Energy Transitions in China and India
Leapfrogging in Wind and Solar Power Technology

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China and India are undergoing rapid transitions towards renewable energy. While their power mix is still dominated by coal, renewables—especially wind and solar—have in recent years outpaced the capacity addition of coal.[1] Both countries have managed to become global leaders in the wind and solar markets in a relatively short period of time. In 2016, China and India ranked first and fourth, respectively, in the world in terms of capacity addition of wind and solar photovoltaic (PV) technologies.[2] They were also home to several domestic, globally competitive wind and solar PV manufacturers. The rapid growth of clean-energy industries points to the potential of environmental leapfrogging, which suggests that developing countries might be able to follow more sustainable development pathways than those experienced by industrialized countries.[3] The leapfrogging in wind and solar power technologies in China and India is largely because of strong government targets and policy support. Therefore, these cases serve as useful examples of how government policy can guide energy transitions in the power sector. By comparing the wind and solar industry development in China and India, this paper discusses how government policy influences development and deployment of wind and solar technologies, explore what challenges remain for the further scaling up of the clean-energy industries, and draw lessons for a transition into a low-carbon power sector.

China's Quest for Indigenous Wind and Solar Industries

The growth of China's renewable energy capacity is driven by strong government targets, policy support, and active investments by state-owned enterprises, especially the "big-five" power utilities. These utilities—China Power Investment, Datang, Huadian, Huaneng, and National Energy Investment Group—contributed to 39 percent of the total non-hydro renewable capacity installed in 2016.[4] In the 12th Five-Year Plan

[1] International Energy Agency (IEA), "World Energy Outlook 2017" (Paris, 2017); World Institute of Sustainable Energy (WISE), "Renewables India 2017: Towards Grid Parity" (Pune, 2017).
[2] REN21, *Renewables 2017: Global Status Report* (Paris: REN21, 2017).
[3] Jim Watson and Raphael Sauter, "Sustainable Innovation through Leapfrogging: A Review of the Evidence," *International Journal of Technology and Globalisation* 5, no. 3/4 (2011): 170, doi:10.1504/IJTG.2011.039763.
[4] Kate Chrisman, Jon Creyts, Lena Hansen, Becky Li, and Zihe Meng, *State of the Market 2017: Cor-*

(FYP)—the party's centrally produced economic guidance that includes growth targets and industry-specific objectives—covering the 2010–15 period, wind and solar were identified as high-value strategic industries, essential to the future of the Chinese economy.[5] In January 2017, China announced targets for renewable energy deployment over 2016–20, the 13th FYP period. Wind and solar comprised a major part of the renewable energy targets: 210 gigawatts (GW) of wind and 110 GW of solar energy by 2020, up from 129 GW of wind and 43 GW of solar energy in 2015.[6] If these targets were met, wind and solar would account for 16 percent of China's total power generation capacity in 2020.

Table 1. China's Renewable Energy Targets and Achievements under the 12th FYP and the 13th FYP

Targets

	12th FYP targets for 2015	Achievements in December 2015	13th FYP targets for 2020
Wind	105 GW	129 GW	210 GW
Solar	35 GW	43 GW	110 GW
Hydropower	290 GW	320 GW	380 GW
Bioenergy	13 GW	10 GW	23 GW
Geothermal	0.1 GW	0.03 GW	N/A
Total	443 GW	502 GW	723 GW

Source: IEA, *Renewables 2017: Analysis and Forecasts to 2022* (Paris: IEA), 39.

China's Wind Industry

China's wind industry has expanded rapidly since the mid-2000s, serving almost exclusively its domestic market. The Chinese government's Wind Resource Concession Program was a key driver of wind development in China between 2003 and 2007, during which wind farms meeting a certain localization rate were selected through a competitive bidding process for government-selected sites and various preferential treatments. Another major driver was the Renewable Energy Law in 2006, which set a legal framework for mandatory grid connection and full purchase of renewable energy projects, and authorized the establishment of feed-in tariffs (fixed, subsidized power

porate Renewable Procurement in China (Boulder, CO: 2017).

