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The Political Economy of Wind Power in China

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The Political Economy of Wind Power in China: Challenges and hopes to transform China's electricity sector

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Senior Thesis

University of California, Berkeley

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Challenges and hopes to transform China's electricity sector

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Interdisciplinary Studies Field Senior Thesis

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List of Acronyms

EIA	United States Energy Information Administration
FIT	Feed-in Tariff
GW	Gigawatt, 10^9 watts
IEA	International Energy Agency
kWh	Kilowatt Hour
MW	Megawatt, 10^6 watts
NDRC	National Development and Reform Commission
RE Law	Renewable Energy Law
RMB	*Renminbi*, China's currency
RPS	Renewable Portfolio Standard
SERC	State Electricity Regulatory Commission
SGCC	State Grid Corporation of China
SOE	State-owned Enterprise
VAT	Value-added Tax
WTO	World Trade Organization

Abstract

This thesis has two main lines of research that investigate the recent explosive growth in China's wind sector: 1) an analysis of China's key wind power policies; 2) an examination of technical and political challenges facing wind power development in China. Section two discusses why the Chinese central government has sought to promote wind power. Section three analyzes the policy design of China's Wind Concessions Program, renewable portfolio standard (RPS), and wind power feed-in tariff (FIT). Sections four, five, and six examine technical and political challenges to wind power and find that transmission constraints, a lack of flexible generation sources (such as natural gas), ambiguous wind curtailment regulation, and limited rare earth metal reserves—all pose challenges to the development of wind power. I conclude that the recent growth of China's wind sector has had a negligible impact on mitigating China's contribution to anthropogenic climate change and that the aforementioned technical and political challenges will severely constrain the development of Chinese wind power over the next decade.

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Without the many people that have provided me with guidance and support throughout the past year, this thesis would not have come into existence. My thesis advisor Rakesh Bhandari expressed relentless enthusiasm in my ideas, asked valuable questions about my assumptions, and helped keep my work logically rigorous. Fredrich Kahrl, a PhD student in the Energy and Resources Group at UC Berkeley, generously met with me in person and maintained extensive email correspondence as we ironed out certain details of my analysis. His advice and critical assessments of my research approach added much needed dimensions of complexity and layers of depth to this thesis. Joanna Lewis, a Georgetown professor and expert on China's wind sector, directed me toward important data and helped me access the original texts of China's wind power policies. Finally, I offer deep thanks to members of my family and members of my student housing cooperative Lothlorien for proofreading my work and for keeping me inspired about life.

1. *Introduction:*

Over the past half decade, China's wind power sector has boomed. In 2009, China surpassed Denmark, Germany, Spain, and the United States to become the world's largest manufacturer of wind turbines.[1] In 2010, half of the world's installed wind turbines were erected in China, as China added 18.9 gigawatts (GW) of new wind farms and overtook the US to lead the world with the most installed wind power capacity.[2] Some scholars contend that "wind is and will likely continue to be the principal non-hydro renewable resource in China," as Chinese wind resources are abundant and wind power is cheaper than solar or biomass.[3] As the top emitter of greenhouse gases worldwide, China appears to be seizing the development of wind power as a pivotal step to transition away from fossil fuels and forge a low-carbon electricity system.

In this paper, I aim to add depth and complexity to the discussions on the implications of China's recent status as a global leader in wind power. Indeed, journalists and even scholars seem decisively divided over whether China will irreparably damage the planet or lead a green energy revolution. To paint a clearer picture of the development and potential trajectory of China's wind sector, I will first examine how central government policies have sparked the mass production and installation of wind turbines in China. With the intentions of 1) uncovering how China built its wind sector and 2) offering lessons for other countries, I will examine the design of several policy mechanisms that many observers claim have enabled the explosive growth of Chinese wind power. Following this policy analysis, I contextualize China's wind power growth statistics and analyze the role of wind and its potential future in the generation mix of China's

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[1] Keith Bradsher, "China is leading the race to make clean energy," *The New York Times*, 30 January 2010.
[2] "China adds 18.9 GW of new wind power capacity in 2010," Global Wind Energy Council, 6 April 11, http://www.gwec.net/.
[3] F. Kahrl et al., "Challenges to China's transition to a low carbon electricity system," *Energy Policy* 39 (2011): 4035.

electricity system. In so doing, I offer a qualitative evaluation and prediction—as opposed to a definite forecast—for scholars and policymakers who wish to understand the implications of China's rapidly growing wind sector and rapidly growing electricity demand. By extension, this analysis will also help shed light on China's evolving role in anthropogenic climate change.

Five sections make up the analysis portion of this paper. In section two, I briefly discuss the motivations behind the Chinese central government policies that promote wind power. Section three is an analysis of several government policies, with special emphasis on China's 2009 feed-in tariff for wind power, which have promoted and enabled the ferocious growth of China's wind sector. Section four focuses on transmission and regulation challenges facing China's wind sector. Perhaps most important, in section five I explore controversies over the implications of China's wind energy statistics—as some observers believe, myself included, that the growth figures are misleading and ignore much needed disclaimers. Finally, section six briefly discusses China's near monopoly over the production of rare earth metals and the role of natural resource limitations in wind turbine manufacturing. It should also be noted that I only address onshore wind power in this paper, not offshore wind power—a very small yet growing piece of China's wind sector.

In order to better demonstrate the relevance and timeliness of this paper, it is first necessary to provide some context for China's electricity system and the significant impact that China and its forecasted economic growth portend for climate change. According to estimates by the International Energy Agency (IEA), China's electricity sector in 2007 accounted for 50% of China's energy-related CO_2 emissions, and over the 2009-2020 period the electricity sector will be responsible for 62 percent of the growth in China's energy-related CO_2 emissions.[4]

[4] International Energy Agency (IEA), *World Energy Outlook 2009* (Paris: OECD/IEA, 2009).

According to forecasts by the US Energy Information Administration (EIA), by 2035 China will account for "nearly three-quarters of the world increase in coal-fired [electricity] generation."[5] Given the share of CO_2 emissions for which China's electricity system is responsible, China's certain status as the top emitter worldwide of CO_2, and the anticipated construction of new coal-fired power plants, an examination of China's efforts to integrate wind power into its electricity generation mix and to diversify away from fossil fuels is pertinent for any predictions about the future state of the planet.

Finally, I will briefly discuss the data and sources used in my research. It is important to note that an overwhelming majority of the scholarly articles referenced in this paper comes from English language journals. I found very few comprehensive Chinese scholarly journal articles covering Chinese wind policy and discovered that many Chinese scholars writing on wind power choose to publish their works in English. However, I have incorporated Chinese language sources in the form of newspaper articles, notices from various Chinese ministries, and the original text of the wind policies. In general, English sources have provided theoretical frameworks and context, while Chinese sources have served as the raw data for my analysis. Where possible, I have tried to cite the most up-to-date statistics, which at times means relying on reports from journalists as many official Chinese statistics for 2010 have not been published at the time of this writing.

2. The political impetus for wind power

Before analyzing specific wind power policies, it is helpful to first discuss why the Chinese government aims to promote wind power. In order to understand why China's policymakers would want to spend the political and financial capital necessary to develop wind

[5] "International Energy Outlook 2011," US Energy Information Administration, September 2011.

power, one must first understand coal, the backbone of China's energy economy. Coal, which powers nearly 80 percent of China's electricity sector, has historically been abundant and cheap, enabling China's phenomenal economic growth over the last three decades. However, China's once abundant coal reserves are now waning. At the end of 2007, the ratio of total coal reserves to annual production was 45 to 1 and by the end of 2010 that ratio dropped to 35 to 1—meaning that at 2010 rates of extraction China's coal reserves would run out in 35 years.[6] As China's energy demand surges to new heights, China's reliance on coal will continue to diminish this ratio and further reduce the remaining lifespan of coal, thereby threatening the stability of China's electricity supply.

Apart from diminishing reserves, coal presents a host of other challenges to China's electricity sector. In her 2005 dissertation on Chinese wind power development, Joanna Lewis, a China wind energy expert, notes that the domestic pollution from coal-fired power plants has prompted Chinese policymakers to consider shifting away from a fossil fuel-based economy. Coal-fired power plants (and heavy industry factories) release nitric oxide and sulfur dioxide, causing acid rain and other forms of air pollution which have led to many premature human deaths and destroyed agricultural lands.[7] According to some estimates, acid rain has inflicted damage on more than one-third of China's land cover and has cost the Chinese economy 2 percent of its annual GDP.[8] Thus, from the perspective of sustaining high rates of economic

[6] For the 2007 and 2010 statistics please see: BP Statistical Review of World Energy, 2008 and 2011. It is also important to note that I have discovered two sources which claim the 2007 ratio is 118 years, but this is in fact incorrect, as 118 years was the ratio for India, not China, in that year. The error appeared in Ma, Hengyun, Les Oxley, and John Gibson, "China's energy situation in the new millennium," *Renewable and Sustainable Energy Reviews* 13 (2009): 1781-1799, and was later cited in an unpublished UC Berkeley thesis.
[7] Joanna Lewis, "From technology transfer to local manufacturing : China's emergence in the global wind power industry," Ph. D. Dissertation, University of California Berkeley, 2005, 42.
[8] Judith A. Cherni and Joanna Kentish, "Renewable energy policy and electricity market reforms in China," *Energy Policy* 35 (2007): 3617.

growth, Chinese policymakers have begun to view China's reliance on dirty coal-fired power plants as a weakness.

In terms of health and safety, coal-generated pollution has caused sharp increases in respiratory illnesses and frequent coal mining accidents led to the deaths of nearly 6000 Chinese coal miners in 2005 alone.[9] Transportation difficulties have also been a challenge for coal. Most of China's coal reserves lie in mountainous regions far from industrial centers and China's highly populated eastern seaboard; consequently, the transport of coal to urban areas has saturated China's railway and highway systems. Although China's railway system is expanding, it has lagged the growth of coal production, leading to shortages of supply and rising coal prices across the country.[10]

From a long-term perspective, however, by far the largest concern over China's coal use has been climate change. By the end of 2010, China accounted for one quarter of global CO_2 emissions,[11] and China's electricity sector has been identified as the single largest source of CO_2 emissions in the world.[12] Domestically, China faces a multitude of potential disasters related to climate change. Qiang Wang, an energy scholar from the Chinese Academy of Sciences, offers a succinct explanation of the climate change dangers threatening China:

> . . . China will be one of the worst impacted regions in the world if climate changes as predicted. For example, global warming could make China's agricultural output reduced by 5–10% by 2030, thus adding stress to a country that has 20% of the world's population and only 7% of the arable land. In addition, three main industrial centers of China are on lowland areas: the Gulf of Bohai region with the Beijing-Tianjin axis, the Yangtze River delta radiating inland from Shanghai, and the Pearl River delta

[9] Yun Zhou, "Why is China going nuclear," *Energy Policy* 38 (2010): 3758.
[10] Yun Zhou, "Why is China going nuclear," 3757.
[11] Nina Chestney, "China's CO_2 Emissions rose 10 percent in 2010: BP Data," *Reuters,* 8 June 2011.
[12] F. Kahrl et al., 4032.

