Bocconi

IEFE
Centre for Research on Energy and Environmental Economics and Policy

Working Paper Series - ISSN 1973-0381

Green Growth: A Case Study on the Danish and Chinese Sectoral Innovation Systems

Enrico Botta

Working Paper n. 53

February 2013

IEFE - The Center for Research on Energy and Environmental Economics and Policy at Bocconi University
via Guglielmo Röntgen, 1 - 20136 Milano
tel. 02.5836.3820 - fax 02.5836.3890
www.iefe.unibocconi.it – iefe@unibocconi.it

Green growth: A case study on the Danish and Chinese Sectoral Innovation Systems

Enrico Botta[a]

[a] IEFE – Center for Research on Energy and Environmental Economics and Policy, Bocconi University

Abstract

The purpose of this paper is to provide relevant insights to policy makers interested in developing a green innovative industry. In order to shed lights on the process of building a competitive green industry, the paper leverages the conceptual framework of innovation systems. Therefore, the first paragraph reviews the theory of innovation system, explaining the reason behind the choice to use a sectoral approach. The second paragraph exploits the industry life cycle perspective to describe the evolution of the wind turbine technology. Then, within the next two paragraphs the key constituting elements of the Chinese and Danish systems are described. Finally, building on our understanding of the evolution of the wind turbine technology and of the configuration of the two sectoral innovation systems, the differences and similarities between the two cases are discussed and the key conclusions from the perspective of a policy maker are presented. Our main argument is that the stage of technological evolution together with the maturity of the domestic sector is one of the main explanatory variables that allows to understand which functions (and how) should be activated by the policies aiming at developing a green SIS.

Keywords: Sectoral innovation system, Green growth, Renewable energy, Wind turbines industry, Denmark, China

JEL Codes: O30, O25, Q48

Contents

1 Innovation systems in the economic literature

The concept of system innovation was originally elaborated in 1987 by Freeman (1987). Generally speaking an innovation system can be defined as "*the elements and relationships which interact in the production, diffusion and use of new, and economically-useful, knowledge*" (Lundvall, 1992). The seminal work on innovation system (IS) is often considered the empirical analysis on fifteen different countries performed by Nelson in 1993. Within his work, Nelson leveraged the concept of National Innovation Systems (NIS) which has been for a long time discussed in the literature. An often remarked weakness of this high level of aggregation is that it fails to explain why specific sectors strive and others succeed within the same country. As such, scholars have advanced less aggregated definition of innovation systems. One of the first contributions was the concept of technological innovation systems (TIIs) that focuses mainly on the technological knowledge underlying a sector and defines IS as entities that create novel technologies while at the same time support established ones (Carlsson and Stankiewicz, 1995). A different approach has been pursued by Cooke (1997) who advanced the definition of Regional Innovation Systems (RIS). Generally speaking, the usage of the RIS framework is usually linked to the need of explaining why a specific geographical area is a more successful "locus of innovation" than others in a close proximity (an often quoted example is the Silicon Valley). A more recent approach defines the boundaries of innovation system at sectoral level while strongly building on the assumptions typical of evolutionary economics such as heterogeneity of actors and role of learning capabilities in explaining system evolution (Breschi and Malerba, 1997, 2005). More precisely, Sectoral Systems of Innovation are defined as *"...composed by the set of heterogeneous agents carrying out market and non-market interactions for the generation, adoption and use of (new and established) technologies and for the creation, production and use of (new and established) products that pertain to a sector"* (Malerba, 1999). Within a sectoral IS, a key role is played by the actors active in the sectors, both firms and non-firm organizations (such as universities, financial institutions, central government, local authorities as well as the users of the technology). The interactions among these agents are affected by institutions, defined as common norms that shape the behavior of individual agents, and by the policies and instruments implemented by the government.

While the literature did not reach an agreement on the proper boundaries of a IS, a group of authors recently focused on the functions a system should perform. Already in 2000, Rickne discussed what 'functionality' each type of actor can provide to new technology based firms and provided a long list of functions. Edquist (2001) completed a literature review of several definitions of SIs and their functions. Johnson (2001, 2003) argued that the fundamental activities of an innovation system amount to five. A result later on confirmed by Liu and White (2010) who identified five essential functions while Bergeek (2008) utilized an "eight functions approach" in his work. As this brief literature review shows, the definitive list of functions of IS is still debated. However, several authors agree on the benefits that this approach provides. The key advantage of adopting a functional approach is that it eases the comparison of different IS. As Johnson and Jacobsson (2000) emphasized, "a set of functions [..] have to be fulfilled in order for the growth of an industry to be supported. We suggest that we can evaluate the performance of an innovation system by assessing its ‘functionality’, i.e. how well these functions are served.” However, the benefit of adopting a functionality approach is not limited to an easier comparison but it serves also the broader objectives of this paper. In fact, as underlined by Negro (Negro et all, 2007), this approach has two further benefits. Firstly, it allows for a more systematic method of mapping determinants of innovation. Secondly, the possibility of comparing different systems along a specific function provides a clear set of policy targets for the policy makers[1] (Negro et all, 2007; Jacobsson and Johnson, 2000).