[5] Government of China, *Zhonghua Renmin Gongheguo Guominjingji Huo Shehui Fazhan Di Shier Ge Wu Nian Guihua Gangyao [The 12th Five-Year Plan for Economic and Social Development of the People's Republic of China]* (Beijing: Government of China, 2011).

[6] Measured in both PV and concentrated solar power. Government of China, "The 13th Five-Year Plan for Economic and Social Development of the People's Republic of China" (Beijing: Government of China, 2016).

tariffs).[7] The wind market reached a record level of capacity addition (31 GW) in 2015, when wind developers rushed to complete their projects before the planned reduction in feed-in tariffs in the same year.[8] The market growth has slowed down since then, but China remains the world's largest wind market, with 188 GW of installed capacity in December 2017.[9]

China's Solar Industry

China's solar industry had primarily served the foreign market, particularly in Europe, until 2009, when the Eurozone crisis led to a cutback of feed-in tariffs in key European markets and dampened the financial incentives for Chinese solar investors. The Chinese government made a major effort to rescue the Chinese solar industry, introducing nationwide solar feed-in tariffs in 2011 and increasing the initial target of solar energy deployment for 2015 from 5 GW to 35 GW.[10] Subsequently, China's domestic solar market has grown rapidly, with annual growth rates consistently exceeding 50 percent since 2011. In 2017, the new solar-capacity addition hit a record level of 53 GW to reach cumulative capacity of 130 GW, a higher figure than the 110 GW solar target set for 2020.[11] Critically, the per unit price of energy of both solar PV and onshore wind energy has fallen to the point where it can compete without significant government assistance, a major milestone in an industry where price is king.[12]

Integration Challenges

The unprecedented growth of wind and solar capacity in China has brought significant challenges for the integration of the intermittent renewable energy sources into China's coal-heavy electricity system. This has resulted in a widespread problem of wind and solar curtailment. Curtailment is when grid operators command wind and solar generators to reduce power output, which is typically done to minimize transmission congestion and to reduce excess generation during low load periods.[13] China experienced record levels of wind curtailment in 2016, accounting for 17 percent of the annual wind generation.[14] Smaller yet increasing amounts of solar generation have also

[7] National People's Congress, *The Renewable Energy Law of the People's Republic of China* (Beijing: National People's Congress, 2005).
[8] Global Wind Energy Council (GWEC), *Global Wind Report: Annual Market Update 2015* (Brussels: GWEC, 2016).
[9] GWEC, *Global Wind Statistics 2017* (Brussels: GWEC, 2018).
[10] Matthew Hopkins and Yin Li, "The Rise of the Chinese Solar Photovoltaic Industry: Firms, Governments, and Global Competition," in *China as an Innovation Nation*, ed. Yu Zhou, William Lazonick, and Yifei Sun (Oxford: Oxford University Press, 2016), 306–32.
[11] Mark Osborne, "China Officially Installed 52.83 GW of Solar Modules in 2017," *PV-Tech*, January 22, 2018, www.pv-tech.org/news/china-officially-installed-52.83gw-of-solar-modules-in-2017.
[12] International Renewable Energy Agency (IRENA), *Renewable Power Generation Costs in 2017* (Abu Dhabi: IRENA, 2018).
[13] Lori Bird, Debra Lew, Michael Milligan, E. Maria Carlini, Ana Estanqueiro, Damian Flynn, Emilio Gomez-Lazaro, Hannele Holttinen, Nickie Menemenlis, Antje Orthus, et al., "Wind and Solar Energy Curtailment: A Review of International Experience," *Renewable and Sustainable Energy Reviews*, 2016, doi:10.1016/j.rser.2016.06.082.
[14] IEA, *World Energy Outlook 2017* (Paris: IEA, 2017).

been curtailed in the last couple of years.