encompassing Hong Kong and Guangzhou. A sea level rise of a meter would inundate 92,000 km^2 [equivalent to the size of Hungary] of land in these three regions.[13]

As climate change threatens to flood the homes of hundreds of millions in the coastal regions and stress China's already overstretched food production, Chinese policymakers have also faced mounting pressures from other nations concerned with the consequences of climate change. While it is unclear to what extent international pressures on Chinese policymakers to reduce CO_2 emissions have been successful, it is clear that leading up to the 2009 Copenhagen Summit the Chinese central government became increasingly concerned with China's contribution to climate change. Elizabeth Economy, a China environmental expert at the Council on Foreign Relations, explains that leading up to the Copenhagen Summit policymakers began to share the belief that "a lower carbon economy will be good for economic modernization, that there is money to be made through the development and sale of climate-related technologies, and that domestic energy security depends in part on expanding the role of renewable energy resources at home."[14]

These beliefs—that low carbon development will strengthen China's economy and energy security—have been rhetorically affirmed by China's highest ranking government officials. In recent years, Hu Jintao, the General Secretary of the Chinese Communist Party, has advocated for China to lead human development into the next phase of 'ecological civilization'—as opposed to the 'industrial civilization' promoted by Western nations. In Hu's words, ecological civilization is "sustainable development that will promote harmony between humans and nature, realize economic development in coordination with population, resources,

[13] Qiang Wang, "Effective Policies for Renewable Energy-the example of China's wind power-lessons for China's photovoltaic power," *Renewable and Sustainable Energy Reviews* 14 (2010): 703.
[14] Elizabeth C. Economy, *The River Runs Black: The environmental challenge to China's future* [Ithaca, NY: Cornell University Press, 2010], 191-2.

and the environment . . . to persevere along a path of productivity, abundant life, and healthy ecology."[15] More importantly, the Chinese central government has begun to concretize these values of ecological civilization by enacting GDP energy intensity reduction targets and clean energy goals during China's 11th and 12th 5-year plans (2006-2010 and 2011-2015, respectively).

In December 2009, the Chinese central government announced that by 2020 China would reduce its energy intensity of GDP by 40-45 percent, relative to 2005 intensity levels. Also in 2009, the central government revised an earlier renewable energy target,[16] mandating that China supply 15 percent of final energy demand from 'non-fossil-fuel sources' by 2020.[17] The distinction between 'non-fossil-fuel sources' and 'renewable sources' is significant, as nuclear energy can now ease the burden of renewable energy sources having to fulfill the 15 percent target.

Nuclear power plants currently generate 2 percent of China's electricity,[18] but the National Development and Reform Commission (NDRC), China's chief economic planning agency, estimates that China will expand its nuclear capacity from 10.8 GW to between 70 and 80 GW by 2020.[19] In early 2011, however, observers had reason to believe that the disastrous meltdown of the Fukushima nuclear power plant in Japan could shift Chinese political support away from nuclear and further bolster the already growing wind sector. On March 16th 2011, the Chinese State Council halted the construction of 27 new nuclear plants, declaring that safety approvals for all new plants would be indefinitely withheld until new safety rules were

[15]Yu Keping [俞可平], "Scientific Development and Ecological Civilization" [科学发展观与生态文明], *Marxism and Reality Bimonthly* [*马克思主义与现实* (双月刊)], *no.* 4 (2005): 4-5. (My translation.)
[16] The earlier target, enacted in 2006, stipulated that China meet 15 percent of its primary energy consumption with renewable sources by 2020.
[17] Eric Martinot and Li Junfeng, "Renewable Energy Policy Update for China," *Renewable Energy World* 13, *no.* 4 (Jul/Aug 2010): 53.
[18] International Energy Agency (IEA), *World Energy Outlook 2010* (Paris: OECD/IEA, 2010).
[19] Y. Zhou et al., "Is China ready for its nuclear expansion?" *Energy Policy* 39 (2011): 777.

implemented.[20] One day after China suspended its nuclear program, the European Union Climate Change Commissioner, Connie Hedgegaard, released an analysis to the press declaring offshore wind power to be cheaper than nuclear power.[21] In the wake of the Fukushima meltdown, *The Guardian* also published an article titled "Japan nuclear crisis prompts surging investor confidence in renewables," revealing the high aspirations of several green energy investment groups.[22] Given the halted construction of China's nuclear power plants and the worldwide excitement for renewable energy, it would seem that the Fukushima meltdown would have a positive impact on the growth of China's wind sector.

However, without conducting interviews with wind energy investors and Chinese state-owned enterprises (SOEs), it will be difficult to assess how the Fukushima meltdown has affected investment in China's wind sector. It appears that the suspension of nuclear power plant construction will be temporary, as the newly drafted safety assessments, according to one China nuclear energy expert, "have had no detrimental effect on any of the projects under construction."[23] Therefore, it is reasonable to assume that the Chinese central government will also rely on the expansion of nuclear power to decouple China's energy economy from fossil fuels. Furthermore, with strong public opposition to China's large-scale hydroelectric projects,[24] wind and nuclear seem to be the two most viable of all non-fossil-fuel energy sources to help China meet its clean energy targets. According to Xu Yichong, the author of *The Politics of Nuclear Energy in China*, nuclear power is an option for base-load generation (i.e. a constant

[20] "China halts new nuclear build as Japan crisis worsens," Business Green News, 16 March 2011, http://www.businessgreen.com/bg/news/2034460/china-halts-nuclear-build-asjapan-crisis-worsens.
[21] Fiona Harvey and Terry Macalister, "Wind power cheaper than nuclear, says EU climate chief," *The Guardian*, 17 March 2011.
[22] John Vidal and Fiona Harvey, "Japan nuclear crisis prompts surging investor confidence in renewables," *The Guardian*, 5 March 2011.
[23] Yun Zhou, "China's pause for thought," *World Nuclear News*, 16 September 2011, http://www.world-nuclear-news.org/RS_Chinas_pause_for_thought_1609113.html.
[24] Zhou, 3759.

power source that will not fluctuate with demand or other variables) and will therefore not compete with wind power. She claims the two power sources are complementary.[25] Given China's dependence on coal and its complementary nature with nuclear power, it only seems logical and practical that the Chinese central government would invest its political and financial resources to cultivate China's wind power potential. The details of key government support mechanisms for China's wind sector are the subject to which I now turn.

3. Wind power policy in China

Over the last two to three decades, the Chinese central government has passed a variety of laws to promote the growth of renewable energy technology and production, but only in the last decade have these laws made an impact large enough to gain international attention. In this section, I will outline the historical development of China's wind policies and then analyze what I believe have been the three most effective and influential policies on China's wind sector. These three policies include the Wind Concessions Program, the Renewable Portfolio Standard (RPS), and the feed-in tariff (FIT) for wind. In addition to describing how the policies work, I will also highlight problems of policy enforceability and effectiveness—issues that have been well documented in nearly every domain of Chinese environmental law.[26]

In 1994, the Ministry of Electric Power issued a pronouncement titled "Opinion on Wind Power Construction and Management," which marked China's first mandate to require provincial grid companies to connect wind farms to the grid. The policy also obligated grid companies to purchase all wind-generated electricity at a price "high enough to cover wages and material costs, as well as the repayment of principal, interest, and a 15% profit share for the

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[25] Xu Yichong, "The Politics of Nuclear Energy in China," (guest lecture, University of California Berkeley, 12 October 2011).
[26] Economy, 211-13.

producer."[27] In theory, the policy would make wind power a low risk and highly attractive industry for investors, but in practice the grid companies had more incentive not to abide by the mandate. In China, the price of electricity to end users is set by the central government, and for years the government-fixed price has not reflected the higher costs of wind-generated electricity (as contrasted with coal-fired power plants). Therefore, rather than lose profits by extending the grid to uptake expensive electricity, the grid companies often ignored the unenforced mandate and left the wind industry to shrivel up in its infancy. The government fixed price for electricity still affects the willingness of grid companies to construct more transmission lines because the low price simply makes extensions of the grid prohibitively expensive.[28]

Several observers believe that the Chinese wind industry did not really begin to take off until 2003, the year that the NDRC passed and implemented the Wind Concessions Program. Eric Martinot, an internationally recognized scholar of renewable energy, claims this policy "marked a turning point in wind industry and technology development in China,"[29] while Lewis asserts that the concessions were "a key driver of wind development between 2003 and 2007."[30] Given the lack of effective incentives to build wind farms prior to the Concessions Program, and the growth from 0.5 GW to 5.9 GW of wind power capacity during the policy's implementation, Lewis and Martinot's assessments seem very credible.

The Concession Program allowed wind companies to bid for wind farm development rights to the richest wind resource sites in China. Additionally, the NDRC lured investors into

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[27] Liu and Kokko, 5523.
[28] Cherni and Kentish, 3622.
[29] Eric Martinot, "Renewable power for China: Past, present, and future," *Frontiers of Energy and Power Engineering in China* 4, *no.* 3 (2010): 288.
[30] Lewis, 284.

the bidding process by promising to construct access roads and transmission lines and by granting preferential tax and loan conditions. Han et al. describe the bidding:

> Wind energy developers – usually power companies combined with a wind turbine manufacturer – are invited to bid for the development of a location. The one who offers the best price per kWh [kilowatt hour] on the terms provided will win the concession and thus the right to produce electricity on the site.[31]

Once a wind energy developer and the government negotiate a price, in what is known as a Power Purchasing Agreement, the price applies for the first 30,000 hours of the wind farm's operation;[32] however, the scholars referenced here disagree on how Chinese law deals with pricing after the initial 30,000 hours. Furthermore, to complement the Concessions Program, the NDRC passed a 70 percent 'localization' requirement (国产化率) in 2005. The localization requirement stipulated that for 50 megawatt (MW) and larger wind farms "at least 70% of wind turbine equipment must be produced domestically, and the construction of wind farms that do not meet the localization requirement will not be permitted."[33] According to one source, the localization requirement does more than simply foster local production and jobs; in fact, local manufacturing eliminates the need to import foreign equipment, thereby enabling the large-scale development of wind power.[34] Interestingly enough, following the passage of the localization requirement, the number of newly-built 49.5 to 49.9 MW wind farms surged, as those smaller wind farms are only subject to approval by provincial authorities. Sub-50 MW wind farms have come to constitute 93 percent of all Chinese wind farms; consequently, China's National Energy Bureau is taking steps to repeal the authority of provinces to approve wind

[31] Han et al., 2945.
[32] Liu and Kokko, 5523.
[33] NDRC, "Notice on Requirements Related to Wind Power Construction Management" [关于风电建设管理有关要求的通知], May 2005, no. 1204. http://www.ndrc.gov.cn/nyjt/nyzywx/t20050810_41378.htm. (My translation.)
[34] Cherni and Kentish, 3620.

farms, thereby nationalizing standards for all sizes of wind farms.[35] The broader jurisdictional conflict between the central and provincial governments is a topic which will be addressed later in this paper.

