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R&D collaboration for wind energy in China: Local diversity, achievements and limits

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Abstract

This paper examines the role played by government-enterprise-university collaboration in enhancing China's R&D capacity with a particular reference to wind energy. Drawing on a comparative study of three provinces, Xinjiang, Shanghai and Guangdong, this paper presents two major findings. First, the three provinces, though embedded in the same national technological innovation system, reveal a local diversity in their models of government-industry-university collaboration. Xinjiang illustrates a *hierarchical* model while Shanghai's model is a highly *institutionalised* one. Guangdong has adopted a *market* model. Our second finding is that while these different collaborative models have enhanced the R&D capacity for wind energy, they exposed two major limitations: quality assurance and the lack of market competition. One reason for these limitations appears to be under-investment of public resources in the wind power industry. Enterprises have replaced the government as the key driver for R&D. We conclude that there is a need to better define the comparative strengths of central government and provinces, and between the government, enterprises and universities in China's technological innovation systems, and to develop a better designation of their respective tasks and responsibilities.

Introduction

The capacity to innovate, design and produce new products and services is the key to attain global competitiveness for many economies (Koh and Wong, 2005). The development of domestic wind turbine industries is a key area of technological innovation in many developed (such as Germany and the US) and emerging countries (such as China and India) and represents an element in these countries' strategic plans to restructure their economies in a way that is more innovation-based and sustainable (BMU, 2007a, b; DOE, 2008; IWTMA *et al*., 2009).

However, technological innovation has been as a major challenge for the development of wind energy worldwide. From basic R&D to applied R&D, and from component manufacturing (e.g. gear boxes and blades) to assembling entire wind turbines, the wind turbine manufacturing industry requires technological innovation in many ways. This technological innovation process is a challenge because it is subject to financial risk, long payback periods, and risks of failure in the R&D processes (Lewis, 2007).

Different countries have adopted various approaches to enhancing R&D capacity for wind energy with different outcomes. Germany and Denmark have been the pioneers in the global wind turbine manufacturing industry (IEA, 2009). They are good examples of western economies in which the R&D systems for wind energy are characterised by incremental innovation that require sustained trial-and-error learning processes and an emphasis on basic R&D rather than focusing on applications only (Burton, 1993). Another distinctive feature of these western models is the important role of small and medium enterprises (SMEs) and industrial associations (Burton, 1993).

In contrast, the R&D system for wind energy in China has demonstrated some unique characteristics. While most of the leaders in wind energy introduced substantial R&D efforts in the late 1970s (Lewis and Wiser, 2007), China is a relative late-comer in this field. Major R&D programmes for wind energy have grown in number and scale in China only in recent years following the enactment of the nation's renewable energy law in 2005 (Baker and McKenzie *et al.*, 2007).

However, China's R&D system has enjoyed the advantage of being able to leapfrog the R&D process. R&D policies for wind in China emphasise the importance of developing self-sufficient domestic wind turbine manufacturing industry in the shortest time. The Chinese model therefore tends to focus on getting things done rather than achieving the highest quality. Chinese manufacturers have been relied on purchasing production licenses from foreign counterparts to leapfrog the innovation process (Liu, 2006). Another characteristic of the Chinese system is the key role played by the government and state-owned enterprises (CWEA, 2010).

Although wind energy has potential to promote a more sustainable future in China, the outlook for this form of renewable energy in China is by no means clear. The exponential growth of new wind farms in recent years doubled China's installed capacity of wind energy each year between 2004 and 2009, reaching 24 GW by the end of 2009 (Mah and Hills, 2010a). China has also played a more central role in the international stage. In 2009, China overtook Germany and ranked second in the world in terms of cumulative installed capacity. China also topped the world for newly installed capacity in 2009 (Li *et al*., 2010). Wind energy, however, has remained a fringe energy source in China. Wind energy contributes only 1.4 percent of the country's total electricity generation and just 2.8 percent of total installed generating capacity (end 2009) (Mah and Hills, 2010). Limits on technological innovation capacity, quality assurance, and reliable supplies of components have been identified as major limitations constraining the growth of wind energy in China (Li *et al.*, 2010; Mah and Hills, 2008).

It is in this context that this paper aims to provide a better understanding of the R&D system for wind energy in China. It does so from the perspective of governance for technological innovation capacity. The paper focuses on a particular governing strategy – collaboration between government, enterprises and universities – in enhancing R&D capacity.

Government direct investment, demonstration funding, policies and institutions are important to R&D capacity in both developed and emerging economies (Burton, 1993; Koh and Wong, 2005; Kempener *et al*., 2010). However, by focusing on government-enterprise-university collaboration, this paper argues that a more bottom-up and inclusive approach that relies more on horizontal linkages between the government and actors outside the government is also critical to the R&D capacity for wind energy in China.

This paper begins by exploring major theoretical perspectives on the notion of R&D capacity. We then provide an overview of the evolution and characteristics of China's R&D system in general, followed by a detailed comparison of the local R&D systems for wind energy in three provinces, Xinjiang, Shanghai and Guangdong. By contrasting the three cases, we then offer policy recommendations for promoting R&D activities for wind energy in China.

R&D collaboration in theoretical perspectives

Our analysis draws on social science theories concerning technological innovation systems and governance. The literature on technological innovation systems first emerged in the late 1970s and offers an understanding of the complexity and dynamics associated with R&D activities including those in the area of renewable energy (Huang and Wu, 2007; Hoogma *et al*., 2002).

Central to the literature on the technological innovation systems is its systemic perspective. Technological innovation requires not only technological advancements but also co-evolution in the institutional, policy, behavioural, organisational and other elements in a technological system (Cames *et al*., 2004; Praetorius *et al*., 2009). Technological innovation is a societal transformation process that involves not only government, but also the interactions of a dynamic network of agents in the "generation, diffusion, and utilisation of technology" (Carlsson and Stankiewicz, 1991: 93). This transition process is a complex and difficult one in which uncertainty, power relations and institutional barriers have to be addressed (Geels, 2007; Praetorius *et al*., 2009).

Network building is a key to enhancing innovation capacity (Jacobsson and Lauber, 2006; Jacobsson and Johnson, 2000). The literature suggests that a broad range of actors, including firms, governments, universities and research institutes (Liu and White, 2001a) are linked in various forms of networks such as those based on user-supplier relationships (Fischer, 2001) as well as those of a political nature (Jacobsson and Lauber, 2006; Jacobsson and Johnson, 2000).

However, the actual mechanism of network building are not well studied, and this explains why this literature has thus far had only a limited impact on policy (Rondé and Hussler, 2005; Geels, 2007). Collaborative governance therefore is a relevant concept that may complement the literature on the technological innovation systems to illuminate how networks develop within the innovation systems for wind energy in China.

