Electricity reform and sustainable development in China

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Abstract
Reducing the environmental impact of supplying electricity is a key to China’s sustainable development, and a focus of both domestic and international concerns with greenhouse gas emissions. The environmental performance of the electricity sector is strongly affected by its institutional arrangements: regulatory frameworks, wholesale markets, pricing mechanisms, planning and coordination, and enforcement and incentive mechanisms. These arrangements are set to change as electricity reforms inaugurated in 2002, but sidetracked by several years of supply shortages, are being resumed. In this paper we examine the impact of electricity reform on environmental sustainability by analyzing case studies of four environmental initiatives in the electricity sector: retirement of inefficient generators, installation of pollution control equipment, renewable energy development, and efforts to promote energy efficiency. We find that implementation of these policies falls short of objectives for two main underlying reasons: conflicting priorities between central and provincial governments, and ineffective regulation. Sustainability will be best served not by redoubling short-term supply-oriented, market-based reforms, but by better aligning central and provincial government incentives, and by developing competent, independent regulation at the provincial level. China’s central government and sub-national governments in industrialized countries can both contribute to the latter goal.

Keywords: China, sustainable development, electricity reform, energy policy, climate change

1. Introduction
Recognizing that environmental damage undermines long-term prosperity, China’s central government has made ‘sustainable development’ a policy centerpiece [1, 2]. Nowhere does the transition toward more sustainable economic growth pose a greater challenge than in China’s electricity sector, which powers a booming economy and allows hundreds of millions of Chinese to enjoy a middle-class lifestyle, but is also responsible for numerous environmental insults that threaten human and ecosystem health [3]. The impacts of pollution from coal-dominated electricity generation in China are felt both domestically and abroad, with the country’s burgeoning greenhouse gas (GHG) emissions a subject of growing international concern [4, 5].

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governance is shared in important ways with provincial governments, financial institutions, and the electricity industry itself. Beginning in the mid-1980s, the Chinese central government initiated a series of electricity reforms that have transformed the former vertically-integrated, centrally-planned, state-owned electricity industry into one that is substantially more diverse and market-based. Although this transformation has been instrumental in encouraging new investment, electricity reforms have had mixed results. Reforms have both supported and conflicted with other government initiatives affecting the electricity sector, making the sector an arena of conflict among competing policy priorities (e.g., economic growth, environmental protection, energy security, political stability), mechanisms (e.g., markets, planning, regulation), and interests (e.g., the central and provincial governments).

This paper assesses the interaction between electricity reform and the environmental dimension of sustainable development by analyzing four important environmental policy initiatives in the electricity sector: (i) replacing inefficient power plants with efficient plants; (ii) increasing the share of generation from renewable sources; (iii) expanding compulsory use of pollution control equipment for coal-fired generating units; and, (iv) promoting energy efficiency and demand-side management.

The analysis asks two questions: (1) have these policies succeeded in their goals of reducing either the per-unit environmental impacts of electricity consumption, or consumption itself, and what are the proximate and underlying causes of success or failure? (2) What do these environmental case studies reveal about China’s progress in electricity reform, based on the metrics of transparent and efficient regulation; effective and impartial enforcement; competitive and efficient wholesale markets; efficient pricing mechanisms that reflect full social marginal costs; and planning and coordination mechanisms that achieve efficient dispatch, reliable grid operations, and adequate, timely investment in transmission and distribution infrastructure [6]?

As of 2008, China has reached a critical juncture for both sustainable development and electricity reform policies. Electricity reforms originally approved in 2002 but delayed due to electricity supply shortages are now poised to resume. Like previous reforms, the new round of reforms emphasizes short-term, supply-oriented, market-based solutions over long-term, demand-oriented, regulatory solutions. The ultimate goal of the present analysis is to assess whether the latest reforms are likely to promote ‘sustainable development’, and if not, to identify other ways forward.

2. The institutional landscape of China’s electricity sector

Over the past three decades, China’s electricity sector has undergone a profound institutional transformation from a vertically-integrated, state-owned electricity monopoly to an unbundled, corporatized system in which individual plants and companies operate on a commercial basis, but central and local government agencies remain heavily involved. Here we briefly describe the sector’s governance structure and key reforms.

Before 1985, China’s electricity sector was governed as a single state-owned electricity monopoly. Beginning in 1985, spurred by supply shortages that were slowing China’s industrial growth, generation was opened to local government and private foreign investment, and independent power producers were allowed to sell their power to the grid at prices that provided competitive rates of return, leading to rapid growth of new capacity. In 1997, as part of then-premier Zhu Rongji’s government reorganization, the Ministry of Electric Power was transformed into the State Power Corporation (SPC) and put on a commercial footing, while its regulatory and financial functions were transferred to other ministries, including the Ministry of Finance and what is now called the National Development and Reform Commission (NDRC) [7–10].

In 2002, the State Council passed a comprehensive set of electricity sector reforms under its Electricity Reform Plan (电力改革方案 [diànliāng gǎifǎ mófāng], commonly referred to as Article 5. As part of a reform package common in electricity sector restructurings worldwide [11, 12], Article 5 ‘unbundled’ the SPC into five generating companies and two grid companies. Through Article 5 the State Council sought to accomplish three main objectives: (1) break entrenched monopolies in the electricity sector by more clearly separating the functions of government and business, which remained ambiguous even after the dismantling of much of the country’s central planning regime and commercialization of state-owned enterprises [13]; (2) support and encourage this separation through the creation of markets based on competitive pricing mechanisms and regional wholesale power trade; and (3) create and institutionalize a specialized central government agency, the State Electricity Regulatory Commission (SERC), to regulate the new system.

Progress on Article 5 reforms was impeded almost immediately by severe electricity shortages that began in 2002 and continued through 2006. Compared to a demand forecast of 5% annual growth during China’s 10th Five-Year Plan (2001–2005) [14], actual demand grew by an average of 12.7% from 2001 to 2006 (see figure 1), outstripping supply. The resulting supply shortages forced authorities to temporarily shelve reforms and attend to ensuring resource adequacy. After more than three years of regional electricity rationing, the China Electricity Council (CEC) forecast in early 2007 that a ‘basic’ balance between electricity supply and demand had been restored [17]. With shortages no longer perceived to be the most pressing priority, electricity reforms are set to resume [19].