Although the Wind Concession model prompted the development of China's richest wind sites, the policy's implementation also had two notable shortcomings. First, sometimes developers bid so low that once they won they were unable to finance the construction and maintenance of the wind farm. Second, private companies, including very competent foreign companies, rarely bid for projects because Chinese SOEs dominated the concessions with their excessively low bids. To address the problem of low bids, the NDRC changed its method for calculating contract prices from the lowest bid to the average bidding price in 2007.[36] However, the Concessions Program formally ended in 2007, and by that time other policies and renewable energy goals were well underway. In total, the Concessions Program added 3.4 GW of installed wind capacity, a significant increase when compared to China's installed wind capacity prior to the policy, which stood at 0.47 GW in 2002.[37]

While the Concessions Program marked an important turning point for China's wind sector, most analysts agree that the framework set forth by the 2006 Renewable Energy (RE) Law,[38] was the true watershed moment for the development of wind power in China. According to scholars Cherni and Kentish,[39] the 2006 RE Law provides the basis for implementing a Renewable

[35] Wu Qi, "China to limit onshore development with new law," Wind Power Monthly, last accessed October 8, 2011, http://www.windpowermonthly.com/News/MostRead/1081366/China-limit-onshore-development-new-law/.
[36] Liu and Kokko, 5524.
[37] Martinot and Li, 52.
[38] Some analysts refer to the 2006 RE Law as the "2005 RE Law" because of its adoption by the National People's Congress on 28 February 2005. However, because the law did not take effect until 1 January 2006, I find it more appropriate for policy chronology to call the policy by the year of its implementation.
[39] Cherni and Kentish analyze an unofficial English translation of the RE Law, which suggests that a more thorough and definitive analysis could be conducted by looking at the original Chinese text. The translation they use can be found at: http://www.renewableenergyworld.com/assets/download/China_RE_Law_05.doc. It should also be noted

Portfolio Standard (RPS)[40] and the framework for a FIT system. From my research, however, it appears that these policies were not fully codified, nor did they have any impact, until later amendments were added to the law. Indeed, one analyst describes the RE Law as an "umbrella legislation" where the details of implementation have been carried out by subsequent ministerial regulations and measures.[41]

In essence, the RE Law establishes a framework of responsibility—in Martinot's words, it "requir[es] the national government to formulate development targets, strategic plans, and financial-guarantee measures for renewable energy."[42] Indeed, since the law's inception, over a dozen subsequent measures have been announced to flesh out the framework. Before analyzing the later addendums, I will first briefly highlight the sections of the 2006 RE Law that are most relevant to wind power. These highlights are from my own review of the NDRC's online Chinese text of the 2006 RE Law.[43]

Article 14 clearly articulates, and reasserts, that grid companies must engage with grid-connection agreements with, and extend transmission lines to, approved renewable power companies (e.g. wind farms). Unlike the 1994 "Opinion on Wind Power Construction and Management," this mandate includes a compliance mechanism, stating that national electricity regulatory institutions shall force grid companies which fail to comply with article 14 to compensate for pecuniary losses of the renewable power companies. If grid companies fail to

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that Cherni and Kentish mistakenly attribute China's Wind Farm Concession Program to the 2006 RE Law; in fact, the NDRC established the Wind Farm Concession Program as a separate piece of legislation in 2003.

[40] An RPS obligates electricity suppliers to source a proportion of their power from renewable energy generation; RPSs usually allow suppliers to trade renewable energy certificates amongst themselves in order to meet the mandated targets. RPS can also be referred to as Mandatory Market Share (MMS).

[41] Jinlong Ma, "On-grid electricity tariffs in China: Development, reform, and prospects," *Energy Policy* 39 (2011): 2637.

[42] Martinot, 53.

[43] NDRC, *The People's Republic of China Renewable Energy Policy* [中国人民共和国可再生能源法], February 2005, http://www.chinalaw.gov.cn/article/xwzx/fzxw/200912/20091200176803.shtml.

compensate the renewable power companies, the state electricity regulatory institutions shall impose a fine (article 29). Moreover, article 14 obligates various ministries[44] to draft renewable power goals, defined in terms of the percentage share that renewable power shall hold out of total power generation. In these respects, the RE Law considerably strengthens the obligation that grid companies must integrate power from renewable sources, and it provides the basis for an RPS.

As for ensuring the profitability of wind power, Article 19 states that: in order to promote the development of renewable energy, the State Council shall set and publically announce the on-grid electricity prices for renewable sources with timely adjustments based on the conditions of technological development of each renewable energy source. Elaborating further, article 20 declares that the State Council shall set the grid price for renewable energy and any difference in the cost of renewable energy *vis-à-vis* conventional energy will be shared in a nationwide increase of the end-use price of electricity. In this manner, both articles 19 and 20 design a cost sharing mechanism that guarantees the profitable sale of renewable power, and they have provided the foundation upon which the NDRC implemented the revised and elaborated FIT for wind power in 2009.

Although the 2006 RE Law theoretically designed a FIT for wind power, the absence of discussion on the 2006 FIT suggests that the revised 2009 FIT for wind power was when the policy actually made an impact. In August 2009, the NDRC passed a revised FIT for wind which aimed to ensure the profitable uptake of wind power to the grid.[45] The FIT has divided China's territory into four pricing brackets based on wind resource intensity, ranging from 0.51

[44] These ministries include any ministries that manage energy, state electricity regulatory institutions, and the Ministry of Finance.
[45] Liu and Kokko, 5524.

RMB/kWh in resource rich regions to 0.61 RMB/kWh in regions with the least wind resources. This segmented pricing system obligates grid operators to buy wind power in low wind resource regions at a higher price, thereby adjusting for the less profitable opportunities for wind power production in those regions.[46]

An analysis of China's FIT for wind is important for several reasons. First, in the year following the FIT's passage, China made its largest absolute expansion of wind power capacity. Second, while it is difficult to determine if this large expansion was a direct result of the FIT, there is supporting evidence from Denmark and Germany that generous FITs often result in the rapid growth of wind development, far surpassing the targets set by the authors of the policies.[47] Furthermore, I have found no published research placing China's FIT in an international context (i.e. comparing its structure to the FITs of other countries), nor have I found any English language research describing China's cost sharing mechanism—the necessary foundation for the implementation of a FIT. For these reasons, I will investigate in more detail how China's wind power FIT is structured.

At its core, the Chinese wind power FIT offers wind farm developers a guaranteed electricity price, which applies for 20 years of a given wind farm's operation.[48] However, in order to evenly spread the extra costs of purchasing wind power across the nationwide end use price for electricity, a cost sharing mechanism is also in place to share the extra cost amongst all grid companies so that no single company bears an uneven financial burden. To put it another way, because wind farms are not evenly distributed across all the districts of different grid

[46] Joanna Lewis, "Building a national wind turbine industry," 284.
[47] Volkmar Lauber, "REFIT and RPS: options for a harmonised Community framework," *Energy Policy* 32 (2004): 1409.
[48] "PR China," Global Wind Energy Council, last accessed 28 October 2011, http://www.gwec.net/index.php?id=125.

companies, certain grid companies will end up purchasing more wind power than others, and a cost sharing mechanism ensures that no minority of grid companies is penalized for buying wind power. Thus the cost sharing mechanism underlies and facilitates smooth operation of the FIT.

Internationally, different variations of cost sharing mechanisms have been adopted. Germany and Denmark currently employ a cost sharing mechanism whereby grid companies purchase wind power at the price fixed by the FIT and then at the end of the year all grid companies calculate and level the extra costs so that each grid company bears equal financial burden.[49] Spain, on the other hand, allows grid companies to pay the minimal market price for electricity and then the Spanish Ministry of Finance directly subsidizes renewable power generators to guarantee FIT payments. The UK and the US have adopted obligatory RPSs, which rely on a market system of tradable renewable energy credits and evenly distribute additional electricity costs onto end users.[50]

In China's case, the 2006 "Trial Measure on Management of Cost-Sharing for Renewable Energy Power Generation Prices and Expenses" states that any difference between the price set for renewable power and the on-grid price for coal-fired power plants with approved desulfurization technology shall be shared across power sales at the provincial and regional levels.[51] In order to facilitate this sharing of power sales, the NDRC implemented a system for trading "renewable power generation surcharge credits" [可再生能源电价附加配额证] whereby

[49] National Renewable Energy Laboratory (NREL), "A Policymaker's Guide to Feed-in Tariff Policy Design," Technical Report, July 2010, 97.

[50] Shi Jingli [时璟丽], and Wang Zhongying [王仲颖], "Analysis of Renewable Energy Cost-Sharing Methods" [可再生能源电力费用分摊方式分析], *Renewable Energy* 30 [可再生能源] *no. 6* (June 2008): 13-16.

[51] During 2006 this took place through power purchasing agreements in the Wind Concessions Program, as the national FIT had not yet been implemented. It should also be noted that the word "regional" is not a direct translation; the Trial Measure states "provincial and above" which I found potentially confusing. For the Trial Measure referenced here, please see: NDRC, "Trial Measure on Management of Cost-Sharing for Renewable Energy Power Generation Prices and Expenses" [可再生能源发电价格和费用分摊管理试行办法], January 2006, http://www.gov.cn/ztzl/2006-01/20/content_165910.htm.

grid companies that purchase renewable power at the "surcharge" price (that is, the extra cost above the price for desulfurized coal power) are eligible for credits that they can then sell to other grid companies who lack credits.[52] A special committee from the NDRC oversees the system for trading renewable power credits and verifies the quantities of purchased renewable power with renewable power generators.

From January through September of 2010, the NDRC and SERC reported the quantity and value of all renewable power credit transactions over the nine-month period.[53] As one would expect, grid companies from windier provinces with more wind farms sold credits to the grid companies from less windy provinces with fewer wind farms. For example, the Inner Mongolia Power Company, which operates in western Inner Mongolia and has access to some of China's strongest winds, sold nearly 1.3 billion RMB (roughly $200 million in 2010 US Dollars) in renewable power credits to power companies in less windy provinces, including Guangdong, Henan, and Hebei. In another instance, the Xinjiang Power Company, from China's westernmost province, sold nearly 480 million RMB in credits (roughly $70 million in 2010 US dollars) to power companies from Beijing, Hubei, Anhui, Yunnan, and Shaanxi. Over the nine-month period, 23 companies bought credits, while a minority of 10 power companies sold credits. In total, Chinese power companies traded just over 4.3 billion RMB (roughly $635 million in 2010 US dollars) in renewable power credits to meet their quotas.

Having examined the structure of China's cost sharing mechanism, I will now turn to China's FIT—the mechanism which determines and ensures the profitability of wind power. China's FIT is classified as a market-independent FIT because it is a *fixed-price model* that

[52] Shi Jingli and Wang Zhongying.
[53] NDRC, "Notice regarding January-September 2010 Renewable Power Price Subsidy and Quota Exchange Program" [关于 2010 年 1-9 月可再生能源电价补贴和配额交易方案的通知], 2011 no. 122, http://www.sdpc.gov.cn/zcfb/zcfbtz/2011tz/t20110215_394858.htm.

offers set prices for wind power regardless of the market price of electricity. More specifically, fixed-price models operate independently of other market variables, such as inflation and the price of fossil fuels. One negative consequence of the fixed-priced model, however, is that the policy will result in gradually declining revenues for wind developers, as "the purchase price offered to developers does not change in some way to track the changes in the broader economy, [so] the actual value of the revenues obtained will tend to decrease over time."[54] In effect, market-independent FITs will offer higher revenues in the early years, thereby encouraging the aggressive expansion of renewable power capacity; but in the later years, market-independent FITs will diminish the marginal rate of return. Indeed, China's rapid deployment of wind farms in 2010 and 2011 could be viewed as the early aggressive expansion encouraged by a market-independent FIT.

