Exploiting the Implementation Gap: Policy Divergence and Industrial Upgrading in China's Wind and Solar Sectors

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Abstract

This article argues that manufacturing policies of Chinese local governments have provided an important corrective to some of the weaknesses inherent in the central government's indigenous innovation framework, most importantly its inattention to the importance of advanced manufacturing capabilities for innovation. Based on an original dataset of over one hundred executive interviews conducted with 43 Chinese wind and solar firms, I identify both central government R&D funding and continued local government support for manufacturing as critical factors in enabling innovation among China's renewable energy firms. In particular, this article shows that firms have utilized a combination of both central and local government policies to establish unique engineering capabilities required for innovation in commercialization and scale-up to mass production. The findings suggest that continued local government support for the manufacturing economy has not undermined central government innovation policies, but has (1) broadened the range of resources available to entrepreneurial firms and (2) enabled new options for industrial upgrading that are outside the conceptualization of innovation underlying the central government's indigenous innovation framework.

Keywords: Wind energy; solar energy; innovation policy; industrial upgrading; manufacturing

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As China has overtaken the United States to become the world's largest energy consumer and contributor of greenhouse gases, it has also developed vast and growing environmental technology industries.[1] In 2013, more than 60 per cent of the world's solar panels were manufactured in China, a country that had virtually no domestic solar industry just ten years prior. In the same year, Chinese

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1 International Energy Agency 2010.

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manufacturers produced a third of the world's wind turbines, and China was the largest manufacturer of wind energy technologies by a factor of two.[2]

The rapid development of renewable energy industries in China is surprising on two counts. First, leading Chinese wind and solar manufacturers are not competing in global renewable energy sectors with inferior technologies, but are bringing to market advanced wind and solar energy technologies that are on a par with or better than those of competitors in advanced economies. As early as 2007, solar cells produced by Chinese manufacturers beat competition from Japan and Germany in cell efficiency for the dominant solar cell technologies available at the time.[3] In the wind industry, new wind turbine technologies, including gearless turbines and ultra-compact turbines, were first commercialized in China.[4]

Second, China's wind and solar industries have developed in a policy environment in which central and local governments have pursued divergent, at times outright conflicting, policy goals. After decades of relying on technology transfers from foreign-invested firms, China's central planners have encouraged autonomous technology development in domestic renewable energy sectors, most recently under the umbrella of China's "indigenous innovation" policies (*zizhu chuangxin* 自主创新). Such central government science and technology (S&T) policies have funded R&D activities in wind and solar firms and have attempted to close firms that are unable to meet R&D spending targets.[5] Governments at the sub-national level, by contrast, have been reluctant to support the development of R&D capabilities with uncertain future payoffs. Instead, they have continued their support of traditional manufacturing activities in development zones, often protecting local businesses even when central policies have encouraged industry consolidation.[6]

Literature on central–local state relations in China has documented challenges for policy implementation in areas ranging from environmental regulation to industrial policy when central and local governments have pursued divergent goals.[7] In this context, this article examines whether continued local government support for the manufacturing economy has undermined the central government's indigenous innovation strategy in renewable energy sectors, or whether divergent policies offered at different administrative levels have in fact been complementary in supporting industrial upgrading and innovation in green energy industries.

Surveying firms on what government policies and programmes they have utilized and how, I find that firms have indeed participated in central government

2 Earth Policy Institute 2015.
3 Marigo 2007.
4 Interviews, CEO, European wind turbine manufacturer, 17 August 2011; CTO, Chinese wind turbine manufacturer, 29 August 2011.
5 Liu and Cheng 2011; OECD 2008.
6 Bradsher 2010; Haley and Haley 2013.
7 Heilmann, Shih and Hofem 2013; Huang 2002; Kostka and Hobbs 2012; Mertha 2008; Thun 2006. See also in this issue: Eaton and Kostka 2017; Gilley 2017; Shin 2017.

programmes to support innovation, but have not used such policies to establish the type of autonomous capabilities in technology development envisioned by central government planners. As Chinese firms have found renewable energy technologies to be accessible through collaboration and licensing in global supply chains, they have utilized central government R&D funding to build capabilities that could not be gained from foreign partners. In particular, firms have focused on establishing engineering and design skills required to prepare new technologies for commercialization and scale-up to mass production.[8] In doing so, China's wind and solar firms have repurposed central government resources, but, importantly, have also relied on local government support for the manufacturing economy. These findings suggest that the implementation gap between central and local policies has enabled industrial upgrading at the hands of entrepreneurial firms, even if the types of innovative capabilities that firms have acquired differ from both central and local government plans.

The next section situates the analysis through a brief review of the literature on political decentralization and central–local state relations in China. The subsequent sections review government policies for new energy sectors, showing how firms have utilized central and local policies in the process of building innovative capabilities. The conclusion returns to broader implications for industrial upgrading and environmental governance in China.

Central–Local State Relations and Industrial Upgrading in China

China's development model has long been characterized by experimentation at the sub-national level. Particularly in the early decades of reform, scholars attributed much of China's economic dynamism to the policies of local governments. Dependent on local fiscal revenues, local governments were encouraged to act in growth-oriented ways, intervening on behalf of local businesses and managing the local economy "like a diversified corporation."[9] Studies carried out more recently have documented, however, that the economic incentives of local governments have often prevented the implementation of central government policies, leading to the so-called implementation gap. Sub-national officials have, for instance, failed to enforce environmental regulations to protect local firms. They have repurposed high-technology zones into export processing clusters and have resisted the implementation of sectoral industrial policies that threatened to hurt local businesses.[10] In this context, observers have warned that divergent incentives of central and local officials have created obstacles for industrial upgrading and environmental governance alike.[11]

8 Nahm and Steinfeld 2014, 289–290.

9 Oi 1992.

10 On challenges in the implementation of environmental regulation see, e.g., Kostka and Hobbs 2012; Mertha 2008. On labour standards, see Lee 2007; O'Brien and Li 2006. On industrial policy, see Heilmann, Shih and Hofem 2013; Thun 2006.