Although continued reforms will have a strong bearing on the environmental impact of China’s power sector, many of the sector’s sustainability issues stem from a contested, de facto federalism that has characterized the country’s administrative system over the past two decades and presents major obstacles for enforcing national policy. After the central government relinquished its power sector monopoly in 1985, local governments began to take a larger role in approving projects and providing finance for rapidly growing provincial electricity
sectors. Thus when the SPC was dismantled in 2002, it owned only 46% of China’s generating capacity [10]. Although ownership and lines of control in China’s electricity sector are more complex—and opaque—than these figures might imply, they do suggest the large amount of capacity that is at least nominally under provincial government jurisdiction [8]. In a system where central government regulators with provincial branches are tasked with enforcing national laws and standards, this mismatch in ownership and incentives has created a major regulatory impasse. Central government agencies often have only modest authority over provincial governments and agencies, even those that are formally part of their vertical chains of command [13, 17, 18].

Compliance has become a paramount issue in China’s electricity sector sustainability, resulting less from the public-private tensions often found in OECD countries than from the central–provincial tensions described above. As a consequence, while China’s central government has issued progressive and stringent laws, regulations, and standards, perverse electricity sector outcomes are common. For example, despite the installation of significant wind capacity and desulfurization equipment, actual wind generation and SO₂ removal have been lower than expected. These issues are further explored in the supply-side and demand-side case studies that follow.

3. Sustainable electricity development: the supply side

At the end of 2007, China had the world’s second largest installed capacity for electricity generation (713 GW) and was the world’s second largest electricity consumer (3246 TWh), behind the United States. But it is the rate of growth in generation and capacity since 2000—both of which more than doubled between 2000 and 2007—that is without precedent. In 2006 alone, China added 114 GW of new capacity, more than the entire African continent’s 2004 total installed capacity, and more than the 2004 total installed capacity of any European country except Germany [5]. Under a reasonable range of GDP growth and electricity elasticity assumptions, meeting increases in demand will require building an additional 525–900 GW of new capacity between 2008 and 2020, roughly one large (∼1000 MW) power plant per week [6]. To put these numbers in context, the European Union’s total installed capacity in 2004 was 657 GW [22]. The IEA estimates that an annual investment of US$70 billion will be necessary to build China’s electricity generation, transmission, and distribution infrastructure until 2030 [23]. From 2000 to 2020, the increase in China’s electricity demand, the capacity additions to meet that demand, and the investment required to build that capacity will be unmatched in human history. By comparison, the highest net capacity addition in the US over a 20 year time frame was 420 GW from 1965 to 1985 [22].

Coal is the both the predominant fuel and the chief sustainability issue in China’s electricity sector. Coal accounted for 72% of China’s total generation capacity, 78% of total electrical energy, and 95% of fossil fuel generation in 2004 [24]. The electricity sector represents a growing share of China’s total coal use, rising from 26% in 1990 to 50% in 2006 [25]. Despite the central government’s ambitious goals for increasing generation from natural gas, nuclear, hydropower, and renewable energy, in both its reference and alternative scenarios the IEA projects that the share of coal in China’s capacity and generation portfolios will actually increase over the next two decades as rapid growth in electricity demand dilutes the shares of coal alternatives [24].

Coal-fired power generation in China has produced disproportionate and increasingly serious environmental impacts. The electricity sector accounted for 57% of China’s sulfur dioxide (SO₂) emissions, 44% of its particulate matter (PM) emissions, 80% of its oxides of nitrogen (NOₓ) emissions, and 49% of energy-related carbon dioxide (CO₂) emissions in 2004 [23–25]. Domestically, SO₂ and particulate emissions are the primary official environmental concerns associated with coal-fired generation. Acid rain now covers one-quarter of China’s land area, and several studies have documented the considerable costs of particulate pollution to Chinese cities [26–29]. Nationally, the World Bank estimates the cost of air pollution in China at 3.8% of GDP [3]. Internationally, CO₂ emissions and to a lesser extent transboundary particulate and mercury emissions from power generation in China are a greater concern. CO₂ emissions

5 Capacity and generation data for China for 2005, 2006, and 2007 are from the China Electricity Council (CEC) website, http://www.cec.org.cn/(in Chinese). Data for 2004 capacity for Africa and the EU are from the Energy Information Administration (EIA) website, http://www.eia.doe.gov. Germany’s total installed capacity (TIC) in 2004 was 120 GW; France had the second largest TIC at 113 GW.

6 As a lower bound, we use the 2006 IEA forecast of 5710 TWh by 2020 [21], which implies an electricity consumption growth rate of 4.4% from 2007 to 2020. As an upper bound, we derive a forecast of 7673 TWh from middle of the road GDP growth projections of 9% from 2008 to 2010, 7% from 2010 to 2015, and 6% from 2015 to 2020, and an assumption that electricity consumption grows as fast as GDP from 2007 to 2020. These two projections imply incremental consumption of 2464–4427 TWh by 2020. Using an average 2000–2007 overall capacity factor (GWh/GW·year) of 0.53, this implies an incremental demand of 525–900 GW.
from coal-fired power plants in China accounted for 18% of the gross growth in global energy-related CO₂ emissions between 1990 and 2004 [22, 24].

How to reduce the impacts from coal-fired electricity generation is perhaps the most important question facing China’s sustainable development. From a supply-side perspective, there are four ways to reduce the impacts of electricity generation, all of which are tied in some way to coal.

Per kWh Impact = 1 kWh × \( \frac{1}{\eta} \) × \( \frac{1}{HV_{FUEL}} \) × EF × (1 – PCF).

The above relationship shows the per kWh air quality and GHG impact of carbon-based fuels, where \( \eta \) is a unitless thermal efficiency parameter, HV is the fuel heating value (in energy units per mass unit), EF is a fuel-specific emission factor (pollutant units per fuel mass unit), and PCF is a unitless technology specific pollution control factor. As this relationship shows, there are four supply-side options for reducing impacts: increasing the average efficiency of thermal power plants, using higher heating value fuels, reducing or eliminating the emission factor by switching to lower impact or alternative fuel sources, and lowering the value of the final term by adding pollution controls.

We focus on the more significant three of these options here: increasing the average efficiency of coal-fired power plants, switching fuel sources, and adding pollution controls. Technological advances in all three areas hold out promise for China’s sustainable development. However, as we show for each area below, technology is a means that itself requires a process, and greater attention to process is a necessary condition for a more sustainable electricity sector in China.

3.1. Increasing the average efficiency of coal-fired power plants

At an average, national level, thermal efficiency in coal-fired generation is a measure of a country’s total coal use divided by the total amount of power generated with that coal. In other words, average efficiency for coal-fired power plants is akin to fleet efficiency for vehicles, reflecting the mean of a distribution of generating units that range from highly efficient to highly inefficient. As noted above, higher thermal efficiencies mean that power plants burn less coal to generate the same number of kWh, which in turn produces less overall air pollution and GHGs.

