Climate Policy

ISSN: 1469-3062 (Print) 1752-7457 (Online) Journal homepage: www.tandfonline.com/journals/tcpo20

China's policy initiatives for the development of wind energy technology

Yixin Dai & Lan Xue

To cite this article: Yixin Dai & Lan Xue (2015) China's policy initiatives for the development of wind energy technology, Climate Policy, 15:1, 30-57, DOI: 10.1080/14693062.2014.863549

To link to this article: https://doi.org/10.1080/14693062.2014.863549

Published online: 08 Jan 2014.

Vol. 15, No. 1, 30–57, http://dx.doi.org/10.1080/14693062.2014.863549

climate policy

research article

China's policy initiatives for the development of wind energy technology

YIXIN DAI*, LAN XUE

School of Public Policy and Management, Tsinghua University, Beijing 100084, China

Public policy has played an important role in the development of wind energy technology. However, compared to the rich literature on the supporting mechanisms for frontrunner countries, little research has focused on the latecomers, especially regarding the catch-up and take-over process. The key policy initiatives that would enable latecomers to fulfil their technology leapfrogging goals are also unclear. Using the empirical setting of the Chinese wind energy market, four phases of technology development based on technological capacity and market development status are identified. The logic of the policy initiatives selected for each phase is then illustrated in light of the prevailing sectoral goals and macro policy framework. The findings confirm the interactive relationship between the various factors and also illustrate that technological capacity is the fundamental factor for achieving sustainable leapfrogging.

Keywords: China; leapfrogging; macro policy; policy initiative; wind technology

1. Introduction

In response to the threat of climate change, various nations have accelerated the process of their policy making in order to shift from a high-carbon, resource-sapping mode of development to a low-carbon, sustainable one. Technological breakthroughs are regarded as the 'magic bullet' for tackling climate change adaptation and mitigation (Grubb, 2004). Thus, strong governmental policies and programme designs for promoting technological development continue to be essential for combating climate change (Michaelson, 1998).

The research so far has focused on frontrunner countries in wind technology and has sought to identify the important factors contributing to their overall success, especially from the technology push and market pull perspectives. In regard to technological improvement, a 'learning by doing' and bottom-up strategy with interactive relationships among producers and users has proven to be more efficient than a top-down (but isolated) research pattern (Kamp, 2002). Notably, technological improvements that occur in small incremental steps may be more appropriate for wind energy development than large-scale, pure, scientific research (Heymann, 1998). In addition, market cultivation policy is believed to have an essential influence on technology development (Neij, 1997).

From the point of view of market formation and exploration, building up a domestic market with demand-side policies is essential. This includes early market subsidies and feed-in tariffs (Munksgaard

*Corresponding author. *Email:* yixindai@tsinghua.edu.cn

& Morthorst, 2008), domestic market building and the accumulation of experience (Lewis & Wiser, 2007), and renewable portfolio standards (Menz & Vachon, 2006).

The wind energy literature has recently started to devote more attention to developing countries, particularly to China. Although China was a latecomer to wind energy, it quickly caught up with other countries, and has now become a world leader in wind turbine manufacturing and installation capacity (Lewis, 2007). However, the development of Chinese wind energy technology goes against the received wisdom in the existing literature in at least two ways.

First, the phenomenon of technology catch-up in which latecomers can adopt the technology or products of frontrunners in order to skip some of the normal development stages is well documented in the literature (Goldemberg, 1998). However, latecomers rarely manage to bypass frontrunners (Goldemberg, 1998), something that China has achieved. As an advanced developing country, China promoted domestic industry development as well as domestic research and development (R&D) capacity building to achieve a competitive state (Lewis, 2007; Sauter & Watson, 2008). There is thus a literature gap regarding the path of technological development and the effects of policy initiatives on technological improvement, especially when they are connected to a country's specific national technological, social, and economic context (Cherni & Kenitsh, 2007; Lema & Ruby, 2007; Liu & Kokko, 2010; Zhang et al., 2009).

Second, unlike the frontrunner countries, who designed their wind energy policies with the strategy of technology push and market pull in mind, the Chinese wind energy programme placed more emphasis on the functions of their policies and adopting industrial, marketing, and technology policies at different development phases. Significant differences between the design of China's policy initiatives and those of frontrunner countries can also be observed. For example, China has continued to fund top-down research on basic R&D, pilot turbine testing, demonstration projects, and even commercialization (Wang, Qin, & Lewis, 2012), while adopting large-scale, concentrated wind deployment patterns that rely heavily on domestic market exploitation (Li et al., 2007).

The differences between China's policy initiatives and those of frontrunner countries are thus hardly explained by the current literature. Further research is needed to understand why China designed such policy initiatives to boost the development of wind energy technology, how these have promoted the accumulation of technological capacity, and whether they can be generalized to other developing countries.

In this article, the logic behind China's wind technology policy initiatives is analysed, and the essential factors involved in forming these initiatives are identified. In Section 2, a review of the theoretical literature on the formation of policy initiatives regarding technological development and technology catch up is provided. The various factors (i.e. technological, market factors, sectoral, and macro policies) are then integrated into a comprehensive framework. In Section 3, the results of a case study on the development of Chinese wind technology are presented. The relationships between national macro policies, sectoral policies, and policy initiatives are then analysed in addition to the different development stages of the technology. The interactive relationship between the three factors and the role of technological capacity in 'leapfrogging' is discussed in Section 4. Some conclusions are offered in Section 5.

2. Understanding Chinese wind energy policy initiatives

China's policy initiatives for developing wind technology follow the theory of innovation and leapfrogging. In this section, the literature is reviewed in three stages. The basic method for designing policy regarding the orthodox theory of innovation (in which technology push and market pull policy initiatives are carefully selected to promote technological improvement) is first summarized. Second, the influence on policy of the theory of technology leapfrogging over local policy initiative selection (in which developing countries learn from developed countries and bypass certain stages of innovation with the help of government policy) is discussed. Third, a comprehensive framework to evaluate the design of technology development policy initiatives under the influence of leapfrogging both at the sectoral and macro levels is presented.

2.1. Policy initiative design

A policy initiative is a series of policy actions to directly fulfil certain policy goals. Broader than a single policy, a policy initiative includes a group of policy tools that share some common characteristics and that are closely linked to a specific target. Sectoral policies focus on subdivisions of an economy, such as energy policy, climate policy, and education policy. Macro policies (or a macro policy framework) are those policy initiatives that serve as the overall development guide for other policies. For example, a national sustainable development strategy in response to climate change can be regarded as a macro policy goal. By contrast, an energy policy that aims to boost renewable energy or an environmental policy that aims to reduce air pollution can both be regarded as sectoral policies. Sectoral policy goals, although not directly push/pull technology development, lead to further policy initiatives design with technology improvement as result. For example, feed-in tariffs (FITS), with clear target to stimulate wind energy industry development, may also pull wind energy innovation indirectly. Also, national strategy change towards low-carbon development may increase wind research fund to push wind technology policy initiative design.

2.2. Policy initiatives design boosting technology development

A nation that wishes to engage in technology innovation can design its policies at the sectoral level. Its innovation goals can be set at the sectoral level while detailed policy initiatives can be designed to fulfil them. Such policy initiatives can involve independent technology development, international technology transfer, or leapfrogging.

Independent technology development follows a linear model with respect to the strategies of both technology push and market pull (Braun, 2008; Organisation of Economic Co-operation and Development [OECD], 2005). Technology improvement is motivated by the development of basic science and knowledge, increasing social demand, or a combination of the two (Dodgson, Gann, & Salter, 2008). The range of possible policy tools for promoting innovation behaviour includes policies on R&D, technology, infrastructure, regional development, and education (Edquist, 2001). Although these policy tools belong to multiple policy domains, they all facilitate technology development by virtue of being technology push or market pull initiatives (see Figure 1). For example, technology push policies can encourage R&D activities, while science and technology policies can increase innovation through research funding and public research projects. Demonstration projects can help innovation to reach the pilot scale, while R&D tax deduction regulations can encourage private investment in innovation.

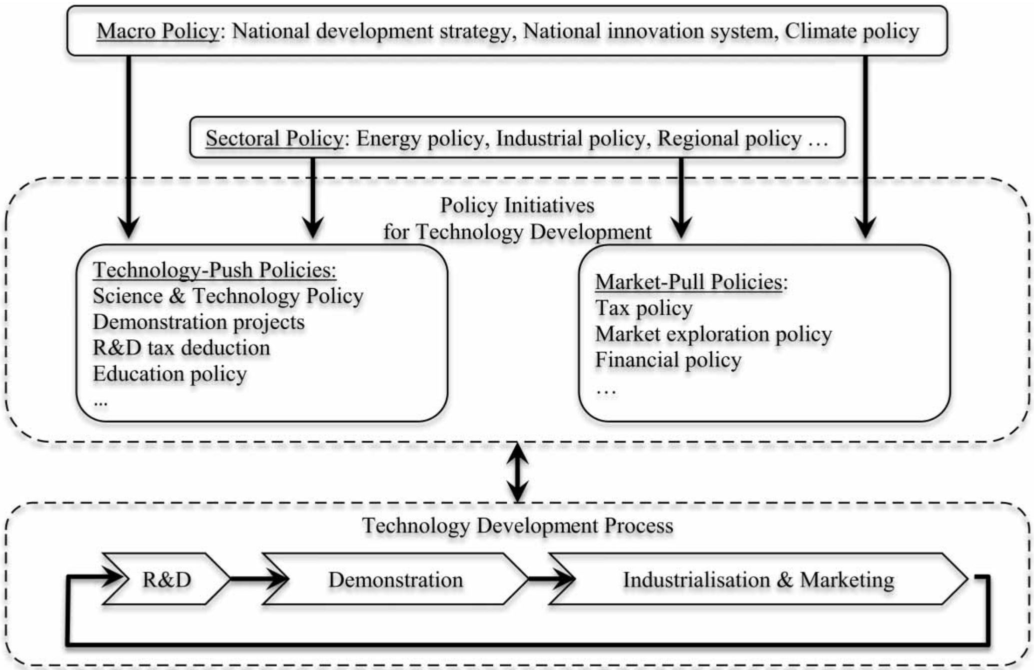

Figure 1 The conventional innovation process and supportive policies

Alternatively, market pull policies can generate market capacity to further lower the cost of technology. Market exploration, tax, and financial policies can be initiated independently or jointly to generate market demand during the innovation process. Finally, national standards and regulations can function as market maintenance tools. For example, technology policies can increase the technology supply by rewarding innovators for the public goods generated from knowledge spill-overs, while environmental policies can pull market demand by punishing environmental damage. Both of these can realize the policy goal of green growth (Popp, 2012)