11 Eaton and Kostka 2017; Ernst and Naughton 2008; Gilley 2017; Shin 2017; Steinfeld 2004.

The effect of divergent government objectives in policymaking in China merits renewed attention in light of recent central government efforts to bolster the technological capabilities of domestic firms. After decades of encouraging foreign-direct investment and technology transfers to domestic industry, China's central leadership in 2006 announced an indigenous innovation strategy to wean Chinese firms off technology imports.[12] China's central government acknowledged the need for continued collaboration with global partners on scientific research and R&D, but also set goals for industry to develop a growing share of new technologies without foreign help.[13] In high-technology sectors, the central government set new requirements for technological capabilities and targets for firm spending on R&D to weed out uncompetitive enterprises.[14] Such policies focused on a set of strategic emerging industries (*zhanlüexing xinxing chanye* 战略性新兴产业), renewable energy sectors among them.[15] Central government plans subsequently called for the establishment of autonomous technological capabilities in virtually all segments of wind turbine and solar supply chains.[16]

Existing literature on China's decentralized development model has focused on the ways in which incentives for local governments to create short-term economic growth have collided with long-term central government plans, creating an implementation gap between central goals and local outcomes. Implicit in such research have been assumptions about the importance of centralized and hierarchical government bureaucracies capable of implementing national policies.[17] Divergent policy goals at sub-national levels have been regarded as a threat to the implementation of central government policies, as they have offered firms the option of shirking by prioritizing short-term economic gains over long-term policy goals. In this context, Kostka and Hobbs have argued that successful cases of implementation have relied on local government attempts to "bundle" central government directives with compensatory benefits for enterprises and additional policies of more immediate interest to local officials.[18]

This article seeks to shift the focus from bureaucratic discipline and enforcement to an analysis of how firms, the consumers of government policy, have responded to divergent policies of central and sub-national governments. In contrast to existing approaches, which have studied policy divergence as a problem of enforcement, I examine the possibility of policy complementarity of central and sub-national wind and solar policies. Through a firm-centred study of policy support for industrial upgrading in environmental industries, I investigate whether the implementation gap indeed undermined central government's upgrading

12 Liu and Cheng 2011; State Council 2006.
13 Kennedy 2013.
14 Lewis 2013, 66–74.
15 State Council 2010.
16 See, e.g., Ministry of Science and Technology 2012; National Energy Administration 2012.
17 Amsden 1989; Johnson 1982.
18 For a discussion of policy bundling in China, see Kostka and Hobbs 2012, 768–770.

Table 1: **Interview Counts**

	# of Interviews	# of firms interviewed
Wind turbine manufacturers	19	13
Wind turbine component suppliers	12	11
Solar PV manufacturers	14	12
Solar PV component suppliers	19	7
Industry associations	6	n/a
Government interviews	23	n/a
Banks, VCs, investment firms	14	n/a
Total	107	43

goals, or whether, as I argue, policy support offered at municipal and provincial levels has broadened the range of upgrading tools available to renewable energy firms. Local governments in China have been reluctant to implement key elements of the national strategy for indigenous innovation, yet in doing so they have also maintained institutional support for manufacturing activities no longer subject to central government support. Innovation in wind and solar industries has not resulted from successful attempts to bridge the implementation gap through policy bundling or better enforcement. Rather, this research highlights that the implementation gap itself has broadened the resources available to entrepreneurial firms seeking to upgrade in environmental sectors in China.

The core of the analysis is based on 107 interviews with senior executives in 43 Chinese wind and solar firms conducted between 2010 and 2014 (see Table 1). Interviews were semi-structured and offered insights into firm decision-making in response to broadly different sets of incentives and policies offered at central and local levels of government. Interview data was triangulated with information from statistical yearbooks, policy documents and data culled from municipal gazetteers. The following sections detail central and local renewable energy policies before examining firm behaviour in the context of policy divergence.

National Context: Indigenous Innovation

From the first technical trials of imported wind turbine technologies in the mid-1980s, central government policies to support domestic renewable energy industries have been guided by a desire to create new energy technologies that are both affordable and developed autonomously by Chinese firms. To achieve these goals, Beijing has pursued a three-pronged strategy of creating domestic markets, providing incentives for technology transfer, and supporting R&D activities in enterprises and research institutes.

Since the mid-1990s, core research programmes administered by the Ministry of Science and Technology (MOST) – including the Key Technology R&D Programme, the National High-Technology R&D Plan often referred to as the 863 Programme, and the 973 Programme for Basic Research – have supported the domestic development of wind and solar technologies.[19] Funds available for renewable energy research have increased significantly since the Ninth Five-Year Plan (1996–2000), when MOST first included designated funds for renewable energy in its research portfolio. Between 2001 and 2005, the 863 Programme dispensed 20 billion yuan for applied research to universities and enterprises, including to renewable energy firms.[20] In 2006, the central government declared the pursuit of "indigenous innovation" as a central goal of the 11th Five-Year Plan (2006–2010).[21] The Medium- and Long-term Strategic Plan for the Development of Science and Technology (MLP) laid out the central leadership's intention to place indigenous innovation at the core of China's developmental strategy.[22] The MLP called for a reduction of imported technology, set targets to increase R&D spending to 2.5 per cent of GDP, and selected a range of industrial sectors for special treatment, green energy among them.[23] Central government R&D programmes received increased funding and the 863 Programme now included clean energy technologies as a focus area.[24]