In 2007 China’s average heat rate for coal-fired power plants was 357 kg (SCE)/MWh (9920 Btu kWh⁻¹), translating into a thermal efficiency of 34.4% [30] and roughly 5% higher than the US equivalent [31]. The central government’s target heat rate for 2020 is 320 kg(SCE)/MWh (8886 Btu kWh⁻¹), or a thermal efficiency of 38.4% [32]. This 4% point increase in average efficiency would represent a considerable coal and pollution savings for China. At 2006 generation levels, coal inputs would fall by 125 million tons, a reduction of roughly 10%. Because this fleet average is affected by both ends of the efficiency distribution, achieving the 2020 heat rate goal will require both increasing the efficiency of new generating units (a push factor) and reducing the inefficiency of older generating units (a pull factor).

![Figure 2](image) Capacity, on-grid generation, and number by generation unit size. Beijing Municipality, Hebei Province, Shanxi Province, and Tianjin Municipality, 2004. (Note: sizes listed above are not inclusive (i.e., 100–300 MW is >100 MW and <300 MW) sources: generation data are from SGCC [34]; capacity and number data were disaggregated based on aggregate power plant data in SGCC and through an exhaustive web search.)

For standard Rankine cycle coal-fired power generation, efficiency increases with boiler and turbine size, and beyond that with more advanced power cycles, such as those associated with supercritical and ultra-supercritical boiler technologies. To ensure that new installed capacity achieves the highest possible efficiency, China’s central government has mandated that all new generating units must be at least 600 MW and use at least supercritical boiler technologies. As of end 2005, 22 supercritical units had been commissioned in China and half of all new coal-fired unit orders were for supercritical units [33]. Regardless of whether government mandates are met, this rate of adoption for more advanced coal-fired generation technologies represents a significant step toward a lower environmental impact electricity sector, driven in part by economic incentives through the need to adapt to higher coal prices.

While increasing the efficiency of coal-fired generation is a function of bringing more efficient generating units online, reducing inefficiency requires taking more inefficient generating units offline. Due in part to domestic manufacturing constraints, generating units less than 300 MW account for most of the generating units and actual generation in China. Figure 2 illustrates this point using the four provinces in the North China Power Grid (NCPG) [3]. In 2004, units less than 300 MW accounted for 53% of the NCPG’s total installed capacity and generation, and 87% of the total number of generating units in its service area. Given that many of the more efficient power plants now being installed have efficiencies in the 38–40% range, achieving an average fleet efficiency of 38.4% will require replacing a significant portion of existing generation with capacities less than 300 MW, which includes, as figure 2 shows, a significant portion of units in the 100–300 MW range, many of which were built in the 1980s.

Efforts to close small, inefficient generating units in China are more than a decade old. In the late 1990s, the
NDRC, China’s chief planning agency, drew up a schedule for retiring 16 GW of generating units over the period 1999–2010; notably, only one of these units was larger than 55 MW. This program of mandatory retirements lacked incentives for the plant owners and met with substantial local resistance. In early 2007, the NDRC announced a new strategy for closing inefficient generating units, this time lowering the feed-in tariffs for smaller units and allowing generators to build new capacity to replace retired capacity [35]. An additional incentive program announced in early 2008 allows generating units that have been slated for retirement to remain open and receive a quota for electricity generation for 3–5 years beyond their closure dates, and to sell this generation quota to larger generating units [36]. To accelerate the retirement process, the NDRC mandated that during the 11th Five-Year Plan all conventional thermal generating units less than 50 MW and specified units up to 200 MW will be required to close, constituting a total of 50 GW [35].

These recent strategies have proved more effective. In 2007 central government agencies shut down 553 generating units, totaling 14.4 GW, 43% above the official target for 2007 [30]. Although the scope and speed of closures should be seen as a success, the majority of generating units that have been closed thus far have been owned by China’s five largest national generating companies (the Big Five), which are nominally still under central government administration and have clear incentives for closing inefficient generating units. In 2007, the Big Five owned less than 40% of China’s total installed capacity, but accounted for 61% of small plant closures [30]. Many of the remaining small power plants are under the jurisdiction of provincial governments, and the next phase of closures will require bridging the enduring incentive gaps between China’s central government and its provincial governments.

As noted above, provincial governments have been active in electricity sector planning, financing, and operation since the mid-1980s. In 1986, provincial government were given the authority to approve projects less than 50 MW and, during times of electricity shortages, provincial governments have used both this authority and other means to circumvent the national project approval process; as much as one-quarter of China’s total generating capacity in 2005 was never formally approved by central government agencies [37]. In many cases, these power plants were constructed with provincial, and in some cases even municipal or county, government finance, both through the banking system and indirectly through fiscal allocations. The strategic impasse between the central government and local governments over the closure of inefficient generating units is thus a mismatch of priorities between an environmentally-minded planner and a local investor.

At the heart of this impasse is the question of who pays for closures, or more specifically the legacy employment and finance issues associated with small power plants. Closing smaller generating units, and particularly the 100–300 MW units that comprise the bulk of less efficient generation, before the end of their planned operational life will in effect strand these assets, leaving tens to hundreds of thousands of people unemployed and creating a financial burden on local governments to support displaced workers, and generating a significant strain on provincial banks. While one approach to bridging this divide would have the central government simply pay off the legacy costs of older power plants, a likely more cost-effective strategy for the central government is to incentivize local governments to internalize environmental goals. In either case, bridging this divide will require a negotiated, potentially more broadly defined, solution between central government agencies and provincial governments.

3.2. Switching fuel sources by increasing the share of renewable energy

There is ample scope for reducing the share of coal-fired generation in China. As table 1 illustrates, China’s central government has plans to bring more than 460 GW of non-coal generation capacity online over the next two decades. The majority of these planned installations consist of hydropower and natural gas, but nuclear power and renewable energy are also expected to play significant roles. The government’s commitment to developing renewable energy resources was enshrined in a country’s Renewable Energy Law, passed in January 2006, which lays out a subsidized tariff structure for electricity generated from renewable energy, a compulsory grid connection mandate for renewable energy projects, and a rule that requires utilities purchase all the renewable energy produced in their service area.

