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POLICY BRIEF

PB 17-5 Against the Wind: China's Struggle to Integrate Wind Energy into Its National Grid

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Authors' Note: Some of the figures and calculations in this Policy Brief have been published in Lam, Branstetter, and Azevedo (2016). This Policy Brief provides a thorough analysis of the policy decisions and policy contradictions that have driven China's unexpectedly high cost of carbon mitigation and the policy reforms that might be needed to correct it. We gratefully acknowledge the financial support from the following sources: Fundação para a Ciência e a Tecnologia (Portuguese Foundation for Science and Technology), the Carnegie Mellon Portugal Program, CMU's Scott Energy Institute and the Climate and Energy Decision Making Center (CEDM). We thank Sally Xu, Jørgen Villy Fenhann, and Yang Liu for valuable assistance with the data used in this study.

CAN XI JINPING KEEP THE BOLD PROMISES HE MADE IN HANGZHOU?

President Xi Jinping got to bask in a rare moment of international approval at the G-20 Summit held in Hangzhou September 4–5, 2016. Standing next to the then American president, Barack Obama, with whom he often sparred, President Xi declared that his country, the world's largest carbon emitter by a growing margin, would work with the United States, the second-largest emitter, to significantly reduce the carbon intensity of its economy. In the context of a G-20 meeting that produced little else of substance, the joint declaration by China and the United States made global headlines. But can Xi deliver?

Unlike Obama, President Xi and his predecessors have not had to contend with a legislature dominated by an opposition party that refuses to recognize the reality of climate change. Seeking to dramatically expand renewable energy's share of its primary energy by exploiting its considerable wind energy resources, China launched an unprecedented wind farm construction boom a decade ago. On the surface these efforts appeared to yield great success, with China's wind generating capacity growing more than 100-fold in less than 10 years.

Close examination of China's aggressive top-down approach to the promotion of renewable energy reveals that it has fallen far short of its ambitious goals.

But close examination of China's aggressive top-down approach to the promotion of renewable energy reveals that it has fallen far short of its ambitious goals. Turbines were quickly installed—but many of them were not connected to the power grid. After some turbines were connected, the state-owned enterprises (SOEs) that operate the national grid often refused to accept energy from them. These problems led to inefficiencies that are without precedent in the Western world. They help explain the shocking fact that although its installed wind energy capacity is 75 percent larger than that of the United States, China produces 14 percent less wind energy than the United States. Even in a political system with

Table 1 Primary energy consumption in China, by fuel source, 2007–14 (million tonnes of oil equivalent)

Fuel source	2007	2008	2009	2010	2011	2012	2013	2014
Oil	369.3 (17.3)	376.0 (17.0)	388.2 (16.8)	437.7 (17.7)	460.0 (17.2)	482.7 (17)	503.5 (17)	520.3 (18)
Natural gas	65.6 (3.1)	75.6 (3.4)	83.2 (3.6)	99.4 (4.0)	121.4 (4.5)	136.0 (5)	153.7 (5)	166.9 (6)
Coal	1,573.1 (73.7)	1,598.5 (72.2)	1,679.0 (72.6)	1,740.8 (70.4)	1,896.0 (70.8)	1,922.5 (69)	1,961.2 (68)	1,962.4 (66)
Nuclear	14.1 (0.7)	15.5 (0.7)	15.9 (0.7)	16.7 (0.7)	19.5 (0.7)	22.0 (1)	25.3 (1)	28.6 (1)
Hydro	109.8 (5.1)	144.1 (6.5)	139.3 (6.0)	163.4 (6.6)	158.2 (5.9)	197.3 (7)	208.2 (7)	240.8 (8)
Non-hydro renewables	1.9 (0.1)	3.6 (0.2)	6.9 (0.3)	13.1 (0.5)	24.6 (0.0)	33.8 (1)	46.1 (2)	53.1 (2)
Total	2,133.7	2,213.3	2,312.5	2,471.2	2,679.7	2,794.5	2,898.1	2,972.1

Note: Figures in parentheses indicate percentage of total annual consumption.
Source: Data from BP (2015).

a strong centralized government, China's push for renewable power faltered in the face of entrenched interests, weak incentives, and conflicting policy priorities.

After accounting for the cost of building wind capacity that was not effectively utilized by the national grid, the cost of wind energy in China in the mid-2000s was twice as high as projected. A decade later costs had declined, but they were still 50 percent above projections. Consequently, the cost of carbon mitigation by replacing coal-generated electricity with wind energy has been four to six times higher than official estimates.

In Hangzhou President Xi reiterated China's commitment to further expand its renewable energy generation capacity. But China's struggle to use the capacity it has already built has intensified as growth in electricity demand has slowed, coal-fired power plants have been forced to contend with widespread excess capacity, and a global coal glut has raised the price of carbon mitigation. Without further policy reform, China will find it difficult to make good on the ambitious promises made by its leader in Hangzhou.

A nationwide cap-and-trade program could bring the divergent interests that have hindered China's progress into much better alignment. Such a system can help foster progress toward meeting China's climate change goals only if the price set on carbon emissions is high enough to force a shift away from cheap coal—something that would require official willingness to raise energy prices at a time of weak demand and pervasive overcapacity in China's energy-intensive industries. Over the past decade, whenever environmental goals have clashed with the perceived need to support economic growth, the latter has usually won out. Given President Xi's ambitious economic growth targets for the rest of his expected two terms, the tension between growth and clean energy is likely to persist.