Given these elements, this paper firstly leverages the SIS approach in order to correctly identify all the key elements in the two systems. The reasons for this choice are numerous. For instance, the weaknesses of geographical bounded IS emerge clearly in studying both the Chinese wind turbine case due to the presence of several leading firms located in different regions and the Danish case because of the global nature of Vestas[2]. Instead, the TIS framework with its strong focus on technology seems to be overlooking several important elements that are well described in the SIS approach. Furthermore, the recent application of SIS to the analysis of the catching-up process within five different industries and the possibility to leverage this relevant work also contributed to the choice of using a Sectoral Innovation System framework (Malerba M., Nelson R., 2012). Then, the functionality approach is used to compare the two systems. This choice is supported by several recent studies dedicated to green energy industries (del Río P., Bleda M., 2012; Negro S. et al, 2007). As discussed, there is not common agreement on the list and number of functions an innovation system should perform. Among the different contributions, we leverage the list proposed by Bergek et all (2008) given their relevance to the case considered.

[1] Innovation system analyses and sustainability transitions: Contributions and suggestions for research, Jacobsson A., A. Bergek A. / Environmental Innovation and Societal Transitions 1, 2011.
[2] Vestas is the Danish leading wind turbine manufacturer and it is now a globalised firm with worldwide dispered R&D and production facilities. As such, difficult to frame within a regional or national IS approach.

Function	Description	Example in wind turbine industry
To create and diffuse 'new' knowledge	This is the key function and at the same time one of the main objectives of an innovation system	- This entails the basic process of technology development, like the improvement of aerodynamic understanding of wind turbine behavior or development of power control functions
To guide the direction of the search process among users and suppliers of technology	This function includes guidance with respect to both technological choice (i.e. the choice of specific design configurations), and market choice. Guidance can be provided "*by identification of problems of a technical nature, changing factor prices, the formation of standards or regulation and relationships to competent customers, or by various policy interventions*" (Johnson, 2000)	- Selecting the turbine design that will be the most appreciated by the market
To foster Entrepreneurial Experimentation	The testing of new technologies, applications and markets whereby new opportunities are created and a learning process is unfolded.(Bergek, 2009)	- Presence of different manufacturers that experiment with different technologies
To mobilize resources	Each innovation system has to be able to provide the relevant actors with the required resources ranging from capital to knowledge, qualified personnel and complementary	- Examples of necessary resources for the turbine industry are: specialized engineers, working financial markets, etc.
To facilitate the formation of markets	Not all markets emerge spontaneously. Some might require high investments by firms before being created, to clear political and legislative ground to favor the new technology, creation of an initial demand, etc.	- Even if nowadays wind turbines have reach grid parity in specific conditions, demand for this good would not have emerged without support measures (eg. FIT tariffs).
To provide legittimation	Bergek (2008) defines legitimation as "*the social acceptance and compliance with relevant institutions. Legitimacy is not given but is formed through conscious actions by organizations and individuals*."	- Legitimation entails not only the public acceptance of the voters for measures to support the industry but also the building of thrust among investors in the technology.
To create positive externalities	This function is key requirement of a systemic approach to knowledge creation and it is based on the presence of networks and relevant institutions that create positive external economies in the form of an exchange of information, knowledge and visions.	- Knowledge externalities might emerge in several ways, like: cluster of specialized firms, collaboration among academia and the industry, etc.