However, the actual innovation processes may not follow the sequence specified by the linear model and may in fact be more complicated and discontinuous. In reality, various innovation activities are likely to intersect, and the order in which they occur may vary. For example, R&D may occur through-out the process of innovation, while the experiences from demonstration and commercialization provide feedback for R&D activities and promote further technology improvement.

Recent innovation theories have tried to accurately describe the innovation process and have, *inter alia*, adopted concepts such as network innovation, the social innovation network, and national innovation and regional innovation systems (Coenen, Benneworth, & Truffer, 2012; Freeman, 2002; Fromhold-Eisebith, 2007; Markard & Truffer, 2008). However, despite the advances in describing the innovation process, the design of major policy is still based, at a fundamental level, on technology push or market pull strategies (Isaksen & Nilsson, in press).

2.3. Policy design for technology leapfrogging

Technology improvement also comes from technology transfer between firms, regions, or even nations. Technology leaders enjoy first-mover advantages in gaining control of resources that their followers may not (Grant, 2003). Meanwhile, technology latecomers can save costs and/or avoid risk by taking advantage of the technology gap to avoid certain developmental mistakes or leapfrogging certain stages of technology innovation (Brezis, Krugman, & Tsiddon, 1993). Leapfrogging is sensitive to context. In order to leapfrog, a lagging country must have (1) the capacity to absorb the technology (i.e. it must have the technological capacity and the right organizational setting), (2) the capacity to assess the advanced technology (i.e. developed countries must be willing to provide either the technology or the financial resources to the developing country), and (3) the capacity to design strong policy initiatives (Perkins, 2003).

Leapfrogging practices may require policy designs at different levels in order to connect with the technology context of the lagging country. Leapfrogging via the deployment of new technologies or products generates changes at the sectoral policy level in the lagged country. Policy initiatives to promote rapid market expansion (e.g. the fast spread of computers) or infrastructure building (e.g. the extension of telecommunications infrastructure) may drive latecomers to embed the new technology into their social and technological environment. Subsequently, leapfrogging requires huge amounts of effort in technology adoption and application, which calls for suitable macro-level policy environment changes in the lagging country (Murphy, 2001). When leapfrogging occurs at the national level such that the latecomers catch up with the overall development mode of the frontrunners, policy initiative supports should appear at the macro level (Giovannetti, 2013; Nemet, 2009; Perkins, 2003). For example, if a developing country switches from a high-carbon to a low-carbon economy, national strategy settings must be reshaped to develop along a cleaner development path (Gallagher, 2006).

With leapfrogging goals being set either at macro policy level or at sectoral level, no existing literature provides detailed guidance on how to design policy initiatives to fulfill these goals. For example, after a catch-up strategy is set, how should science and technology policy be designed to provide R&D resources in the country? How should a domestic market be cultivated for better technology adoption?

Given this lack of guidance, further analysis is needed regarding the interaction between traditional innovation policy initiatives and those targeted at leapfrogging. For example, should lagging countries focus more on technology transfer or on basic R&D? How will the leapfrogging policy at the national level influence policy initiatives at the level of specific industries and technologies?

2.4. Technology leapfrogging with sectoral and macro level policy goals

To fully understand technology development and technological innovation in developing countries, a comprehensive policy framework is needed that combines innovation theory and leapfrogging theory (see Figure 1).

The policy framework is structured in three layers. The first layer is the set of policy initiatives, which contains a detailed set of policy tools to realize policy goals that target technology development. With technology improvement as the ultimate target, this model simplifies the technology development process, one that starts from R&D, moves to marketing demonstration, and then returns for further R&D. Technology push policies (e.g. science and technology policy) propel this process forward at the R&D stage, while market pull policies (e.g. governmental procurement policy and taxation policy) drag the process out at the marketing stage. For complicated innovation processes, in which different stages intersect or even exchange positions, these policy tools could still function well at certain technology development stages. Policy tools would overlap to form policy initiatives.

Given that technology development can be triggered via different policy goals, the second layer of the model involves sectoral policies that set up targets and goals for the larger policy initiatives. Sectoral development involves policies that focus on subdivisions of an economy, which target periodical sector development goals other than innovation goals. Yet sectoral technology development must be realized through policy initiatives either as technology push policy designs (e.g. the research project on a 1.5 MW low-speed wind turbine supported by China's National High-Technolgy R&D Program of China; also known as the '863 Program') or as market pull policy designs (e.g. the first Chinese off-shore concession project in 2010, which was aimed at exploring the off-shore wind market). It is worth noting that industrial policy is sector-specific. With a policy goal of increasing the competitiveness and technological capacity of a certain industry sector, industrial policy could by satisfied by a set of detailed policy initiatives such as product subsidies, technological research funding, or research allocation policy designs.

The third layer of the model involves macro policy goals (e.g. national development strategies or a national innovation system) that indirectly shed light on technology development. From a technology development point of view, the complexity of the innovation process calls for an overall guiding policy to provide an 'inclusive and heterogeneous' policy design that facilitates technology development among stakeholders (Bauer, Lang, & Schneider, 2012). Sectoral policy may not serve this function well because innovation is not a subdivision of the economy. Thus, a national-level guidance policy should be added to the model to guide technology development. In addition, in developing countries, the execution of national-level development leapfrogging requires a strong top-down design process to deconstruct the catch-up strategy into national development strategies, sectoral plans, and (ultimately) a set of policy initiative designs.

To successfully promote technology development, sectoral goals and macro policy goals should jointly influence policy initiatives (see Table 1). Policy initiatives supported both by sectoral and macro policy goals would pave the way for policy design and implementation, while policy initiatives without any support from goal setting at the higher levels of policy design would likely encounter difficulties. Although a policy initiative that did not have one or other of the policy goals (i.e. sectoral or macro policy) could still be selected as an alternative policy, it would not be ideal. Alternatively, if no policy initiative were originally designed at all, it may be because policy goals have already emerged either from the sectoral or macro policy level. In this case, new policy initiatives should be selected to fulfil these goals. When both the sectoral and macro policy layers reach agreement on promoting a given technology, innovation policy is likely to be well designed and implemented under all levels with support from each layer (see Table 1). Similarly, if sectoral policy is strong in innovation improvements but the national macro policy does not provide enough support, the policy effect will be limited no matter how strong the policy initiatives might be.

Overall, the policy initiative design represents the combined effects of national strategies, sectoral development goals, and innovation targets that incorporate the technological and market situations.

TABLE 1 Matching combinations among three layers for technology development

Policy layer	Matching combinations							
Macro policy	+	+	+	−	−	−	+	−
Sectoral policy	+	−	−	+	−	−	+	+
Policy initiatives	+	+	−	+	+	−	−	−
Innovation effect[a]	+ + +	+	−	+	−	− − −	+	−

Notes: + + +, +, −, − − − represent strong positive effect, positive but small effect, negative but small effect, and strong negative effect, respectively.
[a]The overall policy effect equals the absolute sign of the three layers.

The development of China's wind energy sector is presented in the next section as a case study to illustrate the interrelationships between the three layers.

3. Case study: policy initiatives in the Chinese wind sector

First, Chinese wind energy sector experienced a fast growth in the past 30 years (Figure 2). It started as a technological and market latecomer in the 1980s with low generation capacity, almost no technology deployment, and a total reliance on foreign technology. However, by 2011, China had generated 40% of the global generation capacity (Chinese Wind Energy Association [CWEA], 2012), installed 17.63 GW of wind turbines, and had become the global leader in terms of annual installation capacity. In the same year, China also exported 141 wind turbines, with a total capacity of 220 MW, to five countries (CWEA, 2012). Therefore, the case of China represents an integrated catch-up process alongside industrial, technological, and product development. Second, China has provided various policy supports for wind technology development through both technological development policy initiatives (Guérin & Schiavo, 2011) and sectoral policies and national strategies (Lewis, 2007; Wang et al., 2012). The rich information available regarding this case study ensures that the interplay between key factors – such as technological improvement, market conditions, and the macro policy framework – can be fully explored.

From the perspective of technological improvement and market growth, the overall development of the Chinese wind technology sector can be divided into four distinct phases[1] (see Table 2). Each phase indicates a particular level of catch up in terms of technological capacity and the market situation. In each phase, policy initiatives, the sectoral goals, and macro policies are presented to illustrate the relationships between the key factors necessary to understand the technology development path. (See Appendix for a detailed list of China's wind policies between 1994 and 2011.)