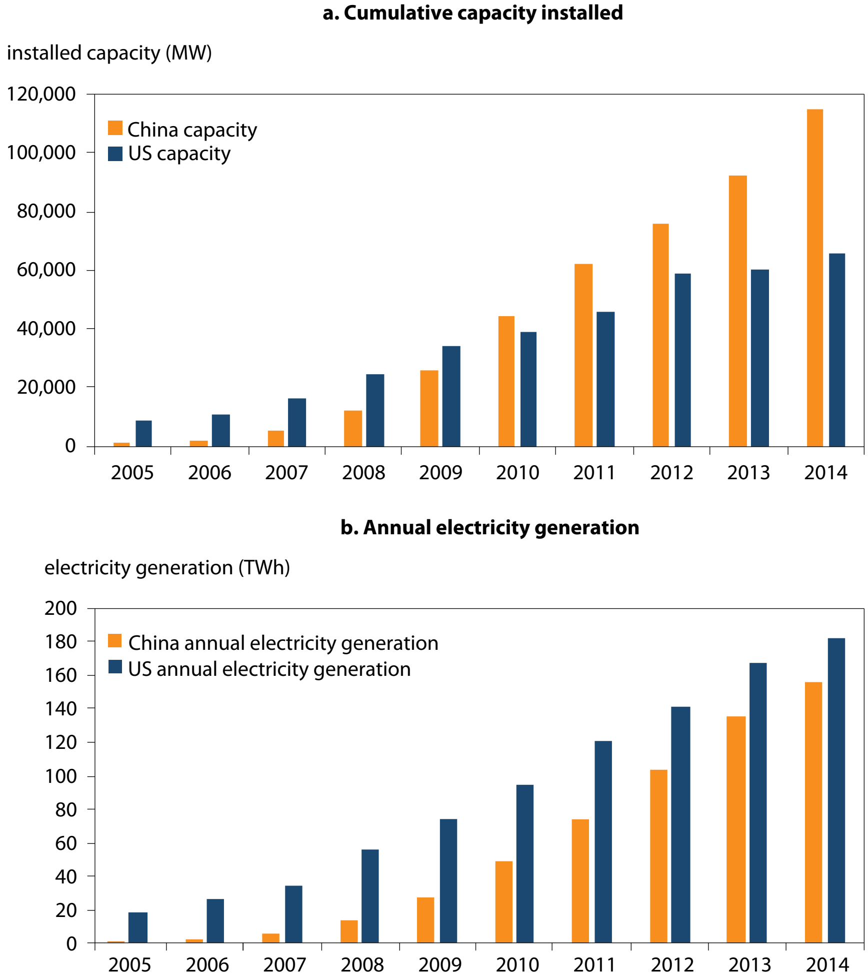
CHINA'S WIND ENERGY BOOM

Increasingly intensive use of its abundant domestic supplies of coal made China the world's largest emitter of greenhouse gases by the mid-2000s. The environmental consequences of rapidly expanding coal use in domestic thermal power generation and energy-intensive manufacturing became increasingly apparent to China's own population and to foreign visitors. China responded with an aggressive embrace of alternative energy. Passage of the Renewable Energy Law in 2005 signaled the central government's strong commitment to the rapid development of renewable energy in China. The State Council, China's most powerful governmental body, codified that commitment into extremely ambitious renewable energy targets. The National Development and Reform Commission (NDRC) called for renewable energy sources (including hydropower, wind, and solar) to account for 10 percent of China's primary energy consumption by 2010 and 15 percent by 2020 (NDRC 2007). When these goals were set, total renewable energy sources accounted for only about 6 percent of primary energy consumption, and almost all of that 6 percent came from hydropower (table 1).

From the outset it was clear that wind energy would play an especially central role in meeting these targets. China's geography provides it with significant wind resources. The central government's embrace of renewable energy thus set into motion the greatest construction boom in the history of the global industry. In less than a decade, China went from having virtually no wind power capacity to being in the global forefront (figure 1). In 2001 it had only a little more than 400 MW of cumulative installed capacity; by 2010 its capacity had expanded by more than 100-fold, to 44.7 GW, allowing China to surpass the United States as the country with the most installed wind capacity (GWEC 2012). By 2014 China's wind energy installed capacity outstripped that of the United States by some 75 percent.

China's rapid wind energy build-out has been lauded by green energy advocates (such as Thomas Friedman) and received favorable reviews from serious academic studies (such as Lewis 2013). US trade officials and foreign wind turbine producers were less impressed. Notice 1204, a rule promulgated in 2005 as part of the Renewable Energy Law, required that at least 70 percent of wind turbine components supported by the law had to be manufactured in China—a clear violation of World Trade Organization (WTO) rules.

Figure 1 Installed capacity and electricity generation from wind in China and the United States, 2005–14



Note: The cumulative installed wind capacity in China has surpassed that of the United States in 2009–10. However, as of 2014, annual electricity generation in the United States was still larger than in China. Plot produced by the authors using data from AWEA (2015), CWEA (2015), and CEC (2015).

Source: Lam, Branstetter, and Azevedo (2016). © IOP Publishing Ltd.

In 2004 indigenous firms and Sino-foreign joint ventures accounted for only 17 percent of national installed capacity. To take advantage of China's ambitious wind farm development program while meeting its requirement for local manufacturing, Western firms scrambled to transfer technology to Chinese affiliates and local joint venture partners. Other Chinese government programs that subsidized research and the licensing of foreign technology supported these efforts. When the US government threatened to file a WTO case against China's local content requirements, China quietly dropped them.[1] By the time the legal requirement was formally rescinded, however, indigenous firms and Sino-foreign joint ventures dominated the Chinese market. The biggest wind farm build-out in history was supplied overwhelmingly with domestic equipment.[2]

1. Keith Bradsher, "To Conquer Wind Power, China Writes the Rules," *New York Times*, December 14, 2010, www.nytimes.com/2010/12/15/business/global/15chinawind.html?pagewanted=all (accessed on July 12, 2012).