Collaborative governance, or governing through collaboration, has its roots in the governance perspective. The term “governance” can be traced back to the Latin and ancient Greek words for the “steering” of a boat (Jessop, 1998). Central to the concept of governance is the move away from government to governance (Pierre & Peter, 2000). Since the mid-1990, there has been a recognition of the limits of the ability of government to govern (Cope *et al.*, 1997; Kettl, 2000; Satterthwaite, 1999). Governance therefore emphasises the need for governments to reach out downwards to localities, and to move out to civil society and to engage with markets (Pierre and Peter, 2000; Stoker, 1998; Satterthwaite, 1999).

The move away from government to governance aims to enhance governments’ capacity to govern, that is the capacity to steer society towards collective goals (Pierre and Peter, 2000). New governing strategies include multi-level governance (Goodwin and Painter, 1996; Lyons and Deutz, 2010; Scharpf, 1997), public-private collaboration (Ansell and Gash, 2008; Austin, 2007; Eweje, 2007), public participation (Beierle and Cayford, 2002; Beierle and Konisky, 2001; Chess and Purcell, 1999) and policy learning (Fiorino, 2001; Gouldson *et al*., 2008; Mah and Hills, 2009).

Governing through collaboration is a multi-actor, multi-sector approach to problem-solving (Mah and Hills, 2010a). Collaboration is a form of partnership that emphasises the engagement of a broad spectrum of actors to pool together their inputs (Ansell and Gash, 2008; Cordery, 2004; Cuthill, 2002; Eweje, 2007), and the achievement of not only individual ends but also additional, shared benefits (Thomson and Perry, 2006).

Collaborative governance is a relevant perspective to analyse China’s technological innovation system for a number of reasons. Firstly, the global trend of shifting towards broader linkages between universities and industry in innovation is evident (Wu, 2007), suggesting that many of the potential solutions to R&D problems require inputs from diverse stakeholders outside the government itself.

Second, in the Chinese context, economic reforms and the associated administrative and enterprise reforms over the past three decades have gradually given industrial linkages, competition, incentives and learning a more important role in innovation performance (Liu and White, 2001a, b; Motohashi and Yun, 2007).

However, although collaboration may appear to be a governing strategy that can strengthen China's innovation capacity, the literature in this regard is limited, and the outcomes appear to be mixed. Works by (Chang and Shih, 2004), for example, have found that although R&D collaboration has become increasingly common in China, it has been unable to make a major contribution to the efficiency of China's innovation system.

Furthermore, the inherent differences between the Chinese and western innovation systems contexts may limit the explanatory power of western perspectives on governance, collaboration and innovation systems in China. Despite three decades of economic reform, state-owned enterprises rather than private firms still dominate the Chinese economy particularly in the "strategic sectors" such as the electricity sector (Pearson, 2005; Mah and Hills, 2008). The state rather than private profit-seeking firms appear to be the major driving force for innovation in China (Verspagen, 2006). The weaknesses in China's legal system are also a limiting factor for inter-firm collaboration which is a crucial element in technological innovation processes in the West (Liu and White, 2001a).

The analysis of China's R&D capacity from the perspective of collaboration therefore generates a number of interesting research questions, including:

- Has government-industry-university collaboration enhanced R&D capacity, i.e. the governing capacity to steer society to reach R&D goals, in China?
- What are the mechanisms that are critical to the contributions? Who are the key players? What are the key forces for change?
- What are the limits of such collaboration in the context of China? What are the constraints and how do they limit the innovation process? How can these barriers be overcome?

Methodology and the three selected provinces

To address these research questions, this paper adopts a comparative case study approach (Yin, 2003) to exploring whether and how government-enterprise-university collaboration can strength the R&D capacity in China in the specific context of wind energy. By systematically comparing and contrasting the evolution of government-enterprise-university collaboration and the development of wind energy in the three provinces of Xinjiang, Shanghai and Guangdong, and by advancing explanations for those similarities and differences (Miles and Huberman, 1994), our analysis will provide a better understanding of the nature, diversity, mechanisms, prospects as well as the limitations of collaboration in the Chinese context.

This study focuses on three Chinese provinces, namely Xinjiang in the northwest, Shanghai on the east coast and Guangdong in the southeast for comparative case-study. The provinces were selected because they represent a diversity of political, socio-economic and environmental contexts across China (Table 1).

Xinjiang is an autonomous region which is economically backward, politically unstable, and has been under the close control of the central government (Chung, 2003; Shichor, 2005). Shanghai, on the other hand, is one of the four municipalities directly subordinated to the central government, and has been economically and politically pivotal to the country (World Bank, 2006; Tang, *et al.*, 1997). In contrast, Guangdong is one of the wealthiest Chinese provinces (HKTDC, 2009) and has enjoyed a relatively higher level of policy autonomy granted by the “special policy and flexible measures” (Cheung, 2002). Provinces, autonomous regions, municipalities, and special administration regions are all granted political status as a provincial-level administrative unit in China (Qi *et al.*, 2008; OECD, 2005).

The three provinces also differ in terms of their R&D systems including gross domestic expenditure on R&D (which includes national and local public expenditure), science and technology appropriations by the local government as well as R&D personnel by region (Table 2). In all these key aspects of R&D, Xinjiang substantially lags behind Shanghai and Guangdong while Guangdong was the top among the three in these three aspects. For instance, the gross domestic expenditure in Xinjiang in 2008 was 1.6 billion yuan, which was only about 3 percent of that of Guangdong (CSTS, 2009).

The case studies presented here draw on data and information derived from desktop research, semi-structured interviews and field visits. 23 semi-structured interviews were conducted in 7 field trips to Beijing, Xinjiang, Shanghai and Guangdong between 2006 and 2010. The interviewees were key informants and stakeholders in the development of wind energy in the three provinces and in China. They included government officials, senior executives from utilities, wind farm developers, wind turbine manufacturers, academics, and scholarly/ industrial associations. As some interviewees agreed to be interviewed only anonymously, this study indicates interviews by number. The first two letters indicate the location (BJ for Beijing, XJ for Xinjiang, SH for Shanghai, and GD for Guangdong), the two digits indicate the interview numbers, and this is followed by the year of the interviews. The list of interviews is provided in the appendix.