Table 1: Function of innovation system. Author's elaboration on*: Bergek A., Jacobsson S., Carlsson B., Lindmark S., Rickne A., Analyzing the functional dynamics of technological innovation systems: A scheme of analysis, Research Policy 37, 2008*

2 Market and Technology

In order to correctly frame our analysis, we firstly review the trajectory drawn by the wind turbine technology. This analysis is extremely important since the evolution of the two SISs started with a lag of several years and, as we will see, during two different technological stages. The two most common models of industry evolution are the *Product life cycle* and the *Industry life cycle* which, while retaining many similarities, differ for the strong focus on technological innovation that is typical of the later model. Given the importance of innovation within our discussion, the analysis builds on the latter model (Aberthany and Utterback, 1978) which identifies four different stages within the "life" of a technology. Briefly described, the first stage or "infancy stage" is characterised by several design options, niche market, users defined as "early adopters" and high costs. During this stage, technological and market uncertainties prevail, a great deal of changes takes place contemporaneously and outcomes may vary significantly. Successively, we enter the fluid stage. Usually during this phase only a few remaining designs compete in the market. As the experience increases, the market forces select a dominant design[3] (growth stage); this process proceeds together with a gradual shift from product to process innovation. As the technology matures and the product becomes a commodity (specific stage), the industry faces a process of concentration[4] while R&D focuses on process innovation. Finally, if a rejuvenation does not happen, the market for the technology usually decreases as other products gradually satisfy the market needs. The analysis reveals how the wind turbine technology evolved in a technological paradigm and how it is currently undergoing the maturity stage. A conclusion that is confirmed by the process of industry consolidation and the decreasing price for MW of wind energy. Finally, the technology currently exploited by two leading manufacturers in the two countries is compared. The results suggest that the Chinese SIS is very close to (if not already have) catch-up with the technological frontier for onshore turbines.

2.1 The infancy of the technology

From the beginning of the last century until the'80, the industry went through its first stage where[5] multiple design options were competing. The principal design options characterizing the early phase of the industry were: optimal size; number of blades; horizontal or vertical design; upwind or downwind design. The issue of rotor optimal size was highly discussed and the first studies were carried out by Palmer C. Putnam that concluded that the most economical design would have had a diameter between 54-68 meters (Maltha, 2005). Of course, his opinions were highly challenged and still in 1974 the NASA-manager Josef Savino wrote: "No one knows at this time what a cost-effective wind electric plant is going to look like ultimately and how big it will be" (Maltha, 2005). Another important question mark in

[3] A Dominant Design is a product design that is adopted by the majority of the producers typically creating a stable architecture on which the industry can focus its efforts – Schilling, 2005, page 50

[4] Usually oligopolies take place

[5] A critical contribution to this section derives from: (i) Joffry Maltha; "The evolution of the worldwide wind turbine industry 1975-2005:"Explaining the Danish industrial leadership"; Master thesis at Eindhoven University of Technology (TU/e) September 2005. (ii) Advances in wind turbine design, Frost and Sullivan, 2008.

the industry was the optimal number of blades a turbine should have had. The higher the number of blades, the higher is the rotor power coefficient; nevertheless, the impact of additional blades is strictly decreasing and quickly the gains are offset by the cost of the additional blades (Maltha, 2005; Hau, 2000). A final trade off was the one between horizontal or vertical design[6]. Within the vertical model, the blades are attached to the rotor tower and the structure broadly looks like an eggbeater. These turbines consist of two or three blades with the main rotor shaft placed vertically with blades; gearbox and generator are placed on the ground. The advantages of a vertical axis configuration[7] include its utility in areas where wind directions are variable, less expensiveness, and easier maintenance (Frost and Sullivan, 2008). Nevertheless this configuration has two main disadvantages. First of all, the drag created by the rotation of the blades causes noise and vibration. Secondly, the wind speed that is encountered near the ground level is very low and therefore the overall efficiency was low. On the other hand, the horizontal axis model[8] presents blades that are similar to those attached to airplane propellers. These turbines are "pointed into the wind and have a gearbox, a main rotor shaft and electrical generator in the nacelle at the top of a tower" (Frost and Sullivan, 2008, pp. 8). Horizontal design soon emerged as the favorite design option and its dominance is still unquestioned. Furthermore, the affirmation of the horizontal design would have resulted also in the affirmation of the "upwind design" since, because of fatigue failure due to the turbulence produced behind the tower, this turbine is usually placed upwind of the tower.