3.1. Demonstration period (1986–1995)

Although China has huge wind resources within its territory[2], the initial exploration and deployment of wind technology aimed to contribute to the rural energy supply. In the 1950s and 1960s, wind

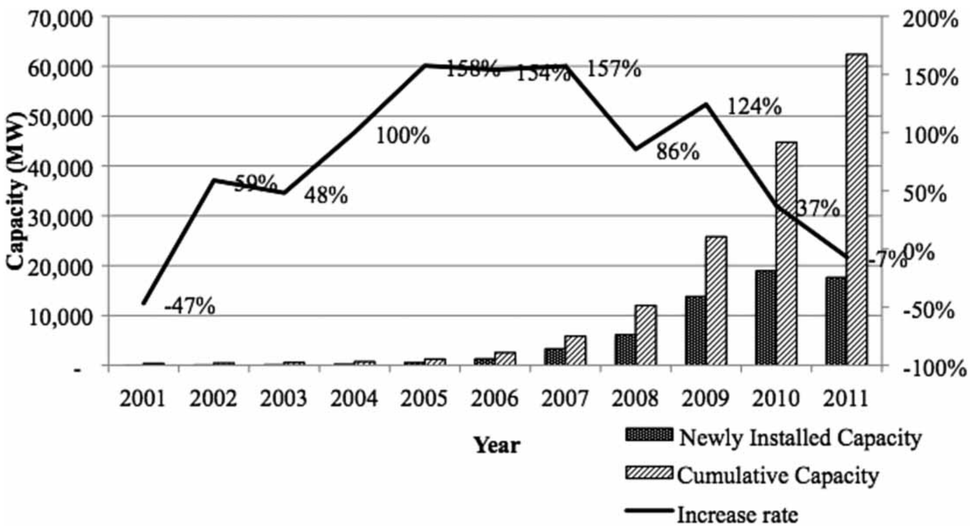

Figure 2 Change in installation capacity in the Chinese wind energy industry (2001–2011).
Source: Calculated based on data provided by the CWEA (2012).

production mostly focused on wind-powered water-lifting machines. The development of the actual wind energy sector did not start until the 1980s.

3.1.1. Technological capacity

The development of wind technology in China started from a low technological base compared to the frontrunner countries. A pilot study and trial deployment of wind electricity generation began in the 1970s in response to the global energy crisis. At that time, there were neither demonstration sites for wind turbines nor any commercial wind technology manufacturers in China. It was not until the early 1980s that a few public research institutes began to research, demonstrate, and assemble wind turbines. Due to the lack of knowledge regarding wind technology, the industry had difficulties in commercializing products and upgrading the technology in response to market feedback. As the market was expecting advanced and mature technology with competitive pricing, a majority of the domestic technologies did not have a chance to become commercialized before they were already outdated (Li et al., 2007). Besides the normal R&D programmes with their technology development goals, no additional policy initiatives that emphasized wind energy technology development were adopted.

Worldwide, wind technology also started to develop in the 1970s. Originally, Chinese wind technology only lagged behind slightly in terms of R&D. This gap soon became huge both in terms of R&D and deployment due to the lack of research conducted in China. By the time the leading turbine in the world reached a capacity of 600 kW in 1994, China had only just begun to fund research on 200kW turbines through the Key Technologies R&D Program in the 8th Five-year Plan period.[3] China's immature technology not only increased the production and installation costs, but also presented risks and uncertainties for potential users, preventing the technology from being commercialized.

TABLE 2 Wind technology development path in China

Phases		Technology capacity			Market size		Policy factors	
		Cutting-edge technology	Technology source	Domestic technology	Annual installation (MW)	Accumulated installation (MW)	Macro Policy Framework	Sectorial Policy
Plateau period (2010–present)	2012				15,900	78,264	Quality of development; Indigenous innovation; Financial crisis;	Deployment;
	2011	6 MW	Domestic R&D	6 MW (protocol)	17,631	62,364		
	2010		Domestic R&D	5 MW (protocol)	18,928	44,733		
Market boom period (2003–2009)	2009		Domestic R&D	2.5 MW, 3 MW	13,803	25,805	Indigenous innovation; Commercial merger; WTO pressure;	Renewable energy law; Environmental protection;
	2008		Intl. Technology Licensing	2 MW	6,154	12,002		
	2007			3,311	5,849			
	2006	5 MW			1,288	2,537		
	2005		Joint research/ International technology licensing	1.2 MW, 1.5 MW	507	1250		
	2004	3.6 MW			197	743		
	2003	2.3 MW			98	546		

Early development period (1996–2002)	2002				66	447	Imported technology; Joint ventures; Technology licensing; Technology improvement;	Climate policy priority
	2001				42	381		
	2000	2 MW	International technology licensing	750 kW		342		
	1999	1.3 MW						
	1998	1 MW				224		
	1997		International technology licensing	600 kW		146		
	1996							
Demonstration period (1986–1995)	1995	600 kW					Economic development; Market mechanism; Imported production lines; Science and technology development;	N/A
	1994							
	1993		Domestic R&D	200 kW		4.2		
	1992							
	1991	450 kW	Imported from Germany	250 kW				
	1990	500 kW						
	1989							
	1988	150 kW						
	1987							
	1986	100 kW	Imported from Denmark	55 kW	0.165	0.165		

Sources: Li et al. (2007), Li et al. (2010), Li et al. (2012). Website of the Gold Wind (retrieved from http://www.goldwind.cn/web/about.do?action=story), Sinovel (retrieved from http://www.sinovel.com/milestone.aspx), DongFang Electric Corporation (DEC) (retrieved from http://www.dongfang.com/index.php?app=introduce&id=5), Siemens (retrieved from http://www.energy.siemens.com/hq/en/renewable-energy/wind-power/references.htm), Vestas (retrieved from http://www.vestas.com/en/about/profile#history), Gamesa (retrieved from http://www.gamesacorp.com/en/gamesaen/history/), and Suzlon (retrieved from http://www.suzlon.com/about_suzlon/milestones.aspx?l1=1&l2=1&l3=65).

3.1.2. Market conditions

From 1986 to 1995 there was barely a wind energy market in terms of either demand and supply. From the demand side, the domestic and international wind markets remained underdeveloped. China had rich reserves of coal, which enabled it to generate sufficient energy at low cost. Although the pilot wind farms were connected to the grid, they had almost no influence on national energy consumption. As a result, renewable energy only served as 'a supplementary energy format for rural areas or areas without electricity' (Li et al., 2007, p. 18). From the supply side, the existing wind farms were all demonstration projects, none of which had entered into the commercialization stage. They were either built with foreign government donations or funded through foreign government loans. Wind turbines in wind farms were all imported from companies such as Vestas and Gemasa. Although local wind manufacturers began to emerge, they were not competitive (Xie, Ru, Su, Li, & Zhi, 2011). No market pull policy initiatives were adopted in this period either.

3.1.3. Sectoral- and macro-level policy goals

There was no specific wind energy sector from 1986 to 1995. As a result, none of the sectoral goals were set to stimulate policy initiatives for wind energy development. Because of China's rich reserves of cheap coal, the energy sector did not need to change its structure to ensure an adequate energy supply. In addition, there was almost no wind energy equipment manufacturing to call for sectoral policy goals.

At the macro policy level, again, no direct policy goal was set in relation to wind energy. However, other changes at the macro policy level can shed light on the impetus behind policy initiative design decisions for wind technology. On the one hand, China started its nationwide economic reforms in 1978, which soon became the major national strategy during the 1980s. The overall trend emphasized the effort of enlarging the scale of production and reducing costs. The original enterprise manufacturing (OEM) (as a literal as 'three-coming-in-and-one-compensation') model[4] was widespread in Chinese manufacturing sectors, which was seen as China's main competitive advantage. Therefore, if wind sector manufacturing had emerged in this period, the OEM model (i.e. purchasing the production line from frontrunners and exporting wind products to other countries) would have been the policy initiative (Lewis, 2005). On the other hand, Deng Xiaoping emphasized that 'science and technology is the primary productive force' in the keynote speech on the National Conference of Science in March, 18th 1978. At the national level, more attention was gradually being given to scientific development, but this was still only on a small scale.

3.1.4. Summary

Overall, there were few policy initiatives in China aimed at wind technology during this period. With no incentives either in market exploration or technological innovation, the national research project was the only policy initiative designed for the wind sector. During the 7th and 8th five-year periods (between 1985 and 1994), China started to implement a set of national research programmes to support wind technology development R&D. By adding wind development as a national research target, national support for R&D became a continuous policy initiative that boosted subsequent wind energy development.

Lacking original innovation policy design, wind energy technology development was promoted by macro level guidance, although progress was very slow due to the lack of technology capacity and market demand. Meanwhile, leapfrogging was not possible for China while the frontrunners themselves were in the stage of technology exploration. No real development for wind technology innovation was either expected or possible in this situation.

Even so, China managed to accumulate technological capacity at this stage through demonstration wind farm operations. The Chinese government accepted foreign government donations, grants, and special loans to build demonstration projects using foreign turbines. By 1995, there were five experimental wind farms in China, with a total installation capacity of 36.1 MW (Li et al., 2007). The Goldwind operation, for example, sent its operational employees to Denmark for technology training and established the first technician team in the country.