In renewable energy policymaking, the indigenous innovation guidelines led to the expansion of renewable energy markets and increased support for R&D activities. In 2006, the central government passed China's first renewable energy law, which replaced previous renewable energy demonstration programmes with a national feed-in tariff for renewable energy. The law guaranteed higher electricity prices for power generated from renewable sources, the funds for which were recouped through surcharges on electric rates.[25] The Medium- and Long-Term Strategic Plan for Renewable Energy Development, issued in 2007, mandated that 15 per cent of energy demand must be met from renewable sources by 2020.[26] It called for the installation of 30 gigawatts (GW) of wind turbines as well as 1.8 GW of solar capacity by the same year. Both targets have since been revised to 200 GW for wind and 20 GW for solar, respectively.[27] A first nationwide feed-in-tariff for solar energy also created a growing domestic market for solar technologies.[28] By 2009, China was the world's largest market for wind turbines and the largest producer of wind and solar technologies.[29]

In contrast to previous decades, when technology transfers were critical elements of wind and solar policies, the indigenous innovation strategy aimed to close remaining technology gaps between foreign firms and Chinese suppliers by building up domestic capabilities.[30] Direct subsidies for renewable firms were

19 OECD 2008, 443.
20 Campbell 2010, 3; Karplus 2007, 23–24.
21 State Council 2006.
22 Cao, Suttmeier and Simon 2006; OECD 2008, 389; Schwag Serger and Breidne 2007.
23 Ernst 2011, 24.
24 Tan and Gang 2009, 2–4.
25 Schuman and Lin 2012, 91.
26 Lewis 2013, 53.
27 Campbell 2010, 6–8; Lewis 2013, 53.
28 Campbell 2010, 8.
29 Earth Policy Institute 2015.
30 Tan and Gang 2009, 5; Zhao et al. 2011.

now tied to the successful commercialization of new technologies. Since 2008, for instance, Chinese turbine manufacturers have received subsidies for the first 50 turbines of 1 MW capacity or more, as long as they were indigenously developed.[31] The Ministry of Industry and Information Technology in 2010 ordered the shutdown of manufacturers that could not produce wind turbines of 2.5 MW capacity or larger and failed to meet a series of R&D and quality requirements.[32] In the solar sector, the 12th Five-Year Plan for the solar PV industry called for 80 per cent of solar production equipment to be developed domestically by 2015, set ambitious targets for solar cell efficiencies, and called for the development of new thin film technologies. As in the wind industry, the plan encouraged industry consolidation into between three and five large, competitive firms.[33]

Local Context: Manufacturing Policy for Renewable Energy Industries

At the sub-national level, fiscal pressures and the cadre performance evaluation system, which is skewed towards rewarding short-term economic growth, have provided incentives to maintain a focus on mass manufacturing, even as central government policies have increasingly targeted indigenous innovation. In contrast to industrial policies issued in Beijing, such local support for manufacturing has generally not been conditional on the technological capabilities of firms.

The majority of China's wind and solar firms are located in high-tech industrial development zones (HTZs) administered by local governments. Although HTZs were initially established under the national Torch Programme to provide incubator services for small- and medium-sized high-technology enterprises, in practice the economic constraints placed on local governments have caused a reorientation towards mass manufacturing and export processing. For local governments, high-technology zones have become vehicles to increase economic growth and tax revenues within their jurisdiction. To local officials, manufacturing, not innovation, appeared as the most promising use of HTZs. Heilmann, Shih and Hofem 2013 report that only 14 of 53 HTZs established before 2000 still aim to activate and upgrade domestic R&D capabilities. The vast majority instead refocused efforts on attracting foreign investment and export processing activities at the hands of local governments.[34]

Across HTZs, high-tech enterprises are exempt from income tax for two years after becoming profitable. Rates subsequently rise to 7.5 per cent for three years and top out at 15 per cent after that, a substantial discount on the 33 per cent income tax businesses are required to pay outside such zones. Further tax benefits

31 Lewis 2013, 12.
32 Kang et al. 2012, 1913.
33 Ministry of Science and Technology 2012; National Energy Administration 2012.
34 Heilmann, Shih and Hofem 2013.

exist for firms producing "advanced technologies," a category which includes wind turbines, solar panels, and their components. For newly established wind and solar firms, HTZs have cut building taxes, accelerated planning permits, waived VAT and import tariffs on parts and equipment, and permitted accelerated depreciation for high-tech equipment.[35] Localities have also offered discounted land rates to firms seeking to establish manufacturing facilities.[36]

Finally, local governments have channelled preferential loans from state-owned policy banks to support the rapid expansion of manufacturing capacity in renewable energy sectors. Such loans for manufacturing facilities were provided even as central government policies encouraged industry consolidation. It is estimated that between 2010 and 2012, wind and solar firms received credit lines of US$47 billion by Chinese banks. The China Development Bank, one of three state-owned policy banks, reportedly extended US$29 billion in credit to the 15 largest wind and solar firms.[37] Other reports suggest that state-owned banks provided US$18 billion in loans to large wind and solar firms for the expansion of manufacturing facilities. These loans were backed by municipal and provincial governments, allowing firms to expand manufacturing capacity even after the global financial crisis in 2009, when the collapse of European markets led to global overcapacity.[38]

To ensure that firms would rapidly contribute to the local economy, local administrations have frequently made subsidies conditional on meeting production targets and revenue requirements. In many instances, firms were contractually obliged to build facilities with pre-determined manufacturing capacity by a particular date or risk losing government grants, tax reductions, and discounts on land prices. In other cases, local governments informally exerted pressure on firms to rapidly scale production. The CEO of a European wind turbine firm reported that a Chinese partner "constructed a 25,000 square metre facility practically overnight, because local officials had provided financial support and wanted to see results."[39] A president of a solar start-up disclosed that steeply discounted land prices required meeting tax revenue targets, otherwise fines equal to the land discount would have to be paid.[40]

Rather than providing incentives for industry consolidation and the establishment of capabilities in autonomous technology development, local government support targeted speed and scale in manufacturing expansion.

