparent is an important step in creating constituencies to support the domestic deployment of renewable energy in China.

Contrary to popular belief, electricity in China is already expensive. On average, retail electricity prices in China are only about 15 percent lower than in the United States, and for many Chinese provinces electricity prices are no different from the average U.S. Midwestern state.[10] What is different about the United States and China is how these prices are distributed across customer classes. In the United States, residential and small commercial customers pay the highest prices, followed by larger commercial and then industrial customers. In China, commercial and some industrial customers pay high prices, while heavier industry, agriculture, and residents pay lower, heavily subsidized prices (Figure 3). While the U.S. approach is intended to reflect costs, the Chinese approach is intended to support key industries and maintain social stability.

Figure 3. Average Retail Electricity Prices in Beijing and U.S. Average Retail Price, 2009



Source and Notes: Data are from NDRC Announcement on Adjusting Retail Prices for the North China Power Grid, which are available online at http://www.sdpc.gov.cn/zcfb/zcfbtz/2009tz/t20091120_314499.htm. These prices are simple averages across voltage-specific prices. Average prices mask an enormous amount of diversity in retail prices. Beijing has industry-specific prices within "Industrial and Commercial" and "Large Industry," demand and transformer charges, summer and non-summer time-of-use prices that cover all producers except fertilizer manufacturers, and preferential prices for large industry and special economic zones.

The lack of a robust link between prices and costs is systemic throughout China's electricity system. Wholesale generation prices assigned to coal-fired power plants are based on estimates of what it would take to build and operate different types of plants, and these prices do not reflect the actual cost of running the plant.[11] Dispatching of power plants (i.e., turning generators on and off as the requirement for power changes) is also not done with an eye toward costs. Rather than being dispatched in order of lowest marginal cost, as in the United States, in China power plants are assigned roughly the same number of operating hours, which means that the least efficient power plants may run just as much as the most efficient ones.[12] On the transmission and distribution side, the prices that Chinese grid companies are allowed to charge their customers are not based on rigorous assessment of their cost of buying and distributing electricity (Table 2).[13]

Table 2. Differences in Wholesale Generation Pricing, Dispatch, Grid Company Revenue, and Retail Pricing in China and the United States

	China	United States
Wholesale Generation Prices	Benchmark or individually negotiated prices	Market or adjudicated revenue requirement
Dispatch	Equal shares of operating time among generators	Merit order or bid price (lowest marginal cost)
Grid Company Revenues	Residual between total revenues and generation costs	Adjudicated revenue requirement
Retail Prices	Considerations for inflation, industrial support, social stability	Regulated cost-of-service

Notes: Wholesale tariffs for hydropower and nuclear plants in China are typically negotiated on an individual basis. The government has set feed-in tariffs (FITs) for wind and biomass. Tariffs for large-scale solar projects are currently based on a tender system but will eventually be converted to FITs.

As a recent story from the steppes of Inner Mongolia helps to illustrate, the lack of cost-reflective, transparent pricing is a major source of conflict up and down the electricity supply chain. Inner Mongolia is China's windiest province, accounting for around 30 percent of China's wind power potential.[14] Wind, and electricity more broadly, are important parts of Inner Mongolia's economy, and its government has been keen to support the electricity industry. The result has been overbuilding: Inner Mongolia has both more wind and more coal-fired generation than it can use, but does not have enough transmission capacity to export surplus electricity.[15]

A non-trivial portion of Inner Mongolia's wind power never makes it onto the grid, either because it is curtailed (meaning the wind turbines run but the power is not accepted by grid operators, for a variety of reasons including but not limited to congestion on transmission lines), or because it was never connected to the grid in the first place. Wind producers, though, do not get paid unless someone buys power from them, and uncompensated curtailment and lack of interconnection make them unhappy. The Inner Mongolian government has gone to great effort to bring as much wind as possible online, but this has meant that coal plants have had to incur uncompensated costs to accommodate wind producers, which makes coal plant owners unhappy.