3.2. Early development period (1996–2002)

After 10 years of development, wind energy technology in China was slowly progressing, and the market was also growing slowly. In 1996, the National Planning Committee announced the Cheng Feng (literally, 'Ride the Wind') Project, which promoted different policy initiatives for achieving wind technology upgrades. A new era of Chinese wind energy development had begun.

3.2.1. Technology capacity

The Cheng Feng Project was the first set of technology policy initiatives especially designed for the wind energy sector. It clearly elevated the goal of building up technological capacity by mastering the manufacturing of key components, and formed two national assembly plants for further technology transfer via the formation of joint ventures. Thus, in the second phase, China not only imported wind turbines from frontrunners such as Denmark and Germany, but also accessed advanced technologies via technology licensing and joint ventures. These enabled China to bypass technologies with a capacity lower than 600 kW and to increase its technology-absorbing capacity (Li et al., 2007; Xie et al., 2011). Despite this, the technology gap between China and the frontrunners grew even larger due to the rapid technological developments in other countries.

3.2.2. Market conditions

Goldwind, founded in 1998 from a public research institute, was the first domestic wind turbine producer. It sold its first wind turbine in 2000, marking its transformation from a research-oriented institute to a manufacturer (see http://www.goldwind.com.cn/web/about.do?action=story). The Chinese wind energy supply market gradually emerged alongside those of other competitors. Although the wind energy market started to grow, demonstration projects remained the dominant deployment format. During this phase, wind electricity accounted for less than 1% of China's total energy consumption (Li et al., 2007). Table 3 shows the accumulated wind farm development up to 2003.

3.2.3. Sectoral- and macro-level policy goals

Compared with the previous period, 1986–1995, early development period saw changes both at the sectoral and macro policy levels. Although still low in technological capacity and small in

TABLE 3 Chinese wind farm development up to 2003

Year	Total no. of grid-connected wind farms	Total installation capacity (MW)	Max. single installation (kW)	Total no. of wind turbine units
1997	19	145.65	600	397
1998	19	224.25	600	532
2000	26	346.24	750	730
2003	30	567.02	1042	–

Source: Data collected from Chinese Wind Electricity Industry Statistics, http://www.nwtc.cn/Article/ShowClass.asp?ClassID=17.

market size, wind energy began to form a sector after the Cheng Feng Project, forming a clear sectoral goal of upgrading domestic technology capacity (Lew, 2000). The sectoral goal, in this period, was fulfilled by policy initiatives selected under the influence of a macro policy framework. After 20 years of economic reform, new strategies were called upon to avoid overdependence on foreign technologies, according to the OEM model, in all sectors. Two major changes occurred at the macro policy level: the 'success through quality' (State Council, 1996) and the 'promote trade through science and technology improvement' (Ministry of Science and Technology (MoST)/Ministry of Foreign Trade and Economic Cooperation (MoFTEC), 1999) policies, introduced in 1996 and 1999, respectively. These policies put domestic technology improvement on the policy agenda. Meanwhile, Deng Xiaoping's slogan of 'science and technology is the primary productive force' continued to guide other policies at the macro level. At the level of detailed policy initiative design processes, it became essential to understand, absorb, and reinvent domestic manufacturing technologies based on imported technologies. As a result, technological improvement became embedded in the macro policy framework.

3.2.4. Summary

Sector formation led to policy initiatives designed to promote technological push and market exploration. The Cheng Feng Project allowed domestic entities to import 300 kW and 600 kW wind technologies through joint ventures, and urged local firms to localize those technologies. The *Guidelines for speeding up the localization of wind turbines*, issued in 2000 (State Economy and Trade Commission, 2000), reinforced this strategy. These policy initiatives followed the logic of 'exchange advanced technologies via openness' adopted in other manufacturing sectors.[5]

As for market exploration, the 1994 *Regulation on grid-connecting operations in wind farms* (Ministry of Electric Power Industry, 1994) and the 1995 *Electricity Act of the People's Republic of China* (National People's Congress [NPC], 1995) stated the important position of renewable energy in the nation's energy structure, in what is regarded as the first milestone of wind energy law and policy in China (Liao, Jochem, Zhang, & Farid, 2010). Additionally, the 2001 *Notice on the comprehensive utilization of certain resources and the value added tax (VAT) issue on other products* (Ministry of Finance & State Administration of Taxation, 2001) reduced the value added tax on on-grid wind electricity from 17% to 8.5%. Wind farms that purchased local wind products were also offered 'beneficial policy and financial support' (State Economy and Trade Commission, 2000, item 3), such as shortened administrative procedures for project applications and connecting to the grid.[6]

It is worth noting, however, that wind energy policy initiatives were not only generated from technology push and market pull demand just for innovation purpose. Rather, this period saw many policy initiatives generated from sectoral and macro policy goal changes, and promoted technological transfer, localization, and market exploration.

3.3. Market boom phase (2003–2009)

Two changes mark 2003 as the starting point of stage three. First, the global wind energy market *skyrocketed* around 2003, immediately after Iceland ratified the Kyoto Protocol, the 55th country to do so.[7] Second, the Chinese government started to explore the domestic wind market via six rounds of concession projects. The Chinese wind industry experienced a rapid growth in terms of both manufacturing capacity (i.e. technological development) and installed capacity (i.e. development of the domestic market) (Li et al., 2007; Li et al., 2012). Between 2004 and 2010, the Chinese wind energy market experienced an average annual growth rate of 130%, despite the onset of the global financial crisis.

3.3.1. Technological capacity

China's rapid technological progress came about through large-scale technology licensing, joint R&D, and acquisitions. Domestic industries soon developed the capacity to produce large turbines in excess of 1 MW, which greatly reduced the technology gap between China and the frontrunners. For example, in 2004, Goldwind and Vensys, a German firm, started a collaborative project producing 1.2 MW turbines. The collaboration enabled Goldwind to vastly improve its R&D capacity and led to the release of wholly domestically produced 1.2 MW and 1.5 MW direct-drive wind turbines in 2005 and 2006, respectively (see http://www.goldwind.cn/web/about.do?action=story). Similar patterns of technological improvement occurred in the collaborative projects between Garrad Hassan, Zhejiang Windey, and Baoding Tianwei, and between Aerodyn and Shanghai Electric (Liao et al., 2010; Ru et al., 2012). On the one hand, these collaborations provided opportunities for Chinese firms to leapfrog, but on the other hand, foreign firms gained up-close insights into the demand of the Chinese market through these joint ventures.

However, simple leapfrog through product transfer is very easy to fail due to the lacking of market judgment. For example, Vestas, the Denmark wind giant, was the first foreign firm to enter the Chinese market, in the 1980s. It promoted the V52-850 wind turbine in Inner Mongolia and other places. However, when Chinese developers and manufacturers adjusted their demand to larger wind turbines (i.e. 1.5 MW and 2 MW turbines) and desired advanced technology, Vestas still only offered 850 kW turbines as their initial product (as it had done in other parts of the world). A slow response to market requirements, untimely after-sale service, along with high prices meant foreign companies faced harsh competition in the Chinese market.[8] The failure of the V52-850 in the Chinese market was a consequence of more than just technological reasons. Market and sectoral development features also made this product unsuitable for the Chinese market.

Mergers and acquisitions (M&A), especially with foreign R&D and wind design companies, were key methods enabling domestic firms to shorten the technology gap. For example, after acquiring a 70%

share of Vensys in 2008, Goldwind integrated the turbine design capacity of Vensys into its global R&D network, and soon developed the capability for indigenous design.[9]

It is worth noting that China, in the year of 2009, terminated the implementation of the *Notification on the relevant requirements for wind power construction management* (NDRC, 2005), which required that 70% of the equipments used during wind farm construction should be locally manufactured. There were two reasons for this. First, after four years of implementation, even foreign wind manufacturers could meet this requirement by registering local branches. Second, China faced potential challenges from the World Trade Organisation (WTO). The termination of the policy, however, did not change the market share distribution between domestic and foreign manufactures (Li, Shi, & Gao, 2010).

3.3.2. Market conditions

From 2003, six rounds of concession projects were conducted to explore the 2.35 GW domestic wind energy market in China (Jiang & Shi, 2006; Ye, 2010). Yet, all of them took price as the only bidding criteria: first four rounds took the lowest bid and the last two rounds took the medium bid. Along with large domestic market exploration, a FIT was adopted to reduce the wind energy price to a competitive level in 2009. As a result, China's annual wind turbine installations soared from 98 MW in 2003 to 13,803 MW in 2009. This massive increase in annual market size stimulated dramatic increases in market demand and supply. By 2008, China had over 80 wind turbine manufacturers, although the top ten contributed 84.8% of the total production capacity (Li et al., 2010). At the same time, ten wind farm developers shared the developing market (Li et al., 2010) (see Table 4). With 10 GW wind farms entering the first stages of project construction in different spots in 2008, the concentrated wind deployment pattern was formed. These huge market expectations encouraged the industry to develop at an even faster speed. However, low-quality wind turbines started to appear in the market.