Since 2000, Germany has employed a basic fixed-price FIT, and although it doesn't adjust for inflation, its FIT for renewable power perhaps stands as the most famous and successful FIT policy in the world.[55] While some journalists have hinted that China's four tariff prices for wind was a novel idea, China was not the first country to differentiate electricity tariffs based on resource intensity. Germany, France, Cyprus, and Switzerland all already had a system of differentiated FIT payments based on resource intensity, which aimed to "reduce the risks of overcompensation at the windiest sites."[56] Therefore, China's FIT is best viewed as part of a global trend of renewable power policies, not an indigenous innovation.

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[54] Toby Couture and Yves Gagnon, "An analysis of feed-in tariff remuneration models: Implications for renewable energy investment," *Energy Policy* 38(2010): 957.

[55] To clarify, Germany initially adopted a market-dependent FIT in 1991, but later modified the policy to make it market-independent. The fixed-price FIT adopted in 2000 is the policy considered responsible for the dramatic growth of Germany's renewable power capacity. For further information, please see: "Feed-in Tariffs," Online entry in Parliamentary Library, Parliament of Australia, last accessed 15 October 2011, http://www.aph.gov.au/library/pubs/climatechange/governance/domestic/national/feed.htm.

[56] Couture and Gagnon, 957.

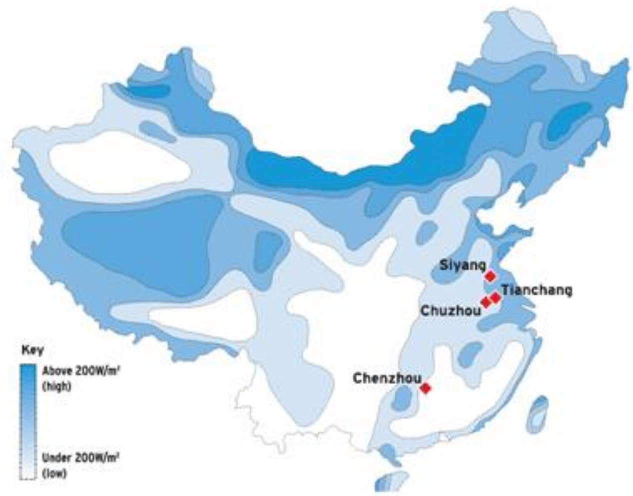

Figure 1: China's Wind Resource Density (W/m^2)
Source: Chinese Wind Energy Information Center

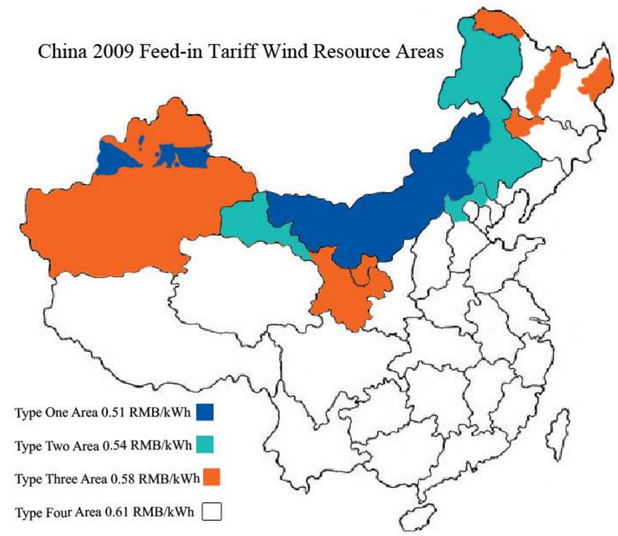

Figure 2: China's FIT Wind Resource Areas
Source: Created by author based on the NDRC's "Notice on Policy to Improve Grid-Connected Power Pricing for Wind Power"

Of China's resource intensity areas, the first three types principally cover areas in the northwest, north, and northeast. The tariffs set for Type One, Type Two, and Type Three areas are 0.51, 0.54, and 0.58 RMB ($0.079, $0.084, and $0.091 USD) per kWh, respectively.[57] These areas hold China's densest wind resources and are the sites of most of China's wind farms. Type Four areas cover all regions not included in the first three types and account for the vast majority of China's inland surface area (marked in white in Figure 2). Because Type Four areas have a generous tariff of 0.61 RMB ($0.095 USD) per kWh and include some regions relatively rich in wind resources, several Chinese wind developers have signed deals with municipal governments to construct wind farms, ranging from 150 MW to 600 MW in capacity, alongside cities in Type Four areas. Because these wind projects are close to urban areas, investors are assured high electricity demand and grid companies need not worry about constructing transcontinental

[57] NDRC, "Notice on Policy to Improve Grid-Connected Power Pricing for Wind Power" [关于完善风力发电上网电价政策的通知], 20 July 2009, http://www.sdpc.gov.cn/zcfb/zcfbtz/2009tz/t20090727_292827.htm.

transmission lines. Shi Pengfei, the vice president of the China Wind Energy Association, believes that "with quality inland wind resources fully occupied and offshore wind power resources grabbed in growingly fierce competitions, China's major electric power companies will naturally set their eyes on building wind farms in weak wind speed areas."[58] Thus, despite all the talk about strong winds in Inner Mongolia, China's FIT may provide high incentives to construct wind farms in areas with much weaker winds.

In order to better understand the incentives provided by market-independent FITs, it is first necessary to provide some context by describing market-dependent FITs. While there are three variations of market-dependent FITs currently employed around the world, for the sake of simplicity I will briefly describe the *premium price model*, as it is the most representative of the three variations. In essence, the premium price model offers renewable power generators a constant premium, or extra amount of money, above the market price of electricity. In so doing, renewable power generators are subject to market volatility, albeit with a constant buffer (i.e. the premium). If electricity prices soar, renewable power generators can experience windfall profits. But if electricity prices drop too low, renewable power generators can go bankrupt. From a policymaker's perspective, the premium price model has greater risk because FIT payments could either be too high or too low, having negative consequences for investor security.[59]

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[58] "Chinese firms seek profit in weak winds," Chinese Wind Energy Information Center, last modified 12 October 2010, http://www.cwei.org.cn/.
[59] Couture and Gagnon, 960.

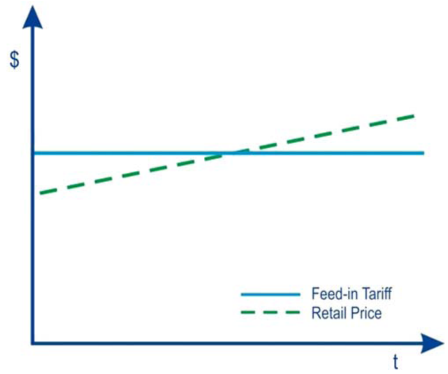

Figure 3: Fixed Price Model
Source: Couture and Gagnon, 957

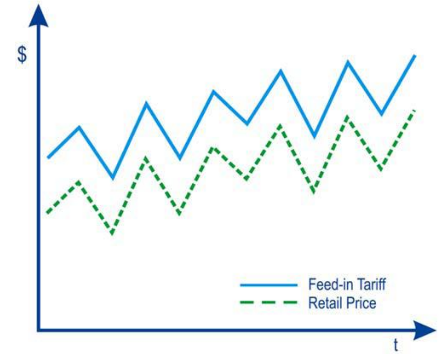

Figure 4: Premium Price Model
Source: Couture and Gagnon, 960

From Figure 3, one can see the long-term stability provided by the market-independent, fixed price model. However, if market electricity prices increase past the FIT payment level, renewable power generators will be unable to reap the extra profits. In Figure 4, market volatility is clearly a factor in determining the survival of renewable power generators in a market-dependent, premium price model. Despite the risks of the premium price model, it is currently employed (sometimes as an option) in the Czech Republic, Slovenia, Estonia, Denmark, and Spain.[60] In China's case, however, there is no free market for electricity, as all electricity prices from given power sources are set by the NDRC.

In Couture and Gagnon's analysis of various FIT designs, they find that market-independent models "tend to offer greater investor security by allowing more reliable and predictable revenue streams for developers." In other words, market-independent models have the ability to generate large amounts of investment. Market-dependent models, on the other hand, tend to be more compatible with deregulated electricity markets, and because remuneration varies with market demand, renewable power generators have an incentive to supply electricity when demand is highest (i.e. when they can make more money). In so doing, supply is

[60] Arne Klein et al., "Evaluation of different feed-in tariff design options—Best practice paper for the International Feed-in Cooperation," Energy Economics Group, 3rd edition (December 2010), 13.

encouraged when electricity is needed most, thereby creating a more efficient electricity market and improving market integration of renewable power sources.[61]

In fact, this analysis reflects a major tradeoff experienced by China's FIT: a market-independent FIT increases investment and accelerates the deployment of wind turbines, but it does so at the expense of efficiency. Here the word 'efficiency' can best be described as the operating efficiency, or capacity factor,[62] which is the ratio of actual energy produced to the hypothetical maximum energy that could be produced (i.e. running full time at full capacity). For example, a grid could be connected to ten wind farms (assume all are of equal size), but only be able to accept electricity from one of them because generation capacity far exceeds demand during certain times of the day and year. The aggregate capacity factor for the 10 wind farms would be 10 percent—a relatively low capacity factor for wind power.

Compared with wind farms from other countries, Chinese wind farms have relatively low capacity factors—again, meaning many wind farms produce little electricity. According to EIA and SERC statistics, in 2007, "1 MW of [wind] capacity produced 2,076 MWh of electricity in the US per year but only 955 MWh in China." One reason for China's low operating efficiency is that transmission lines have not been extended to many wind farms, an issue I will address in sections four and five. However, even when excluding those non-connected wind farms from the calculation, "the electricity produced by 1 MW capacity in China is about 1433 MWh, still significantly lower than the US."[63] Thus, China's rapid expansion of wind power

[61] For a comprehensive discussion on the advantages and disadvantages of market-dependent and –independent FITs, please see: Couture and Gagnon, 961-963.

[62] In a technical analysis, however, efficiency and capacity factor are two separate concepts. Efficiency generally refers to the efficiency by which wind turbine technology converts wind energy into electricity, taking into account factors such as blade design and magnet composition. But, for convenience in my analysis, I use the terms capacity factor and operation efficiency interchangeably.

[63] However, one must be cautious when using annual statistics to calculate capacity factors for wind farms in a country like China. Because China's wind power capacity is rapidly expanding, it would be inaccurate to use annual

capacity and its low operating efficiency *vis-à-vis* US wind farms appear to align perfectly with the incentives provided by its market-independent, fixed-price FIT.