There have been calls for more transmission lines to help alleviate Inner Mongolia's plight, but State Grid Corporation, which would build new lines, would need to get paid enough to recover its costs and deal with wind intermittency issues.[16] The ideal solution would be to ensure that prices reflect all of these costs, which would help to better align incentives. But this would mean passing more costs onto consumers, who have no way to know what they are paying for and are already unhappy about rising prices.[17]

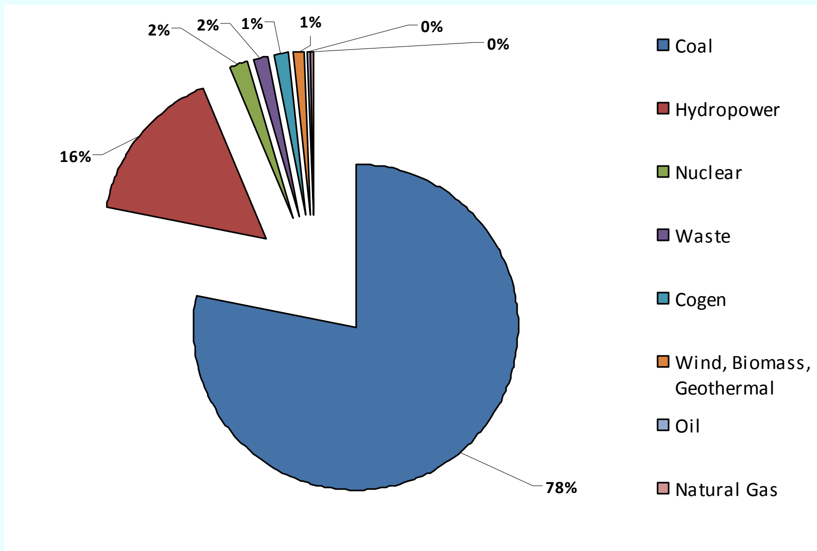
Getting beyond these bottlenecks and the unhappy producers and consumers that result will require more transparent, rule-based, and cost-reflective prices. Moving toward full cost-reflective prices may be a gradual, politically painful process, but even incremental steps toward transparency would improve China's ability to sustain its renewable energy sights.

4. Natural Gas is as Important as Renewables and Nuclear Power for China's Transition to a Low Carbon Electricity System

Coal is the backbone of the Chinese electricity system, accounting for nearly 80 percent of its total generation (Figure 4). Coal-fired generation is also China's main CO_2 problem,[18] and finding alternatives to coal is the centerpiece of China's strategy on climate. Natural gas should be an important piece of that strategy.

Burning natural gas is about 40 percent less CO_2 intensive than burning coal per unit of energy contained in the fuel.[19] Couple that with the fact that natural gas power plants are also more efficient at turning fuel into electricity, and the CO_2 emissions per kWh of a natural gas plant can be about half of what a coal plant's emissions would be.[20]

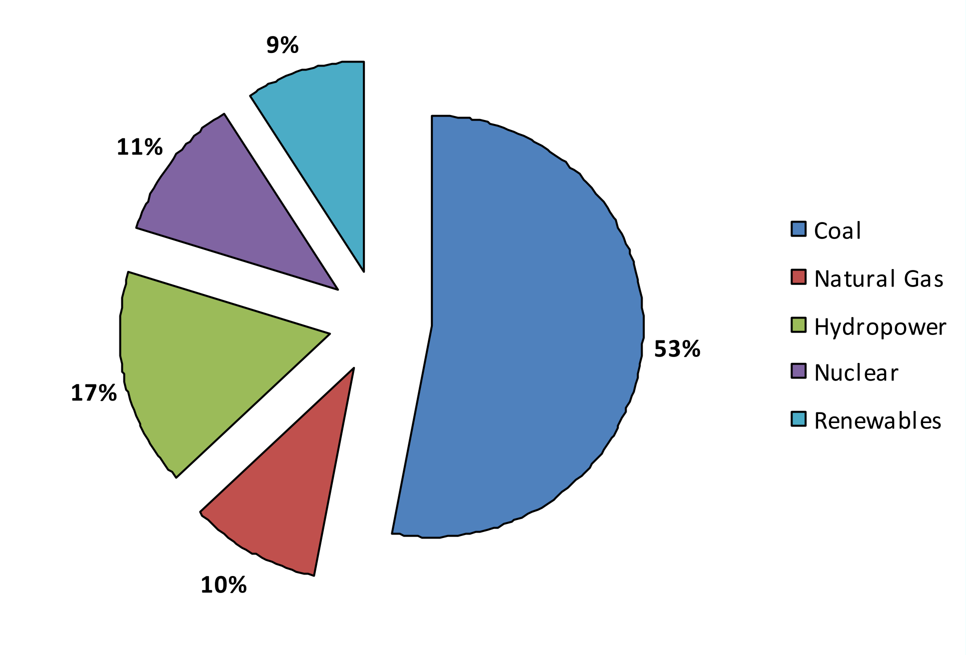
Figure 4. China's Generation Mix, 2009 (GWh)