2. The Chinese were not alone in seeking to keep out foreign wind energy equipment. In 2012 the United States levied antidumping duties on Chinese and Vietnamese manufacturers of wind turbine towers. In 2014 Australia imposed antidumping duties on imports of wind towers from China and South Korea. Trade duties have arguably played less of a role in distorting trade in wind energy equipment than in the solar PV sector, however. Because utility-scale wind turbines are so large that key components do not fit easily into containers or cargo vessels, equipment tends to be manufactured in the country or region in which it is used. Foreign direct investment has generally been a more important channel of globalization than exports (Kirkegaard, Hanemann, and Weischer 2009). The situation is quite different in the solar PV sector, where escalating duties on solar PV modules and key inputs distort trade flows.

China's use of wind energy capacity has lagged far behind installation—to an extent that is without parallel in the industrial West, as shown in figure 1. Indeed, a large share of China's massive installed base of wind energy is supplying little or no power to the national grid. If China were to connect all of its wind turbines to the grid and put them to full use at a 22 percent capacity factor, it would increase its generation of electricity from wind by almost 40 percent—equivalent to installing 32 GW of new capacity.

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HASTE MAKES WASTE: WHY IS CHINA'S UTILIZATION OF WIND ENERGY CAPACITY SO LOW?

Failure to Connect

China doubled its installed capacity every year between 2006 and 2010. However, 25–31 percent of its installed capacity remained offline between 2006 and 2008, and the situation was even worse in 2010, when 34 percent of installed capacity went unused. That fraction has declined sharply since, but it remains much higher than in Western countries, where almost all capacity is used.[3]

Failure to connect generating capacity to the grid reflects both geography and the divergent interests that exist within China's energy system. Much of China's wind resources are concentrated in areas far from the electricity demand centers of its eastern seaboard, and the current grid has limited capacity to carry this energy to industrial centers (Wang, Yin, and Li 2010; Li, Hubacek, and Siu 2012; Li, Li, and Feng 2014; Pei et al. 2015; Zhao et al. 2016). Responsibility for building out that transmission infrastructure lies with two giant state-owned grid companies that manage China's national grid, whose interests have sometimes diverged from the goals of the Renewable Energy Law (Kahrl and Wang 2014).

The group of (mostly) SOEs that operates power generating plants is administratively separate from the two SOEs that manage the grid. The power generators responded enthusiastically to the central government mandate to build out wind generating capacity, because they had every reason to believe that they would be quickly rewarded by drawing on the preferential access to finance they have long enjoyed. The State Electricity Regulatory Commission (SERC) (whose functions were later folded into the National Energy Administration) set up a mandatory connection and purchase requirement for grid operators as well as a priority dispatch system under which renewable generators are given priority in the dispatch sequence. These steps seemed to ensure that new wind energy capacity would be quickly connected and utilized.

Following the lead of Western Europe, China also established feed-in tariffs, to encourage the generation of renewable power. The feed-in tariff system in effect by the late 2000s had four tiers for wind energy generation, ranging from RMB510 to RMB610 per megawatt hour (MWh) (about \$80–\$100), depending on the region's wind resources and electricity demand (Schuman 2010). These payments were similar in value to those in effect in Western Europe and seemed to justify aggressive investment by generation companies. To help pay for the costs of the new programs, the NDRC levied a RMB1/MWh surcharge on consumers (NDRC 2006), which was later gradually increased to RMB8/MWh (about \$1.30).[4] SERC and the NDRC created an interprovincial equalization program through which grid companies that owed more to green energy providers than they had collected through surcharges could draw on the excess surcharges collected in other provinces (Schuman 2012).

Tilting at Windmills: Renewable Energy Mandates versus the Grid Companies

The wind farm construction that ensued suggests that power generators and their financiers saw these policies as very credible. Implementation problems arose almost immediately, however. SERC, the regulatory agency putatively in charge of the electricity and power industry, ordered the grid companies to make whatever investments were necessary to quickly connect new wind energy capacity to the grid and to integrate tens of gigawatts of new, intermittent sources of green energy, often located thousands of miles from demand centers. The grid companies dragged their feet in complying with their mandate to connect, and none of them paid any financial penalty for doing so.[5] Even when wind farms

3. Western developers normally begin working with a distribution utility or transmission system operator to obtain access to the electric power grid early in the wind farm development process, often before construction of the wind project.

4. Leonora Walet, "China Clean Energy Shares Climb on Surcharge Increase," Reuters, December 1, 2011, www.reuters.com/article/2011/12/01/us-cleanenergy-shares- idUSTRE7B00FI20111201 (accessed on March 30, 2013).

5. In the United States or Western Europe, financial institutions do not finance the construction of wind farms unless the installation can be easily and quickly connected to the grid, and no financing flows without binding contracts obligating utilities to purchase the electricity. The absence of these constraints in China allowed

were connected to the grid, their energy contributions were often rejected ("curtailed" in the language of the industry), despite the existence of government directives that supposedly required the grid companies to prioritize the dispatch of renewable energy. Surcharges levied on end-use consumers were supposed to cover connection and integration costs as well as provide feed-in tariffs to wind power producers. However, the complicated process of determining the amount owed to a particular province and the province from which that amount should be collected resulted in long delays in payments. Renewable power generators waited months, then years, to collect the payments they were owed. According to one estimate, the accounts set up to pay renewable integration costs were in arrears by more than RMB1.3 billion in 2009, and the shortfall was expected to reach RMB55 billion in the first half of 2016.[6]

The gap between de jure policy goals and de facto policy practice widened further as the global financial crisis led to an industrial slowdown and a sharp decline in fossil fuel prices, which made the renewable energy targets much more expensive for grid operators to meet. In principle, the Chinese government could have forced the grid companies to buy expensive renewable energy and pass on those costs to their industrial and residential customers. However, the risk of job losses was evidently too high for the country's senior leadership.[7] Wind farms therefore stayed off the grid, and grid operators paid little or no real penalty for curtailment. Even today grid operators are allowed to curtail wind electricity output if providing it threatens the safety or reliability of the grid. Curtailments have to be documented and explained to regulators, who possess the power to fine grid operators if they are not satisfied with the proffered explanations. To date they have imposed no fines.