The factors underlying curtailment are both technical and institutional. China's power sector suffers from an overcapacity problem, as new nuclear, coal, natural gas, and renewable power plants come online at the same time as electricity demand growth slows.[15] In China, thermal power plants are assigned a set number of full load hours every year. Both wholesale and retail power prices are determined by the government and not updated frequently.[16] Therefore, generators have little incentive to lower the thermal operation hours and allow for more renewable generation. Together with the overcapacity situation and the limited flexibility of the existing coal fleet, the tight regulation of power plant operations in China leads to greater challenges for the integration of wind and solar power.[17]

China has begun to address the integration challenge. As part of its anti-air pollution efforts, China is pushing for the early retirement of inefficient coal capacity and banning new coal plants in provinces with high pollution levels.[18] Furthermore, efforts are being made to shift renewable deployment to demand centers by restricting new wind and solar projects in provinces with high curtailment levels.[19] China is also commissioning additional transmission capacity, improving the flexibility of coal-fired power plants, and implementing power sector reforms to provide stronger price signals to generators.[20]

Increasing Cost of Renewable Subsidies

Feed-in tariffs have been a major driver of China's wind and solar market expansion, supporting most of the 200 GW of solar and wind capacity installed over 2009–16.[21] After the amount offered as renewable subsidies almost quadrupled, China is now searching for a more cost-effective renewable incentive scheme. Since 2015, China has cut its feed-in tariffs for wind by 8 to 16 percent and for solar by 15 to 28 percent, depending on the resource potential of different provinces.[22] In a demonstration of the growing maturity of the renewables sector, feed-in tariffs are likely to be replaced by a

[15] Ibid.
[16] Fei Teng, Xin Wang, and LV Zhiqiang, "Introducing the Emissions Trading System to China's Electricity Sector: Challenges and Opportunities," *Energy Policy* 75 (2014): 39–45, doi:10.1016/j.enpol.2014.08.010.in which the interaction between ETS and electricity market reform plays a major role. China's electricity sector is currently in a slow progress towards a more competitive and market-based system. Both equal share dispatching policy and regulated wholesale and retail pricing policies pose significant challenges for implementation of ETS in China's electricity sector. One of the important points of ETS is to give a price for carbon emissions and establish a cost pass-through mechanism (reminded that the essential of carbon pricing is to put a price on carbon emissions that is equal to discounted value of the external damages
[17] IEA, *World Energy Outlook 2017*.
[18] Ibid.
[19] Kathy Chen and Stian Reklev, "China Caps 2018 Energy Consumption Growth, Paves Way for CO_2 Drop," *Carbon Pulse*, March 8, 2018.
[20] IEA, *Renewables 2017: Analysis and Forecasts to 2022.*
[21] Ibid.
[22] Ibid.

market-based approach: tradable, renewable energy certificates. China launched a pilot program to test this idea in July 2017 and aims to make it mandatory in 2018/19.[23]

Leading in Manufacturing, Lagging in Innovation

The Chinese government has strategically pursued the development of indigenous wind and solar power industries, implementing various research and development (R&D) programs (e.g., the 863 Program) and preferential measures for domestic manufacturers (e.g., local content requirements for wind).[24] Collaborative R&D between industry and universities has also played an important role in technological capability development in China's wind and solar industries. Today, Chinese wind turbine manufacturers can produce the vast majority of the onshore wind supply chain domestically, and have started the commercialization of offshore wind projects.[25] In the solar sector, Chinese firms have rapidly expanded into the upstream, more high-tech segments.[26]

Despite their success in manufacturing, Chinese firms are still lagging in innovation capabilities, a clear area of concern for the party: The 13th FYP refers to innovation as the "primary driving force for development," while recognizing China's "capacity for innovation is not strong enough."[27] While global wind and solar PV patent filings, a proxy measure of innovation activities, have increased sharply since the 2000s, most of the wind and solar PV patents are held by firms from the United States, Europe, and Japan; Chinese firms have only recently started patenting in their home market.[28] One reason for China's lagging innovation capabilities is that earlier phases of China's wind and solar industries focused on capacity expansion and cost reduction at the expense of technology improvement and quality assurance.[29] This points to the trade-off between the pace of market expansion and innovation capability accumulation.

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[23] Ibid.