35 Sutherland 2005.
36 Kremzner 1998, 628; Kroll et al. 2008, 191.
37 Bakewell and White 2011.
38 Bradsher 2012.
39 Author interviews: senior administrators, Jiangsu HTZ, 26 March 2015; CEO, European wind turbine engineering firm, 20 May 2011; CTO, Chinese wind turbine manufacturer, 29 August 2011; senior official at Suzhou New District HTZ, 9 January 2012; CEO, European wind turbine manufacturer, 17 August 2011.
40 Author interview, president, solar PV start-up firm, 24 August 2011.

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Exploiting the Implementation Gap

Even before the emergence of domestic wind energy markets and market demand for solar PV technologies in Europe, China's S&T policies created incentives for firms to enter wind and solar industries. Domestic demand for wind turbines resulting from the 2003 Wind Power Concession Programme, subsequent feed-in tariffs, and rapidly growing export markets for solar PV technologies caused additional waves of industry entry.

From the beginning, producers of wind turbines and solar PV technologies took advantage of a public R&D funding. Although China's wind and solar firms used such government grants to fund research and development activities, they did not have to be self-sufficient. Technologies were available to them through multiple global pathways. In the wind industry, Chinese firms had access to turbine technologies through licensing and joint development agreements with foreign manufacturers. The founder of Goldwind reasoned that there was no need to replicate existing technologies. When government programmes encouraged domestic turbine development, Goldwind licensed a design from a German firm and used government R&D funds to build engineering capabilities in commercialization instead.[41] The vast majority of Chinese wind turbine manufacturers entered similar relationships with foreign partners to access turbine technologies. Among the 31 largest wind turbine manufacturers in China, 16 entered license agreements with foreign firms, 14 signed joint-development contracts, six autonomously developed wind turbine technologies, and three started joint venture operations. Seven firms had both joint-development and licensing agreements with foreign firms.[42] The second source of technology for China's domestic turbine manufacturers was provided by global suppliers, many of which eventually established local production facilities.[43] Foreign firms also began sourcing from Chinese suppliers and in turn helped these suppliers meet global technical standards.[44]

In the solar sector, Chinese scientists trained at the world's top solar laboratories founded the majority of firms. Research funding dispensed through the 863 and Torch Programmes and support for high-technology firms in HTZs attracted these scientists back to China. The technological skills of foreign-trained returnees obviated the need for licenses and joint development agreements common in the wind industry, but solar firms still tapped into global technology networks, in particular for production equipment. Centrotherm, a German manufacturer of production lines, began selling its products to China's solar firms as early as 2000.

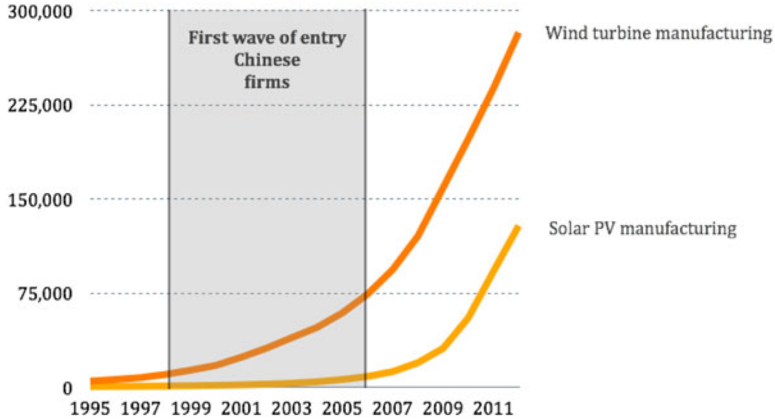
41 Osnos 2009.

42 Compiled from Lewis 2013, 136–137; Wang 2010, 197–203.

43 Wang 2010, 197–203.

44 Information retrieved from company websites; the China Wind Power Center database (http://www.cwpc.cn); Li 2011; *Windpower Monthly* 2005a; *Windpower Monthly* 2005b; *Windpower Monthly* 2006; *Windpower Monthly* 2008.

Figure 1: **Cumulative Global Wind and Solar PV Manufacturing (in MW)**



Source:
Earth Policy Institute 2015. (colour online)

Other foreign equipment manufacturers quickly followed and established Chinese sales networks.[45]

Innovative manufacturing

Foreign partners provided access to key technologies, capabilities, and components that Chinese wind and solar manufacturers were not able to establish in-house. However, they were less capable of helping Chinese producers scale-up new technologies to mass production. When the first Chinese firms entered wind and solar sectors in the late 1990s, production technologies for wind turbines and solar PV technologies had not fully matured and low production volumes still allowed for experimentation and manual labour in bringing new technologies to market (see Figure 1). Few foreign producers of wind turbines were manufacturing at scale, or had done so only very recently. Engineering challenges in the commercialization of wind and solar technologies became acute in 2003, when growing global demand for wind and solar technologies no longer permitted trial-and-error approaches to mass production. Advanced production capabilities and tacit knowledge around design-for-manufacturing were critical to the commercialization of new technologies in highly competitive industries, yet Chinese firms had to establish such skills in-house.