The fraction of installed capacity that is not connected to the grid has fallen since peaking in 2010 (see figure 2). The sharp decline after 2010 largely reflects the delayed construction of the transmission infrastructure needed to connect some of these far-flung wind farms to the national grid. Once the missing pieces of this infrastructure were largely in place, the rate of disconnection fell significantly and almost continuously through 2015, with the decline accelerating in the most recent years.

Unfortunately, curtailment rates remained high even as the global financial crisis receded. The total amount of curtailed electricity increased by a factor of 2.75 between 2011 and 2015 (table 2). The average national curtailment rate fell dramatically between 2012 and 2014, but it rose sharply in 2015. Data from the first half of 2016 show a national curtailment rate of 21 percent—significantly higher than in any year between 2011 and 2015—and the highest curtailment rates typically lie in the second half of the year (NEA 2016c).

Higher curtailment rates cannot be blamed on a temporarily missing piece of infrastructure. The intermittency of wind energy does require that grid operators possess generating capacity that can be rapidly ramped up or down to compensate for wind variability, but grid companies have had plenty of time to set up that capacity and build their skill in deploying it.

Curtailment rates are high and rising because keeping them high serves the financial interests of the grid companies. Since 2014 the growth of China's energy-intensive industries has sharply decelerated, limiting electricity demand. At the same time, global coal prices have fallen sharply, lowering the cost of coal-powered electricity. Overestimating energy demand, the authorities permitted the construction of too many coal plants, forcing many of them to operate well below capacity. The intermittency of wind, and the need for the grid operators to purchase and dispatch the right amount of fossil energy–generated electricity to offset that intermittency, make wind power significantly more expensive for grid companies to use than coal power. Seeking to maximize their margins, the grid companies buy increasingly cheap coal energy and increase curtailment of wind energy.[8] Without policy reform to change their incentives, the grid companies are likely to persist in this behavior as long as electricity demand remains weak and coal cheap—circumstances that could persist for years.

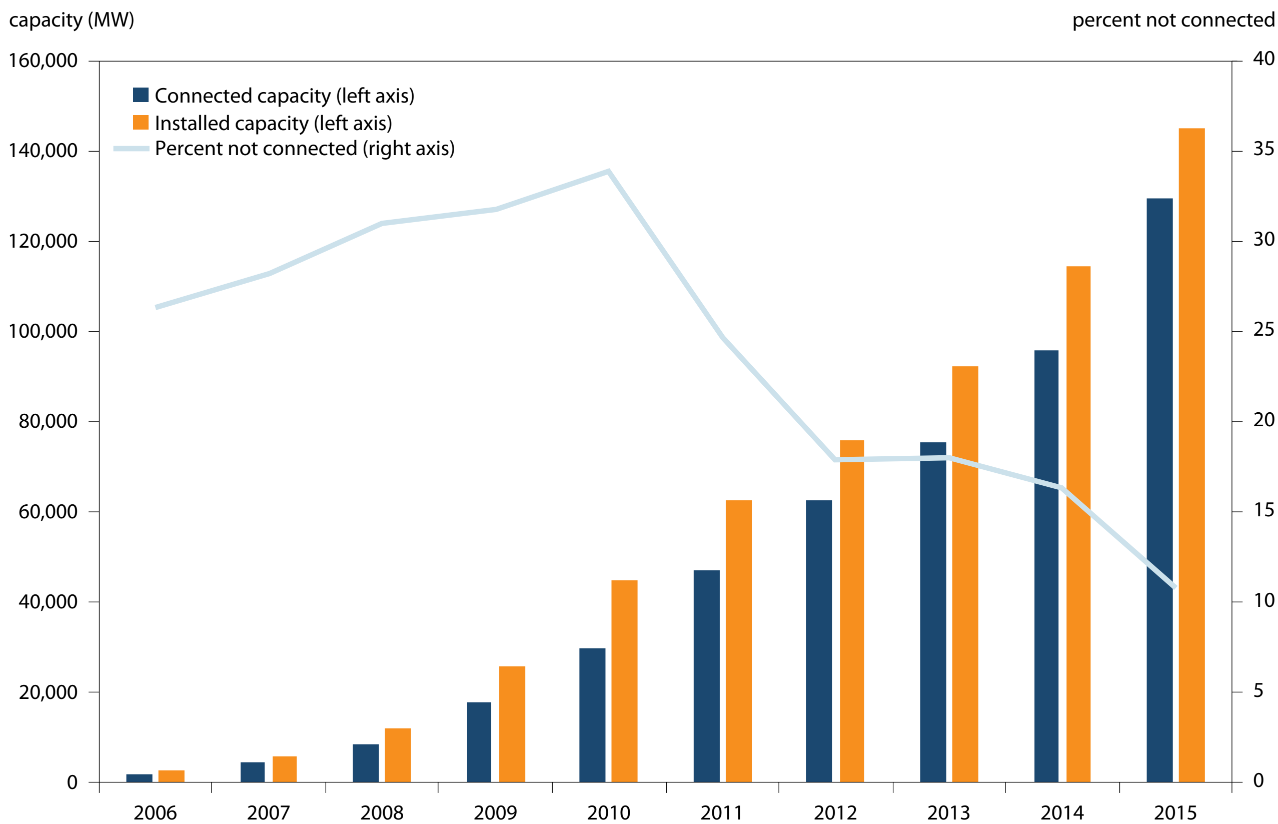
wind farm construction to expand at unprecedented rates but created a lack of grid connection and a degree of curtailment that are not seen in the West.