2.2 Fluid Stage

During the '80, the era of pure technological ferment ended and three competing designs emerged. The first design, and also the most simple, was the heavy 3-bladed upwind concept (H3U). This kind of machines were voluntarily over dimensioned in order to not use sophisticated design codes and to enhance their reliability. The main drawbacks were the expensiveness of three blades, the large quantity of used material and an active yawing mechanism to direct the rotor blades in the wind. The second design "philosophy" aimed at achieving a lighter construction. The solution was placing the rotor blades behind the tower. This way a lightweight three - bladed downwind turbine (L3D) was created. The main advantages were absence of an expensive and heavy yawing mechanism and a reduction of the weight of the design, thus a reduction in overall construction costs (Maltha, 2005). However this type of turbines was affected by additional noise emission and by a disturbed wind flow[9] behind the tower. The third competing design was based on an extreme attention to reduction of weight. This design could be described as a two bladed - light weight and downwind rotor (L2D). The downsides were, however, that the rotor blades were asymmetrical and therefore additional elements were needed to damp the vibrations; furthermore it was subjected to tower shading and the design was extremely complex and relied massively on computer codes (Maltha, 2005). At that time, the two main innovation systems for

---

[6] Currently, the wind turbine industry is characterized by the dominance of the horizontal axis design. In fact, even if turbines can be classified in two broad categories according to the alignment of their axis that could either be vertical or horizontal, virtually all turbines currently in operations are based on the horizontal axis design

[7] There are four kinds of vertical axis WTGs: Savonius, Giromill, Gorlov helical, and Darrieus.

[8] The focus on the Horizontal axis model is due to its dominance in the market.

[9] A phenomenon called tower shading.

wind turbine were the Danish and American. While American manufacturers were focusing on high-tech solutions (light weight and downwind designs), Danish were more concerned with reliability of the machine and with a simple but effective design (Garud e Karnoe, 2003). The following chart shows the different designs still competing in the market during the mid '80 and how firms close to Copenhagen focused on 3 blades upwind design while US manufacturers were pursuing different paradigms.

Model	Country	Rotor Size	Rated output (kw)	N. of blades	Rotor posistion system
Carter	USA	10	25	2	d
Fayette 75	USA	10,1	75	3	d
MAN 40	GE	12,5	40	2	u
Enertech 40	USA	13,4	40	3	d
Holec 45	NL	14,5	55	3	u
Bonus 65	DK	15,2	65	3	u
Vestas 65	DK	15,2	65	3	u
Holec 65	NL	15,5	65	3	u
Micon 60	DK	15,8	60	3	u
Nordtank 65	DK	15,8	65	3	u
Micon 65	DK	16	65	3	u
Energy Sciences 50	USA	16,5	50	2	d
International Dynergy 80	USA	16,5	80	2	d
USWindpower 50	USA	17,1	50	3	d
Vestas 90	DK	17,1	90	3	u
Micon 108-II	DK	18,9	108	3	u
Bonus 120	DK	19,4	120	3	u

Legend: DK= Denmark, GE=Germany, NL= the Netherlands, US=United States, u=upwind, d=downwind.

Table 2: Competing wind turbine designs in the mid '80. *Source: Joffry Maltha; "The evolution of the worldwide wind turbine industry 1975-2005"*

2.3 Growth and maturity

After 1997, the current industrial stage started and quickly the architecture initiated to shape in to what is the current technology paradigm. This stage began when the only major US manufacturer switched to the H3U-concept[10] developed by the Danish firms. When this technology architecture stabilized, the three bladed upwind concept used by the Danes was not necessarily superior to the three bladed downwind turbine but surely more reliable, an element that emerged as a key driver in buyers' selection (Maltha, 2005). The "rise" of a dominant design is confirmed by an analysis of the performance variables that started to improve and by the fact that models showed a sharp increase of power capacity in a way that resembles the Moore's laws for computer chips[11].

[10] Heavy weight three blade design

[11] The rated capacity of commercially available turbines has increased by 2.5 times every five years in the last period. When a technology stabilizes, the focus on R&D concentrates on the performance variables chosen by the market.

After the turning of the century, the focus on innovation has moved to two main dimensions: offshore large size turbines and integration with the grid of large amounts of wind production. The paper focuses on latter element of the technology trajectory. The need to improve the grid integration has been generated by the very same diffusion of wind power which, being not programmable, adds uncertainty to the production side of a network. This poses issues for both owners and grid operators. The power producer is concerned with the electricity produced above the required quantity that is either not paid or might even be charged a negative price (the turbine owners pay the service of having the produced electricity transported). For the grid operator, unexpected variations in power output of wind power could be managed as normal demand variance as far as wind counts for a small percentage of the network generation capability. However, once wind MWs count for a large share of generation, then sudden drops or increase in power might even cause system collapses. As a consequence, several regulators have pushed for an improvement of the technology thanks to stricter connection codes. Usually, updated connection codes require wind turbine to remain online during grid faults[12] (rid-through capability) and to provide power control capability, that is, the ability to perform the activities usually carried out by traditional power plants in order to support the grid (Hansen, 2009). These requirements[13] are for instance visible in the energinet.dk 2004 Regulation[14] for turbines that connect to grids with Voltages above 100 kV.