[24] Hopkins and Li, "The Rise of the Chinese Solar Photovoltaic Industry: Firms, Governments, and Global Competition"; Joanna I. Lewis, "The Development of China's Wind Power Technology Sector: Characterizing National Policy Support, Technology Acquisition and Technological Learning."

[25] Xiaojing Sun, Diangui Huang, and Guoqing Wu, "The Current State of Offshore Wind Energy Technology Development," *Energy*, 2012, doi:10.1016/j.energy.2012.02.054; Jiahai Yuan, Shenghui Sun, Jiakun Shen, Yan Xu, and Changhong Zhao, "Wind Power Supply Chain in China," *Renewable and Sustainable Energy Reviews*, 2014, doi:doi.org/10.1016/j.rser.2014.07.014.

[26] Smita Kuriakose, Joanna I. Lewis, Jeremy Tamanini, and Shahid Yusuf, *Accelerating Innovation in China's Solar, Wind and Energy Storage Sectors* (Washington, D.C., 2018).

[27] Government of China, *The 13th Five-Year Plan for Economic and Social Development of the People's Republic of China*, 12, 20.

[28] Kuriakose et al., *Accelerating Innovation in China's Solar, Wind and Energy Storage Sectors*.

[29] Junfeng Li, Fengbo Cai, Liming Qiao, Hongwen Xie, Hu Gao, Xiaosheng Yang, Wenqian Tang, Weiquan Wang, Xiuqin Li, And Li, et al., *2012 China Wind Energy Outlook* (Beijing: Chinese Wind Energy Association, 2012); Fang Zhang and Kelly Sims Gallagher, "Innovation and Technology Transfer through Global Value Chains: Evidence from China's PV Industry," *Energy Policy* 94 (2016): 191–203, doi:10.1016/j.enpol.2016.04.014.

India's Growing Aspirations for Green Innovations

In 2015, the Government of India set the target of achieving 175 GW of renewables by 2021–22.[30,31] The target anticipates 60 GW of wind and 100 GW solar by March 2022, up from 32 GW wind and 12 GW solar in March 2017. 2016–17 was the first time that the capacity addition of renewables (11.3 GW) surpassed that of conventional sources (10.3 GW) in India.[32] According to the capacity addition scenarios of India's Central Electricity Authority, this trend is set to continue over the 13th FYP—the Government of India's centralized and integrated national economic programs—covering the period from 2017–18 to 2021–22. This is because of the ambitious renewables target for 2022 and the over-achievement of the targeted capacity addition of conventional sources during the 12th FYP period (2012–13 to 2016–17).[33]

Table 2. India's Renewable Energy Targets and Achievements under the 12th FYP and the 13th FYP

Targets

	12th FYP targets for FY 2016–17	Achievements in March 2017	13th FYP targets for FY 2021–22
Wind	15 GW	32.2 GW	60 GW
Solar	10 GW	12.3 GW	100 GW
Small hydropower	5 GW from "other types" of renewable sources	4.4 GW	5 GW
Biomass		8.2 GW	10 GW
Waste-to-Energy		0.1 GW	N/A
Total	30 GW	57.2 GW	175 GW

Note: "Small hydropower" refers to hydropower plants up to 25 MW capacity.

Source: WISE, *Renewables India 2017: Towards Grid Parity*, 4–5.

The growth of India's wind and solar capacity has been driven by private-sector investments supported by government policy at both the central and state levels. The most significant boost was the enactment of the Electricity Act 2003, which provided the first legal framework dedicated to promoting renewable energy in India. The act required each state to promote renewables, including through preferential tariffs and purchase obligations.[34] The wind market has grown rapidly since then, supported by

30 All dates here refer to the fiscal calendar. An Indian fiscal year runs from April 1 to March 31. For example, the fiscal year 2022–23 starts on April 1, 2022 and ends on March 31, 2023.