6. Qixiu Lu, "国家能源局副局长李仰哲：截至上半年可再生能源补贴缺口累计高达550亿元," BJX, August 12, 2016, http://guangfu.bjx.com.cn/news/20160812/761552.shtml (accessed on January 5, 2017).

7. In addition to the problems imposed by state grid companies, developers faced a number of problems associated with wind turbine quality. Several accidents occurred in which turbines suddenly and unexpectedly went offline, hampering efforts to integrate renewable energy into the grid. The accidents reflected the lack of technological experience of many wind turbine manufacturers. Ming et al. (2014) report that 193 accidents occurred in 2011, 54 of which caused capacity losses of more than 500 MW. It is possible that these quality problems are related to China's imposition of strong local content requirements through 2009, which induced developers to use equipment manufactured by Chinese producers with limited experience.

8. There is a formal procedure in which energy demand is projected and then divided among coal power producers, providing each plant with a projected level of power it can sell to the grid, but these allocations are no more binding on grid companies than the regulators exhortations to dispatch wind energy whenever possible. No financial penalties are triggered if grid companies sharply reduce their usage of coal energy in favor of wind energy.

Figure 2 Installed and connected wind energy capacity in China, 2006–15



Note: The line tracks the percentage of China's wind base that is not connected to the grid. Figure produced by authors using data from CWEA (2015), LBNL (2014) for installed capacity, and CEC (2015) for connected capacity.

Source: Lam, Branstetter, and Azevedo (2016). © IOP Publishing Ltd.

Table 2 Curtailment of wind electricity in China, by province, 2011–15 (GWh)

Province	2011	2012	2013	2014	2015
Inner Mongolia	6,958 (32)	11,335 (30)[a]	6,389 (20)	3,568 (9)	9,100 (18)
Gansu	2,680 (27)	3,024 (24)	3,102 (21)	1,384 (11)	8,200 (39)
Xinjiang	101 (3)	215 (4)	431 (5)	2,334 (15)	7,100 (32)
Jilin	696 (15)	2,032 (32)	1,572 (22)	1,002 (15)	2,700 (32)
Hebei	361 (4)	1,765 (12)	2,800 (17)	2,036 (12)	1,900 (10)
Heilongjiang	744 (14)	1,050 (17)	1,151 (15)	953 (12)	1,900 (21)
Liaoning	656 (9)	1,129 (13)	528 (5)	639 (6)	1,200 (10)
Ningxia	—	47 (1)	43 (1)	—	1,300 (13)
Yunnan	—	170 (6)	169 (4)	259 (4)	300 (3)
Shanxi	—	16 (1)	—	—	300 (2)
Shandong	—	—	—	99 (1)	—
Shaanxi	—	—	37 (3)	43 (2)	—
Tianjin	1 (1)	—	9 (2)	6 (1)	—
Total	12,300 (16)	20,822 (17)	16,231 (11)	13,338 (8)	33,900 (15)

a. Average between East and West Inner Mongolia.

Note: Figures in parentheses are curtailment rates. — indicates no curtailment was reported.

Sources: CREIA (2012, 2013); SERC (2013); and NEA (2014, 2015, 2016b).

ESTIMATING THE COST: HOW CURTAILMENT AND LACK OF GRID CONNECTION HAVE RAISED THE PRICE OF WIND ENERGY IN CHINA

China failed to connect a substantial share of it wind turbines to the grid and to utilize a large share of the wind power it generates. The cost of this waste of resources can be estimated by using the engineering concept of a capacity factor.

When engineers forecast the energy delivery capability of a new wind farm, they take into account local wind, grid, and power equipment conditions and construct an ex ante estimate of the amount of energy the farm will create relative to the theoretical maximum achievable if favorable wind conditions persisted around the clock all year long. Good data on these ex ante capacity factor estimates are available for China.[9]

The actual amount of wind energy produced by these farms is measured in order to construct ex post capacity factors, which reflect the impact of disconnection, curtailment, accidents that impede generation, and other influences, including low turbine quality or inefficient operation of equipment in the face of changing wind conditions. To separately capture the effects of grid connection issues and curtailment on the overall performance of Chinese wind farms, we report two ex post capacity factors: ex post installed and ex post connected capacity factor. The former includes all installed turbines, whereas the latter includes only capacity that is connected to the grid.[10]

China's ex post wind capacity factors are much lower than developers projected in their ex ante estimates. Actual power generation data yield an ex post capacity factor for 2012 for connected turbines of just 19 percent (15 percent for all installed turbines)—8 percentage points lower than the Clean Development Mechanism ex ante capacity factor and 12 percentage points lower than the capacity factors observed in the United States (EIA 2015). Had all of China's wind turbines been connected and operated at the Clean Development Mechanism estimated capacity factor, China could have generated as much as 243 terawatt hour (TWh) of electricity—56 percent more than it did.

Effect on the Levelized Cost of Electricity

The energy engineering systems literature uses a measure known as the levelized cost of energy (LCOE) to compare energy sources and track their costs over time. The LCOE is the cost level at which electricity generation can financially break even over a project's lifetime:

$$LCOE = \frac{\sum_j^n \frac{FC_j + VC_j}{(1+r)^j}}{\sum_j^n \frac{GE_j}{(1+r)^j}} \quad (1)$$

where j indexes the year, FC and VC indicate the project's fixed and variable investment costs, GE is the total amount of generated electricity, and r is the discount rate. A project's projected electricity generation is the product of its installed capacity, its average capacity factor, and its operational time.