Source: CEC (2010)

Natural gas accounted for 0.1 percent of China's generation mix in 2009.[21] Getting to 10 percent gas by 2020 would reduce CO_2 emissions by somewhere between 300 and 425 million metric tons (Mt), depending on final demand.[22] This is comparable to all of California's current energy-related CO_2 emissions (390 $MtCO_2$ in 2008).[23] Combined with aggressive end use efficiency policies that limit demand to 6,000 TWh and the alternative energy build out in Table 1, hitting a 10 percent gas target would restrain CO_2 emissions from China's power sector to around 3,500 $MtCO_2$ in 2020, which would limit the sector's emissions growth to 15 percent over 2007 levels.[24] With the share of coal further reduced, China's generation mix would start to look more like the United States (Figure 5). Note that this does not require shutting down existing coal plants, but rather building fewer of them in the future in lieu of natural gas plants.

Figure 5. Low Demand, 10 Percent Gas, High Alternative Energy Scenario for China's Generation Mix in 2020 (GWh)



Natural gas power plants could also help to increase the flexibility in China's electricity system. Wind and solar are both intermittent resources, and ensuring that electricity demand and supply stay balanced requires power plants that respond rapidly to changes in wind and solar output. China's current generation mix is dominated by coal, which does not respond as well to rapid changes in output requirements. Gas, on the other hand, can typically be turned on or off relatively quickly. Ultimately, China's power system needs more gas generation if it is to avoid wasting wind energy and increasing the wear and tear on its coal plants as China's electricity consumption becomes more peaky.

Logistically and politically, natural gas power plants may also be comparatively easy to build relative to other kinds of non-coal generation. For instance, there are no guarantees that China will be able to meet its plan for 181 GW of nuclear and hydropower capacity over the next decade. Many of the technical, regulatory, public participation and waste disposal issues related to building such a large number of new nuclear power plants still need to be addressed.[25] Hydropower projects are increasingly being contested on environmental grounds.[26]

So why doesn't China use more gas? For one, it lacks the resources. While the United States accounts for 20 percent of global natural gas production and 4 percent of reserves, China accounts for only 3 percent of production and 1 percent of reserves.[27] What gas China does have access to often goes to higher priority uses, such as fertilizer production and residential heating and cooking.[28]

But China also lacks the "soft" infrastructure for making gas a more meaningful part of its generation mix. Natural gas production and distribution in China is still government run and prices for many end users are kept below world prices, which provides few incentives to expand production. On the electricity side, with China's current pricing and dispatch systems, it is not clear how natural gas plants, which typically have higher variability in operating hours and face highly volatile gas prices, would be able to recover their costs.

China also has less experience with natural gas plants and imports much of the equipment, which makes them comparatively expensive. Whereas in the United States gas plants are much cheaper than coal plants to build but more expensive to run, in China coal plants are cheaper to run and only marginally more expensive to build.[29]

Discussion on how to get more gas in China's generation mix has a long history. The question is: How to make it happen? U.S. experience shows that efficient markets for—and expanded supplies of—natural gas are critical. For China, developing more efficient markets for natural gas will likely require moving to a regulated or a market-based system, either of which will require taking on the national oil companies that dominate gas production. Expanding supply will require large investments in pipelines and LNG terminals that provide access to both domestic and foreign resources, and R&D in new extraction technologies, especially for shale gas. Driving down gas generation technology costs will require policy support, similar to efforts that facilitated large cost reductions in supercritical and ultra-supercritical coal technologies. None of these are impossible, but each would require strong commitments from China's central government.