Table 1: The basic features of the three Chinese provinces selected for this study

	Xinjiang	***Shanghai***	***Guangdong***
Location	Northwest; inland	Central; coastal	Southeast; coastal
Capital	Urumqi	N.A.	Guangzhou
Provincial status	Autonomous region	Municipality	Province
GDP (billion yuan) (2008)	420	1,370	3,570
Population (million) (2008)	21.3	18.9	95.4
Area (km^2)	1,664,900	6,341	179,757
Density (person/km^2)	13	2,980	531
Environment	Energy base for the nation Fragile eco-system	Eco-city vision	Environmental problems have already constrained economic growth
Landscape	Grassland Deserts Glaciers	Alluvial plain	Coastal Low mountain ranges

(Sources: Cheung, 2002; HKTDC, 2009, 2010a, 2010b; Shanghai Statistics, 2008; Zhang, 2002)

Table 2: R&D Statistics in China and major provinces (2008)

	National Total	**Beijing**	**Xinjiang**	**Shanghai**	**Guangdong**
Gross Domestic Expenditure on R&D (100 million yuan)	4616.0	550.3	16.0	355.4	502.6
Local government Science and Technology Appropriation (million yuan)	105,186 (2.14%)	11,219 (5.73%)	1,484 (1.40%)	12,027 (4.64%)	13,252 (3.51%)
R&D Personnel by region (1000 person/years)	1965.36	189.55	8.81	95.13	238.68

(%)：percentage of local public expenditure (地方财政支出)
(Source: authors; data from CSTS, 2009)

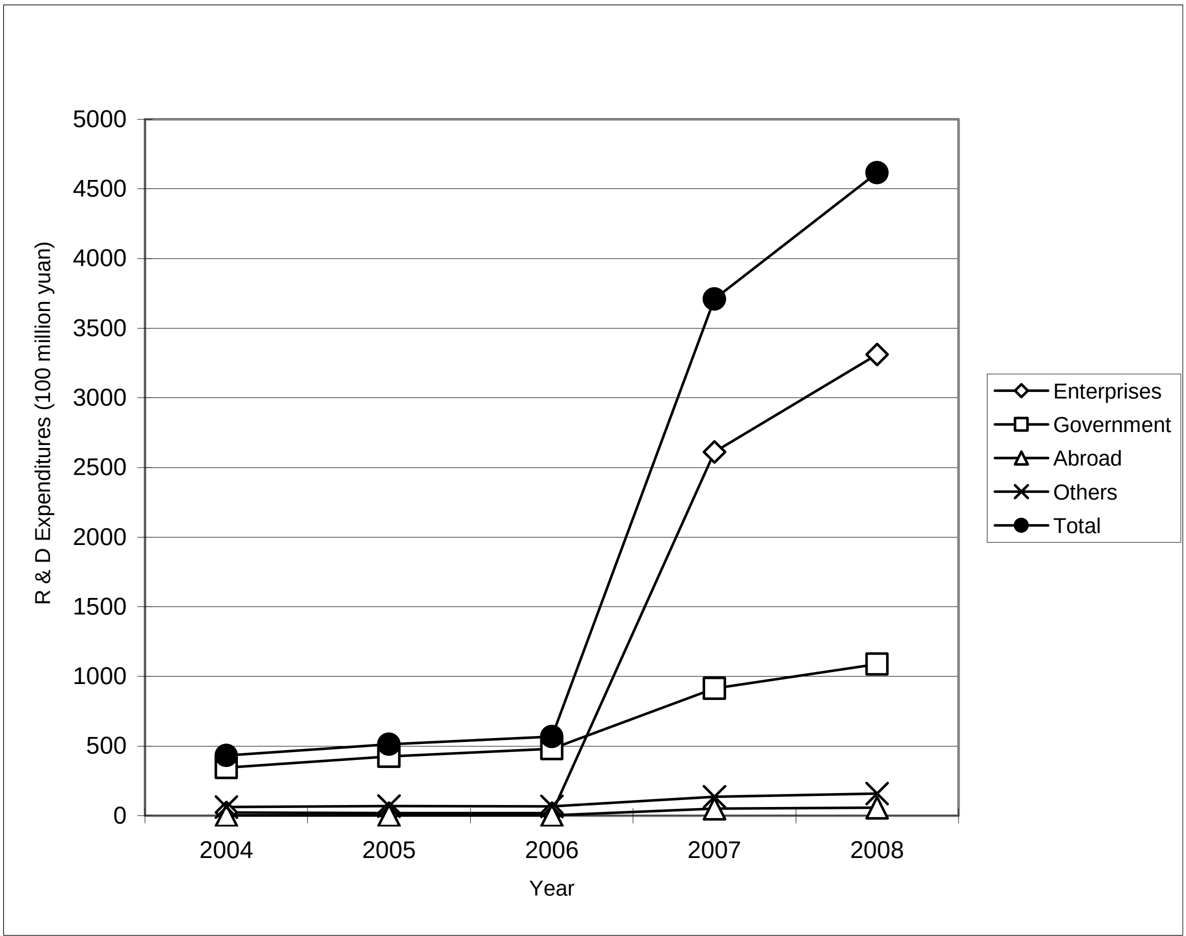
China's R&D systems for wind energy

R&D systems and the associated relations between government, enterprise and university have experienced major changes in China since 1979 as the country has gradually transformed from a planned economy to a socialist market economy (Liu and Jiang, 2001). Before the reforms, China's R&D system was vertically organised in which central government developed R&D plans and allocated R&D work to relevant research institutes (Chang and Shih, 2004). Horizontal linkages between research institutes and industries were virtually non-existent in the pre-reform period (Liu and Jiang, 2001).

Relationships between government, enterprises and universities have experienced major changes over the past three decades. Since the early 1980s, the central government has been decentralizing its R&D responsibilities and its administrative authority (Wu, 2007). The drastic cut in government R&D funding was accompanied by strategies to give enterprises a key role in performing R&D activities, and to foster horizontal ties between enterprises, research institutes and universities (Wu, 2007; Zhang *et al.*, 2009).

Enterprises have become much prominent in China's R&D system since 2006 when the central government introduced the strategy of "enterprise-led indigenous innovation" in its national 2006 Science and Technology Programme. Since then, R&D investment by enterprises has increased rapidly, and has overtaken the government as the main source of R&D funding. While the government R&D investment doubled from approximately 48 billion yuan in 2006 to approximately 109 billion yuan in 2008, R&D investment from enterprises recorded approximately a 200-times increase from 1.7 billion yuan in 2006 to 331 billion yuan in 2008 (Figure 1).

Figure 1: Sources of R&D expenditures in China (2004-2008)



(Source: compiled by authors; data from China Science &Technology Statistics Data Books, 2005-2009, electronically available from http://www.sts.org.cn/sjkl/kjtjdt/index.htm)

This "enterprise-led" strategy has transformed the relationship between enterprises, universities and the Chinese government (Wu, 2007; Zhang *et al.*, 2009). While enterprises have been regarded as the primary driver of China's R&D system (Zhang *et al.*, 2009), there are expanding networks of universities, research institutions and enterprises in many high-tech industries (Liu and White, 2001a, b), including wind energy industry.

It is in this transitional context that China has stepped up its efforts to develop a technological innovation system for wind energy, particularly following the enactment of China's renewable energy law in 2005 (Baker & MeKenzie *et al.*, 2007). The role of the Chinese government has also changed. It has placed greater emphasis on leveraging private R&D spending through various kinds of subsidies, tax incentives and other policies. The National Development and Reform Commission (NDRC), the Ministry of Science and Technology (MOST) and the Ministry of Finance (MOF) are the main agencies in charge of technological policies, and the implementation and allocation of R&D funding for wind energy. The national R&D

programs such as the High-Tech Industry Development Program and Torch Program incorporated wind turbine manufacturing as a key component (Goldwind, 2009).