TABLE 4 Cumulative installed wind turbine capacities by firm (2009, 2011)

Firm	Country of origin	Cumulative capacity 2010 (MW)	Share (%)	Rank (2011)	Cumulative capacity share in 2009 (%)	Rank (2009)
Sinovel	China	10,038.00	22.4%	1	21.9%	1
Goldwind	China	9,078.85	20.3%	2	20.7%	2
DEC	China	5,952.00	13.3%	3	12.9%	3
Vestas	Denmark	2,903.60	6.5%	4	7.8%	4
United Power	China	2,435.00	5.4%	5	3.1%	8
Gamesa	Spain	2,424.30	5.4%	6	7.1%	5
Mingyang	China	1,945.50	4.3%	7	3.5%	7
GE	US	1,167.00	2.6%	8	3.7%	6
XEMC	China	1,069.00	2.4%	9	2.25%	11
East Auto	China	1,073.35	2.4%	10	1.84%	12

Sources: Li et al., 2011; CWEA, 2010.

New challenges began to appear during this period. In particular, the rapid increase in wind energy created the need for flexible and efficient integration of large-scale wind farms. Accordingly, China urgently required suitable grid connection technologies, including long-distance transmission, large-capacity storage, and smart grid technologies (OECD/IEA, 2011). The need also arose for the design of safer wind turbines (e.g. with low-voltage ride through [LVRT] features).

3.3.3. Sectoral- and macro-level policy goals

After 25 years of economic reform towards developing market mechanisms, China eventually adopted the market mechanism as the basis of its macro policy framework. As a consequence, market policy initiatives, such as concession projects, were given greater priority in fulfilling the sectoral goal of increasing the competitiveness of the wind sector. The energy sector, with special focus on renewable energy, also set clear targets following *The Renewable Energy Law* (NPC, 2005).

At the macro level, the policy framework quickly shifted towards climate change concerns by introducing the 2007 *National Climate Change Programme* (NDRC, 2007). The programme still provided new national guidance, principles, and targets, albeit indirectly, to further the development of wind energy (Research Center for Climate Change [RCCC], 2008).

Leapfrogging, as the continuous implementation for the previous rubric of 'technology importation, absorption and re-innovation' (Liu & Hou, 2007, p. 149), became the major mechanism for technology improvement. In 2003, China raised the rubric of a 'scientific outlook on development' (Communist Party of China, 2003), which served as an overarching term and symbolized a new development strategy that embraced sustainable and balanced development with the support of advanced technologies. Accordingly, indigenous innovation replaced the goal of technology localization in the macro policy framework. Policy initiatives under this framework included detailed national technology standards and industrial policies on required rates of localization.

3.3.4. Summary

During the period from 2003 to 2009 there was a boom in policy initiatives in a number of different policy domains, with the majority focused on market policy initiatives. All policy initiatives were designed around this central policy framework, including wind concession projects. Therefore, industrial and financial policy initiatives were geared towards market stimulations, such as the national concession programme starting in 2003, FITs, and tax deductions. At the same time, numerous national plans and laws were formulated about wind energy. The *Renewable Energy Law* (NPC, 2005) and the *Mid and Long Term Renewable Energy Development Plan* (State Council, 2007) built strong market confidence and enabled the rapid development of the industry (Li et al., 2007). This period also saw a number of early attempts to smooth the development of the domestic wind electricity market by introducing energy policies that demanded that all wind electricity be purchased by the grid.

A clear pattern of leapfrogging emerged during this period, when international frontrunners became the major technology sources for China. Yet both policy makers and firms clearly indicated that the ultimate goal for leapfrogging was for technology to overtake international competitors by increasing the indigenous innovation capacity. The combination of a macro policy framework and the innovation process determined the direction of leapfrogging development.

3.4. Plateau period (2010 present)

After 2010, China's annual installation capacity began to decrease.[10] The National Development and Reform Commission (NDRC) suspended construction approval for new wind farms because severe wind curtailment occurred in many wind farms due to grid connection difficulties and market shrinkage (NDRC, 2012a). Although it has remained a leader in wind energy manufacturing with enlarged production capacity and ample private investment, China has experienced a plateau period during which it has tried to define new technological directions and explore new potential markets.

3.4.1. Technology capacity

Leading wind manufacturers have had sufficient indigenous innovation capacity for new technologies. The direction of R&D has changed from large wind turbines to diversified products. Low-speed wind turbines, smart grid technology, and distributed deployment technologies have emerged on the development list for many firms.

Large wind turbines (i.e. 3 MW, 5 MW, and 6 MW) and low-speed turbines still only exist as prototypes. The technology has yet to be tested and evaluated through demonstration projects. A number of firms have prepared large wind turbine technologies for possible offshore market exploration that can be easily implemented when the market niche appears. However, as there has not been clear market exploration nor clear policy guidance on the further development of the new market either at the sectoral or macro level, there has been less motivation to further develop these technologies in China.

3.4.2. Market conditions

Since 2009 there has been a declining trend in the Chinese wind market, despite the fact that China's annual installation capacity has been ranked first in the world. Domestically, wind energy has become increasingly important to China. Although wind energy only accounted for 1.5% of total energy consumption in 2011 (Li et al., 2012), its share is scheduled to increase, with two additional 10 GW wind farms planned and nine large wind farms scheduled to be built by 2020.[11] However, according to the statistics of the State Electricity Regulatory Commission (SERC), Inner Mongolia has experienced the most severe wind electricity curtailment, equivalent to 75.68% of the total wind electricity generated in the area from January to June 2010 (Li et al., 2012). Issues with grid connection seem to be the direct reason for this curtailment, with the large-scale centralized deployment pattern being the deeper reason for wind farms' operational problems in the provinces of Inner Mongolia, Gansu, and Xinjiang (Wang, 2012).

To change the wind deployment pattern, the 12th Five-Year Plan for Renewable Energy Development (NDRC, 2012b) has targeted the exploration of a decentralized wind market. In the southwest of China, a number of decentralized wind farms with low-speed wind turbines have been scheduled close to the location of electricity end-users. This pattern of development may also reduce the demand for grid connection technologies. However, large offshore wind farms have encountered difficulties. For example, although the bidding process for the first round of offshore concession projects in Shanghai has finished, construction is far behind schedule.

TABLE 5 Information about six rounds of concession projects (2003–2009)

Round of concession project	Year	Project location	Designed capacity (MW)	Installed capacity (MW)	Feed-in tariff (CN¥/kWh)
1	2003	Jiangsu	100	100	0.4365
		Guangdong	100	100	0.5013
2	2004	Jiangsu	100	150	0.5190
		Inner Mongolia	100	100	–
		Jilin	100	400	0.5090
3	2005	Jiangsu	200	200	0.5190
		Gansu	100	100	0.4616
		Shandong	150	100	0.6
4	2006	Inner Mongolia	300	600	0.4656
		Inner Mongolia	200	200	0.4656
		Hebei	200	200	0.5006
5	2007	Inner Mongolia	300	300	0.4680
		Inner Mongolia	300	300	0.5216
		Gansu	200	200	0.5206
		Hebei	150	150	0.5510
6	2009	25 projects in total	5250	–	Various

Source: Data collected and summarized from Jiang and Shi (2006) and Ye (2010).

3.4.3. Sectoral- and macro-level policy goals

The worldwide economic and financial crisis in 2007–2008 led to a global slump in the demand for wind equipment due to budget cuts in various countries.[12] The Chinese market, however, continued its rapid growth rate for two more years. Market support came mainly from domestic market cultivation through the six rounds of concession projects. More than 5.2 GW worth of markets was explored in 2009 through these means (see Table 5). It was not until the grid connection problem burst onto the scene in late 2009 and early 2010 that the Chinese wind sector experienced a real decline.

However, there have been no significant changes in policy design at the macro level. Environmental protection, economic development, and indigenous innovation continue to serve as the main policy initiatives. Overall, the macro policy framework has focused on the quality, rather than the speed, of development. This has led to the postponement of new detailed policy initiatives.

3.4.4. Summary

Given the multiple paths open for future technological development and a harsh market climate, no significant policy changes have been instituted. Instead, China has proposed several national standards for wind deployment, including an LVRT standard, a national R&D programme for offshore wind energy demonstration projects, and to develop low-speed wind turbines. Grid connection regulation and reform continues to be of great concern. The pattern of local energy consumption is another policy direction that needs to be explored.

The current policy initiatives encourage reliable technology (e.g. the NDRC requires 2400 operational hours without accident as a condition for special government funding), strict technology standards (e.g. stricter LVRT standards), and the accumulation of future R&D capacity (e.g. laboratory research on 6 MW and 10 MW offshore wind turbine design).

The lack of change at the macro policy level has prevented the design and implementation of new policy initiatives in response to market changes. Nonetheless, the balanced system of policies on science and technology, finance, and industry, together with the existing national standards and laws, are influencing the development of Chinese wind energy technology due to an emphasis on a national quality-win strategy.

4. Discussion

Leapfrogging generates good opportunities for lagging countries to catch up with frontrunners in emerging technologies. However, catch-up mechanisms have not been well explained (Brezis et al., 1993). The leapfrogging experience of China's wind energy sector offers an interesting case in point. In particular, the case allows an analysis of how public policy initiatives have influenced both the development of wind energy technologies and the leapfrogging process itself.

4.1. Wind sector policy design

Echoing Figure 1, three layers of influential factors over the policy design for Chinese wind technology development have been found. The relationships among these three layers are depicted in Table 6.

First, the selection of policy initiatives has been influenced by sectoral goals. More strict environmental protection goals, adjusted national energy structure, and plans in strategic emerging industry have all shed light on the design of policy initiatives. Recently, following the listing of the wind

TABLE 6 Matching among three layers in Chinese wind sector (1986–2012)

	I: Demonstration project period (1986–1994)	II: Early development (1995–2002)	III: Booming stage (2003–2010)	IV: Reflection stage (2011–present)
Macro policy	−	−	+	+
Sectoral policy	−	+	+	+
Policy initiatives	+	+	+	−
Innovation effect[a]	−	+	+ + +	+

Notes: + + +, +, −, − − − represents strong positive effect, positive but small effect, negative but small effect, and strong negative effect, respectively.