Closing Thoughts

Moving beyond "hard" technology in the U.S.-China energy and climate conversation will require more engagement on "soft" technologies—approaches to analysis, planning, pricing, information disclosure, regulation, and public engagement—where the United States has almost a century of experience but China, for historical reasons, is just starting to get its feet wet. Such engagement, focused on the electricity sector, could have far-reaching energy security and environmental benefits for both China and the United States.

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[1] Final energy consumption refers to the energy that's actually consumed, disregarding the energy lost in conversion and distribution. China's original goal was to get 15 percent of total primary energy from renewables by 2020. In 2009 this goal was changed to final energy consumption and broadened to include nuclear power (Martinot, 2010).

[2] This forecast is the IEA's Reference Case scenario for China for 2020 (IEA, 2009).

[3] This estimate assumes average capacity factors of 0.38 for hydropower, 0.25 for wind, 0.89 for nuclear, 0.71 for biomass, and 0.20 for solar. Hydropower, wind, and biomass capacity factors are based on historical averages. Wind and solar capacity factors are rule-of-thumb estimates.

[4] The high and low forecasts here correspond to scenarios 1 and 4, respectively in SGERI (2010).

[5] The high case is 74 percent of 8,510 TWh, whereas the low case is 68 percent of 6,947 TWh, which explains the sizeable CO_2 reduction for a relatively small percentage change in coal share. More specifically, 74 percent of SGERI's 8,510 TWh estimate is 6,306 TWh of coal-fired generation, which, at a coal emission factor for China of 1.0 $kgCO_2\ kWh^{-1}$ (IEA, 2009), equates to 6,306 $MtCO_2$. 68 percent of 6,947 TWh is 4,743 TWh of coal-fired generation and emissions of 4,743 $MtCO_2$. The difference of 1,563 $MtCO_2$ is 51 percent of the IEA's (2009) estimate of 3,060 $MtCO_2$ from electricity generation in China in 2007.

[6] The IEA (2009) estimates that in 1990 electricity accounted for 6 percent of China's final energy consumption, whereas by 2007 it accounted for 19 percent. The IEA projects that this share will rise to 27 percent by 2020.