In the case of wind power, a project incurs an initial fixed capital cost and subsequently some variable costs (in the form of operations and maintenance). A wind farm is typically in service for 20 years. The analysis here assumes that the discount rate is 8 percent (the China power industry's benchmark internal rate of return) and that operations and maintenance accounts for 20 percent of the total investment cost. All currency values are deflated to 2004 level using the World Bank's currency deflator for China.

The unit cost of wind capital equipment in China fell 26 percent between 2004 and 2012, from RMB8.9 million to RMB6.6 million/MW; it is among the lowest in the world. By comparison, the average project cost per unit capacity in the United States was about $1.7 million/MW (about RMB10.7 million/MW) in 2012 (Wiser and Bollinger 2013).[11]

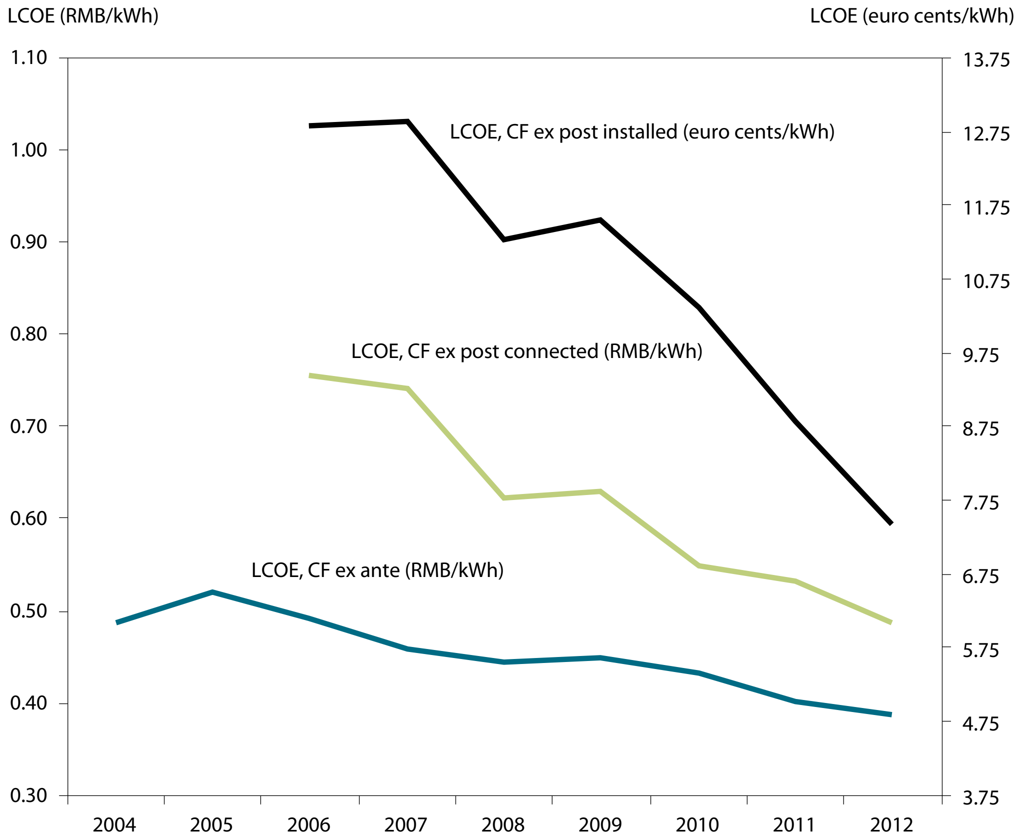
Estimates of the LCOE depend on the capacity factor used (figure 3). Using the Clean Development Mechanism ex ante capacity factor yields an LCOE of RMB0.49/kilowatt hour (kWh) in 2006 and RMB0.39/kWh in 2012. Using ex post installed capacity factor (that is, taking into account the significant fraction of the wind base that was not connected during this period) raises the LCOE to about RMB1.03/kWh (12.8 euro cents) in 2006 and RMB0.59/kWh (7.9 euro cents) in 2012.

9. China has been an enthusiastic participant in the Clean Development Mechanism, set up under the Kyoto Protocol, in which developing countries can sell carbon emissions reduction "credits" to rich countries with binding obligations on emissions reduction. Seeking funding for this program, many Chinese wind farms had neutral third-party engineering firms certify their ex ante capacity factor estimates. Data for wind farms scattered across China are therefore available for 2004–12.

10. In both ex post cases, the assumption that the new capacity has one year to generate electricity regardless of when the projects were completed within that year will yield lower capacity factors.

11. The Clean Development Mechanism initial investment costs include the cost of the turbine and related expenses, such as grid connection, civil works, and other miscellaneous items. The project costs reported in Wiser and Bollinger (2013, 34) "reflect turbine purchase and installation, balance of plant, and any substation and/or interconnection expenses."

Figure 3 Estimated levelized cost of wind energy (LCOE) in China under different assumptions about capacity factors (CF), 2004-12



Note: Computed LCOE using ex-post capacity factor is consistently higher than using ex-ante capacity factor. The China Electricity Council did not release wind electricity generation data before 2006. Plot produced by authors using data from CEC (2015) and UNEP (2015).

Source: Lam, Branstetter, and Azevedo (2016). © IOP Publishing Ltd.