The main fields of R&D research on wind energy focus on resolving technological problems in some key components of domestic wind turbines such as gear boxes and power control systems. Recently, there has been growing interest in smart grids and energy storage.

The Chinese model of R&D for wind energy has achieved some successes. The costs of wind energy have been driven down substantially as the domestic market has been increasingly localised. Domestic wind turbine manufacturers dominate the Chinese market, accounting for about 70 percent of China's supply market (Li *et al*., 2010). Wind cost per kWh ranged from 7,000 (for domestic turbines) to 10,000 (for imported turbines) yuan in the mid 2000s (Liu, 2006), but by 2010 it had been driven down to below 4,000 yuan (CWEI, 2010). Chinese manufacturers have also begun to emerge as a global player in recent years. Three manufacturers, Sinovel, Goldwind and Dongfang were ranked among the top 10 global manufacturers of wind turbines in 2009 (REN 21, 2010).

Despite these achievements, innovation capacity and quality control remain major concerns. The reliance on foreign technology in the past resulted in a relative weak capacity for innovation particularly in relation to basic R&D (Interview XJ/1/ 2008). While the leading domestic manufacturers have started to develop 5 MW or larger turbines (REN 21, 2010), manufacturers in the West have already installed wind turbine of 7.5 MW (REN 21, 2010). Chinese wind turbine manufacturers also still rely on foreign counterparts for certain core turbine technologies such as gear boxes (Liu, 2006; Interview GD/01/2010). Other concerns include the quality of domestic turbines, a lack of reliable supply of components and an under-developed network of ancillary services such as certification bodies (Li *et al.*, 2010; Mah and Hills, 2008).

R&D collaboration models for wind energy: local diversity across Chinese provinces

Under China's national R&D system for wind energy, a diversity of local R&D systems has emerged. The local models in Xinjiang, Shanghai and Guangdong are discussed as follows.

(a) Xinjiang: a *hierarchical* model

Located in the far northwest inland of China, Xinjiang is economically backward and environmentally fragile (HKTDC, 2010b). However, with some of the best wind resources in China (Tang, 2009; Editorial Committee, 2005), the autonomous region has some significant achievements in wind energy in recent decades.

One distinctive feature of the development of wind energy in Xinjiang has been its association with Goldwind Science and Technology Co. Ltd. (金风 *Jinfeng*) – one of the leading domestic wind turbine manufacturers in China. The growth of Goldwind has reflected the effectiveness of a hierarchical model of government-enterprise-university collaboration in promoting wind energy.

Goldwind is a Chinese company whose beginnings can be traced back to a small company, Xinfeng, which was wholly owned and founded by the Chinese government in 1998 in Urumqi, the capital of Xinjiang (Goldwind, 2009). Despite its remote location, Goldwind has been China's leading domestic wind turbine manufacturer since the early 2000s and was ranked second only in 2009 after being surpassed by Sinovel (CWEA, 2010). It has also entered the world's top 10 manufacturers list for the first time in 2006 (Lewis, 2007). Goldwind occupied approximately 20 percent of the Chinese market in 2009 (CWEA, 2010). By August 2010, Goldwind had sold more than 9,000 wind turbines with a total electricity generation capacity of 26 billion kWh (Goldwind, 2011).

A distinguishing feature of Xinjiang's hierarchical model is the pivotal role of the central government. The central government has played a critical role in acting as an incubator and pacesetter for the domestic wind turbine industry and therefore created a conducive environment in which Goldwind was able to grow rapidly.

Following the enactment of China's renewable energy law in 2005, the central government introduced a number of policies for wind energy (Mah and Hills, 2008). To Goldwind, the most important policies are the tendering pricing policy (this policy is commonly known as concession model in China, and was first introduced in 2003) (Gardiner, 2007; Mah and Hills, 2009) and the associated domestic content requirement (which was later officially introduced in 2005 requiring wind turbines used in China to meet a 70 percent domestic content (NDRC, 2005). The tending pricing policy effectively created a substantial market demand for domestic wind turbines, including those produced by Goldwind (Lewis, 2005, 2006; Interviews XJ/02/2007, XJ/03/2007).

Another distinctive element of Xinjiang's R&D model has been the establishment of the National Windpower Engineering Technology Research Center (NWTC). This is a national laboratory for wind energy in China. In effect, the NWTC has served as an important institution for Goldwind to build up its R&D capacity. The extensive networks that Goldwind has built up with industries, universities and research institutes in China and abroad has facilitated access to external sources of R&D knowledge and market information (Interviews XJ/02/2007, XJ/04/2007). These learning networks have enabled Goldwind to be an organisation that is very inclusive and one that places emphasis on learning in its internal management. This organisational culture has been a critical factor for Goldwind to strengthen its capacity for technological innovation, rather than imitation.

The role played by the Chinese government and the NWTC in Xinjiang's model of R&D reveals some interesting government-enterprise relationships in China's R&D system. The NWTC, China's sole national wind energy laboratory, was established in Urumqi in 2005, and is affiliated to Goldwind (Yu, 2007). However, although the NWTC has state status, it is Goldwind that is the leading player in the NWTC playing a determining role in all key aspects – from financing to planning and to daily operation (Interview XJ/06/2007).

While the Chinese government provided the set-up costs of the NWTC (a one-off set-up cost of 8 million yuan was provided, in which 5 million yuan came from the central government and a matching fund of 3 million yuan was provided by the

Xinjiang Government) (Interview XJ/05/2008), Goldwind has been responsible for most of the operational costs as well as the daily operation of the NWTC which amounts to approximately several million yuan every year (Interview XJ/06/2007).

Although the government's direct funding on the NWTC may not be substantial, the affiliation with a national laboratory has provided critical, intangible support to Goldwind. Being the hosting institute for China's national wind energy laboratory, the company has gained not only the much needed credibility and prestige to build up the brand name of Goldwind, but has also established a pivotal role in the industry.

This pivotal role has allowed Goldwind to establish intensive linkages, horizontally with industrial associations, wind turbine manufacturers, component suppliers as well as government officials in China and abroad, and vertically with its component suppliers and end-users, i.e. wind farm developers (Interviews XJ/02/2007, XJ/06/2007). Its collaborators included the Xinjiang Agriculture University, Delft University of Technology in the Netherlands, Garrad Hassan and Aerodyn (Goldwind, 2009). The collaboration has enhanced human capital for Goldwind because research students and graduates from the wind energy technology program of Xinjiang Agriculture University were offered placements in Goldwind (Interview XJ/4/2007).

Vertical linkages with its component suppliers and end-users are also critical to Goldwind's R&D capacity, in particularly its learning processes. Goldwind has introduced secondment arrangements with both its component suppliers and its end-users. Goldwind sent small teams of its engineers to work closely with suppliers and wind farm developers on site to address technological problems that were found in the production process or in the construction or operation (Interviews XJ/02/2007; XJ/07/2008). This learning from experience has been regarded as a critical way for Goldwind to identify and assess R&D problems, formulate solutions, and therefore improve the R&D quality (Interviews XJ/01/2008; XJ/06/2007).