What I have presented here, however, is a simplified and theoretical analysis of China's FIT incentives based on evidence from other countries. Admittedly, I have no evidence to suggest that the FIT is a primary driver of high investment in and low operating efficiency of Chinese wind farms, but the policy's design does appear to reinforce these trends. Naturally, other factors must be at play. These factors could include wind development subsidies and the refusal (and sometimes inability) of grid companies to purchase wind power, a practice known as wind curtailment. (I will examine more possible explanations for the low operation efficiency of Chinese wind farms in section five.) Moreover, as previously mentioned, China's National Energy Bureau recently announced that 93% of Chinese wind farms have been approved by local authorities, which puts in doubt the assumption that all Chinese wind farms are eligible for the central government's FIT. However, even though sub-50 MW wind projects are approved locally and may use another tariff, Lewis still believes that all local tariffs in China are heavily influenced by the national FIT.[64] Examining exactly how prices are set for these smaller wind farms, which make up the vast majority of all Chinese wind farms, would most likely require fieldwork and ought to be an area of future research.

Another key policy that aims to expand China's wind power capacity is the NDRC's RPS, which has mandated a market share for renewable power. The 2007 Mid- and Long-term Renewable Energy Implementation Plan provides the specific implementation clauses for the

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output to calculate a capacity factor for a wind farm that came online in the middle of the year. The wind farm would only operate for half the year while the calculation would assume that it operates for the full year, thereby leading to an artificially low capacity factor. For the US-China comparisons of operation efficiency cited here, please see: F. Wang et al., "China's renewable energy policy: Commitments and challenges," *Energy Policy* 38 (2010): 1875.

[64] Joanna Lewis, email message to author, 2 November 2011.

RPS framework outlined in the 2006 RE Law. The plan mandates that all large[65] grid companies must generate 1% of their total output from non-hydro renewable sources by 2010 and 3% by 2020. Furthermore, power producers with a generation portfolio of more than 5 GW must have non-hydro renewable power capacity compose 3% of their generation mix by 2010 and 8% by 2020.[66] Because of this mandate, and because the vast majority of Chinese manufactured solar panels are too expensive to install domestically, China's large power companies have turned to wind farms as a solution for meeting their renewable portfolio standards. According to Lewis, this mandate has been "one of the primary reasons these companies have been developing large wind projects over the last few years."[67] Again, I must emphasize that without conducting interviews, which Lewis does not cite, one can only speculate to what extent the RPS has been a 'primary reason' for power companies to develop large wind farms.

Many laws have contributed to the growth of wind power in China, but analyzing their effectiveness and determining which laws have been most fundamental in sparking wind power's explosive growth over the past half decade is a much harder task. In this analysis, I have primarily focused on three wind policies, while omitting many others. Examples of other Chinese wind policies include low-interest loan programs implemented in 1999, the 2002 value-added tax (VAT) reduction for wind turbines, and the 2008 Ministry of Finance subsidy for turbine manufacturers. (It should be noted that the Ministry of Finance repealed its turbine manufacture subsidy in 2011—the end result of a formal World Trade Organization (WTO) trade dispute in which US trade representatives argued that China was illegally subsidizing its wind

[65] For renewable share of total electrical output, the policy does not specify what the minimum capacity threshold is for a "large" grid company. The following sentence, however, defines the size of grid companies for the mandate on the renewable share of total power capacity.
[66] NDRC, "Mid- and Long-term Renewable Energy Implementation Plan" [可再生能源中长期发展规划], August 2007, http://www.china.com.cn/policy/txt/2007-09/04/content_8800358_5.htm.
[67] Lewis, 285.

technology sector.[68]) For the reasons already mentioned, I have focused on three of China's most recent policies and am unable to quantitatively determine to what extent each policy, or the combined framework of all policies, is responsible for the recent growth of China's wind sector.

Other scholars, however, have attempted to assess the extent of policy causation. Lewis points to the Wind Farm Concession Program, followed by the 2009 wind power FIT, as two critical policy catalysts for growth. Liu and Kokko contend that the RPS policies "have been more effective for promoting wind power than any of the incentives operating through the pricing system [e.g. FITs]."[69] Others emphasize complementary policies, such as local manufacturing content requirements and the VAT reduction, which I have omitted from my discussion. Regardless of the effectiveness of individual policies, perhaps a more important issue to discuss is the weak regulatory enforcement that has consistently challenged the Chinese central government's aim to foster foreign investment, adopt advanced technologies from foreign firms, and ensure that power companies extend transmission lines to wind farms. In addition to the challenges posed by a weak regulatory system, China also has an outdated electrical grid which has difficulty absorbing a rapidly expanding flow of wind power. Both of these issues—weak regulation and an outdated grid—represent the greatest pitfalls in China's wind policy and deserve discussion.

4. Weak regulation and an outdated grid:

Although multiple laws mandate that renewable energy be given priority access to the grid, the wind power policies currently in place offer no financial incentives for grid companies to construct the ultra-high voltage transmission lines necessary to deliver power from China's six

[68] "China to End Challenged Subsidies in Wind Power Case," International Centre for Trade and Sustainable Development, 13 June 2011, last accessed 28 October 2011, http://ictsd.org/i/news/biores/108435/.
[69] Liu and Kokko, 5529.

major wind farm bases in northwestern China to the industrial centers in southeastern China.[70] In a policy brief for the Center for American Progress, Wong et al. note that "[a]s many as one-third of China's wind farms are not connected to the transmission grid due to the lack of incentives for grid companies to build out transmission lines to interconnect with clean-energy projects in remote areas."[71] A report by Citigroup released similar findings, estimating that "about 30% of wind power capacity in 2008 was not connected to the electrical grid."[72] Lewis reports that by the end of 2009 only 65 percent of wind capacity was grid-connected due to delays in the extension of transmission lines.[73]

The NDRC has recognized this issue and noted in its 2011 Energy Outlook that only 31.07 GW of wind power were connected to the grid, meaning that the US still boasts more grid-connected wind power than China.[74] Shi Fengpei, the vice chairman of the Chinese Wind Energy Association, reminds us that the Chinese government only records statistics and sets national targets for wind power based on installed capacity, and he laments that there has been little emphasis on measuring real energy production from wind.[75] All of these findings illustrate how China's underdeveloped grid has contributed to the low operating efficiency of Chinese wind farms and highlight the point that statistics of installed wind power capacity do not

[70] Wang, 708.
[71] Julian L. Wong et al., "Out of the running: How Germany, Spain, and China are seizing the energy opportunity and why the United States risks getting left behind" (Report, Center for American Progress, Washington DC, March 2010), 26.
[72] Vivian Wai-yin Kwok, "Weaknesses in Chinese Wind Power," Forbes.com, 20 July 2009, http://www.forbes.com/2009/07/20/china-wind-power-business-energy-china.html.
[73] Joanna Lewis, "Building a national wind turbine industry: experiences from China, India and South Korea," *Int. J. Technology and Globalization* 5, *nos.* 3/4 (2011): 304.
[74] "2010 Energy Economy Situation and 2011 Outlook" [2010 年能源经济形势及 2011 年展望], National Energy Bureau, 28 January 2011, http://nyj.ndrc.gov.cn/ggtz/t20110128_393339.htm.
[75] Shi Fengpei, "Booming Wind Power Market and Industry in China," (Report, Chinese Wind Power Association, 2008), 8.

translate into real electricity generation. (It should be noted here that wind intermittency and curtailment, discussed in detail in section five, also limit electricity generation).

To compound the problem, Chinese grid operators have also complained about having to accommodate too much wind power. It is true that a bottleneck for the uptake of wind power emerges as the ratio of wind power to total power increases in a local grid. Because wind is 'intermittent' it can only supply a certain percentage of a grid's power generation if grid operators wish to reliably meet electricity demand and prevent brownouts. But, in the opinion of one analyst, Chinese grid operators have been unreasonably "sluggish" to accommodate the rapid development of wind energy, as they have proposed that wind should meet 8 to 10 percent of China's electricity demand.[76] By contrast, wind has met up to 43 percent of Spain's electricity demand,[77] and according to a renewable power analyst from Pacific Gas and Electric, one of the largest electric utility companies in California, wind can reach penetration levels of roughly 40 to 50 percent before compromising the stability of supply.[78]

The unresponsiveness of utility companies to connect wind farms to the grid reveals part of a larger and more daunting predicament for the Chinese wind power industry: Chinese laws are weak, and weak laws do not entice foreign companies. Cherni and Kentish contend that the chronic lack of foreign investment in China's wind sector stems from weak regulation, noting that "contractual agreements are notoriously difficult to enforce, and this fails to foster investor confidence, with the risk of default on power purchase contracts [being] one of the most important institutional barriers to investment in China's electricity sector."[79] In several instances,

[76] Wang, 709.
[77] Ibid., 709.
[78] Ian Quirk, personal communication with author, 22 October 2011.
[79] Cherni and Kentish, 3623.

local power bureaus have also unilaterally revised power purchasing agreements, leaving investors with zero equity return.

From the wind turbine industry perspective, some industry insiders fear overcapacity of outdated turbines, specifically in the 600-850 kW turbine segment (foreign competitors usually produce 2 to 3 MW turbines). Han et al. recommend that China revise its local content requirement which currently incentivizes domestic turbine manufacturers to import hardware rather than software (i.e. manufacturing knowledge and technology).[80] Liu and Kokko propose that China preempt its potential 600-850 kW turbine overcapacity problem by shifting production to larger and more sophisticated turbines, including those suitable for offshore wind farms. But foreign firms, such as Vestas, the largest wind turbine company in the world, have been reluctant to produce more sophisticated turbines in China for fear of technological theft from local competitors.[81] In 2011, the American Superconductor Corporation, a US-based clean energy firm, filed civil suits in Beijing against China's largest turbine manufacturer, Sinovel, claiming that Sinovel stole valuable software that controls wind turbine operation.[82] These two cases—the allegations against Sinovel and the reluctance of Vestas to produce more advanced turbines in China—highlight one of China's broader dilemmas: its weak regulatory system has historically hindered the efforts of the Chinese central government to promote technology transfer and to persuade developed nations to repeal their restrictions on high-technology exports.[83]

Besides China's need for strengthened regulation and oversight of grid operators, a handful of scholars also agree that China's electrical grid desperately needs upgrades if China

[80] Han et al., 2951.
[81] Liu and Kokko, 5528.
[82] Rebecca Smith, "Chinese Turbine Firm Tied to Software Theft," *Wall Street Journal*, 24 September 2011.
[83] Economy, 209-12.

wishes to wean itself off of coal.[84] As mentioned earlier, the construction of new transmission lines has lagged the construction of new wind farms, leaving roughly one third of wind farms unconnected to the grid at the end of 2008 and 2009.[85] This lack of grid connectivity has squeezed the profit margins of many wind farm operators, especially as the regions with the strongest winds and most wind farms tend to have the weakest grid infrastructure development.[86] Furthermore, even wind farms that are connected to the grid have had difficulty selling their power during peak winds because grid companies refuse to buy the power when the existing grid is too weak to handle intermittent surges of wind power.[87] In April of 2011, Inner Mongolia had 6.4 GW of power surplus (enough to meet Greece's nationwide electricity demand) because of its large thermal and wind generating capacity; the surplus, however, could not be exported to other provinces due to a lack of transmission capacity.[88]

To address this problem, Kevin Liu, a research associate at the China Environmental Forum, suggests that policymakers view China's grid problems as an opportunity for US-Chinese energy cooperation and recommends that China adopt foreign technology to build a smart grid,[89] which would help to stably uptake more wind power into the grid.[90] Regardless of the potential benefits from US-Chinese technology cooperation, however, China's plans and funds for developing a smart grid are already well underway. In fact, many industry insiders