Effect on the Cost of Carbon Mitigation

The cost of carbon mitigation (CCM) using wind electricity is the difference between the LCOE for wind and the LCOE for the base energy source wind replaces, divided by the carbon emission factor (EF):

$$CCM_t = \frac{LCOE_t^w - LCOE_t^b}{EF_t} \qquad (2)$$

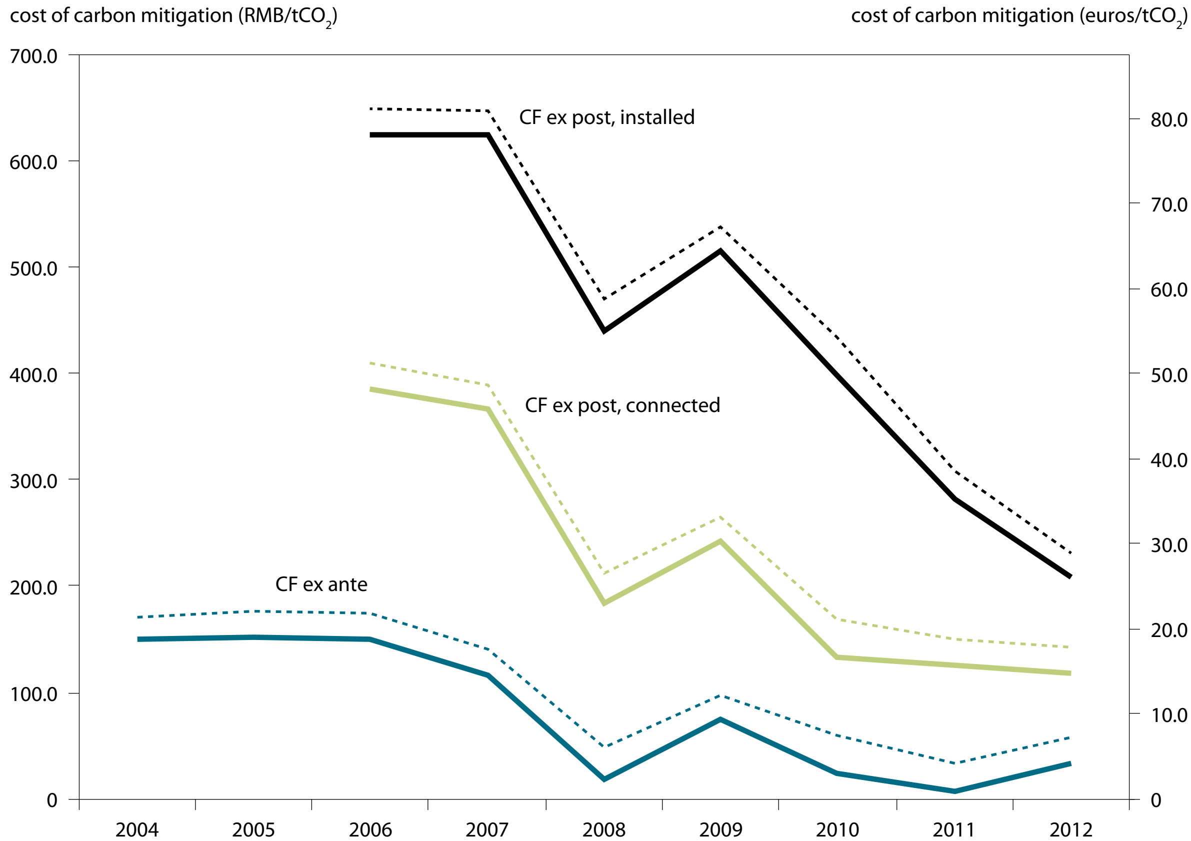
where t indexes the year. Because coal-fired power plants make up a large majority of China's electricity generating capacity, the LCOE of coal is used as the baseline. A generation cost model developed by Environmental Energy Economics (E3 2012) was used to compute the LCOE of coal in China.[12] Average annual data for 5500-grade coal prices were obtained from Qinhuangdao Port's Free-On-Board Price.[13] Annual national average utilization hours come from the China Electricity Council. As a substantial portion of China's coal power plant fleet consists of smaller-scale, less efficient "subcritical" plants, the baseline case assumes that these plants make up China's entire coal fleet. However, the number of more efficient supercritical plants is on the rise; they made up about 30 percent of China's thermal capacity in 2011 (IEA 2012). A second scenario therefore examines a fleet that consists exclusively of supercritical plants. Data for average annual emission factor comes from the Clean Development Mechanism project database.

Using Clean Development Mechanism ex ante estimates for capacity factors indicates that mitigation costs fall from RMB149.1/tCO_2 (€18.6) in 2004 to RMB33.7/tCO_2 (€4.2) in 2012 for the baseline case (assuming all plants are subcritical) (solid blue line in figure 4).

12. To be consistent with our LCOE model using Clean Development Mechanism data, we focus on investment costs and ignore related taxes.

13. Bohai Coal Price Index (BSPI), www.cqcoal.com (accessed on February 24, 2016).

Figure 4 Cost of carbon mitigation under different assumptions about capacity factors (CF) and the baseline levelized cost of energy (LCOE), 2004–12



Note: In each capacity factor scenario, we assume the coal plants replaced by new wind power plants are either all subcritical (solid line) or all supercritical (dotted line). Plot produced by authors using data from CEC (2015) and UNEP (2015) for wind LCOE, E3 (2012) and Qinhuangdao Port's Free-On-Board Price for coal LCOE, and IGES (2015) for emission factors. The China Electricity Council did not release wind electricity generation data before 2006. All currency numbers are deflated to 2004 prices.

Source: Lam, Branstetter, and Azevedo (2016). © IOP Publishing Ltd.

Under the ex post installed capacity factor assumption, the cost of carbon mitigation is four to six times higher than the ex ante estimates. The 2012 cost of carbon mitigation is comparable to the European emission allowance nominal price at its peak, though it is several times higher than the current market price. The cost of carbon mitigation in the past few years was probably much higher given the precipitous drop in coal prices. Lower capacity factors are also likely to have pushed up the cost of carbon mitigation.

DISCUSSION AND CONCLUSIONS: CHINA'S LONG MARCH TO DECARBONIZATION

China has struggled to turn its massive investment in new wind power generating capacity into green energy that actually feeds the grid. Despite China's strong centralized government, the powerful state-owned grid companies have consistently evaded administrative mandates that forced grid companies to act against their economic interests. Fully cognizant of the expense of linking distant wind farms to the grid, the grid's operating companies took a go-slow approach that kept much wind generating capacity off-line for years. Caught between low fossil energy prices, guaranteed generation hours for coal plants, and weak demand, grid companies at times refused to use wind energy even when it was available.