(b) Shanghai: an *institutionalised* mode

Unlike Xinjiang or Guangdong which have a relatively long experience in the wind energy industry, Shanghai is a latecomer in the domestic wind turbine manufacturing industry. Shanghai also lacks a strong local market for domestic wind turbines (Mah and Hills, 2010b). However, the city does possess a number of distinctive strengths for its entry into this emerging, and highly competitive industry (Interviews SH/01/2006, SH/02/2006). One of the Shanghai's strengths is its institutionalised R&D model.

The entry of Shanghai Electric Group (上海电气 *Shanghai Dianqi*, SE), a major state-owned conglomerate, through its subsidiary Sewind (上海电气风电设备有限公司 *Shanghai Dianqi Fengdian Shebei Youxian Gongsi*) has become a local driving force for wind energy in Shanghai (Interviews SH/02/2006; SH/03/2008).

Set up in 2005, Sewind is a late-comer to the Chinese market, but it has already started to close the gap between itself and other leading domestic manufacturers such as Goldwind. As of mid-2008, Sewind was only able to mass-produce a MW-scale turbine (1.25 MW) and only one wind farm, in Shandong Province, was using its turbines (Interview SH/03/2008). However, two years later in 2010, Sewind is now able to mass-produce 2-MW wind turbines. It has manufactured more than 400 wind turbines which have been installed in 21 wind farms in China (Shanghai Electric, 2010). Sewind has recently expanded its business to offshore wind turbines. It set up a manufacturing base for offshore wind turbines in Jiangsu Province in 2009 (Shanghai Electric, 2011).

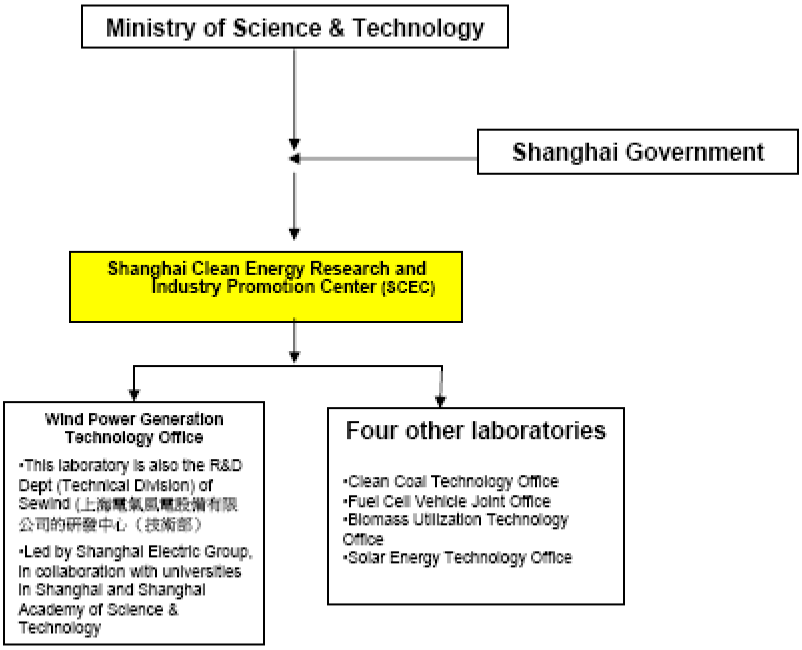
Several factors have been significant in the development of Sewind. While Shanghai Electric's expertise and experience in the conventional electricity businesses, and its financial capacities have facilitated Sewind's rapid growth (Interviews SH/03/2008; SH/4/2008), another key factor has been a highly institutionalised form of state-enterprise-university collaboration in Shanghai.

In contrast to Xinjiang's hierarchical model, the Shanghai model is distinguished by its institutionalised structure. An illustrative example of this element is the establishment of the Shanghai Clean Energy Research and Industry Promotion Center (上海清洁能源研究与产业促进中心 *Shanghai Qingjie Nengyuan Yanjiu yu Chanye Cujin Zhongxin*, SCEC) in May 2006. Modeled on the US National Renewable Energy Laboratory (NREL), the SCEC was established to enhance the R&D capacity of the wind turbine manufacturing industry in Shanghai through a government-enterprise-university collaboration (SCEC, 2009).

The SCEC is a unique institutional "product" of the close linkages between the central and Shanghai governments in R&D (Interview SH/02/2006; SCEC, 2009). It was established under a special collaboration arrangement between the Ministry of Science and Technology in Beijing and the Shanghai government. Such Ministry-Municipal collaboration (部市合作 *bushi hezuo*) is the first of its kind in China and is a unique institutional arrangement to Shanghai.

The SCEC is more sophisticated in its internal structure when compared with that of the NWTC. It has set up five laboratories, and one of them is the Wind Power Generation Technology Office (Figure 2).

Figure 2: Organisational structure of the Shanghai Clean Energy Research and Industry Promotion Center (SCEC)



The SCEC is highly institutionalised that it receives annual public funding and in terms of its internal structure. Unlike the NWTC in Xinjiang, which relies on Goldwind for most of the operational costs, the SCEC in Shanghai receives regular government funding. The SCEC has 12 full-time staff and receives a funding of about 100 to 200 million yuan every year from the Science and Technology Commission of Shanghai Municipality (上海科学技术委员会 *Shanghai Kexue Jishu Weiyuanhui*, STCSM) (Interview SH/05/2008).

This highly institutionalised model of R&D in Shanghai appears to have benefited the development of wind energy in this city in two ways. First, the SCEC has played an important role in strengthening the R&D capacity for wind energy technology in Shanghai and in particular that of Sewind. The Wind Power Generation Technology Office under the SCEC has in effect been Sewind's R&D department. Through the coordination by the SCEC, Sewind, three major universities in Shanghai (namely Shanghai Jiao Tong University, Tong Ji University and Shanghai University) and the Shanghai Academy of Science and Technology collaborated, and pooled together their skills, expertise and laboratory facilities (Interviews SH/03/2008, SH/04/2008).

Such collaboration has helped Sewind to ensure the R&D outputs are responding to the needs of the market, and are able to deliver outputs in a shorter period (Interviews SH/03/2008, SH/04/2008). One of those collaboration projects was able to deliver a R&D output in one year, requiring only half the time planned (Interviews SH/03/2008, SH/04/2008).

Another major contribution of the SCEC is its regular studies on the R&D needs of the industry. Those studies, based on site visits and interviews with stakeholders, have contributed to an effective feedback process between industries and research institutes, and have been a source of intelligence for the Shanghai Science and Technology Commission to identify R&D gaps and to set strategic priority areas for R&D funding programs (Interview SH/06/2006).