The growing importance of capabilities in scale-up and commercialization coincided with the increased emphasis on the development of domestic innovative capabilities in China's national S&T policy framework. Almost all of China's leading wind and solar producers participated in central government R&D programmes, yet few firms utilized such programmes to build capabilities resembling

45 Nussbaumer et al. 2007, 109.

the indigenous innovation goals set by the central government. Most firms maintained relationships with foreign firms, jointly developing or licensing new renewable energy technologies, even as they received R&D funding under the umbrella of China's indigenous innovation policies. In such collaborations, China's wind and solar firms focused their R&D efforts on building skills that could not be accessed by means of global production networks: knowledge-intensive capabilities in scale-up and mass manufacturing that I refer to as skills in *innovative manufacturing*.[46]

These engineering capabilities went beyond mere fabrication and assembly, as renewable energy manufacturers in China utilized engineering and design knowledge to rapidly translate complex technologies into mass-manufacturable products. Innovative manufacturing included improvements to process designs long associated with manufacturing innovation, but also entailed changes to product designs to accommodate mass production requirements and to meet cost targets for final products. R&D teams in China's renewable energy firms met production and cost targets through the substitution of materials, the redesign of components, and the reorganization of internal product architectures to allow for better and faster manufacturability at scale. As executives repeatedly highlighted in interviews, most firms had access to new technologies through relationships with global partners, so it was those capabilities in achieving speed and cost of manufacturing that set firms apart in highly competitive market environments for wind turbines and solar modules.[47] Out of 25 wind turbine and solar PV manufacturing firms interviewed for this project, 19 discussed the importance of design capabilities in achieving cost and speed targets in the commercialization of renewable energy technologies, even if technologies were originally developed by an external firm. Nine of the 13 wind turbine manufacturers interviewed reported having either significantly redesigned licensed turbine technologies or observed such improvements in technologies licensed by local partners and competitors.

The specialization in innovative manufacturing entailed advanced capabilities in product design, yet it differed from the conception of autonomous technology development at the core of Beijing's indigenous innovation strategy. Chinese wind and solar firms engaged in learning and industrial upgrading, but they did so without developing the full range of industrial capabilities required to invent, commercialize and produce green energy technologies. In spite of government plans to create autonomous local enterprises, China's wind and solar firms have developed highly specialized capabilities within collaborative relationships in global supply chains.

46 For a detailed discussion of innovative manufacturing in China, see Nahm and Steinfeld 2014.

47 Author interviews: R&D Engineer, wind turbine manufacturer, 24 March 2015; Senior VP global supply chains, Chinese solar manufacturer, 13 March 2011; CTO and director of R&D at Chinese solar manufacturer, 26 August 2011; head of China operations, European wind turbine engineering firm, 13 January 2011; CEO, European wind turbine engineering firm, 20 May 2011; CTO, Chinese wind turbine manufacturer, 29 August 2011; CEO, Chinese solar cell manufacturer, 10 August 2011; president, Chinese wafer manufacturer, 26 August 2011. CEO, Chinese cell and module manufacturer, 28 June 2013. See also Nahm and Steinfeld 2014.

Repurposing national innovation policy

Despite differences between central government goals and the individual upgrading strategies of firms, China's wind and solar firms heavily utilized R&D support offered through the Ministry of Science and Technology. Renewable energy firms often used central government R&D programmes to establish two divisions within their research and development facilities. A first group of engineers targeted the development of new wind and solar technologies to match the technological standards of competitors, as intended by the central government programmes. A second R&D division, however, focused on the challenges of scale-up and mass production. It is in this division that the most advanced Chinese wind and solar firms established unique capabilities in bringing new technologies to market. At the wind turbine manufacturer Ming Yang, out of 300 R&D staff in 2010, about one third focused on the development of new technologies, while the remaining engineers worked on bringing technologies to mass production.[48] Similarly, Trina Solar reported that among 425 employees working in its R&D division in 2012, 79 focused on technology development and the remaining 346 engineers devised technical solutions to problems in commercialization and manufacturing.[49]

Wind and solar manufacturers participated in central government R&D programmes, but used such funds to develop engineering capabilities in innovative manufacturing while accessing technology through collaboration with foreign partners. Goldwind, for instance, received central government funding for almost every generation of wind turbine it developed, including gearless turbine technologies accessed through licensing, collaboration, and the subsequent purchase of a majority stake in Germany's Vensys. Under the 9th and 10th Five-Year Plans, Goldwind participated in national science and technology programmes for R&D and commercialization of 600 KW, 750 KW and 1 MW-scale turbine systems. It also received direct funding from the Ministry of Science and Technology for the improvement and optimization of its 1.2 MW turbine as well as support from the provincial-level Department of Science and Technology for R&D on 1.5 MW, 2.5 MW and 5 MW turbines. Yet Goldwind continued to rely on Vensys's R&D teams in Germany for technology development and used government R&D support in China to improve its skills in adjusting, improving and preparing these turbine designs for mass production (Table 2).[50] The fact that Goldwind succeeded in almost every round of central government research funding suggests that the Ministry of Science and Technology, which dispensed such grants, at least implicitly tolerated the repurposing of government funds for collaborative technology development.

48 China Ming Yang Wind Power Group Limited 2011, 54.
49 Trina Solar 2013a, 64–65.
50 CRESP 2005; Tan and Seligsohn 2010.

Table 2: **Goldwind Participation in the 863 Program**

Year	Program Goal	Technology Source
1998	600 KW turbine	Jacobs Energie, Germany (license)
2001	1.2 MW turbine (direct drive)	Vensys, Germany (license)
2005	1.5 MW turbine (direct drive)	Vensys Germany (license)
2010	2.5/5 MW turbine (direct drive)	Vensys Germany (joint development)
2012	10 MW offshore	Vensys Germany (joint development)

Source:
Cresp 2005; Ministry of Science and Technology 2007; Tan 2012.