[a]The overall policy effect equals the absolute sign of the three layers.

energy industry as one of the major strategic emerging industry in China in 2009, a series of market pull policies were designed. For example, the Development Plan of National Strategic Emerging Industries during the 12th Five-Year-Plan Period (2011–2015) (State Council, 2012) targeted at the" promotion of large amount of investment in the renewable energy industry by 2020. Meanwhile, a clear-cut, long-term national sectoral goals were adjusted when the nation added environmental protection and energy structural adjustments into the national strategic goals. For example, the 2007 *Mid- and Long-Term Renewable Energy Development Plan* (State Council, 2007) set a target of 15% for the renewable energy share of total energy consumption by 2020, and is thought to have been one of the most important factors for the fast development of the Chinese wind energy sector (Li et al., 2010). Vestas also confirmed this point and declared that the stable wind policy in China is one of the most important reasons for firms to push technology development in the country, even during the slow market period. This clearly indicates how much influence sectoral goals can have over detailed policy initiative design. Although no elimination of sectoral goals has been observed in this case, it is reasonable to assume that if a sectoral priority disappears, relevant policy initiatives may be eliminated simultaneously.

Second, the case study has also revealed an interesting relationship between detailed policy initiatives and macro level goals. Although the market and technology conditions remained the same during the early development phase, the policy initiatives changed significantly due to the shift in national macro level policy towards technology improvement. Moreover, when the wind energy market and related technologies encountered substantial difficulties after 2009, policy initiatives were unable to respond in time due to the existing macro level policy design. This could be labelled as 'policy tool selection inertia'[13]; prioritization in the macro policy framework towards the use of certain policy tools (i.e. market-oriented policy tools) would set the priorities among all possible policy tools. However, the preliminary findings here call for further observation of the inertia between different layers of policies in future research.

It is also worth noting that Chinese wind policy initiatives have been designed with top-down features. Strong governmental intervention appears both in technology R&D and market exploration policies. This complies with the macro philosophy of 'focusing resources to achieve big progress' (Deng, 1993, p. 377) in Chinese policy design since the 1980s. However, it also conflicts with WTO rules, especially after 2009. Facing international trade conflicts, policy initiative designs in the Chinese wind energy sector need another round of policy learning, which requires changes at the macro level concerning international market rules.

4.2. Leapfrogging

It can be observed that a period of technology leapfrogging has occurred, enabling the Chinese wind sector to bypass the technology development stage. This was especially the case during the early phase of China's technology development when it bypassed the transitions from 50 kW to 250 kW, 250 kW to 600 kW, and 750 kW to 1 MW.

China's technology leapfrogging, which took technological improvement as the core element of development, did not stop at technology adoption and usage (Lee & Lim, 2001). Rather, technology overtake and indigenous innovative capacity gradually became a key goal for its leapfrogging strategy. This sectoral goal has greatly shifted the design of policy initiatives: policy initiatives are now designed with strong government intervention on wind technology improvement, including national R&D programmes and a localization requirement. India, for example, has also embraced leapfrogging as a strategy in the development of its wind energy sector. However, India has not relied on independent technologies and has instead (long before the creation of a domestic wind market) adopted advanced wind energy technology through technology transfer and licensing from European companies. Accordingly, neither a strong R&D policy nor a local protection policy was adopted there (Narian, 2013).

Furthermore, changes in the national macro strategy from economic development towards environmental protection and climate change mitigation have also influenced the leapfrogging process, which shifted from a manufacturing-centred technology requirement to a deployment-centred requirement. Together with the development of the wind sector, new leapfrogging directions might appear, e.g. grid control technology and material science (Wang et al., 2012).

4.3. Technological capacity as the basis for leapfrogging

The literature on leapfrogging argues that latecomers can either follow the frontrunner's level of technology development or overtake it. Technological capacity is a precondition for successful leapfrogging, especially for technology overtaking.

During the process of 'catch up', when the requisite technology source is available in frontrunner countries, it is much easier to boost technology deployment without having the domestic technological capacity. For example, India gained all the key wind technologies from international technology transfer without ever gaining equal domestic R&D capacity. As long as the technology can fulfil market requirements, market exploration encounters no technological barriers. Following the adoption of the 2003 *Electricity Act* (Department of Commerce, Government of India, 2003), which served as a major wind market exploration policy, wind farms developed at a much greater rate in different parts of India (Narian, 2013).

For the Chinese wind sector, technology overtaking happened at a later stage when the local industry developed a sufficiently strong technological base to absorb the advanced technology. This is consistent with the literature in that it suggests that technology leapfrogging requires that the receiver has enough technology in place to absorb the additional capacity. Moreover, the added capacity may further benefit latecomers by improving future R&D capacity if they choose to pursue this (Lewis, 2007).

However, when the lagging country is trying to surpass the frontrunners, local technology capacity becomes essential. For example, without a solid base of technological improvement, market exploration strategies may encounter difficulties or generate new problems. This has clearly been the case with China's centralized wind deployment after 2009. Due to the distribution of resources, China opted to deploy a large-scale, centralized pattern of wind generation. As China is the largest market to have adopted this deployment pattern, less mature technologies are available to solve the complex problems in long-distance wind electricity transmission. Although the most cutting-edge technology – ultra high voltage direct current (UHVDC) – has been studied in different countries, China has became the showcase with its ± 800 kV transmission projects (Siemens, 2008; Wang, 2012). Accordingly, market exploration without the necessary technology can delay or even ruin market development.

5. Conclusions

Technology development has advanced rapidly over the past three decades in response to climate change. Even so, the technology gap between the frontrunners and latecomers cannot be easily bridged without the help of government-led public policies. Accordingly, it would be an oversimplification to suggest that technological 'catch up' occurs naturally without carefully designed policy initiatives.

An attempt has been made to reveal the complicated relationships underlying policy initiative designs by examining the relationships between sectoral goals and macro policy during the course of the development of the Chinese wind energy sector. Using the policy initiatives selected in the Chinese wind sector as a case study, three observations have been made. First, this study confirmed Paraskevopoulou (2012) that the design of policy initiatives was subject to the multiple influences of sectoral goals and macro policy. Policy initiatives, sectoral goals and macro policy need to match in order to achieve better policy impact. Secondly, leapfrogging decision happens at different levels. Firm level leapfrogging influence firm decision, while leapfrogging decisions at the sectoral level or macro policy level influence policy initiative design of the country. Chinese wind energy case presents leapfrogging decision starting at the macro policy level, then down to technological and firm level. With macro level and sectoral level emphasis, leapfrogging could be fulfilled with strong governmental intervention not limited to innovation policy, but other options such as sectoral policy or even national development mode change, which in turn influences all levels of leapfrogging decisions. Third, China's technology capacity ultimately determined whether it would surpass the frontrunners.

These observations can be generalized and applied to the technology catch-up attempts in other developing countries. Notably, policy initiatives in other developing contexts can be designed differently, even if the two countries share a similar technology base and market conditions. For example, although China and India have both undergone wind technology catch-up, India from the outset gained its core wind technology mainly through acquisition and international technology transfer. The little national research support and few market exploration policies provided by the Indian government can be seen to reflect the national belief in free market mechanisms. This fundamental difference between the two countries at the national strategy level thus led to the adoption of different policy initiatives.

Similarly, the observations made above can also be generalized to other climate change technologies. For example, photovoltaics are experiencing a period of rapid market growth. Some have suggested borrowing the policy initiatives from the wind sector to support the development of solar technology, such as large-scale domestic market exploration. However, more consideration needs to be given to technological competitiveness and market potential. Finally, further theoretical and empirical research is needed on the determinants of technology development policies. A better understanding of the mechanisms underlying policy initiatives design would help guide developing countries in mitigating the causes of climate change.

Notes

1. Studies have categorized Chinese wind energy sector development along different dimensions. For example, Ru et al. (2012) categorize the process into four stages according to innovation mode, while Qi (2013) separate it

along with the changes of the executive (implementation) organizations on energy-saving technology. The National Development and Reform Commission (NDRC, 2009) also separate sector development into four stages according to its market development features. In this research, both technology development paths and market development status have been combined and the wind energy development process has been separated accordingly.