Another distinctive feature of Shanghai's institutionalised model is the role of academic associations, which are relatively institutionalised, in the energy policy-making system in the city. While academic associations were much less active in Xinjiang and Guangdong, academic associations, particularly the Shanghai Consulting and Academic Activities Center for Academicians of Chinese Academy of Engineering (上海市中国工程院院士咨询与学术活动中心 *Shanghaishi Zhongguo Gongchengyuan Yuanshi Zixun yu Xueshu Huodong Zhongxin*; hereafter referred to as the Shanghai Center for ACAE) and the Shanghai Energy Research Society (上海市能源研究会 *Shanghaishi Nengyuan Yanjiuhui*, SERS) have been active in offering advice on energy policies to the Shanghai Government. These two associations are the local branches of their corresponding associations at the national level, and these institutional linkages with national associations have allowed them to access to expertise outside Shanghai. This emerging political network has also helped the SCEC to prioritise R&D resources for renewable energy (Interviews SH/07/2008; SH/08/2008).

(c) Guangdong: a *market* model

Possessing an extensive coastline, Guangdong has been one of the early movers in developing wind energy in China. The first wind farm was built on Nan'ao Island in the 1980s. Guangdong had a total installed wind energy capacity of 500 MW by the end of 2009 (GD DRC, 2010). Mingyang is a major domestic wind turbine manufacturer based in Guangdong while there are also a number of small private entities entering this emerging industry (Interview GD/01/2010). Ranked fourth in China in 2009 (CWEA, 2010), Mingyang however is still a relatively small manufacturer. There was a substantial gap in market share between Mingyang and the top three companies (CWEA, 2010).

The Guangdong model of government-industry-university collaboration is distinguished by its market-oriented elements. While Guangdong has been catching up in local government R&D investment (Guangdong STS, 2011), the Guangdong Government tends to place emphasis on creating a level playing field, encouraging a large number of market players, promoting market competition and placing less emphasis on picking a winner.

A distinctive initiative in Guangdong's model is its Enterprises' Science and Technology Commissioners Action Plan (企业科技特派员计划 *Qiye Keji Tepaiyuan Xingdong Jihua*). This action plan was introduced in 2008 by the Guangdong government to provide incentives for enterprise-university collaboration. The action plan aims to enhance the innovation capacity of Guangdong. It involves selecting young R&D personnel from Chinese universities, appointing them as "commissioners" and stationing them in designated enterprises for a period of one year. The commissioners are expected to carry out a broad variety of "missions" that may include formulating R&D strategies for their designated enterprises, establishing a long-term enterprise-university collaboration system, participating in R&D, and nurturing R&D personnel (Guangdong STC, 2008a).

In October 2008, the first batch of 143 Science and Technology commissioners was dispatched to 140 enterprises in Guangdong (Guangdong STC, 2008a, b). Since then, three more groups of commissioners have been dispatched and the action plan has gradually grown in scale. By July 2010, about 1,000 commissioners had been dispatched to 872 enterprises (Guangdong STC, 2010). The action plan is intended to facilitate network building for R&D and collaboration with parties within and outside Guangdong (Guangdong STC, 2008a).

The latest development of this action plan is the establishment of about 30 "Enterprises' Science and Technology Commissioners Work Stations (企业科技特派员工作站 *Qiye Keji Tepaiyuan Gongzuozhan*) by end 2010 in Guangdong. Any enterprise that has employed at least three "commissioners" is eligible to apply for setting up a "work station" within its company with funding provided by the Guangdong Government.

It is however too early to evaluate the effectiveness of the action plan because only a small number of the commissioners have been dispatched to wind turbine manufacturers (Guangdong STC, 2008a, 2008b, 2010). Much of implementation data of the action plan are also not publicly accessible (Interview GD/02/2011). However, the action plan has been welcome by the wind energy industries and the researchers in the field as a useful model for strengthening Guangdong's innovative capacity (Interviews GD/01/2010, GD/03/2008; GD/04/2008).

There are a number of the important features of the Guangdong's market model of R&D collaboration. In contrast to the models in Xinjiang and Shanghai which have tended to try to pick winners, one of the potential strengths of the Guangdong model is its creation of a level playing field for a large number of enterprises of all sizes, from SOEs and SMEs, and universities in Guangdong to participate. The action plan in effect allows local enterprises and universities to have relatively equal access to the state funding support. It also allows a more bottom-up approach to collaboration that encourages a broad search of technological options and creation of knowledge by a relatively large number of actors (Jacobsson and Bergek, 2004; Interview GD/01/2010).

Another distinctive feature of the Guangdong model is the active role played by a local university. A major barrier for the Chinese academics in Xinjiang and Shanghai to collaborate with industries is the lack of incentives in the current appraisal systems in Chinese universities. The appraisal systems tend to reward academic outputs rather than collaboration with the private sector (Interviews XJ/01/2008, SH/04/2008). In contrast, the South China University of Technology based in Guangzhou has introduced a new university regulation titled "Selection Measures of the Enterprises' Science and Technology Commissioners (企业科技特派员选派办法 *Qiye Keji Tepaiyuan Xuanpai Banfa*)". The new regulation provides preferential arrangements in terms of promotion and welfare for scholars who have served as a "commissioner". This is a pioneering rule that creates structured incentives in the university appraisal system for the Commissioners Action Plan (GD STD, 2008b).

Critical evaluation and prospects for China's government-industry-university collaboration

Our analysis suggests that while these local models are all embedded in the same national technological innovation system, they are not uniform across provinces. By comparing and contrasting the three case studies, our analysis can highlight some interesting findings in relation to the current government-enterprise-university collaboration for wind energy in China.

(1) Local diversity and the importance of contextual factors

Our analysis has distinguished three local models of government-business-university collaboration. While it is not within the scope of this study to assess which model is the best for enhancing R&D capacity, this differentiation is instructive in examining local diversity and the breadth of the local possibilities in overcoming problems in R&D processes.

Our findings suggest that the three models differ in a number of ways, including relationships between governments, enterprises and universities, formats and scale of their networks, and the processes and dynamics involved. While the Xinjiang model has reflected a pivotal role of the central government, the Shanghai model has its strengths in the institutional design. In contrast, the Guangdong model is distinguished by its emphasis on an arms-length policy style and the creation of a level playing field for a large number of enterprises to compete.

Our analysis has also highlighted certain contextual factors to explain the differences in R&D collaboration models in these three provinces. Each province, with its particular political and socio-economic contexts, has developed different collaborative relationships to overcome technological challenges in the emerging wind energy industry.

In Xinjiang, the relatively backward local economy has in part contributed to its need to rely on the central government to take a leading role in its hierarchical model of R&D. In Shanghai, the agglomeration of top-ranked tertiary institutions has created a conducive environment for a more deliberative style of energy policy-making (Shanghai Almanac Editorial Board, 2007; Shanghai Center for ACAE, 2006). This has allowed associations such as the Shanghai Energy Research Society to play a more active role in its institutionalised model of R&D. In Guangdong, the tradition of being in the vanguard of China's economic reforms over the past three decades (Cheung, 2002; Yeung, 1998) has been conducive to its market model of R&D which tends to place more emphasis on market competition.