Other wind turbine manufacturers, such as Mingyang and Sinovel, similarly received support from the 863 Programme for turbine development while retaining foreign partners.[51] Mingyang, which first licensed a turbine design from the German design firm Aerodyn in 2006, intensified its collaboration with the German firm over time. Its latest and most technologically advanced turbine generation – a compact, lightweight turbine technology for use in offshore wind installations – was also based on Aerodyn technology. While Aerodyn supplied the basic technology, commercializing these turbine concepts required changes to product design and substitution of materials to reduce cost and necessitated the production of novel componentry that suppliers were unable to deliver. To build engineering capabilities to address these challenges, the firm utilized central government R&D funds.[52] Sinovel maintained a similar relationship with Austria's Windtec, contributing its skills in commercialization and scale-up to collaborative processes of product development.[53]

Solar manufacturers also took advantage of central government R&D programmes while collaborating with global partners. LDK Solar, for instance, participated in a national project under the 863 Programme to develop environmentally friendly solar PV production processes and took part in two Torch Programme initiatives to improve solar wafers and reduce industrial waste in wafer cutting.[54] EGing Solar received a National Torch-Plan High-Tech Company designation,[55] and China Sunergy obtained 863 Programme funding to develop mono-crystalline solar cells.[56] When central-government policy allowed the establishment of state key laboratories in enterprises in 2007, two solar firms, Trina Solar and Yingli, were among the first that opened such nationally accredited and centrally funded research laboratories on site.[57]

51 Mingyang 2014; SinoCast 2011.
52 China Ming Yang Wind Power Group Limited 2011.
53 Their collaboration did not end well. Sinovel and AMSC are currently embroiled in an intellectual property lawsuit. See Lewis 2013, 116–118.
54 LDK Solar 2014.
55 Solar 2014.
56 CSUN 2013.
57 Trina Solar 2013b; Yingli Green Energy Holding Company Limited 2010.

Among solar firms, too, innovation had a flavour different from the autonomous capabilities in technology development that central government programmes envisioned. Sourcing key technologies abroad, R&D divisions in China's solar manufacturers instead focused on the rapid integration of new technologies, materials and components into existing manufacturing processes. In a case illustrative of this phenomenon, JA Solar worked with the US start-up Innovalight to utilize a new nanomaterial in PV manufacturing. In collaboration with engineers from the National Renewable Energy Laboratory, Innovalight had determined that its nanomaterial could drastically increase the efficiency of silicon cell technologies. Yet it was under a collaborative research agreement with JA Solar (and in JA solar test facilities in China) that engineers from the two companies adjusted the material for use in large-scale solar PV production. What Innovalight engineers contributed in upstream R&D capabilities, JA Solar made up for in knowledge about how components needed to be adjusted to work on existing production lines.[58] Similar capabilities allowed CSUN to be the first solar firm to commercialize selective emitter cells, a technology based on a commonly known scientific principle that no other company had yet been able to realize. CSUN, in bringing selective emitter cells to market, worked closely with German suppliers of production equipment and materials. The research that allowed the process to work, however, was conducted in CSUN facilities in Nanjing.[59]

The specialization in innovative manufacturing among China's wind and solar firms was a combination of existing capabilities in mass production, which were abundant in China's industrial parks, and new skills in product design and design-for-manufacturing, which were supported through China's domestic S&T infrastructure and indigenous innovation programmes. As such, capabilities in innovative manufacturing were not the outcome of targeted government intervention, but were established at the hands of entrepreneurial firms. These firms identified opportunities in global supply chains and subsequently repurposed and combined a wide range of government resources to improve existing capabilities to respond to such opportunities.

Building on the manufacturing economy

Virtually all of China's wind and solar firms are physically located in high-tech industrial development zones, where they have established innovative manufacturing capabilities in an environment that has not only offered investment incentives to firms, but has also encouraged a focus on mass production. In principle, the institutional support for manufacturing in China's HTZ opened opportunities for the shirking of upgrading goals set by the central government. In practice, however, local governments enabled the development of knowledge-intensive skills in commercialization and scale-up through the provision of financial

58 JA Solar 2010; Wang 2011.
59 CSUN 2011.

support for manufacturing expansion at a time when financial markets in Europe and the United States were reluctant to lend to emerging green energy industries.

Almost all of China's wind and solar firms relied on local governments to enter renewable energy industries and to fund the production facilities on which innovative manufacturing capabilities could be applied. Goldwind, for instance, set up its first manufacturing plants in Urumqi's HTZ, where it participated in a tax refund programme for high-tech manufacturing enterprises that returned 15 million yuan in taxes to local firms in 1999 alone.[60] In 1998, the Baoding municipal government supported the creation of Yingli Solar in Baoding's High-Tech Industrial Zone with a 166 million yuan investment. In return, the local administration required the establishment of 3 MW of production capacity, an ambitious goal for a single firm at a time when the United States, then the global leader in PV production, had a national production capacity of 54 MW.[61] Trina Solar relocated its operations to a Changzhou HTZ in 2002 to qualify for preferential income taxes, yet moved to a neighbouring zone in 2004 after its original tax discount expired.[62] Mingyang set up its headquarters in the National Torch High Technology Industry Development Zone in Zhongshan, Guangdong province, in 2006.[63] In 2010, after the company was listed on the New York Stock Exchange, its annual report disclosed 111.1 million yuan in cash grants by local governments to support R&D, the improvement of manufacturing facilities and the acquisition of land.[64]

For firms setting up production facilities, HTZs offered access to financing, channelling bank loans and other forms of funding to local firms. The special focus on new energy industries in national science and technology plans made China's state-owned financial institutions more willing to lend to wind and solar companies, but local governments were critical brokers in such deals, particularly when the first wind and solar firms were founded. Loans were frequently guaranteed by municipal government entities or by local state-owned firms that partnered with wind and solar firms. The city of Wuxi, for instance, invested US $6 million in return for a 75 per cent equity stake in the solar PV producer Suntech in 2001. To fund the rapid expansion of Suntech in the following years – by 2006, Suntech was the world's third-largest producer of solar panels – local officials brokered a series of bank loans for the company.[65] For a single 68,0000-square-metre production facility launched in 2005, a 200 million yuan investment was financed through such connections.[66] In 2007, Yingli Solar borrowed US$17,821,402 from the Bank of China backed by a local state-owned