Among renewable energy resources, wind power has the most potential in the near term to be rapidly scaled up, and hence we confine our discussion here to renewable energy from wind. Recent surveys by China’s National Meteorological Bureau estimate the country’s 10 m theoretically exploitable terrestrial wind resources at 297 GW at 10 m hub height [41]. In the last five years China has witnessed a dramatic scale-up of installed wind capacity, from 0.6 GW in 2003 to more than 4 GW at the end of 2007. The rapid growth in wind capacity has led some observers to question whether central government goals for installed wind capacity in 2010 (5 GW) and 2020 (30 GW) might be too low [41].
So far, a disturbing trend is that rapid wind capacity growth has not been matched by actual performance. In 2006 and 2007, China’s average capacity factor for wind was 0.16, whereas average capacity factors in OECD countries are typically between 0.20 and 0.30. The reasons for this are unclear. Speculatively, it is possible that because many provincial power systems have few capacity resources such as combustion turbines with which to integrate intermittent wind generation, that a significant amount of wind generation is ‘shed’ (goes unused) in China when the system cannot absorb it. It is also likely that current procurement and wholesale pricing schemes for wind emphasize capacity and fail to provide adequate performance-based incentives.

Although installed costs for wind power have come down considerably over the past decade, wind is still more expensive in China than coal and requires a subsidy to make wind projects economically viable. As with all subsidies, a key question for China’s wind subsidy is how much the premium should be and who should pay for it. Before 2006, wind concessions were bid on through a competitive tendering system. With the passage of the Renewable Energy Law, the wind industry had hoped to receive a fixed feed-in tariff to support more a more stable growth environment. Those hopes did not materialize. The NDRC reportedly maintained its competitive tender system because of concerns that a fixed premium above the average tariff for desulfurized coal would disproportionately benefit wealthier eastern regions that have higher average tariffs for desulfurized coal.

By most accounts, the competitive tendering system has created significant distortions that, for instance, support the building of installed wind capacity but not actual generation of electricity from wind power. The majority of concessions have been awarded to lowest cost bidders, and in many cases these bids have been below the perceived cost of generating electricity from wind [41]. These firms are often state-owned enterprises (SOEs) that have either been attempting to secure resources and markets for the longer term, or have overestimated wind resources or underestimated their costs [41]. As a result, a number of wind projects are not currently economically viable.

Not all wind projects are approved through this competitive bidding process. As noted previously, provincial government agencies have the authority to approve and price projects less than 50 MW, and these projects are often negotiated on an individual basis. The scale of such projects, as suggested in media anecdotes [42], is considerable, particularly in inland areas. With roles in both planning and implementation, provincial government agencies are key actors in the wind industry. Such involvement, though important on the regulatory side, has created tensions between provincial and central government agencies over the question of who pays the premium for wind and how much that premium should be.

China’s wind premium, in this case the difference between the wind tariff and the cost of desulfurized coal, is paid for with a 0.001 yuan kWh\(^{-1}\) public benefit surcharge added onto retail electricity prices. The revenues from this surcharge are collected at a national level, and distributed to provincial grid companies on the basis of their generation from renewable energy, including wind. Competitive and provincially fixed wind tariffs have varied considerably, ranging from as low as 0.41 yuan kWh\(^{-1}\) for projects won through the competitive tendering process to as high as 0.80 yuan kWh\(^{-1}\) in projects approved by local governments [41]. Li and Gao [41] estimate that a reference price for wind power in China should presently be between 0.5 and 0.6 yuan kWh\(^{-1}\) and capped at a maximum of 0.65 yuan kWh\(^{-1}\), depending on the region. Based on this range, for provincially-approved projects whose wind tariff exceeds 0.65 yuan kWh\(^{-1}\) national ratepayers are essentially subsidizing provincial government development strategies through the public benefits surcharge. Considered together, China’s tariff and tendering schemes for wind generation have resulted in disappointing performance in projects that have been underpriced and a high cost to society in projects that have been overpriced.

3.3. Adding controls on sulfur dioxide pollution to coal-fired power plants

Sulfur dioxide (SO\(_2\)) is a respiratory irritant and precursor to acid rain produced primarily through the combustion of sulfur-containing fuels, such as coal, coke, and, to a lesser extent, petroleum products. Both the absolute levels and continued growth of SO\(_2\) emissions have become an increasing focus of concern for China’s central government over the past decade. By 2005, China was the world’s largest emitter of SO\(_2\) [3]. In spite of an ambitious goal of reducing SO\(_2\) emissions by 10% during the 10th five-year plan, China’s SO\(_2\) emissions instead increased by 31% (6 million tons) from 2001 to 2005 [25]. Recognizing the seriousness of a continued inability to control SO\(_2\) emissions, the State Council included a reduction goal (10% over 2005) for SO\(_2\) and other major pollutants as one of two binding quantitative targets in the central government’s 11th Five-Year Plan. Among the numerous approaches to reducing SO\(_2\) emissions, worldwide the two most prevalent strategies include switching to low sulfur coal and installing flue gas desulfurization (FGD) equipment, also known as ‘scrubbers’. Given the presently limited options for the former in China, the latter has become the Chinese central government’s primary strategy for reducing SO\(_2\) emissions. FGD is a post-combustion technology that, in all of its forms, involves transferring SO\(_2\) from the gas phase to an aqueous phase in a ‘scrubbing’ solution, and treating and disposing of that solution. FGD equipment requires both a non-trivial capital investment and an operating cost, as the equipment itself is electricity intensive.

In 2002, SEPA announced that all new, expanded, or retrofitted coal-fired generating units would be required to install FGD equipment [20]. To incentivize new and existing power plants to install FGD, in 2003 SEPA began levying an emission charge of 0.6 yuan kg\(^{-1}\) SO\(_2\) on SO\(_2\) emissions, and in 2005 the NDRC introduced a 0.015 yuan kWh\(^{-1}\) feed-in adder for FGD-equipped generating units. In response
to the latter measure in particular, by the end of 2007 roughly half of all thermal generating units in China had installed FGD equipment, a 53-fold increase from 2005 [30]. Although this surge in adoption can be attributed in part to falling capital costs—as FGD components are now almost all domestically manufactured, FGD capital costs in China were roughly one-fifth those in developed countries by 2007 [30]—from a policy perspective this is a remarkable achievement. Despite a 17% increase in thermal generation from 2006 to 2007, SO$_2$ emissions from thermal generation decreased by 7.5% [30].

Installation of FGD equipment has not always translated into its use. As has been widely reported in the Chinese media, many generating units that have installed FGD equipment are not actually using it [43, 44]. In theory, if more than half of all thermal generating units had installed and were running functional FGD equipment, reductions in SO$_2$ emissions between 2005 and 2007 should have been at least 3-4 times higher than the roughly 1 million tons in reported emission reductions between 2006 and 2007.\textsuperscript{10} This discrepancy stems, in part, from the low and often nonexistent costs of noncompliance and the fact that the feed-in adder may be sufficient to cover capital costs but is likely not sufficient to cover the efficiency penalty of actually running the FGD equipment.