As a result of needs expressed by both regulators and buyers, grid integration and the design of wind turbines, which were separately managed until 2000, become two blended issues (Hansen, 2009). This led to the diffusion of variable speed and power electronics as common features in modern turbines. Variable speed design allows turbine to function with multiple wind speeds while power electronics enables several functions of traditional fossil fuels plants like control of active power and reactive power, active voltage control, etc. Currently all newly installed wind machines are variable speed and differ mainly according to the type of generator and to the method of power control (EWEA, 2010). Two are the most common designs currently produced. The first design utilizes a Doubly-Fed Induction Generator (DFIG) and an inverter which is connected to the grid. In this system, up to approximately 40% of the power output goes through the inverter to the grid, the other part goes directly to the grid, and the window of speed variations is approximately 40% up and down from synchronous speed. The second common design leverages different types of generators and is interfaced to the grid via a full-

[12] Faults can be defined as severe system disturbances, during which the voltage can drop to low levels for short periods and can be due to natural causes (e.g. lightning), equipment failure or third party damage. Around a decade ago, wind turbines were only required to be disconnected from the grid when a grid fault was detected. However currently, due to the increased capacity of wind power in some power systems, such a disconnection could generate control problems of frequency and voltage in the system, and as worst case a system collapse

[13] Several reviews of grid codes are available in the literature. See for example Wu Q., Xu Z., Østergaard J., (2010) or Altın M. et al (2010).

[14] EnergiNet, Transmission System Operator of Denmark for Natural Gas and Electricity (2004), "Wind turbines connected to grids with voltages above 100 kV - Technical regulations for the properties and the control of wind turbines," Technical Regulations

power converter. Being completely decoupled from the grid, this latter design allows for a larger range of operating speeds and has a broader set of voltage control and reactive power capabilities. However, both models of wind turbine are able to *ride through fault* and to provide several advanced functions like power curtailment, ramp rate limitations and reactive power functions (EWEA, 2010)[15]. Therefore, it is possible to argue that turbines that meet the current technological paradigm are variable speed and able to perform functions of power control.

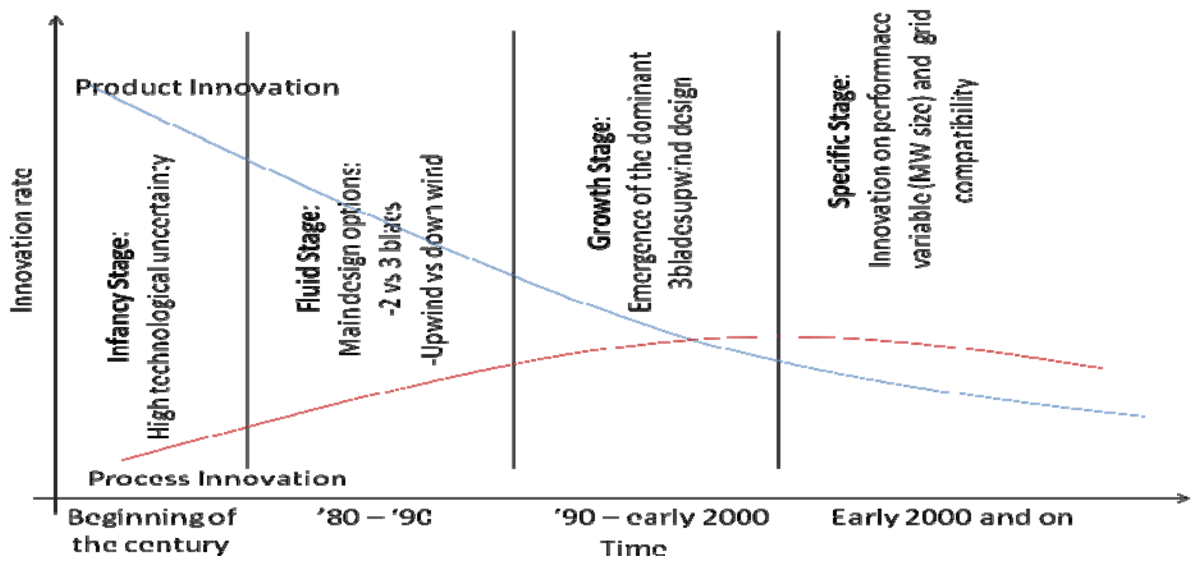


Figure 1: Industry life cycle (illustrative purposes). Source: Author's elaboration.