60 *Urumqi Yearbook* Editorial Committee 2000, 116.
61 *Baoding Yearbook* Editorial Office 1999, 111.
62 Trina Solar 2009, 36.
63 Guang Dong Mingyang Wind Power Technology Co. Ltd 2007.
64 Guang Dong Mingyang Wind Power Technology Co. Ltd 2007, 53.
65 Ahrens 2013, 3–4.
66 *Wuxi Historical Annals* Editorial Office 2006, 293.

firm.[67] In 2009, Trina Solar secured a five-year credit line of US$303,279,927 from a syndicate of banks to expand its manufacturing capacity.[68] Not only was local government support critical in securing the loan, but local guarantees also allowed Trina to obtain waivers on loan conditions that are usually attached to large investments in high-risk, emerging industries.[69]

Access to large-scale financing of course provided no guarantee for upgrading. Localities lent indiscriminately and contributed to overcapacity in global renewable energy markets. Between 2009 and 2011, the capacity utilization of existing solar PV manufacturing plants fell from just over 60 per cent in 2009 to just under 50 per cent in 2011.[70] Even though, in the aggregate, only half of China's solar PV plants were running at capacity, solar PV firms continued to receive credit to expand manufacturing facilities, preventing industry consolidation and protecting firms that were no longer able to compete. At the same time, however, local financing made possible the physical infrastructure on which innovative manufacturing skills could be applied in ways that central government R&D funding alone did not. Firms could not fund their way to engineering capabilities in commercialization, yet the availability of financing for production facilities enabled the specialization in innovative manufacturing in China's most capable wind and solar firms. In interviews, foreign partners of solar firms praised the R&D conditions in Chinese firms, where financing for manufacturing facilities allowed firms to dedicate entire production lines to testing and experimentation with new technologies.[71]

Once localities had successfully attracted firms, a second set of policies and institutions supported the activities of local firms in a more targeted way. Municipal governments were active agents in the composition of the local economy, interpreting central directives to promote strategic industries in ways that were compatible with existing industry structures. Although many of the early wind and solar firms were simply established in proximity to their parent companies or in the hometowns of their founders, municipalities attracted supplier firms and companies from related industrial sectors. For instance, Wuxi, the city where Suntech was founded in 2001, courted a large number of suppliers, including glass manufacturers and firms supplying silicone and other materials required for PV production, to set up local facilities.[72] Baoding, where Yingli had started the domestic solar PV industry in 2001, ultimately branded itself as a "green city," attracting a wide range of renewable energy firms and suppliers with complementary capabilities to its local industrial parks.[73]

67 Yingli Green Energy Holding Company Limited 2008, F-28.
68 Trina Solar 2010, F-30.
69 Trina Solar 2013a, F-35–36.
70 Zhao, Wan and Yang 2015, 183.
71 Author interviews: CEO, Chinese solar manufacturer, 20 August 2011; CTO and director of R&D at Chinese solar manufacturer, 26 August 2011; CEO, German equipment manufacturer, 10 May 2011; CTO, German equipment manufacturer, 11 May 2011.
72 *Wuxi Historical Annals* Editorial Office 2003, 219; Wuxi historical annals editorial office 2006, 292.
73 *Baoding Yearbook* Editorial Office 2004/2005, 155.

In other cases, wind and solar firms chose HTZs specifically for the existing local industrial base. A history of shipbuilding and the presence of related supplier industries, including bearings manufacturing, persuaded Sinovel to open its first manufacturing facilities in Dalian.[74] Tianjin became a popular destination for domestic wind turbine producers after the city had successfully attracted foreign wind turbine manufacturers and their suppliers.[75] In Changzhou, where Trina Solar and EGing Solar were producing cells and solar PV modules, the municipal government counted 109 firms manufacturing products and components for power generation equipment, including transformers, inverters, electrical insulation and switching equipment.[76]

For domestic manufacturers seeking to upgrade their innovative manufacturing skills, these local economies created supplier networks capable of delivering large quantities of raw materials at short notice. They permitted close interaction with suppliers on tweaking equipment and adjusting material composition to match product designs and manufacturing processes. For engineering teams seeking to find ways to accelerate product commercialization, local economies offered a range of partners focused precisely on large-scale production of renewable energy technologies. The president of a solar PV start-up explained their locational choice in proximity to other solar PV manufacturers with the availability of used production equipment on which engineering teams could cheaply test the manufacturing of new product designs.[77] Others emphasized the presence of local suppliers with whom they could collaborate on incorporating substitute materials or improving production equipment design.[78]

HTZs also funded individual commercialization projects in firms. Many such programmes focused not on laboratory research, but on the commercialization of new technologies and the transition to mass production. Almost all localities set up municipal innovation funds, providing grants for innovation-related activities in local firms. These grants supported activities to overcome challenges in the commercialization of new technologies, rather than the development of such technologies themselves. Although most grants went directly to firms, localities also used such programmes to fund facilities such as public test centres and other types of complementary capabilities for firms in the local economy. In Dalian, the municipal government in 2006 supported Sinovel in the commercialization of a 1.5 MW turbine technology based on a license from a German firm, in the process adapting the turbine for deployment under harsh climate conditions. Two local suppliers, Dalian Tianyuan Electrical Machinery and Dalian Wazhou Group, developed components for the new turbine. The local government also aided Dalian Wazhou in constructing a test platform for

74 *Dalian Historical Annals* Editorial Office 2007, 130–139.
75 Tianjin municipal government 2010, 241–242.
76 *Changzhou Yearbook* Editorial Committee 2005, 173.
77 Author interview, president, solar PV start-up firm, 24 August 2011.
78 Author interviews: CTO and director of R&D at Chinese solar manufacturer, 26 August 2011; CTO, Chinese wind turbine manufacturer, 29 August 2011.