In principle, the combination of a mandatory requirement for installing pollution control equipment, economic incentives for installing that equipment, and sufficiently harsh economic penalties for not using it should be sufficient to produce massive reductions in China’s SO$_2$ emissions. Although China’s central government has provided both a mandate and incentives, central government agencies have not been able to consistently and effectively enforce disincentives. The persistence of SO$_2$ emissions in China’s electricity sector reflects, in part, the continued lack of a robust regulatory framework for the sector, and the lack of capacity to carry out more effective planning, data collection, monitoring, and enforcement. On a broader level, the SO$_2$ case is again emblematic of a fundamental mismatch in priorities between China’s central and provincial governments, leaving the central government unable to enforce national environmental laws and regulations at the local level.

The obstacles that the Chinese central government has met in regulating SO$_2$ emissions so far does not bode well for its ability to regulate CO$_2$ emissions under a global cap and trade system. In such a system, OECD countries might pay to capture and sequester carbon at Chinese power plants. Many of the monitoring, enforcement, and verification issues that could arise in such a system would be similar to those faced in China’s current SO$_2$ regulatory stalemate. The inability to enforce compliance with SO$_2$ regulations is symptomatic of a more fundamental institutional breakdown, where emissions markets and technology are not sufficient to ensure that local enterprises abide by central government regulations.

\textsuperscript{10} Assuming that 50% of China’s SO$_2$ emissions are from thermal power generation, that 50% of thermal generation is covered by FGD equipment, and that equipment has an average removal efficiency of 70%, emission reductions between 2006 and 2007 should have been roughly 3–4 million tons.

4. Sustainable electricity development: the demand side

Many of China’s sustainable development challenges have their roots in the country’s rapid economic growth over the past three decades. Although supply-side solutions to sustainability challenges in the electricity sector have received more attention, breaking the link between economic growth and electricity consumption could significantly reduce the Chinese electricity sector’s environmental impact. In addition, to the extent that they are able to flatten out future cycles of excess and shortage in capacity, measures that slow the pace of electricity demand growth—end-use energy efficiency and demand-side management (EE/DSM)—would make sustainability challenges more tractable and provide Chinese policymakers with more space to focus on longer-term planning for the sector. Capturing the potential of EE/DSM will require more than just more efficient end-use technologies and more advanced metering. EE/DSM must be integrated into the electricity sector’s regulatory processes, which in turn requires overcoming the lack of incentives and regulatory capacity at a provincial level.

At a national level, the Chinese central government has made reducing the energy intensity of economic growth a major policy priority. As part of its 11th Five-Year Plan, the State Council set a binding goal of reducing the energy intensity of GDP by 20% by 2010.\textsuperscript{11} As consumer of half of China’s coal, reducing electricity consumption per unit of GDP will be important in meeting this energy intensity goal. Electricity use is widely assumed to increase in lockstep with economic growth. For two decades (1980–2000), China challenged this assumption by decoupling electricity demand from economic growth (see figure 3). The electricity elasticity of China’s economic growth averaged 0.89, low relative to a value of 1.5 that might be expected for a rapidly developing country [23]. Beginning in 2001, however, this trend reversed, and electricity demand grew significantly faster than GDP, with an average electricity elasticity of 1.22 from 2001 to 2006.

The main factor in this reversal has been a rapid increase in heavy industrial demand. Industry has historically been China’s largest electricity consumer, accounting for 60% of the country’s electricity consumption in 2006 [17]. In the mid-1990s, industry’s share of total electricity consumption fell as low as 55%, with residential and commercial demand expanding their shares. This decline reversed abruptly in 2004, as electricity use in industry grew by 22 and 15%, respectively, in 2005 and 2006 (see figure 4), a result of dramatically increased output from a number of energy-intensive heavy industries, including steel, aluminum, and cement, beginning about 2002.

The underlying cause of this growth in output remains a topic of debate; both increased global trade tied to China’s currency valuation, and overinvestment in fixed assets tied to loose lending policies at state-owned banks, have been cited [20]. If this phenomenon results from imbalances that

\textsuperscript{11} This was judged sufficiently important to be one of only two specific quantitative goals in the 11th FYP, the other being the GDP growth target itself [47].
can be corrected through macroeconomic policy, then the rate of industrial electricity demand growth may decline on its own. On the other hand, if recent trends reflect a medium- to long-term structural change in China’s economy, meeting the State Council’s energy intensity goal represents an even greater challenge. To this prospect must be added the long-term trend in residential and commercial demand.

On a decadal timescale, growth rates for commercial and residential electricity use have exceeded growth rates for industrial energy use. From 1993 to 2004, residential and commercial energy grew by annual averages of 17% and 12%, respectively, compared with 9% annual average growth in industry [15]. Most importantly, low per-capita residential electricity consumption levels in China (216 kWh/person in 2005 [46]) indicate a staggering growth potential for residential and commercial energy use, even if China only attains world-average levels but particularly when compared against OECD consumption; as a basis for comparison, US per-capita residential electricity consumption was 4533 kWh/person in 2005 [22]. As the share of residential and commercial electricity consumption grows, there will be secondary effects on peak demand and pollution. Driven by air conditioning loads, rapid increases in residential and commercial consumption have caused system load factors—traditionally high in China due to the large industrial share—to fall [47]. Because China does not have natural gas ‘peaker’ plants, peak load must instead be served by coal-fired generating units, which likely has a high environmental cost because reserve units must be kept spinning.

By all accounts there is a huge potential for EE/DSM to dampen industrial, commercial, and residential electricity demand growth and slow the decline of load factors in China. Hu et al [47] estimate that end-use energy efficiency and DSM measures could reduce China’s need for new capacity by more than 160 GW by 2020. However, without a strong commitment to EE/DSM in China’s electricity reform process, this ‘negawatt’ potential is unlikely to materialize. Indeed, as described in the first case below, China’s supply-focused electricity reform process as currently envisaged may even work counter to EE/DSM improvements.

The importance of managing electricity demand growth has been recognized implicitly in the State Council’s 20% energy intensity target and explicitly in NDRC policy documents [16, 32]. But managing demand growth through EE/DSM faces challenges similar to those described earlier for the supply side: fundamental asymmetries in priorities, incentives, information, and institutional capacity between China’s central and provincial governments. Moreover, EE/DSM lacks both institutional and economic footholds in China. In OECD countries, EE/DSM is often deployed through electric utility programs and incentives, whereas China’s efforts to reduce energy intensity have been directed at a sectoral and administrative level [48]. Electricity rates, while closer to the marginal cost of supply than they once were, remain subsidized, which effectively undervalues EE/DSM. For both utility programs and pricing, institutionalizing EE/DSM in China will require more attention to institutional incentives and a broader society-wide dialog on the benefits and limits of higher electricity prices.