[7] Details for implementing the DSM law are still being worked out. The 0.3 percent is likely a pilot level.
[8] Short of cash in the 1980s, China's central government began to allow non-state investment in the electricity sector and to decentralize both ownership and operations to provincial governments. Provincial-level companies control a majority of generation assets (Ma and He, 2008), and day-to-day operations are under the jurisdiction of provincial grid companies. The private sector plays only a minor role in China's electricity sector.
[9] This anecdote is from Wang (2006), writing in the Communist Party School journal Study Times.
[10] This difference in costs is calculated on an exchange rate basis. China's average retail electricity price was \$83 MWh^{-1} in 2009 (SERC, 2010), while the average retail price in the U.S. was \$97 MWh^{-1} in 2009 (EIA, 2010a). Data from SERC do not include surcharges; we include these adders using a 27.20 Yuan MWh^{-1} nationally averaged surcharge (SERC, 2010).
[11] Benchmark prices (*biaogan dianjia*) are the most recent of a series of wholesale generation pricing strategies China has used since the 1980s. The benchmark price is based on an estimate of annual operating hours, which, if hours fall below this estimate, underestimates actual levelized fixed costs. It is also based on estimates of coal prices, heat rates, and assumes a load factor of 100 percent, which can lead to underestimates of variable costs.
[12] This approach to dispatch is intended to ensure that power plants generate sufficient revenues to repay their capital costs. The economic and environmental inefficiency that it creates is not lost on either the public or policymakers. In June 2010, the investigative reporting show *Jiaodian Fangtan* did an exposé on the equal shares dispatch system, entitled "Efficiency Bottlenecks Cause by Generation Quotas," online at http://www.youtube.com/watch?v=FAx7ZcDde6k&feature=related). Five provinces began to pilot an energy efficient dispatch (*jieneng diaodu*) system in 2005, but this pilot has met with a number of obstacles and has yet to be extended to other provinces (Gao and Li, 2010).
[13] By law, the State Electricity Regulatory Commission (SERC) has the authority to review and approve grid company costs, but its oversight is currently weak. Grid company costs are not transparent; roughly one-third of costs were classified as "Other" in 2008 (Cai, 2010).
[14] Liu and Kokko (2010) report that Inner Mongolian wind has a technical potential of 150 GW, with a total technical potential of 519 GW in China's 9 leading wind provinces.
[15] By December of 2009, the Western Inner Mongolia Power Grid (WIMPG) had 4 GW of installed wind capacity and 33 GW of thermal generating capacity but a peak demand of only 16 GW (Zhang, 2009). There are only two 500 kV AC transmission lines connecting WIMPG to the North China Power Grid (NCPG) to the south, which limits export capacity.
[16] A further, and potentially more important, issue is that the WIMPG is China's only independent provincial-level grid and, as such, is not under the State Grid's authority. Part of the State Grid's reluctance to build new transmission between WIMPG and NCPG is reportedly that it wants to regain authority over WIMPG. See, for instance, "An Embarrassment to Inner Mongolia's Wind Development: Hold Up in Grid Construction Leads to Waste," *China Economic Herald*, 12 June 2010.
[17] To deal with rising coal costs, retail electricity prices were raised five times between 2005 and 2009, once in 2005, once in 2006, twice in 2008, and once in 2009.
[18] The IEA (2009) estimates that 50 percent of China's energy-related CO_2 emissions came from the electricity sector in 2007, and predicts that the electricity sector will be responsible for 62 percent of the growth in energy-related CO_2 emissions between 2009 and 2020.
[19] For instance, the IPCC's 2006 IPCC Guidelines for National Greenhouse Gas Inventories proposes a default emission factor of 56.1 tCO_2 TJ^{-1} for natural gas and 96.1 tCO_2 TJ^{-1} for sub-bituminous coal.
[20] For instance, the IEA (2009) uses gross, China-specific emission factors of 1.1 $kgCO_2$ kWh^{-1} for coal and 0.6 $kgCO_2$ kWh^{-1} for natural gas in 2007, and 1.0 $kgCO_2$ kWh^{-1} and 0.5 $kgCO_2$ kWh^{-1}, respectively, beyond 2015.
[21] These data are from CEC (2010).
[22] This assumes that natural gas is displacing coal. With final demand of 6,000-8,510 TWh and coal and natural gas emission factors of 1.0 and 0.5 $kgCO_2$ kWh^{-1}, respectively, CO_2 emission reductions would range from 300-425 $MtCO_2$.
[23] California CO_2 emissions are from the Energy Information Administration (EIA) website: http://www.eia.gov/oiaf/1605/state/state_emissions.html.
[24] In this scenario, natural gas generation would reach 600 TWh in 2020; hydropower, nuclear, and renewable generation would reach 2,219 TWh; and, assuming that other generation sources (e.g., waste, cogen, geothermal) are negligible, coal generation would reach 3,181 TWh. At the emission factors above, this would imply 3,181 $MtCO_2$ from coal and 300 $MtCO_2$ from natural gas, or 3,481 $MtCO_2$ of total emissions. Electricity sector CO_2 emissions were 3,060 $MtCO_2$ in 2007.
[25] See, for instance, Zhou et al. (2011) and Wang (2009).
[26] For instance, the Ministry of Environmental Protection (MEP) has shown greater concern over the ecological impacts of large dams in Southwest China, suspending projects on the Jinsha River in 2009 and setting in motion conflict between MEP and the NDRC.

[27] Reserve and production estimates are for 2009, from BP (2010).
[28] Priority uses are spelled out in NDRC (2007). China has a growing number of natural gas-fired combined heat and power plants in major cities, which are an example of how a priority use can be combined with electricity generation.
[29] In the United States a new coal plant costs more than \$2,000 kW^{-1} to build, while a natural gas combined cycle plant would cost around \$900 kW^{-1} and a simple cycle combustion turbine would cost around \$600-700 kW^{-1} (EIA, 2010b). In China a supercritical or ultra-supercritical coal plant might cost \$500-600 kW^{-1}, whereas a natural gas plant would run around \$500 kW^{-1}. Data for China are based on cost estimates developed for SERC in an unpublished report.