[84] Han et al., Liu and Kokko, Cherni et al, and Lewis.
[85] Peter Fairley, "China's Grid-Limited Wind Energy Potential," Carbon-Nation, 15 September 2009, last accessed 4 November 2011, http://carbonnation.info/2009/09/15/chinas-grid-limited-wind-energy-potential/.
[86] Yvonne Chan, "Infrastructure woes hamper China wind farms' push for profitability," *Business Green*, 24 July 2009, last accessed 4 November 2011, http://www.businessgreen.com/.
[87] Coco Liu, "China Rebuilds Its Power Grid as Part of Its Clean Energy Push," *The New York Times*, 20 April 2011.
[88] "Some regions brim with power amid shortages," Chinese Wind Energy Information Center, 27 May 2011, http://www.cwei.org.cn/windpowerfor/News_Content.aspx?ID=4077.
[89] A smart grid uses two-way digital communications technology to coordinate electricity demand from consumers with supply. In so doing, smart grids can increase the maximum uptake of intermittent energy sources into an electric grid.
[90] Kevin Liu, "Wising up: Smart Grid as New Opening for U.S. China Energy Cooperation," (Research Brief, China Environmental Forum, August 2009).

have acknowledged that China now leads the world in continental-scale ultra-high voltage transmission lines, which only exist as blueprints in the US and Europe.[91]

As the world's largest transmission company, covering 88 percent of China and serving over 1 billion customers, the State Grid Corporation of China (SGCC) completed the planning phase in 2010 for the construction of a nationwide smart grid. The plan aims to invest a total of $601 billion USD in smart grid infrastructure and technology by 2020 with the following goals: "improve the efficiency of the existing electricity grid, expand the grid to provide electricity to rural areas, manage power demand to avoid outages and overloads, and connect power-generating facilities in the western part of the country to the heavily populated east coast."[92] Because of the SGCC's smart grid investments, China has emerged as the largest and most important smart grid market in the world and has fostered numerous collaborative projects with foreign technology companies.

Perhaps most relevant to the current development of wind power is the SGCC's West-East Electricity Transfer Project which proposes to build three major transmission lines, each with 20 GW of transmission capacity, by 2020.[93] The construction of ultra-high voltage transmission lines will undoubtedly provide a crucial foundation upon which China can integrate its rapidly expanding wind power capacity. Although many observers have viewed the lag between grid expansion and wind capacity expansion as a problem, one Chinese energy law specialist contends that "a race between generating capacity and grid capacity is the type of

[91] Peter Fairley, "China's Potent Wind Potential," Technology Review, Published by MIT, 14 September 2009, http://www.technologyreview.com/energy/23460/page1/.
[92] Daniel Jung, "11 Smart Grid trends to watch for in 2011," TMCnet Smart Grid, 19 January 2011, http://smart-grid.tmcnet.com/.
[93] "China: Rise of the Smart Grid," Special Report, Zpryme Research & Consulting, January 2011.

problem most nations should relish."[94] In my opinion, the race between wind power capacity and grid capacity is a positive sign for China's goal of decoupling its economy from fossil fuels. But it is also important to note that the current lack of ultra-high voltage transmission lines will most likely mean that wind power will not reduce the anticipated expansions of coal and nuclear power over the next decade. Therefore, because the transmission lines will take a decade to build, I believe it is unlikely that wind will significantly expand its share of overall electricity generation before 2020.

5. China's growth statistics for wind power—misleading?

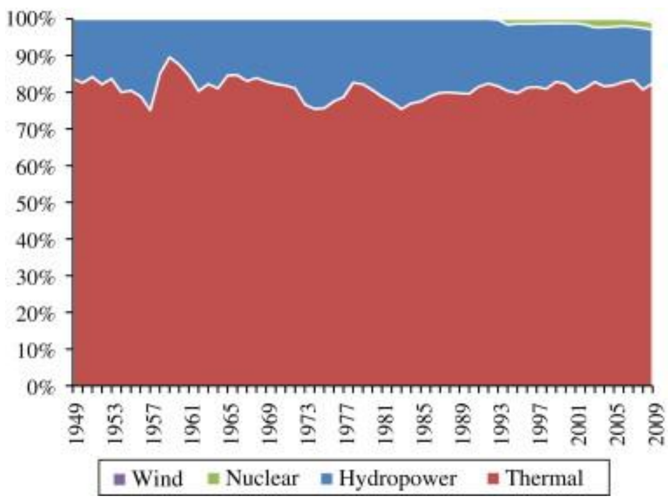

Figure 5: China's electricity generation mix. Source: Karhl et al., 2.

While China's energy statisticians have been known to report inaccuracies,[95] I have found no debate amongst journalists or industry analysts surrounding the 44.7 GW of installed wind power capacity that China boasted at the end of 2010 (equivalent to half of England's total power plant capacity).[96] This figure is indeed impressive: in one decade,

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[94] Louis Schwartz, "The Power Grid and Wind Industry in China: An Update," Renewable Energy World, 19 May 2011, http://www.renewableenergyworld.com/rea/news/article/2011/05/the-power-grid-and-the-wind-industry-in-china-an-update.

[95] Jonathan Sinton, "Accuracy and Reliability of China's Energy Statistics," *China Economic Review* 12, *no.* 4 (2001): 373.

[96] "China adds 18.9 GW of new wind power capacity in 2010"

China's wind capacity grew 149-fold from a mere 0.3 GW in 2000.[97] To understand the implications of 44.7 GW of wind power capacity, we must put this figure in the context of China's overall electricity generation capacity and add some cautionary caveats.

In 2010, China's total power generation capacity reached 900 GW.[98] Given this figure, one can calculate that in 2010 wind power only accounted for roughly 5 percent of China's overall electricity generation capacity.[99] Although China's recently released 12th 5-year plan proposes to construct an additional 70 GW of wind farms by 2015,[100] coal is still expected to dominate China's electricity generation mix. It is important to note that in 2009, coal-fired power plants generated 78 percent of China's electricity (see Figure 5). Hence, although China's wind sector has grown massively, it has only made a small dent in replacing fossil fuel sources of electricity.

When assessing the implications of China's wind growth statistics, it is important to keep in mind the relative size of wind power capacity in the context of China's projected future electricity demand. Based on five different electricity demand scenarios, analysts at China's State Grid Energy Research Institute forecast that between 2009 and 2020 China's electricity demand will grow by 70 to 130 percent.[101] The IEA projects that China's demand will triple between 2009 and 2035, noting that "[t]he capacity additions required to meet China's electricity needs over the period 2009-2035 are staggering: between 2009 and 2025 China will have added new capacity equivalent to the current installed capacity of the United States."[102] Given these

[97] Karhl et al., 4.
[98] "China's power generation capacity leaps above 900 mln kilowatts," *Xinhua News*, 20 September 2010.
[99] It is important to note that power generation capacity and energy consumption are two distinct measures.
[100] "How Does China's 12th 5-Year Plan Address Energy and the Environment," *ChinaFaqs* post, 7 March 2011, http://www.chinafaqs.org/blog-posts/how-does-chinas-12th-five-year-plan-address-energy-and-environment.
[101] Hu Zhaoguang [胡兆光] et al., *Outlook for China's Electricity Demand (2010)* [中国电力需求展望（2010）], (Beijing, China Electricity Publishing Co. [中国电力出版社], 2010).
[102] International Energy Agency, *World Energy Outlook 2010*, 232.

forecasts, if wind power is to replace fossil fuel sources of electricity in the future, it must not only compete with existing coal-fired generation, but also with the anticipated expansion of coal-fired generation that will be built to meet China's future electricity demand. Hence, rather than focus on the absolute numbers for wind power growth, it is more meaningful to analyze the relative share that wind power holds in China's electricity generation mix and its potential to meet China's forecasted demand.

With the often quoted line that "China is building two new coal-fired power plants each week," and wind power's current share of total electricity generation standing at less than 1 percent,[103] it is difficult to remain optimistic about the potential for wind power to meet a significant portion of China's forecasted electricity demand. If the expansion of coal generation continues to outpace the development of wind farms, as has been the trend through 2009, the share of coal-fired generation in total electricity generation will increase rather than decrease.[104] Statistics from 2010, however, suggest that this trend towards a higher proportion of coal-fired generation is slowing and may soon reverse, as the Chinese central government has been phasing out the smaller and less efficient (thereby more polluting) coal-fired power plants and the number of grid-connected wind farms continues to grow.[105] But one must still recognize that as of 2011, despite the phenomenal growth of wind farms, coal-fired generation has been by far the fastest growing source of electricity. Furthermore, instead of solely extrapolating from statistical trends to develop a sense of wind power's future in China, one must consider other technical and political challenges that wind developers face.

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[103] Joanna Lewis, interviewed by *Energy Now News*, uploaded on 23 January 2011, http://www.youtube.com/watch?v=KGINdMnMrsQ.
[104] F. Wang et al., 1875.
[105] Graham Lloyd and Stephen Matchett, "China still in thrall to King Coal," *The Australian*, 16 March 2011.

Another caveat concerns the quality of Chinese-produced wind turbines. Wong et al. point out that the efficiency of domestically manufactured turbines is inferior to those of leading foreign-made turbines.[106] Han et al. suggest that "not only the quantity but also the quality of localized [Chinese] turbines should become an important policy objective," raising the question of technology transfer from foreign firms to domestic firms.[107] Jim Watson, director of the Sussex Energy Group at the University of Sussex, says doubts remain about the ability of China's domestic wind manufacturers to produce offshore wind turbines with advanced enough software and control systems to withstand the strong sea winds and battering from ocean waves.[108] Han Junliang, president of China's largest turbine manufacturing company Sinovel, agrees with Watson and cautions that China may run the risk of overcapacity with outdated technology; he stresses that "[t]he Chinese wind power industry is in urgent need of advanced technology."[109] In the wake of the 2008 global economic downturn, overcapacity is an especially valid concern because the Chinese government has targeted wind power as a key growth area for its economic resilience plan. Also, nearly all of Chinese wind turbine manufacturers are SOEs that "could be operating with soft budget constraints – aiming to meet objectives other than profit maximization," making them even more prone to overproducing low quality wind turbines. Some observers warn that Chinese firms may take excess turbines (the cost of which has been driven down by the Ministry of Finance's turbine manufacture subsidy) and dump them on foreign markets, provoking international trade conflicts.[110]

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[106] Wong et al., 26.
[107] Jingyi Han et al., "Onshore wind power development in China: Challenges behind a successful story," *Energy Policy* 37 (2009): 2950.
[108] Jim Watson, "China's low-carbon leadership headlines fail to capture the reality," *The Guardian*, 18 April 2011.
[109] "China's wind power sector faces challenges," UPI.com, 22 February 2010, http://www.upi.com/.
[110] Yingqi Liu and Ari Kokko, "Wind Power in China: Policy and development challenges," *Energy Policy* 38 (2010): 5527-8.