(b) The achievements of the government-enterprise-university collaboration

Our analysis suggests that collaboration between governments, enterprises and universities for wind energy in the three provinces has enhanced innovation capacity. This observation is consistent with the perspective of governance which draws attentions to the limits of the ability of governments at different levels, and emphasises the need for the government to reach out to wider society to govern (Stoker, 1998; Satterthwaite, 1999).

Our case studies demonstrate that collaboration has allowed enterprises to achieve a number of collaborative benefits in various R&D processes in different phases of technological innovation: from generation to diffusion and utilisation, as categorised by Carlsson and Stankiewicz (1991).

In relation to the generation phase of technological innovation, the experiences of Goldwind in Xinjiang and Sewind in Shanghai have shown that such collaborations has been able to improve R&D quality and produce some R&D outputs more rapidly.

In the diffusion stage, Goldwind's research network which has extended abroad is a good example illustrating how collaboration can facilitate knowledge transfer. Another example is the placement programs in Goldwind and the Enterprises' Science and Technology Commissioners Action Plan in Guangdong. Such close collaboration between universities and enterprises has facilitated a two-way diffusion process of technological knowledge. In relation to the utilisation stage, the feedback processes between end-users (i.e. wind farm developers) and Goldwind are a good example illustrating how such an industry-end-user network can strengthen the innovation capacity of an enterprise.

How, then, can such collaborative advantages be achieved? Our analysis sheds light on the conducive conditions that appear to facilitate government-enterprise-university collaboration in the Chinese context.

A key condition is the presence of networks. This observation reinforces one of the key insights of the perspective to of technological innovation systems. Work by Jacobsson and Lauber (2006) for example has highlighted the important role of networks in enhancing innovation capacity. Our analysis has shown that network building is also a key element in the Chinese context and in the wind energy sector. Governments, enterprises and universities in our three case studies were linked in various forms, from formal government-industry institutions (as in the NTWC in Xinjiang and the SCEC in Shanghai) to informal/ ad-hoc institutions (as in the case of the Enterprises' Science and Technology Commissioners Action Plan in Guangdong), to manufacturer-supplier-end user networks (as in the case of Goldwind in Xinjiang) and to an emerging political network (as in the case of Shanghai Center for ACAE).

It is important to note that while such political networks can play an important role in facilitating innovation processes (Jacobsson and Lauber, 2006; Jacobsson and Johnson, 2000), they appear to act differently in many important ways when compared with their counterparts in the West. The political network that emerged in Shanghai is a good example to illustrate this observation. Although the network based in the Shanghai Center for ACAE and the Shanghai Energy Research Society was able to penetrate into the policy-making system for energy by playing an active role in offering policy advice to the Shanghai Government, its role of agenda-setting was passive. When they are consulted and to what extent their advice can influence the final policy decisions is largely arbitrary and subject to the discretion of the government.

Our findings also complement the literature on networks by identifying a variety of processes that are critical to network building processes. Those include: capacity building (for example, through the placement programmes), resources pooling (for example, through consolidation of various government funding sources and private funding as shown in Guangdong's Enterprises' Science and Technology Commissioners Action Plan and Xinjiang's R&D model), feedback processes (for example, between end-users and manufacturers so that field data on the performance of domestic turbines can be integrated into Goldwind's R&D processes), and the accumulation and transfer of technological knowledge.

(c) The collaborative limits

Although our three case studies have shown that such government-enterprise-university collaborations has been able to make some important achievement such as accelerating the R&D processes and improving R&D quality, they also revealed two major limitations: the problem of quality control and the lack of market competition. A reason for these limitations appears to be under-investment of public resources in the wind industry.

The problem of quality control for domestic turbines has attracted growing attention from Chinese policy-makers and the industry (Li *et al.*, 2010). While major incidents of wide-scale turbine failures that could have led to a collapse of any major manufacturer have not happened in China, wind energy experts have been cautious about the quality of domestic wind turbines (Interviews BJ/01/2010; BJ/02/2009; GD/01/2010).

An illustrative example of the issue of quality assurance of domestic wind turbines is provided by China's first offshore wind farm in Shanghai. The thirty-four 3-MW domestic wind turbines which have been built along the Shanghai Donghai Bridge did not go through field testing. This project has raised some concerns across the wind energy industry in China over the project risks in part because generally field testing is a standard procedure for wind turbine accreditation in the West before turbines can be sold in the market (NWTC, 2009; Interview SH/09/2008).

Another major limitation of China's innovation system for wind energy is the lack of market competition. Although there has been keen competition among some 50 domestic wind turbine manufacturers in recent years, the top Chinese domestic wind turbine manufacturers, Sinovel, Goldwind and Dongfang (all of them are state-owned enterprises) already account for approximately 60 percent of China's market in 2009 (CWEA, 2010). The local R&D collaboration models in Xinjiang and Shanghai tend to "pick the winners" in the technological deployment processes – Goldwind in Xinjiang and Sewind in Shanghai were able get access to major government support while the models do not encourage a large number of new entrants (Interview XJ/08/2008). Guangdong's market model appears to be one that tries to encourage market competition. However, its effectiveness has yet to be properly assessed.

These major limitations of collaboration are to a large extent the result of a retreat of the government from R&D in the wider Chinese context. This analysis is instructive in informing the debate between a "shrinking state" and the renewed interest in a more state-centric approach in the literature on governance (Sbragia, 2000). The "enterprise-led" strategy of R&D was introduced in 2006 with the intention of stimulating the motivation of and mobilization of resources in enterprises and universities for R&D. A major drawback of this strategy however is that many of the public services for the wind energy industry such as quality assurance, the healthy development of the entire industry including its supply chain, and knowledge transfer and accumulation have not been adequately developed.

Although the NWTC in Xinjiang and SCEC in Shanghai are public service platforms, they are locally-based and enterprise-led, and are oriented by enterprises' priorities rather than the interests of the whole industry. In contrast, such public service platforms for wind energy in the West such as the Risø in Denmark (Buen, 2006) and the National Renewable Energy Laboratory in the US (Li *et al.*, 2006; Loitera and Norberg-Bohmb, 1999) are much more competent in addressing issues such as testing and accreditation that concern the development of the entire wind energy industry.

This problem of under-investment of public resources can be illustrated by the case of the NWTC in Xinjiang. Although this is a national laboratory for wind energy, many of the public services which were intended to be delivered by the NWTC have not been developed. The NWTC's plan to provide publicly accessible laboratories has yet to be realised. The existing laboratories are earmarked for Goldwind's needs as a priority and have already been operating at full capacity for the company. R&D investment for the wider public benefit has received much less attention from NWTC (Interview XJ/01/2008).

Some progresses have recently been made as the NWTC has submitted a funding application for 4.5 million yuan in mid-2008 to fund a lab unit for testing wind turbines (Interview XJ/01/2008). If approved, the proposed lab unit is planned to be built by 2012 and made accessible to all domestic manufacturers (Interview XJ/01/2008). However, such progresses have been slow and are not responsive enough to meet the needs of the industry.