4.1. Utility incentives for investing in energy efficiency and demand-side management

There are often barriers to adoption of EE/DSM by households and firms, despite EE/DSM’s positive net cost savings. Energy efficient technologies often require higher up-front costs and additional finance, savings accrue over time, and the benefits of those savings include positive externalities that are not explicitly priced into technology costs. This temporal and public goods characteristic of energy efficient technologies often impedes their deployment. Without institutional innovations to overcome cost barriers—such as providing EE/DSM incentives to customers through utility programs, and allowing the utilities to recover the costs—
developed that is capable of overseeing incentives and cost-stakeholder incentives are aligned, and a regulatory system still be an effective entry point for demand-side policies if demand. Despite these obstacles, provincial LSEs might difficulty by reducing incentives for LSEs to reduce electricity compliance. Competitive T&D could add a new layer of side reforms in China will lack a provincial foothold and structures for China's LSEs, efforts to implement demand-

to achieve the same ends at lower cost. It also emphasizes low. But an overemphasis on the supply-side benefits of grid competition over regulatory approaches that have worked in other countries. Like many other countries with large geographical areas, China’s electricity grid is regional rather than national, with six primary regional synchronous grids, each composed of provincial sub-grids. Although five of the six grids are interconnected through AC and high voltage DC backbones, inter-regional and intra-regional transmission capacity is relatively constrained. For practical purposes, many of China’s grids operate at the level of provincial control areas.

In China the word ‘utilities’, in the sense of load serving entities (LSEs), most appropriately describes provincial grid companies, rather than national grid companies per se. Whereas national and regional grid companies are responsible for inter-regional and inter-provincial dispatch, respectively, dispatch for provincial grids is under the jurisdiction of provincial grid companies. Provincial grid companies have historically favored provincially-owned generating units in allocating operating hours, often to the exclusion of more efficient units owned by national grid companies, the Big Five, or independent power producers [50]. This local protectionism has frustrated central government agencies, and breaking the monopoly of provincial grid companies, as well as the SGC and SPG at a national level, has been an enduring theme of China’s electricity reform process.

China’s 2002 electricity reforms originally conceived of a two-stage reform process, where the separation of generation from the grid would be followed by the unbundling of transmission and distribution (T&D). With the onset of electricity shortages, these plans were shelved; reforms have had little impact on grid companies so far. In large part because of chronic underinvestment in the grid, the central government views restructuring and competition in T&D as a major priority going forward [19]. In principle, inter- and intra-regional competition in T&D provides a means of encouraging much needed grid investment while keeping electricity rates low. But an overemphasis on the supply-side benefits of grid competition ignores the potential for demand-side measures to achieve the same ends at lower cost. It also emphasizes competition over regulatory approaches that have worked in other countries.

At the same time, without major changes in incentive structures for China’s LSEs, efforts to implement demand-side reforms in China will lack a provincial foothold and central government agencies will be hard-pressed to enforce compliance. Competitive T&D could add a new layer of difficulty by reducing incentives for LSEs to reduce electricity demand. Despite these obstacles, provincial LSEs might still be an effective entry point for demand-side policies if stakeholder incentives are aligned, and a regulatory system developed that is capable of overseeing incentives and cost-recovery for LSEs. OECD experience indicates that this kind of regulation almost certainly must occur at the provincial, rather than the national level. It will also have to evolve without the advantage of a well-developed legal framework and traditions of stakeholder process and public oversight, in contrast to OECD experience.

Despite electricity reforms, China does not actually have independent regulators in its electricity sector. The State Electricity Regulatory Commission (SERC), established in 2003 as part of the reform process, lacks both the mandate and the resources to be a strong, effective regulator in the sector. Although SERC has steadily gained power and responsibility, in many of its functions it still plays a secondary regulatory role to the NDRC [23]. The NDRC is the de facto chief regulator in China’s electricity sector, with control over pricing, project approval, and the design and implementation of the reform process itself. Although there have been calls for unbundling policy and regulation in China’s electricity sector by separating the functions of the NDRC and SERC [23], the NDRC remains dominant; it is possible that no less powerful an entity would be able to achieve policy consensus in Beijing. Moreover, given the central–provincial jurisdictional issues already discussed it is not clear that empowering SERC at a national level would significantly improve its effectiveness in regulating the sector.

OECD experience has shown that LSEs are the logical implementer of energy efficiency programs in the electricity sector. LSEs are usually in the best position to understand the potential for energy efficiency within their systems, and to design and conduct technology or pricing programs for their customers to achieve reductions in energy consumption or demand. Effective implementation of energy efficiency programs is the result of the interaction between the LSE and its local regulator, which combines mandatory requirements with incentives. Under cost of service regulation in the US, this takes the form of providing metrics for the cost-effectiveness of energy efficiency programs in an integrated resource planning (IRP) and rate-making context, and an incentive structure that allows efficiency savings to be shared among ratepayers and utility shareholders. In California, regulators have taken the further step of decoupling utility revenues from energy sales, to remove the LSE’s concern that aggressive energy efficiency programs will lead to revenue loss.

Such measures would be difficult for national level regulators to impose in a large, complex electricity system, such as the US or China. The effective role of national regulators, as in the case of the Federal Energy Regulatory Commission (FERC) in the US, is to regulate interstate power transactions, and leave rate regulation and other concerns specific to local utilities to independent regulators in the states. The challenge in China is that China’s LSEs are not independently regulated, and the provincial governments to which they are accountable have by and large not taken the initiative to implement demand-side reforms of their own accord. Without provincial initiative, and thus provincial incentives to reduce load growth, demand-side regulation in China is unlikely to take hold. In the short-term, the central government needs to provide the incentives to obtain provincial government buy-in, without which central government plans for integrating demand-side strategies into energy policy are
likely to be ineffective. For both China’s central government and the international community, there exists a significant opportunity to support EE/DSM through collaborative capacity building at a provincial level\textsuperscript{12}.

In the long run, the key is development of effective provincial level independent regulators with well-defined jurisdiction and legally-grounded enforcement powers. In OECD countries, regulatory systems have developed in the context of constitutionally-based systems of federalism, legal frameworks with an independent judiciary, and mechanisms for transparency and public accountability that are still evolving in China. Whether an effective provincial regulatory system can evolve independently of such foundations, based simply on the recognition by local stakeholders that it is in their long-term self-interest, or whether it must await developments in the larger political arena, is an open question.