2. The data vary in different reports and documents. The data cited here come from the interview with the Center for Wind and Solar Energy Resources Assessment, China Meteorological Administration, on 17 July 2012. Interviewees included Li Zechun, Zhu Rong.
3. The program is counted along with the National Five-year Plan period.
4. The OEM is a manufacturing model that uses foreign materials, components, and parts to produce value added products and sells them back to foreign countries. This was the major manufacturing model in China during the 1980s.
5. 'Exchange advanced technologies via openness' is firstly raised by Ye Jianying in June, 1978 after he received Gu Mu's visiting report to Western European countries. Then the phrase has been widely used in practice (Xia & Zhao, 2012).
6. Taken from 'Guidelines for speeding up the localisation of wind turbines' (State Economy and Trade Commission, 2000), issued in 2000, and 'Regulations on supporting the further development of wind power' (State Economic and Trade Commission, 1999), issued in 1999.
7. According to this agreement, the United Nations Framework Convention on Climate Change (UNFCCC) would come into force when the following was achieved: '(r)atification by 55 States to the Convention, incorporating States included in Annex I which accounted in total for at least 55% of the total carbon dioxide emissions for 1990 of the Parties included in Annex I' (Kyoto Protocal, Article 25, UNFCCC, 1997). When Iceland ratified the UNFCCC, the first half of this requirement was met. Many countries took this as a milestone for the UNFCCC itself.
8. Taken from an interview with Vestas Beijing on 20 July 2012 and the Government Relation Department.
9. Interview on 17 July 2012 with Goldwind's public relations department and the vice-president for R&D.
10. Project approval information is collected on the National Energy Administration(NEA) website at: http://www.nea.gov.cn/zcfb/xmsp.htm
11. China installed 18.9 GW, 17.6 GW, and 12.9 GW wind generation capacity in 2010, 2011, and 2012, respectively.
12. In 2009, the drop in turbine installation was clear both in the US (from 7086 units in 2008 to 5685 in 2009), and in Europe (from 5444 units in 2008 to 4885 units in 2009) (BTM Consult, 2011).
13. The concept of policy inertia originated in monetary policy literature and has been used to describe gradual policy changes based on existing policy designs.

References

Bauer, J., Lang, A., & Schneider, V. (2012). *Innovation policy and governance in high-tech industries: The complexity of coordination*. Bücher: SpringerLink.

Braun, D. (2008). Organising the political coordination of knowledge and innovation policies. *Science and Public Policy*, *35*, 227–239.

Brezis, E., Krugman, P., & Tsiddon, D. (1993). Leapfrogging in international competition: A theory of cycles in national technological leadership. *The American Economic Review*, *83*, 1211–1219.

BTM. (2011). *International wind power development: World market update 2010, forecast 2011– 2015*. Ringkøbing, Denmark: BTM Consult.

Cherni, J., & Kenitsh, J. (2007). Renewable energy policy and electricity market reforms in China. *Energy Policy*, *35*, 3616–3629.

Chinese Wind Energy Association (CWEA). (2010). Chinese wind turbine manufacture market situation and its developing trend in 2009. *Wind Energy*, *1*, 34–37.
Chinese Wind Energy Association (CWEA). (2012). Statistics of Chinese wind energy installation capacity 2011. Retrieved from http://www.cwea.org.cn/upload/2011年风电装机容量统计.pdf
Coenen, L., Benneworth, P., & Truffer, B. (2012). Towards a spatial perspective on sustainability transitions. *Research Policy*, *41*, 968–979.
Communist Party of China. (2003). Communique of the 3rd Plenary Session of the 16th CPC Central Committee. Retrieved from http://www.china.com.cn/chinese/zhuanti/sljszqh/421625.htm
Deng, X. (1993). *Works of Deng Xiaoping* (Vol. 3, p. 377). Beijing: People's Publishing House.
Department of Commerce, Government of India. (2003). Electricity Act. Retrieved from http://powermin.nic.in/acts_notification/electricity_act2003/preliminary.htm
Dodgson, M., Gann, D., & Salter, A. (2008). *The management of technological innovation*. London: Oxford University Press.
DongFang Electric Corporation (DEC). History of DEC. Retrieved from http://www.dongfang.com/index.php?app=introduce&id=5
Edquist, C. (2001). *The systems of innovation approach and innovation policy: An account of the state of the art*. Lead paper presented at the DRUID Conference, National Systems of Innovation, Institutions and Public Policies, Aalborg.
Freeman, C. (2002). Continental, national and sub-national innovation systems: Complementarity and economic growth. *Research Policy*, *31*(2), 191–211.
Fromhold-Eisebith, M. (2007). Bridging scales in innovation policies: How to link regional, national and international innovation systems. *European Planning Studies*, *15*(2), 217–233.
Gallagher, K. (2006). Limits to leapfrogging in energy technologies? Evidence from the Chinese automobile industry. *Energy Policy*, *34*, 383–394.
Gamesa. History of Gamesa. Retrieved from http://www.gamesacorp.com/en/gamesaen/history/
Giovannetti, E. (2013). Catching up, leapfrogging, or forging ahead? Exploring the effects of integration and history on spatial technological adoptions. *Environment and Planning A*, *45*, 930–946.
Goldemberg, J. (1998). Leapfrog energy technologies. *Energy Policy*, *26*, 729–741.
Goldwind. History of Goldwind. Retrieved from http://www.goldwind.cn/web/about.do?action=story
Grant, R. (2003). *Cases in contemporary strategy analysis*. Oxford, UK: Wiley-Blackwell.
Grubb, M. (2004). Technology innovation and climate change policy: An overview of issues and options. *KEIO Economic Studies*, *41*(2), 103–132.
Guérin, E., & J. Schiavo. 2011. Pushing and pulling: The bumpy road to effective renewable energy policy. *Bridges Trade BioRes Review*, *5*(1). Retrieved from http://ictsd.org/i/news/bioresreview/103559/
Heymann, M. (1998). Signs of hubris: The shaping of wind technology styles in Germany, Denmark, and the United States, 1940–1990. *Technology and Culture*, *39*, 641–670.
Isaksen, A., & Nilsson, M. (in press). Combined innovation policy: Linking scientific and practical knowledge in innovation systems. *European Planning Studies*, (ahead-of-print), 1–18.
Jiang, L., & Shi, P. (2006). Implementation situation of wind power concession bidding projects in China and analysis. *Electric Power Technologic Economy*, *18*(4), 1–10.
Kamp, L. (2002). *Learning in wind turbine development* (Dissertation). University of Utrecht.
Lee, K., & Lim, C. (2001). Technological regimes, catching-up and leapfrogging: Findings from the Korean industries. *Research Policy*, *30*, 459–483.
Lema, A., & Ruby, K. (2007). Between fragmented authoritarianism and policy coordination: Creating a Chinese market for wind energy. *Energy Policy*, *35*, 3879–3890.
Lew, D. (2000). Alternatives to coal and candles: Wind power in China. *Energy Policy*, *28*, 271–286.
Lewis, J. (2005, December). *Part of the climate change problem . . . and the solution? Chinese-made wind power technology and opportunities for dissemination*. Breslauer Symposium, University of California International and Area Studies, UC Berkeley. Retrieved from http://escholarship.org/uc/item/8rt4q01 k#page-1

Lewis, J. (2007). Technology acquisition and innovation in the developing world: Wind turbine development in China and India. *Studies in Comparative International Development*, *42*, 208–232.
Lewis, J., & Wiser, R. (2007). Fostering a renewable energy technology industry: An international comparison of wind industry policy support mechanisms. *Energy Policy*, *35*, 1844–1857.
Li, J., Cai, F., Tang, W., Xie, H., Gao, H., Ma, L., … Dong, L. (2011). *China wind power outlook: 2011*. Beijing: China Environmental Science Press.
Li, J., Cai, F., Xiao, L., Xie, H., Gao, H., Yang, X., … Li, X. (2012). *China wind power outlook: 2012*. Beijing: China Environmental Science Press.
Li, J., Gao, H., Shi, P., Shi, J., Ma, L., Qin, H., & Song, Y. (2007). *China wind power report: 2007*. Beijing: China Environmental Science Press.
Li, J., Shi, P., & Gao, H. (2010). *China wind power outlook: 2010*. Hainan: Hainan Press.
Liao, C., Jochem, E., Zhang, Y., & Farid, N. (2010). Wind power development and policies in China. *Renewable Energy*, *35*, 1879–1886.
Liu, J., & Hou, Y. (2007). Pondering on the problem of the assimilation and innovation of import technology in China. *Logistics Sci-Tech, 2007*(1), 149–150.
Liu, Y., & Kokko, A. (2010). Wind power in China: Policy and development challenges. *Energy Policy*, *38*, 5520–5529.
Markard, J., & Truffer, B. (2008). Technological innovation systems and the multi-level perspective: Towards an integrated framework. *Research Policy*, *37*, 596–615.
Menz, F., & Vachon, S. (2006). The effectiveness of different policy regimes for promoting wind power: Experiences from the states. *Energy Policy*, *34*, 1786–1796.
Michaelson, J. (1998). Geoengineering: A climate change Manhattan project. *Stanford Environmental Law Journal*, *17*(73), 1–53.
Ministry of Electric Power Industry. (1994). Regulation on grid–connecting operations in wind farms [in Chinese "Feng Li Fa Dian Chang Bing Wang Yun Xing Guan Li Gui Ding". Dian Zheng Fa [1994], No. 461].
Ministry of Finance & State Administration of Taxation. (2001). Notice on the comprehensive utilisation of certain resources and the VAT issue on other products [in Chinese "Guan Yu Bu Fen Zi Yuan Zong He Li Yong Ji Qi Ta Chan Pin Zeng Zhi Shui Zheng Ce De Tong Zhi". Cai Shui[2001]1, No. 98].
Ministry of Science and Technology (MoST) and Ministry of Foreign Trade and Economic Cooperation (MoFTEC). (1999). Action plan to promote trade through science and technology improvement [in Chinese "Ke Ji Xing Mao Xing Dong Ji Hua" (Guo Ke Fa Ji Zi [1999], No. 219)]. Retrieved November 20, 2013, from http://www.most.gov.cn/kjzc/gjkjzc/kjjhgl/201308/P020130823577287031203.pdf
Munksgaard, J., & Morthorst, P. (2008). Wind power in the Danish liberalised power market – policy measures, price impact and investor incentives. *Energy Policy*, *36*, 3940–3947.
Murphy, J. (2001). Making the energy transition in rural East Africa: Is leapfrogging an alternative?. *Technological Forecasting and Social Change*, *68*, 173–193.
Narian, A. (2013). *Technological trajectories for climate change mitigation in Europe, China and India* (Working paper draft). Wind Energy India.
National Development and Reform Commission (NDRC). (2005). Notification on relevant suggestions for accelerating the localisation of wind power construction. Retrieved from http://www.sdpc.gov.cn/nyjt/nyzywx/t20050810_41378.htm
National Development and Reform Commission (NDRC). (2007). National climate change programme. Retrieved from http://www.ccchina.gov.cn/WebSite/CCChina/UpFile/File189.pdf
National Development and Reform Commission. (NDRC). (2009). *Report on the development of Chinese wind energy and the feed-in tariff*. Retrieved from http://www.ndrc.gov.cn/zjgx/P020091126386872388651.pdf
National Development and Reform Commission. (NDRC). (2012a). *Notification on the second rounds of wind energy project confirmation in the 12th five years*. Retrieved from http://www.gov.cn/zwgk/2013-03/19/content_2357381.htm