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industrial-scale precision bearings to support the commercialization of new bearing designs.[79] In collaboration with Suntech, the Wuxi government in 2006 initiated a so-called "530 Programme," providing funds to attract Chinese engineering graduates back into local high-tech development zones and offering grants of 1–3 million yuan for the commercialization of promising technologies. By 2012, 876 local firms were participating in the 530 programme and programme funds had grown to a total of 2.5 billion yuan.[80] The Baoding municipal government funded the development of two public engineering centres in the local HTZ, a centre for virtual engineering and an engineering centre for blade development, both of which offered access to test facilities most firms did not establish in-house.[81]

Local government policies, training institutions and innovation support programmes did not add up to a comprehensive strategy for industrial upgrading, but presented ad hoc responses to the perceived needs of local firms, central government directives to promote innovation, and the need to promote economic growth. For wind and solar firms, these policies broadened the range of resources that could be used to improve engineering capabilities and fund the expansion of manufacturing facilities. Just as central government policies had not deliberately supported the establishment of capabilities in innovative manufacturing, local governments and high-tech development zones did not strategically choose capabilities in technology commercialization as an upgrading goal.

Conclusion

This article has made the case that China's renewable energy firms have exploited the divergence between central and local government policies to establish unique R&D capabilities focused on commercialization and rapid scale-up to mass production. In doing so, China's wind and solar producers have not directly followed central government policy goals, which encouraged the emulation of foreign R&D capabilities and the development of autonomous skills in technology development. Yet neither have they used local government support for mass manufacturing purely to subsidize production cost. Instead, entrepreneurial firms identified in global supply chains the need for innovation focused on preparing complex technologies for mass production and deployed the tools available to them at different levels of government to respond to these opportunities. Such innovation in renewable energy sectors has not resulted from novel enforcement mechanisms or improved bureaucratic discipline to close the implementation gap between different administrative layers in China. Instead, this article has argued that the implementation gap itself has broadened the resources available to Chinese firms seeking to upgrade in global environmental sectors.

79 *Dalian Historical Annals* Editorial Office 2007, 130–139.
80 *Wuxi Historical Annals* Editorial Office 2008, 241.
81 *Baoding Yearbook* Editorial Office 2004/2005, 155.

The case of China's wind and solar sectors suggests that manufacturing policies at the local level have not undermined central government goals of creating innovative green energy industries, even if firms have not developed the full range of engineering skills autonomously to autonomously bring new technologies to market. Local manufacturing policies have complemented national R&D programmes and expanded the types of resources available to wind and solar firms. Such manufacturing support has provided a corrective to the conceptualization of innovation underlying central government policies, which focused primarily on the autonomous invention of new technologies without paying attention to the importance of advanced production capabilities in commercialization and the global nature of innovation in contemporary high-tech industries. At least implicitly, the creative use of government resources was tolerated. Neither central nor local governments have stepped in to prevent the repurposing of existing institutions and policies for innovative manufacturing, even if they did not meet expectations about traditional trajectories of industrial upgrading. The behaviour of the Chinese state has contrasted sharply with that of other East Asian developers, which rewarded firms only when meeting set upgrading goals. The use of disciplinary mechanisms to encourage firms to meet set upgrading goals, which Amsden has identified as an important factor in creating competitive firms in South Korea, would certainly have prevented firms from embarking on innovative manufacturing strategies.[82]

While opportunities for firms to shirk regulatory compliance in China's decentralized development model have been widely documented, the case of renewable energy industries highlights that policy divergence can also enable novel strategies for innovation and industrial upgrading outside the scope of government plans. This complementarity between central and local policies may be particularly applicable to environmental industries, where firms can bridge the gap between central mandates for high-tech innovation and local incentives for manufacturing growth. The implementation gap remains more difficult to overcome in areas of environmental regulation, for instance, where industry is more directly opposed to both central and local government enforcement.[83] Ultimately, however, there is hope that the creation of competitive domestic environmental industries can also help improve broader environmental outcomes in China. Globally, economies in which governments have successfully supported the creation of green energy industries have also been more likely to adopt more ambitious climate and environmental policies with the help of domestic industrial coalitions and broader public support.[84] China's unexpectedly constructive role in the 2015 United Nations climate change negotiations in Paris suggests that it may not be an exception to this trend.[85]

82 Amsden 1989, 145–147; Amsden 2001, 8–12.
83 Kostka and Hobbs 2012.
84 Laird and Stefes 2009; Meckling et al. 2015; Zysman and Huberty 2013.
85 Ye and Wu 2015.

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摘要: 这篇论文讨论了中国地方政府针对制造业出台的政策在很大程度上弥补了中央政府自主创新政策框架内的不足，尤其是矫正了中央政府疏忽了先进制造能力创新的问题。基于对 43 家中国风能太阳能企业 100 位总经理进行的访谈所得到的原始数据的分析，我认为中央政府提供的研发资金和地方政府对制造业的支持都是促使中国可再生能源生产方式进行创新的重要因素。这篇论文特别指出，企业依靠国家和地方的双重政策来实现商业化和获得大规模生产中所特别需要的工程能力。研究指出，地方政府对制造业经济的后续支持没有违背中央政府创新政策的要求，而是(1)为企业提供了更多的可用资源和 (2) 为企业的产业升级提供不同于中央政府自主创新框架之外的新选择。

关键词: 风能; 太阳能; 创新政策; 产业升级; 制造业

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