Up through 2010, critics of China's wind turbine industry tended to focus on problems of inferior technology, overcapacity, and small size, but in 2011 critiques of the industry appear to have shifted somewhat. Chinese turbine manufacturers have been developing prototypes for 3 MW and 5 MW turbines and even have design plans for a 10 MW model, prompting new concerns within China that the manufacturers have become obsessed with size at the expense of quality and reliability. One Chinese engineer, who has worked in China's wind turbine industry since 1988, believes that the current research focus on expanding size ought to shift to increasing efficiency (as foreign turbines still tend to be more efficient) and developing viable technology for offshore wind farms.[111] Thus, although China has begun to develop larger wind turbines, building larger motors does not necessarily translate into building more efficient machines and the issue of inferior turbine efficiency will likely remain for some time.

Yet another cautionary disclaimer to China's rapidly expanding wind power capacity is the reality that, regardless of grid connectivity, strong winds do not power wind turbines all the time. Because of wind intermittency, one cannot assume that wind power's 5 percent share of China's total electricity generation capacity translates into a generation of 5 percent of China's electricity. Bjørn Lomborg, a highly controversial Danish environmentalist, stated earlier this year that the excitement over China's 'green leap forward' should be tempered with the fact that "[w]ind today generates just 0.05 percent of China's energy."[112] To reveal the true effects of wind intermittency, a 2011 study by the Scotland-based John Muir Trust found that in the UK "the average output from wind was 27.18% of metered capacity in 2009, [and] 21.14% in

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[111] Yang Xiaosheng [杨校生], interviewed by Han Wei [韩伟] for *Energy Review* [能源评论], 21 March 2011, http://hanwei809.blog.163.com/blog/static/34590890201122153534470/.

[112] It should be noted that this 0.05 percent figure is the share that wind-generated energy holds in all of China's energy production. All other references in this paper to the percentage share of wind energy refer to China's electricity generation, which is just a part of China's total energy production. Bjørn Lomborg, "Hold the accolades on China's 'green leap forward'," Op-Ed, *The Washington Post*, 20 April 2011.

2010."[113] And given the other findings from this paper, it is certain that China's wind farms have much lower capacity factors. Hence, because of intermittency, wind farms cannot provide the silver bullet that fully replaces coal-fired power plants in China, and the growth statistics for wind power should be understood in this context.

Furthermore, even when the wind is blowing, Chinese wind farm operators cannot necessarily sell all of their power to grid companies. Wind curtailment is the practice whereby grid companies order wind farms to reduce their electricity output in order to maintain a stable electricity supply. Wind farms are capable of rapidly reducing their output (unlike nuclear power plants) and generally do so by pitching the blades of the turbines out of the wind.[114] Grid companies throughout the US and around the world have different procedures for determining when to curtail wind power. Some procedures comprise contractual agreements to pay wind farms for the lost value of wind power, while others may mandate daily operating limits or are based upon thresholds for the percentage of balancing reserve power sources in operation.[115] In China, however, the politics of curtailment are much murkier. While SERC's "Measure on Supervision of Power-Grid Enterprise Purchases of Full Amount of Renewable Energy Electricity" is not an explicit curtailment policy, it effectively defines China's *de facto* curtailment policy in the following clause:

> With the exception of circumstances that are insurmountable or endanger the safety and stability of the electrical grid, [grid companies] shall not limit the electrical output from

[113] "Analysis of UK Wind Power Generation: November 2008 to December 2010," (Report, Stuart Young Consulting and John Muir Trust, March 2011) http://www.jmt.org/assets/pdf/wind-report.pdf.
[114] Michael Goggin, "NREL Releases Wind Curtailment Case Studies," *Renewable Energy World*, 20 November 2009, http://www.renewableenergyworld.com/.

[115] S. Fink et al., *Wind Energy Curtailment Case Studies: May 2008 – May 2009,* National Renewable Energy Laboratory, October 2009, 2.

> renewable sources. Circumstances that endanger the safety and stability of the electricity referred to in this Measure shall be determined by electricity regulatory institutions.[116]

In other words, grid companies can only curtail renewable power if the uptake of renewable power endangers grid stability and electricity regulatory institutions shall define what "endangers grid stability." One problem, though, is that SERC, China's national electricity regulatory institution, often does not have the authority to act as an effective regulator, as the key decision-making power for the electricity sector resides in the NDRC, China's chief economic planning commission. SOEs, including the State Grid Corporation of China (SGCC), are also more powerful than SERC, posing challenges to SERC's ability to enforce its own rules. Moreover, since the 1980s, provincial grid companies have controlled the day-to-day operations of electricity dispatch, which has led to frequent conflict between the central government and provincial governments, frustrating the implementation of national policies.[117]

Given the ambiguous regulatory framework and the vagueness of the phrase "endangers grid stability", it is not clear how the policy is enforced. There is a high likelihood that grid companies curtail wind power as they please. Moreover, according to a study of wind curtailment in North America and Europe, one of the two primary reasons for wind curtailment has been a "lack of available transmission during a particular time to incorporate some or all of the wind generation."[118] Because China currently faces severe transmission constraints, Chinese grid companies are likely to order wind farms to halt generation, as has happened repeatedly with the Western Inner Mongolia Power Grid which relies on only two small transmission lines, built

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[116] SERC, "Measure on Supervision of Power-Grid Enterprise Purchases of Full Amount of Renewable Energy Electricity" [电网企业全额收购可再生能源电量监管办法], 25 July 2007, http://www.gov.cn/gongbao/content/2008/content_961666.htm. (My translation.)

[117] Fredrich Karhl, Jim Williams, and Ding Jianhua, "Four Things You Should Know about China's Electricity System," Research Brief, China Environment Forum, 2011.

[118] S. Fink et al., 46.

over twenty years ago, to export its electricity to other provinces.[119] Although there is little data available for how much wind power has been curtailed, the evidence I have presented here strongly suggests that curtailment is a plausible, and perhaps significant, contributor to the low capacity factors of Chinese wind farms.

Despite the seemingly insurmountable challenge of intermittency, it is important to note that the SGCC has been building pumped storage reservoirs across the country to help maintain grid stability. Pumped storage reservoirs generally complement wind in that they can use wind power to pump water uphill (creating artificial electricity demand at night, as winds are strongest at night) and essentially store the wind energy as suspended water. When electricity demand peaks during the day, a reservoir operator can use gravity to empty the reservoir and push the water through a turbine which then generates electricity. At the end of 2009, China's pumped storage generation capacity stood at 14.55 GW and the SGCC plans to expand that capacity to 21 GW by 2015 and to 41 GW by 2020.[120] Furthermore, in coordination with the SGCC's smart grid plans, "Chinese car industry experts are predicting that China will have upwards of 30 million electric vehicles in operation by 2020."[121] Like pumped storage reservoirs, the batteries of electric vehicles can also store energy and most importantly they can store energy at night when wind farms tend to generate their peak output. These two options for energy storage—pumped storage reservoirs and electric vehicles—will undoubtedly play an important role in integrating wind power into China's electricity system and electricity systems worldwide.

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[119] Kahrl, Williams, and Ding, "Four Things You Should Know about China's Electricity System," . . .

[120] "China's State Grid to raise pumped storage hydropower capacity," *Industrial Fuels and Power*, 14 June 2010, http://www.ifandp.com/article/005063.html.

[121] Schwartz, "The Power Grid and Wind Industry in China: An Update," . . .

Yet another difficulty emerges when wind power is integrated into a predominantly coal-based electricity system. If provincial grid operators choose not to curtail wind, they must curtail coal-fired generation. In the US, coal-fired generation mostly serves as a base-load resource (i.e. it generates the minimum amount of power that utility companies must provide throughout a 24-hour day), while other power sources that are more efficient at cycling,[122] such as natural gas plants, ramp up and down to meet peak electricity demand during the day and to accommodate for other demand fluctuations (these power sources are known as "peaking" and "load following" generation, respectively). By contrast, in regions of China without hydropower resources, coal-fired power plants perform the cycling for load following and peaking generation, which reduces the efficiency of those plants.[123]

This reduced efficiency of coal-fired generation has significant implications for the environmental impact of wind power, as the integration of wind power, and the accommodation for its intermittency, make the rest of China's electricity generation pollute even more. A 2010 study by Bentek Energy, an energy market analytics company, found that the integration of wind power into the generation mix of two utility companies in the US state of Colorado led to increased SO_x and NO_x emissions, while either increasing CO_2 emissions or only abating them minimally.[124] The study identified inefficient cycling by coal-fired power plants and a lack of natural gas power plants as the root causes of the pollution increases. Drawing parallels to

[122] Cycling, as used in this thesis, refers to sudden increases or decreases in power generation output. Cycling occurs for a variety of reasons, including the accommodation for alternative generation, maintenance, equipment failure, or sudden changes in load size.

[123] F. Kahrl et al., 4034.

[124] It is important to note that NO_x and SO_x are not greenhouse gases. NO_x can destroy stratospheric ozone, drive the production of photochemical smog, and contribute to acid rain by forming nitric acid. SO_x, on the other hand, are known for contributing to acid rain by forming sulfuric acid. The environmental impact of both these chemical groups is highly regional, while the impact of CO_2 is undoubtedly global. For the referenced study, please see: "How Less Became More: Wind, Power and Unintended Consequences in the Colorado Energy Market," Bentek Energy, 16 April 2010, http://www.bentekenergy.com/documents/bentek_how_less_became_more_100420-319.pdf.

China's situation, several China electricity system analysts contend that "[u]ltimately, China's power system needs more [natural] gas generation if it is to avoid wasting wind energy and increasing the wear and tear on its coal plants as China's electricity consumption becomes more peaky."[125] Although a similar study has not been conducted for China's utility companies, the operating inefficiencies due to cycling of Chinese coal units have been recognized and investigated by Chinese engineers.[126] Given the highly uncertain environmental impact of Chinese wind power, a quantitative assessment of air pollution changes due to the intersection of wind and coal in China's electricity system should be an area of future research.

It would seem that an expansion of natural gas generation could remedy China's inefficient cycling problems, allowing wind farms to more truly serve as 'clean' energy sources. Moreover, per unit energy produced, natural gas electrical generation emits roughly half the CO_2 emissions that coal-fired generation would emit. At present, however, this remedy would be both politically and logistically difficult to implement. In 2009, China had 24 GW of natural gas generation capacity, but the average capacity factor for all natural gas generation was just 2 percent, meaning that many of the plants were not in use.[127] One obstacle to increased natural gas electricity generation is that China, now the largest electricity-consuming country in the world, only accounts for only 3 percent of global natural gas production and 1 percent of reserves. By contrast, the US accounts for 20 percent of production and 4 percent of reserves. On top of

[125] The term "peaky" means that demand has a more pronounced spike during the day as compared with demand at night. The structure of China's electricity demand is currently shifting away from industry toward the commercial and residential sectors, which demand little electricity at night, but much throughout the day. This structural shift will make China's electricity demand "peakier." For the quoted sentence, please see: Kahrl, Williams, and Ding, "Four Things You Should Know about China's Electricity System," . . .

[126] For 350 MW coal unit efficiency see: Luo Xin [罗鑫] and Zhang Lizi [张粒子], "Study on the Linkage Mechanism of Coal Price and Electricity Charge" [煤电价格传导机制分析及政策建议], *Energy, Technology, and Economics* 22 [能源技术经济], no. 2 (Feb. 2010): 19-22. For 600 MW coal unit efficiency see: Lv Tai [吕太], Wu Haibo [吴海波], Hu Qiaoliang [胡乔良], "Economic Analysis of Optimal Steam Turbine Operation" [汽轮机最佳运行工况的经济性试验分析], Journal of Northeast Dianli University 30 [东北电力大学学报], no. 1 (Feb. 2010).