31 Ministry of New and Renewable Energy (MNRE), *Annual Report 2016–17* (New Delhi: MNRE, 2017).

32 WISE, *Renewables India 2017: Towards Grid Parity*.

33 Central Electricity Authority (CEA), *Draft National Electricity Plan: Volume 1–Generation* (New Delhi: CEA, 2016).

34 IRENA and GWEC, *30 Years of Policies for Wind Energy: Lessons from 12 Wind Energy Markets* (Abu Dhabi: IRENA, 2013).

the central government's decision to implement tax breaks on investments in wind power equipment and by state-level feed-in tariffs. In 2009, the central government introduced a generation-based incentive (GBI), which provides a tariff-based incentive in addition to the state feed-in tariffs. GBI has attracted independent power producers and foreign investors, who have contributed toward the greater performance-orientation and technology upgradation in the wind market.[35]

India's solar market started expanding with the launch of the Jawaharlal Nehru National Solar Mission (JNNSM) in 2010. The JNNSM had initially targeted a 20 GW grid-connected solar capacity by 2022, which was later revised to 100 GW. Solar projects under the JNNSM are allotted after competitive bidding and this led to price discovery and minimization of the financial burden of the renewable subsidies.[36] Given this success, competitive bidding has recently been applied to wind power projects. It remains to be seen whether wind and solar projects can sustain themselves at increasingly lower tariff levels. Nevertheless, onshore wind energy and solar PV are becoming increasingly cost-competitive in India.

Inadequate Manufacturing and Innovation Capabilities

In 2014, the Government of India announced the "Make in India" initiative to "transform India into a global design and manufacturing hub," with renewable energy being one of the priority sectors.[37] While this is an area of critical development, India still faces important challenges in the wind and solar manufacturing industries.

As of June 2016, the manufacturing capacity of solar cells and PV modules in India was 1.5 GW and 4.3 GW, respectively.[38] Given that solar capacity needs to increase by 17.5 GW per year to achieve the 100 GW target by 2022, the current solar manufacturing capacity is far from adequate. Moreover, India's solar manufacturing capacity is absent in the upstream, high-tech segments of the value chain. As a result, India remains heavily dependent on imported solar PV technology, with almost 84 percent of the solar panels being imported during FY 2016–17.[39]

The JNNSM aspires to develop an indigenous solar manufacturing industry. To this end, the central government stipulated a domestic content requirement for solar PV projects funded through the JNNSM. However, solar developers have so far demonstrated a preference for foreign-produced technologies.[40] Solar projects funded through

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[35] Daisuke Hayashi, "The Governance of International Technology Transfer: Lessons from the Indian Wind Industry," in *Challenges of European External Energy Governance with Emerging Powers*, edited by Michèle Knodt, Nadine Piefer, and Franziska Mueller (Surrey: Ashgate Publishing, 2015), 251–68.
[36] Ankur Chaudhary, Chetan Krishna, and Ambuj Sagar, "Policy Making for Renewable Energy in India: Lessons from Wind and Solar Power Sectors," *Climate Policy* 15, no. 1 (2015): 58–87, doi:10.1080/14693062.2014.941318.
[37] Government of India, "Make in India," www.makeinindia.com.
[38] WISE, *Renewables India 2017: Towards Grid Parity*.
[39] Ibid.
[40] Rainer Quitzow, "Assessing Policy Strategies for the Promotion of Environmental Technologies: A Review of India's National Solar Mission," *Research Policy* 44, no. 1 (2015): 233–43, doi:10.1016/j.

state programs—with no domestic content requirement—imported cheaper silicon-based modules from China.[41] In 2013, the United States filed a complaint against JNNSM's domestic content requirement with the World Trade Organization (WTO). The WTO ruled in favor of the United States, and India has recently deleted all of the domestic content requirement clauses from the 5 GW Batch-IV solar scheme in the second phase of JNNSM.[42]

Given the WTO's ruling against the domestic content requirement, India will not be able to use the protectionist measure—at least not at a large scale—to nurture its solar industry. Besides open competitive bidding, JNNSM should provide stronger R&D support to the upstream segments of the PV value chain. For instance, the Indian government has since 2012 provided R&D subsidies for polysilicon, wafer, and cell manufacturing through the Modified Special Incentive Package Scheme.[43] The R&D scheme can be scaled up to improve the competitiveness of India's solar industry.