The still-large gap between installed capacity and renewable energy usage helps explain one of the painful realities of China's green energy push: After a decade of unprecedented expansion, renewables have risen from 6 percent to only 10 percent of China's total primary energy consumption—and hydropower generates 8 percentage points of that total (see table 1). These problems have pushed the cost of wind electricity and the effective cost of carbon mitigation to levels that are dramatically higher than expected.

China is a key battleground in the fight against global warming, and China's president has sought to position his country as an international leader in that fight. The ambitious pledges made by President Xi to curb China's carbon intensity and ramp up its renewable energy share made global headlines. China seeks to meet up to 15 percent of its primary energy consumption from nonfossil fuels by 2020, a percentage that will increase to 20 percent by 2030. To do so, China aims to install 210 GW of wind and 110 GW of solar capacity by 2020—more capacity than it added in the past five years.[14]

The grid connection and curtailment problems documented in this Policy Brief could prevent China from decarbonizing its energy systems even if it meets its ambitious installation targets. To meet the 2020 target, the National Energy Administration estimates that 9 percent of China's total electricity consumption must come from non-hydro renewable energy, a 4 percentage point increase from the current level (NEA 2016a).[15] Should grid connection and curtailment issues remain unresolved, the country's wind farms could lose as much as 50 TWh annually to curtailment, causing China to fall short of its target. Curtailment could also significantly reduce the output of solar farms, which lost 12 percent of the electricity they generated to curtailment in 2015.[16]

What could yield a better outcome? Under a well-organized nationwide cap-and-trade program, grid companies would have to pay more for electricity produced by carbon-intensive sources—and aggressive use of carbon-free electricity would keep those costs down. The right carbon price would flip the incentives of the grid companies, causing them to embrace rather than resist green energy.

China's leaders claim that a nationwide cap-and-trade program will be in place this year. The current level of preparation would seem to put full implementation within a year out of reach.[17] Implementing such a system will change the incentives of the grid companies only if carbon prices is high enough. But raising carbon prices high enough to align the incentives of the grid companies with the nation's putative green energy goals would also raise energy costs for downstream users.[18] How many heavy industry jobs are President Xi and his successors willing to sacrifice on the altar of climate change mitigation?[19] China's history in this regard is not reassuring.[20]

Current macroeconomic trends present daunting challenges as China pushes forward with its ambitious renewable energy development plans. China's economic growth has slowed substantially in recent years. Electricity consumption has stagnated as China's heavy industrial sector has slowed far more than the overall economy. In 2015 China's economy grew 6.9 percent, according to official statistics,[21] but its electricity consumption increased just 0.5 percent. The tepid increase in energy demand coupled with a business-as-usual increase in supply have led to a sharp reduction in utilization rates across all energy sources. Unexpectedly low prices of fossil energy could make the green energy targets more expensive to attain at a time of weak industrial demand and economic uncertainty, particularly in the absence of a sufficiently high carbon price. If capacity building continues, a gap between capacity and utilization can be expected to be a hallmark of China's massive wind power industry for years to come.

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14. Ma Tianjie, "China Outdid Itself Again in Setting 2020 Low-Carbon Targets," chinadialogue, January 5, 2017, www.chinadialogue.net/blog/9113-All-eyes-on-China-s-13th-Five-Year-Plan-for-energy/en (accessed on January 6, 2017).

15. This share was 2.2 percent in 2011.

16. Anonymous, "去年我国" 弃光率"12.6% 管理层出台全额保障收购办法," China Net, June 2, 2016, http://finance.china.com.cn/industry/energy/xnyhb/20160602/3750193.shtml (accessed on January 5, 2017).

17. China has seven pilot emission trading systems, in Beijing, Tianjin, Shanghai, Chongqing, Shenzhen, Hubei, and Guangdong (Zhang et al. 2014). Each pilot was designed locally, with inputs from stakeholders, including provincial and municipal government officials; thought leaders in industry, think tanks, and universities; and others. Allowances and offsets are permitted only to trade on local emissions exchanges. Prices range from RMB23/ton ($3.39) in Hubei to RMB72/ton ($10.62) in Shenzhen (Ge 2014). Trading volume is typically low, primarily because of the overallocation of allowances.

18. Under current plans, firms from eight sectors (power, petrochemicals, chemicals, iron and steel, nonferrous metal, building production and materials, pulp and paper, and aviation) and 18 subsectors would be included in China's national emission trading system (Swartz 2016). The NDRC will set the total allowances, which will initially be allocated through a free allocation/auction system. Over time an auction-only system will be used, in which credits that are not used for compliance can be exchanged or traded. It is unclear how many allowances the NDRC intends to introduce or what the intended price of carbon will be. Conversations with people involved suggest that $12/ton is the intended price floor. This price is much lower than the conservative $20 cost of carbon mitigation estimated by the authors.

19. Many financial analysts who follow the Chinese economy expect it to grow more slowly than President Xi's ambitious growth targets presume. A shortfall in growth—especially one coupled with sharply rising unemployment in the heavy industrial sector—would create political problems for Xi's administration.

20. In the aftermath of the global financial crisis, the Chinese government looked the other way as grid companies ignored mandates requiring grid connection of the new wind farms and dispatch of green energy.

21. Magnier Mark, "China's Economic Growth in 2015 Is Slowest in 25 Years," *Wall Street Journal*, January 19, 2016, www.wsj.com/articles/china-economic-growth-slows-to-6-9-on-year-in-2015-1453169398 (accessed on January 23, 2016).

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