4.2. Electricity pricing for energy efficiency and demand-side management

Pricing is a potentially valuable tool for promoting EE/DSM in China, by encouraging investment in energy efficient technologies. China’s central government has vowed to use higher electricity prices to achieve part of its 20% intensity reduction goal, which raises the question of how high the government is willing or able to raise rates in order to induce conservation [51]. In principle, long-term sustainability demands that China’s electricity prices reflect the full cost of producing and delivering electricity, including externalities, leading to more efficient decisions by producers and consumers. As described below, efforts so far to price electricity closer to the true cost of supply in China have run aground in the country’s complex political economy.

Two competing priorities have driven China’s electricity tariff reforms: the need to keep electricity prices low for the benefit of consumers, and the need to ensure that generators and grid companies receive adequate revenues to encourage long-term capacity investment. Except for a few competitive experiments, these tradeoffs are made by the Pricing Bureau of the NDRC, which sets wholesale ‘feed-in’ tariffs for generators. When tariff reform came to the forefront in the late 1990s, the central government’s new strategy for resolving these tradeoffs was the introduction of competitive wholesale generation and the establishment of regional power markets. As we describe below, neither of these market experiments have taken hold to a meaningful extent, and tariff changes have instead been driven by coal price increases.

Historically, dispatch in China has been based on a uniform allocation system in which each generating unit is assigned annual operating hours based on its capacity. Obviously uneconomic as equal-sized units with differing heat rates would have identical operating hours, this paradigm was challenged beginning in 1997 as nation-wide overcapacity led to generator competition for scarce demand, often with provincial government-owned generating units being favored in dispatch decisions. Frustrated with provincial protectionism, the central government began experimenting with more competitive alternatives in 1999, launching a pilot program in six provinces based loosely on the United Kingdom’s price pool model. The pilot lasted only two years, as electricity shortages and a continued dispatch bias in favor of provincial government-owned assets led to the discontinuation of the experiment [50]. Based on a two-tier part regulated, part competitive tariff system, a second round of regional power market pilots began on a limited scale in 2004 and 2005, covering three regions. For most of the country, however, wholesale tariffs are still set using the traditional, capacity-based approach.

In addition to wholesale competition, the central government has also sought to create regional power markets by linking provincial grids with long-distance transmission lines. The ‘western electricity transmitted to the east’ (xidong xidian) strategy in particular was designed to further two policy goals at once: reducing income inequality by promoting economic development in interior provinces, and improving economic efficiency by exploiting the large differentials in generation costs between interior provinces and the coast. For example, capacity weighted average feed-in tariffs in Shanxi Province, China’s largest coal producing province, were more than 30% lower than in Beijing Municipality in late 2006 (see figure 5). In the absence of competition in regional markets, however, the de facto price integration of provincial grids through coal price liberalization and regional power trade has so far served to raise, rather than lower, electricity prices in the poorer provinces [52], working against the goal of reducing inequality between interior and coastal provinces.

Changes in China’s electricity tariffs over the past five years have been driven not by intra- and inter-regional competition but by rising coal prices. In 1992, the NDRC established a two track system for coal prices, with ‘commodity’ coal prices allowed to rise more rapidly and ‘electricity’ coal prices based on a ‘guiding price’ (指导价格 zhidao jiage) set significantly below the commodity price. As the electricity sector’s share of coal demand increased from 26% in 1990 to 50% in 2006, this system became untenable. In 2004, the NDRC abolished its guiding price and set price bands for negotiations between coal producers and electricity generators. The NDRC widened those bands in 2005; in 2006 it scrapped them altogether.

Many electricity generators were unable to absorb the ensuing fuel cost increases; according to NDRC estimates 1280 power plants lost at total of 12.7 billion yuan in 2005 [19]. In May 2005 the NDRC announced a price ‘co-movement’ (联动 liandong) policy that obligated the agency to adjust feed-in and retail tariffs in the event of a change of 5% or more in coal prices, allowing electricity generators to pass up to 70% of increased fuel costs on to grid companies, and grid companies to pass costs on to consumers. Feed-in tariff increases in 2005 and 2006 have raised retail industrial and residential rates across the country by 10–25% since 2004 [20]. Because of

\textsuperscript{12} See, for example, recent collaboration between California regulators and counterparts in Jiangsu Province, California Public Utilities Commission website, ‘Energy Efficiency and Clean Energy in China: A Briefing on Recent CPUC Interaction and Cooperation with Policy Makers and Regulators in China’, http://www.cpuc.ca.gov/cleanenergy/design/docs/CPUC,CHINA-briefing.pdf.
concerns over inflation, the co-movement policy has not been used since 2006. As a result, even as coal prices have continued to rise, electricity prices have remained flat (see figure 6), which has put greater pressure on electricity generators and led to lobbying efforts on the part of generators to receive higher tariffs.

This dynamic among coal producers, electricity generators, and central government agencies is only one side of the larger process of electricity price formation in the Chinese political economy. Historically, China’s central government was able to raise electricity prices without significant resistance because most end users were state-owned firms [8]. Current rate increases are more contested. Decisions on residential electricity prices have been opened to the public through public hearings. For instance, a proposed 0.065 yuan increase in residential electricity prices in Hubei Province in 2006 was blocked at a public hearing. Industry and local government have also been resistant to price increases. For instance, while the NDRC has nominal authority over local electricity rates, in practice local governments have often intervened to ensure large industrial users pay less than reported rates for electricity [20].

EE/DSM can partially counteract increases in retail electricity rates by reducing consumption, so that customer bills grow less rapidly than rates. Assuming continued upward pressure on commodity prices in China caused by rapid economic growth, the Chinese central government’s best strategy for balancing the practical need to encourage supply with the political need to stabilize electricity bills may be to invest heavily in EE/DSM. Load management during China’s electricity shortages illustrates the potential role that grid companies can play in reducing demand growth through DSM pricing programs, but also how institutionalization of these programs is key to achieving longer-term benefits. Hu et al [47] estimate that DSM measures in 2003 and 2004 reduced peak load by a combined 15 GW. DSM in China, however, has largely developed as an emergency load management strategy to deal with shortages. In some cases municipalities and provinces have institutionalized pricing programs as a means to improve load factors. Beijing, for instance, adopted a four-tier time-of-use (TOU) pricing system where critical peak prices are roughly 3–4 times lowest off-peak prices. After a 5% drop in load factor to 82.31 from 1992 to 1996, through its DSM programs Beijing was able to maintain a constant load factor from 1997 to 2003 [47]. Despite sporadic provincial interest in DSM as a load management tool, demand-side measures to reduce total energy consumption have not generally been integrated into electricity resource planning processes in China.