India's wind turbine industry has a manufacturing capacity of about 12 GW, which is more than double the wind capacity addition in FY 2016–17 (5.5 GW).[44] Despite the abundant manufacturing capacity, most Indian wind turbine manufacturers still lack innovation capabilities. The major R&D activities of wind turbine manufacturers in India are taking place either outside India or at local R&D facilities of multinational companies. Most others depend on foreign help in terms of technology licenses and R&D.[45] The Indian government provides financial support for wind technology research.[46] However, the R&D scheme is underutilized by wind turbine manufacturers, because their profits are not yet sufficient to start investing in R&D and/or they do not wish to disclose R&D results in the public domain.[47] Unlike China, industry-university linkages for wind technology research are not well developed.

Conclusions

There are similarities and differences in the way China and India developed and deployed wind and solar power technologies. In both countries, guaranteed tariff-based incentives (feed-in tariffs and GBI) were instrumental in achieving a large-scale de-

respol.2014.09.003.

[41] Chaudhary, Krishna, and Sagar, "Policy Making for Renewable Energy in India: Lessons from Wind and Solar Power Sectors."

[42] Ministry of New and Renewable Energy (MNRE), *Corrigendum: Amendment in the Guidelines for Implementation of a Scheme for Setting-up of over 5,000 MW Grid-Connected Solar PV Power Projects with Viability Gap Funding (VGF) under Batch-IV of Phase II of the JNNSM* (New Delhi: MNRE, 2018).

[43] Ministry of Communication and Information Technology (MCIT), *Modified Special Incentive Package Scheme (M-SIPS): Enhancement of Scope and Extension of Time and Other Amendments—Revised Notification* (New Delhi: MCIT, 2015).

[44] WISE, *Renewables India 2017: Towards Grid Parity*.

[45] Hayashi, "The Governance of International Technology Transfer: Lessons from the Indian Wind Industry."

[46] MNRE, "Research, Development and Demonstration: Industry Involvement," mnre.gov.in/industry-involvement.

[47] Indian wind turbine manufacturer, interview by Hayashi, March 9, 2013.

ployment of wind and solar power. As the amount of renewable subsidies soared, both countries shifted to a more market-based incentive scheme: tradable renewable energy certificates in China and competitive bidding in India. These deployment policies have been successful in terms of capacity expansion and cost reductions. However, the unprecedented capacity growth in China resulted in a widespread problem of wind and solar curtailment. Wind and solar curtailment is also emerging in India, especially in southern states with high penetration of wind and solar power.[48] India should learn from China's experience in tackling the integration challenge.

A notable difference between the Chinese and Indian approaches is that China has been much more strategic and effective in fostering indigenous manufacturing and innovation capabilities. The Chinese government has supported the development of indigenous industries through various R&D programs and preferential measures. The Indian government has historically played a limited role in wind and solar technology development. Innovation has only recently (re)gained political prominence in India, as exemplified by the "Make in India" initiative and JNNSM. China's state-led approaches to innovation may not be readily applicable to India, because private firms are dominant in its wind and solar industries. Nevertheless, India can benefit from stronger public-private partnership for clean-energy technology research. A suitable arrangement can be made for intellectual property sharing based, for example, on the technology management plan of the United States-China Clean Energy Research Center.[49]

The challenge for both China and India is to establish an institutional framework for managing the trade-off between the pace of the build-up of domestic manufacturing industry and the accumulation of innovation capabilities in the clean-energy industries. Carefully designed innovation policies need to complement the deployment policies.

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[48] Bridge to India, "Southern Region to Lead India in Grid Integration of Renewable Energy," *PV-Tech*, May 26, 2017, www.pv-tech.org/guest-blog/southern-region-to-lead-india-in-grid-integration-of-renewable-energy-bridg.
[49] Joanna I. Lewis, *A Better Approach to Intellectual Property?: Lessons from the US-China Clean Energy Research Center* (Chicago, IL: The Paulson Institute, 2015).