National Development and Reform Commission (NDRC). (2012b). The 12th five-year plan for renewable energy development. Retrieved from http://www.cnenergy.org/wjfg/201302/t20130221_177068.html
National People's Congress (NPC). (1995). Electricity Act of People's Republic of China [in Chinese "Zhong Hua Ren Min Gong He Guo Dian Li Fa"]. Adopted by the 17th Session of the Standing Committee of the Eighth National People's Congress on December 28, 1995, promulgated by the Order No. 60 of the President of the People's Republic of China on December 28, 1995, and effective on April 1, 1996.
National People's Congress. (2005). Renewable law of People's Republic of China. Retrieved from http://www.china.com.cn/chinese/law/798072.htm
Neij, L. (1997). Use of experience curves to analyze the prospects for diffusion and adoption of renewable energy technology. *Energy Policy*, *23*, 1099–1107.
Nemet, G. (2009). Demand-pull, technology-push and government-led incentives for non-incremental technical change. *Research Policy*, *38*, 700–709.
Organisation for Economic Co-operation and Development (OECD). (2005). *Governance of innovation systems. Volume 1: Synthesis report*. Paris: Organization for Economic Co-operation and Development.
Organisation for Economic Co-operation and Development/International Energy Agency (OECD/IEA)/Energy Research Institute of the NDRC. (2011). *China wind energy development roadmap 2050*. Retrieved from http://www.iea.org/publications/freepublications/publication/china_wind.pdf
Paraskevopoulou, E. (2012). Non-technological regulatory effects: Implications for innovation and innovation policy. *Research Policy*, *41*, 1058–1071.
Perkins, R. (2003). Environmental leapfrogging in developing countries: A critical assessment and reconstruction. *National Resource Forum*, *27*, 177–188.
Popp, D. (2012). *The role of technological change in green growth* (NBER Working Paper 18506). Cambridge, MA: National Bureau of Economic Research. Retrieved from http://www.nber.org/papers/w18506
Qi, Y. (Ed). (2013). *Annual review of low-carbon development in China (2011–2012)*. Beijing: Social Sciences Academic Press.
Research Center for Climate Change (RCCC), Ministry of Water Resources. (2008). Introduction of China's national climate change program. *China Water Resources*, *2008*(2), 72–74.
Ru, P., Zhi, Q., Zhang, F., Zhong, X., Li, J., & Su, J. (2012). Behind the development of technology: The transition of innovation modes in China's wind turbine manufacturing industry. *Energy Policy*, *43*, 58–69.
Sauter, R., & Watson, J. (2008). *Technology leapfrogging: A review of the evidence*. Report for UK Department of International Development. SPRU, University of Sussex. Retrieved from https://www.sussex.ac.uk/webteam/gateway/file.php?name=dfid-leapfrogging-reportweb.pdf&site=264
Siemens. (2008). *China showcases UHVDC technology*. Retrieved from http://www.energy.siemens.com/mx/pool/hq/power-transmission/Transformers/HVDC/Case_study_for_800kV_HVDC_Transmission.pdf
Siemens. History of Siemens. Retrieved from http://www.energy.siemens.com/hq/en/renewable-energy/wind-power/references.htm
Sinovel. History of Sinovel. Retrieved from http://www.sinovel.com/milestone.aspx
State Council. (1996). *Programme for Quality Revitalisation 1996–2010* [in Chinese "Zhi Liang Zhen Xing Gang Yao (1996-2010)"]. Retrieved from http://vip.chinalawinfo.com:8081/newlaw2002/SLC/slc.asp?db=chl&gid=16287
State Council. (2007). Mid-long term renewable energy development plan. Retrieved from http://www.sdpc.gov.cn/zcfb/zcfbtz/2007tongzhi/W020070904607346044110.pdf
State Council. (2012). Development plan of National Strategic Emerging Industries during the 12th five-year-plan period (2011–2015). Retrieved from http://erawatch.jrc.ec.europa.eu/erawatch/opencms/system/modules/com.everis.erawatch.template/pages/exportTypesToHtml.jsp?contentid=18862378-715c-11e2-9fa4-3b1a37daf5b5&country=China&option=PDF
State Economic and Trade Commission. (1999). Regulations on supporting the further development of wind power [in Chinese "Guan Yu Jin Yi Bu Cu Jin Feng Li Fa Dian Fa Zhan De Ruo Gan Gui Ding". Guo Jing Mao Dian Li [1999], NO. 1286].

State Economy and Trade Commission. (2000). Guidelines of speeding up the localisation of wind turbines [in Chinese "Guan Yu Jia Kuai Feng Li Fa Dian Ji Shu Zhuang Bei Guo Chan Hua De Zhi Dao Yi Jian"]. Retrieved November 20, 2013, from http://www.gov.cn/gongbao/content/2000/content_60245.htm

Suzlon. Milestone of Suzlon. Retrieved from http://www.suzlon.com/about_suzlon/milestones.aspx?l1=1&l2=1&l3=65

United Nations Framework Convention on Climate Change (UNFCCC). (1997). Kyoto protocal. Retrieved November 21, 2013, from http://unfccc.int/essential_background/kyoto_protocol/items/1678.php

Vestas. History of Vestas. Retrieved from http://www.vestas.com/en/about/profile#history

Wang, N. (2012). *Convey and consumption of large-scale*. Beijing: China Electric Power Press.

Wang, Z., Qin, H., & Lewis, J. (2012). China's wind power industry: Policy support, technological achievements, and emerging challenges. *Energy Policy*, *51*, 80–88.

Xia, L., & Zhao, L. (2012). The historical envolvement of the "exchange advanced technologies via openness". Retrieved from The History of the People's Republic of China website. Retrieved from http://www.hprc.org.cn/gsyj/jjs/jjyxs/201205/t20120515_189465.html

Xie, X., Ru, P. Su, J., Li, J., & Zhi, Q. (2011). The technology innovation mode evolution and policy motivation for Chinese wind manufactures. *Coal Economic Research*, *2011*(4), 10–14,17.

Ye, B. (2010). Policy-driven Chinese wind industry: A note on supportive policy over wind energy sector. *NEDA New Energy*, *2010*(6), 23–24.

Zhang, P., Yang, Y., Shi, J., Zheng, Y., Wang, L., & Li, X. (2009). Opportunities and challenges for renewable energy policy in China. *Renewable and Sustainable Energy Reviews*, *13*, 439–449.

Appendix: List of Chinese policy initiatives on wind technology development (1994–2011)

Policy	Year	R&D	Manufacturing	Deployment	Localization
Regulation on grid-connecting operations in wind farms	1994			√	
The Electricity Act of the People's Republic of China	1995			√	
Riding the wind project	1996	√		√	
Regulations on supporting the further development of wind power	1999		√	√	√
Guidelines of speeding up the localization of wind turbines	2000	√			√
The 10th Five-year Plan for new and renewable energy	2001		√	√	
Notice on the comprehensive utilization of certain resources and the VAT issue on other products	2001				√
Management measure on the preparatory work for wind power concessions projects	2003			√	
Measures on formulating a pre-report on the availability of wind farms	2003			√	
Technological regulation on the selection of wind farm locations	2003			√	
Technological regulation on the measurement and assessment of wind resources	2003			√	

Continued

Appendix: Continued

Policy	Year	R&D	Manu-facturing	Deploy-ment	Locali-zation
Technological regulation on engineering and geological investigations of wind farms	2003			√	
Measures on formulating investments in wind farm projects	2003			√	
National technological regulation on the assessment of wind resources	2004			√	
Notification on the relevant requirements for wind power construction management	2005			√	
Notification on relevant suggestions for accelerating the localization of wind power construction	2005	√	√		√
Interim measures on the regulation of land and environment protection management in wind power construction	2005			√	
Interim measures on special fund management for the development of renewable energy	2006	√			
Renewable Energy Law	2006	√		√	
Mid-Long Term Renewable Energy Development Plan	2007		√	√	
11th Five-year Plan for renewable energy development	2008			√	
Circular of the Ministry of Finance on the adjustment of import tax policies governing high wind power generator units and their key parts and raw materials	2008	√	√		
Interim measure on the management of special funds for wind power industrialization	2008		√		√
NDRC notification on improving price policy for grid-connected wind electricity	2009			√	
Net interim measure on the management of offshore wind power development	2010			√	
Views on accelerating the smooth development of the wind equipment industry	2010	√	√		√