EE/DSM can potentially play an important role in coordinating the two primary needs for electricity prices: rational pricing to reduce negative externalities and encourage supply, and the political imperative to ensure stable electricity bills. However, institutionalizing EE/DSM as a means to allow
higher electricity rates will itself require integrating EE/DSM considerations into debates on the effect of electricity prices on broader policy goals, such as social equity and inflation.

5. Discussion and conclusions

The scale of growth in China’s demand for electricity during the first two decades of the 21st century will likely be unprecedented in human history. Simply meeting this meteoric rise in demand will pose a challenge, requiring trillions of yuan and placing a considerable strain on the country’s natural resources. Meeting this demand sustainably—in a cost-effective, equitable, and environmentally benign manner—will require reforming existing institutions to better manage and guide the electricity sector’s development.

China’s electricity sector has a long, gradual history of reforms that extend back to the mid-1980s. This reform process, driven and punctuated by cycles of surplus and shortage, has increasingly followed the path of market-oriented reforms in the electricity sector seen worldwide, including an ‘unbundling’ of generation from transmission and distribution and an emphasis on opening up the sector to competition. Even as Chinese policymakers’ framework for electricity sector reforms converges toward internationally-accepted principles, as the above cases illustrate China’s electricity sector continues to demonstrate a number of fundamental shortcomings in its basic institutions and functions, either in spite of or because of electricity reforms. Table 2 shows, for each of the key reform objectives described earlier, an example of a currently intractable implementation problem.

These shortcomings illustrate both the difficulties of reforming entrenched institutions and the importance of the broader political economy in which reforms occur. In China’s case, incentive structures among central government agencies, provincial government agencies, and state-owned and private enterprises continue to be misaligned. Misaligned incentives produce a gap between the progressive laws, regulations, and standards set by central government agencies and local implementation.

Nowhere is this gap more apparent than in the environmental performance of China’s electricity sector. China’s coal-dominated electricity generation is the country’s largest source of air pollution and GHG emissions, and reducing the environmental impact of electricity supply is key to China’s environmental sustainability. Technology has an important role to play in cleaning up the electricity sector, including the four cases considered above—more efficient coal-fired power plants, renewable energy, pollution controls, and energy efficiency and demand-side management. In all four of these cases, we illustrate how, despite the promise of technology, neither technological advance itself nor continued market-oriented reforms are sufficient to ensure that new technologies are seamlessly adopted into the electricity sector (see table 3); all of these policies have failed to fully meet the objectives described in the introduction.

Misaligned incentive structures in China’s electricity sector result from two primary shortcomings in governance, clearly visible in the electricity sector but present in many sectors of its economy. First, as a result of China’s incomplete federalist system, central and local government interests frequently diverge, undermining implementation of central government policies. Second, regulation, both economic and environmental, is still inadequate in scope and ineffective in implementation. In the cases above, misaligned incentives result in gaps between quantity-based targets (e.g., desulfurization equipment) and actual performance (e.g., SO2 emission reductions) that have implications beyond

| Table 2. Problems in China’s electricity reforms. |
|-----------------------------------------------|
| **Reform objective**                         | **Implementation problems** |
| Competitive wholesale markets                | • Provincial grid companies are still biased toward local generators, reflecting a mismatch in priorities between provincial and national authorities. |
| Marginal cost pricing                        | • Retail electricity prices are held below the marginal social cost of provision, reflecting government concerns over the economic and social impacts of higher electricity prices. |
| Effective coordination and planning           | • Transmission and distribution investment and construction is insufficient to meet the needs of rapidly expanding generation capacity, reflecting grid companies’ lack of investment incentives. |
| Efficient regulation                         | • Enforcement mechanisms are expensive and ineffective, reflecting *inter alia* the lack of independent regulatory capacity at a local level. |

| Table 3. Environmental policy outcomes in the electricity sector. |
|-----------------------------------------------|
| **Environmental policy**                     | **Outcomes: successes and problems** |
| Promoting advanced coal/retiring inefficient plants | A large portion of new coal-fired generation uses more efficient supercritical technology, but efforts to retire inefficient units have met with local resistance. |
| Renewable energy                             | China’s installed wind capacity has grown rapidly, but feed-in tariff design has created perverse incentives that encourage installed capacity growth but not necessarily higher generation from wind. |
| Pollution control/installing desulfurization equipment | As a result of central government efforts more than half of all thermal generating units have installed desulfurization equipment, but, as a result of the lack of enforcement of penalties for noncompliance, many units are not running that equipment. |
| Energy efficiency/demand-side management     | By all accounts, there is a huge potential for increasing end-use efficiency in China, but EE/DSM programs have not been institutionalized because load serving entities lack mandate or incentives to conduct aggressive EE/DSM programs, and most retail pricing is not designed to encourage EE/DSM. |

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China’s borders. In the SO2 case, for instance, the central government’s difficulties in regulating SO2 emissions do not bode well for hopes to widely deploy carbon capture and sequestration (CCS) technology in China.

What can be done? The problems of center–provincial relations and regulatory weakness are rooted in China’s political economy and history, and the challenges of addressing them should not be underestimated. For center–provincial relations, the larger context is China’s incomplete federalism, which may not be ultimately resolved until an effective constitutional framework is developed. For regulation, effectiveness will depend in large part on the further evolution of legal foundations, adversarial processes, and transparency in both public and business affairs. It may also be challenging for Chinese policymakers to unlearn some of the magical thinking about markets that has pervaded electricity reform efforts worldwide for the last two decades, and instead focus on developing the regulatory capacity needed to set up and police competitive markets, protect consumers in natural monopoly situations, and enforce environmental laws.

Although building the legal framework in China for center–province interactions and regulatory institutions will likely require decades, in the nearer term there are measures that both the Chinese central government and OECD policymakers can undertake to support the emergence of strong, independent regulatory capacity in China’s electricity sector. First, China’s central government needs to create more effective incentives for provinces to align themselves with the center’s environmental objectives. This includes better design of economic incentives for improving environmental performance, but also includes providing encouragement and resources for the development of independent provincial regulation. OECD countries can support these efforts by engaging more extensively with government agencies at a provincial and local level. In this context, a key form of assistance is helping to build regulatory capacity through knowledge bases, resources, and exchanges, as the state of California has recently been doing with Jiangsu Province.

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