[127] F. Kahrl et al., 4035.

China's lack of natural gas resources, the NDRC allocates most natural gas to other priorities, such as fertilizer production and residential heating and cooking.

Further complicating the matter, with China's centrally-planned pricing and dispatch system, "it is not clear how natural gas plants, which typically have higher variability in operating hours and face highly volatile gas prices, would be able to recover their costs."[128] Simply put, China lacks the efficient markets that could make natural gas an economically viable piece of its electricity generation mix. To overcome all of these difficulties, China's central government would most likely need to reform its centrally-planned electricity sector and sacrifice energy security by importing natural gas from neighboring countries. In sum, although natural gas generation would increase the energy efficiency of cycling and offer better system balancing services than coal-fired generation currently provides, it is by no means a simple, quick-fix solution.

Returning to the original question, China's growth statistics for wind power are misleading when understood as either absolute numbers or only in the context of a green-tech race with the US. To understand the climate change implications of this wind power boom and the potential for wind power to make a significant dent in China's forecasted electricity demand, one must consider a much more comprehensive and nuanced analysis. Wind's scant share of China's total electricity generation, transmission challenges, wind intermittency, China's lack of flexible generation such as natural gas, and ambiguous regulation are all issues that must be taken into account. Speculating about wind power's future in China's electricity system is a difficult task, but given the current limits of China's electrical grid, it appears that wind power will be severely constrained over the next decade. More than a decade from now, if given

[128] Kahrl, Williams, and Ding, "Four Things You Should Know about China's Electricity System," . . .

favorable conditions of energy storage, expanded transmission capacity, and a revised curtailment policy, wind power would appear to have the potential to significantly shift China's electricity generation away from coal. For the present moment, however, the answer is clear: despite the past half decade of explosive growth in China's wind sector, coal-fired generation has grown faster than wind generation, wind-generated electricity accounts for less than 1 percent of total generation, and China's emissions of greenhouse gases, already the highest in the world, continue to grow.

6. The challenge of rare earths

In my research on Chinese wind policy and industry, there has been a conspicuous absence of discussion concerning the limited supply of and China's near monopoly over rare earth metals. The rare earth metal Neodymium is indispensable for making the neodymium-iron-boron alloy (of which Neodymium composes 28 percent by mass) that make up the permanent magnets inside of modern wind turbines. According to the US-China Economic and Security Review Commission, China holds 93 percent of the world's production of rare earth metals, and since 2006 China has begun to restrict their exports, provoking concerns over WTO legality.[129] China holds 52 percent of known rare earth reserves, while the US, Russia, and Australia hold 13 percent, 6 percent, and 5 percent, respectively.[130] Furthermore, the mining and processing of rare earths is notoriously toxic for the environment, making it politically difficult for other countries which have rare earth reserves, but stricter environmental laws, to compete with China in production.

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[129] US-China Economic and Security Review Commission, 2009 Report to Congress, 63.
[130] Richard Stone, "As China's Rare Earth R&D Becomes Ever More Rarefied, Others Tremble," *Science* 325 (11 September 2009): 1336-1337.

In September of 2011, the Bureau of Mining Management announced that three of China's major rare earth mines will halt production by the end of the year, citing resource depletion and environmental degradation as reasons for the halting of production.[131] China's tightening control over rare earth metals has huge implications for the global wind industry, as China could easily put foreign manufacturers at a cost disadvantage. Consequently, many foreign companies have set up their manufacturing operations in China, not just for cheap labor, but also to circumvent China's export quotas for rare earths.[132]

Apart from concerns over international trade, the need for neodymium is significant because one cannot assume an infinite growth of wind turbines which use the neodymium-iron-boron alloy. Jack Lifton, a rare earth metals industry specialist, cautions wind power enthusiasts by stressing that neodymium is a limiting natural resource for wind power development and essentially all of it is mined in China. He often reminds wind power advocates that "[i]t has been estimated that to build the latest and most efficient one megawatt capacity wind turbine-powered electric generator, requires one metric ton of the rare earth metal neodymium for use in a permanent magnet made from the alloy neodymium-iron-boron."[133] He also questions whether China's rare earth mines can meet the anticipated domestic demand for neodymium, especially if rumors prove true that the China State Council plans to add a total of 330 GW of wind power capacity between 2011 and 2020.[134] Although making a definitive assessment of how neodymium supply will affect China's future expansion of wind power would overstep the scope of this paper, it is clear that the production process of neodymium causes environmental damage,

[131] Michael Martina, "China halts rare earth production at three mines," *Reuters*, 6 September 2011.
[132] Keith Bradsher, "Chasing Rare Earths, Foreign Companies Expand in China," *The New York Times*, 24 August 2011.
[133] Jack Lifton, "Braking Wind: Where's the Neodymium Going to Come from?" Technology Metals Research, 4 March 2009, http://www.techmetalsresearch.com/.
[134] Jack Lifton, "The Effect of Chinese Domestic Growth on Neodymium and Dysprosium Supply," Technology Metals Research, 13 March 2011, http://www.techmetalsresearch.com/.

bringing into question the status of wind power as a ‘clean energy’ source. And perhaps more importantly, the production of wind turbines will face natural resource constraints in the future, eerily similar to the future constraints of coal-fired electricity generation.

7. Conclusion:

In this paper, I have presented two main lines of research: an analysis of China’s wind power policies and an examination of technical and political challenges facing wind power development. In my policy analysis in section three, I explored how China’s FIT and cost sharing mechanism work, but perhaps more significant is the mass emergence of sub-50 MW wind farms that are circumventing China’s national wind power regulations. It appears that provincial governments have also played an important, albeit poorly understood, role in China’s wind power boom over the past half decade. Increasing the significance of this provincial/central government conflict is the enforcement of China’s curtailment policy, which I discussed in section five. Regarding curtailment, provincial grid companies and provincial regulatory institutions appear to wield *de facto* power and have frustrated attempts by SERC to implement national policies.

My research question for the policy analysis was to explore *how* the policies worked, not *to what extent* have they been working. Asking the *to what extent* question would require interviews with wind farm developers, statistical data for individual wind farms, and speculation on how wind power would develop in the absence of certain policies. In other words, I explored a question of policy design—not policy causation. My findings, however, suggest that future research on Chinese wind power policy should focus on policy causation, especially on the role of provincial governments and provincial grid companies, as they appear to have been key decision makers in much of the politics and the operational effectiveness of wind power.

In section five, I made clear that the absolute numbers for wind power growth are misleading, as they ignore the relative role of wind power within China's rapidly evolving electricity system. When considering the challenges to wind power making a positive environmental impact on China's electricity system—the inefficient cycling of coal-fired power plants, China's lack of natural gas, transmission constraints, wind intermittency, and an ambiguous curtailment policy—it is difficult to remain optimistic about the share of wind-generated electricity growing significantly more than its current 0.7 percent share of total electricity generation.[135] From my examination of these challenges and from looking at wind power's scant share of China's electricity generation, I can easily make the *ex post* assessment that China's growth in wind power has thus far had a negligible impact on the mitigation of China's energy-related CO_2 emissions. Making an *ex ante* assessment of wind power's future role in China's fight against climate change is a much more problematic and speculative task, however.

Different forecasts from research teams around the world still hold hope for wind power in China. The IEA projects that wind-generated electricity will constitute between 3 and 13 percent of total electricity generation by 2035.[136] In two scenarios modeled by the China Energy Group, wind power's share of electricity generation output reaches 6 and 10 percent by 2030 and 13 and 16 percent by 2050.[137] A joint study by the IEA and the NDRC predicts that wind-

[135] The average share of wind-generated electricity in 2009 was 0.73 percent according to SERC, *China Electric Power Statistical Yearbook 2010* [中国电力年鉴 2010] (Beijing: China Electricity Press, 2010), 27. Because unofficial reports have indicated the sustained growth of coal-fired generation throughout 2010 and 2011, I believe it is reasonable to assume that the share of wind-generated electricity still stands at roughly 0.7 percent even though I do not have the support of official statistics.
[136] International Energy Agency, *World Energy Outlook 2010*, 673. The 3 percent projection is based on a business-as-usual scenario and the 13 percent projection is based on an ambitious climate change stabilization scenario.
[137] Mark Levine et al., "China's Energy and Carbon Emissions Outlook to 2050," Lawrence Berkeley National Laboratory, China Energy Group, April 2011.

generated electricity will make up 17 percent of total electricity generation by 2050.[138] This joint study also lists a series of "key actions" which must happen to allow for such a massive expansion of wind-generated electricity. These key actions include reforming China's power sector to make it a market-based system, minimizing curtailment, deploying more hydropower and natural gas-fired plants for improved ramping capability, expanding R&D, and offering wind power training courses in university curricula. All three of the projections mentioned here appear to assume that China will overcome the technical and political challenges that I outlined in section five. In their long-term projections, they are all optimistic about wind power's future in China and their predictions could very well prove true.

Contrary to the optimism expressed in the above projections, I caution that the next decade promises to be a tough and turbulent one for wind, which means that coal-fired generation will most likely pick up the slack. Transmission constraints and a lack of flexible generation will most likely impede wind from having any immediate impact. If we are to consider the development of wind power in the context of climate change, we must reckon with the pollution that will result if China is to meet the next decade of its electricity demand with coal-fired generation. From this perspective, the advent of wind power in China seems much less promising.

Furthermore, the projections I have referenced make no mention of the planet's limited rare earth reserves and they assume limitless production of wind turbines. David Fridley, a senior scientist at the China Energy Group, argues that because neodymium is a limiting natural

[138] International Energy Agency and Energy Research Institute, "China Wind Energy Development Roadmap 2050," Technology Roadmap, 2011.

resource, energy efficiency and conservation will be the keys to solving future energy demand.[139] He emphasizes the important distinction between efficiency and conservation, as gains in efficiency (getting more energy services from less energy) can still allow for increases in overall energy consumption, known as the Jevons Paradox. Conservation, on the other hand, means to do without energy services all together. In Fridley's opinion, efficiency and conservation would by far be the cheapest and ecologically safest options for solving China's forecasted energy demand.

It is clear that wind power alone cannot solve the challenge of China's future energy demand. Wind power must be complemented with other renewable power sources and an economic and cultural shift toward both efficiency and conservation. The necessity of understanding wind power in this nuanced and complex context is a lesson that applies beyond just China's situation. In our era of climate change and threatened energy security, these issues are relevant for policymakers, citizens, and industry insiders in both developed and developing nations. If nothing more, I hope I have demonstrated here the need for comprehensive analysis and broad-minded problem solving in approaching China's energy challenges and those of the world.

[139] David Fridley, interviewed by The Post Carbon Institute, uploaded on 5 August 2010, http://www.postcarbon.org/video/127396-david-fridley-the-pipe-dream-of. It should be noted that in this interview Fridley referred to energy resilience in the US; however, the points he raises can easily be applied to China's energy demand situation.

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