While the Chinese government has reduced its role in directing R&D activities, its remaining power in controlling the economy through supporting SOEs has created a wider Chinese context that has influenced the pathway of the R&D systems in this country. The national R&D systems as well as the local systems in Xinjiang and Shanghai tend to pick winners, rather than encouraging a level-playing field for a large number of private entities. While this Chinese model has succeeded in grooming its own domestic wind turbine industry in a relatively short period of time, it also has its drawback. It appears to be weak in promoting market competition and a broad search of technological options that tend to be facilitated in a market situation where there are a relatively large number of market players (Jacobsson and Bergek, 2004).

Conclusion and policy recommendations

This paper has highlighted the role played by government-enterprise-university collaboration in the context of R&D capacity of wind energy in China. The framework of collaborative governance, supplemented by the concepts of technological innovation and network building, provide an insightful framework for understanding the R&D models and processes. We have identified the local diversity of such collaborative models. Our analysis has offered insights into the benefits and limitations of such collaborative initiatives found in selected Chinese provinces, and the mechanisms of such collaboration.

Our findings have a number of policy implications. First, they suggest that local diversity and contextual factors may be a critical issue for innovation capacity in the context of wind energy in China. R&D policies for wind energy in China need to give more attention to the role that localities may play. Wind energy policies are primarily centered at the national level of the policy-making system. Local governments generally are not given a prominent role in it. Some studies have already found that the effectiveness of some local initiatives for wind energy, such as the green electricity market in Shanghai, has been undermined by the lack of supporting policies at the national level (Mah and Hills, 2010b). A new focus of China's R&D policies would be local contextual factors and the associated local opportunities and constraints to enhance R&D capacity. Policies should provide incentives for provinces to mobilise local resources, cultivate locally based networks, and build up local innovation capacity.

Another policy implication relates to the complementary roles of the central government, the localities and enterprises. The problem of under-investment in public resources as discussed has raised important questions concerning the role of the central government in R&D. The collaborative limits that our analysis has identified suggest that there are major undesirable outcomes as the central government retreats from R&D. This suggests that there is a need to better define the comparative strengths of the central government and the localities, as well as between the governments, enterprises and university in China's technological innovation systems, and a better designation of their respective tasks and responsibilities.

The third policy implication is related to the emerging role of civil society in China. The political network in Shanghai and the business network developed by Goldwind in Xinjiang suggest that there is considerable potential for stakeholders outside government to contribute to the sustainability transition in China. Their resources in terms of expertise, information, social ties and creativity may be particularly useful to strengthen China's governing capacity required to achieve a more sustainable future. However, despite their vast potential, the limited role played by the political network in Shanghai and the relatively limited role played by renewable energy associations in China indicates that there is a need for the Chinese government to introduce institutional changes so that the potential capacities of Chinese civil society can be better activated and utilised.

This paper has implications for further research on governance for innovation capacity. Our findings suggest that local contextual factors and central-local dynamics are critical to the local diversity of R&D models across Chinese provinces. Future research could examine the interactions between national and local contextual factors and their impacts on collaboration outcomes. Debate about a "shrinking state" and renewed interest in more state-centric approaches, and the role governments should play in an evolving governance context has been examined elsewhere (Hood, 1978; Koontz *et al*., 2004; Sbragia, 2000) and could be explored further in the Chinese context. Further research could investigate how the role of governments can be redefined to strengthen China's capacity to develop a more sustainable energy system.

Appendix: List of Interviews

Code	Interviewees Background	Types of interview	Date of interview
BJ/01/2010	Yu Wuming, former general manager of Xinjiang Wind Energy Company; the deputy director of National Windpower Engineering Technology Research Center (NWTC); and a wind energy expert to the Xinjiang government	FI	Oct 14, 2010
BJ/02/2009	Shi Pengfei, Vice President, Chinese Renewable Energy Industries Association; Senior Engineer (Professor), China Hydropower Engineering Consulting Group Co.	FI	Oct 22, 2009
XJ/01/2008	A professor of a university in Xinjiang, and a R&D director of Goldwind	FI	Oct 24, 2008
XJ/02/2007	Li Zhi, Dispatcher, President Office, Goldwind Science & Technology Co. Ltd	FI	Oct 19, 2007
XJ/03/2007	A senior official, Division of Hi-tech Industrial Development, Science and Technology Department of Xinjiang	FI	Oct 20, 2007
XJ/04/2007	Cui Xinwei, Associate Professor, Mechanical and Traffic College of Xinjiang Agricultural University; Chief Engineer, National Wind Power Engineering Technology Research Center of China (a collaborator with Goldwind on R&D)	FI	Oct 26, 2007
XJ/05/2008	Same interviewee as in XJ/03/2007	TI	Oct 23, 2008
XJ/06/2007	Same interviewee as in BJ/01/2010	FI	Oct 24, 2007
XJ/07/2008	Same interviewee as in BJ/01/2010	FI	Oct 25, 2008
XJ/08/2008	A deputy director, Development Research Center of the Xinjiang Uyghur Autonomous Region	FI	Oct 23, 2008
SH/01/2006	Zhou Guoping, Director, General Research Division, The Development Research Centre of Shanghai Municipal Government	FI	Sep 28, 2006
SH/02/2006	Yu Jian, Senior Engineer, Shanghai Clean Energy Research and Industry Promotion Center	FI	Sep 27, 2006
SH/03/2008	A manager of Sewind	FI	Jun 6, 2008
SH/04/2008	Prof Cai Xu, Department of Electrical Engineering, Shanghai Jiao Tong University	FI	Jun 5, 2008
SH/05/2008	Same interviewee as in SH/02/2006	FI	Jun 2, 2008
SH/06/2006	Du Kunjie, Specialist, Shanghai Clean Energy Research and Industry Promotion Center	FI	Sep 27, 2006
SH/07/2008	Shao Xiaobing, Assistant of Academic Activity Department, Shanghai Consulting and Academic Activities Center for Academicians of Chinese Academy of Engineering	FI	Jun 4, 2008
SH/08/2008	Zhang Shurong, professor, Shanghai Energy Research Society	FI	Jun 2, 2008
SH/09/2008	A Senior Engineer of Shanghai Wind Power Co. Ltd.	FI	Jun 2, 2008
GD/01/2010	Prof Yang Ping, New Energy Centre under the School of Electric Power of the South China University of Technology	FI	Aug 12, 2010
GD/02/2011	An anonymous official from Guangdong Science and Technology Commission	TI	Jan 4, 2011
GD/03/2008	Zhu Qiyi, manager, Hui Zhou Chao Zhi Neng Technology Development Co., Ltd.	TI	Dec 18, 2008
GD/04/2008	Same interviewee as in GD/01/2010	TI	Dec 11, 2008

The interview formats included face-to-face interview (FI) and telephone interview (TI).

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