2.4 A case of catch - up?

During the years of the evolution of the turbine technology, which has now reached its maturity, competing firms were located either in US or in Europe. Then, European manufacturers gained an almost unquestionable leadership (in 2006 eight out of ten top manufacturers were headquartered in Europe). Nevertheless, the situation drastically changed during recent years[16] [17] when the ranking for top installed MW began to show an almost inverse relation between market shares of European and Chinese manufacturers. It would be possible to argue that the rise of the Asian firms is simply linked to the fast growth of their domestic market which counted for almost 40% of installed MW in 2011 and where it is difficult for foreign firms to get a stable foothold. However, this conclusion would not recognize the significant technological steps taken by Asian manufacturers. For instance, if we observe the MW size of turbines, the key innovation variable in last years, it is easy to notice a process of catching up with western firms.

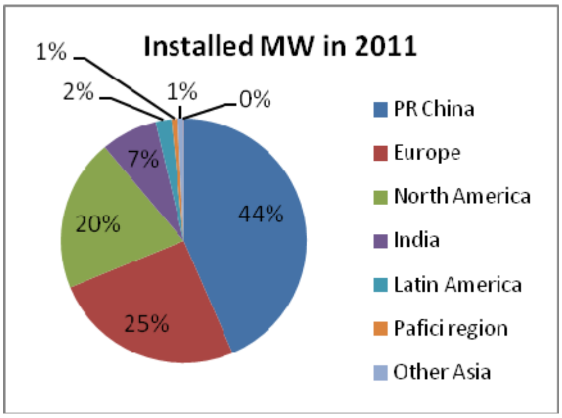
[15] See also Hansen, 2010; Chen, 2011.

[16] Market Share data from BTM consulting

[17] EER - HIS provides different data according to which Goldwin is third and Sinovel is second per market share. Both Sinovel and Goldwin are Chinese manufacturers

Rank	Company Name	Installed MW in 2006	Market Share 2006	Company Name	Installed MW in 2011	Market Share 2011
1	Vestas	4,239	26%	Vestas	5,379	12.90%
2	Gamesa	2,346	15%	Goldwind	3,920	9.40%
3	ge wind	2,326	15%	GE	3,670	8.80%
4	Enercon	2,316	14%	Gamesa	3,419	8.20%
5	Suzlon	1,157	7%	Enercon	3,294	7.90%
6	Siemens	1,103	7%	Suzlon	3,211	7.70%
7	Nordex	505	3%	Sinovel	3,044	7.30%
8	repower	480	3%	United	2,961	7.10%
9	Acciona	426	3%	Siemens	2,627	6.30%
10	Goldwing	416	3%	Mingyang	1,209	2.90%
11	Others	689	4%	Others	8,966	21.5%
	Tot.	**16,003**	**100%**		**41,700**	

Table 3: Wind turbine industry: market shares in 2006 and 2011. *Source: BTM consulting.*



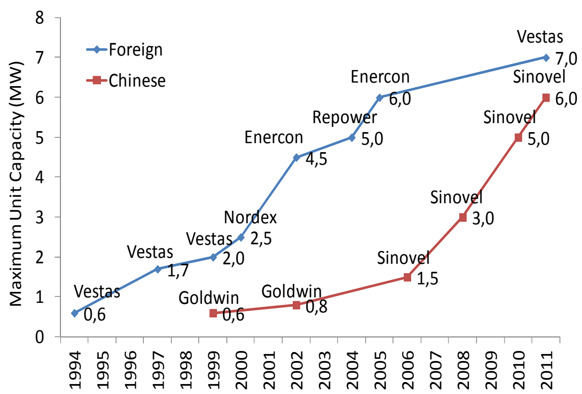


Figure 2: ***Installed MW in 2011.*** *Source: Author's elaboration on EWEA data.*

Figure 3: *Comparison of turbines size produced in China and Rest of the world*. Source: Peng, "Behind the Development of Technology: The Transition of Innovation Modes in China's Wind Turbine Manufacturing Industry".

Furthermore, the comparative analysis of the products of the leading manufacturer for each country (Vestas and Goldwin) shows that the catch-up does not involve only size but also more advanced functions like power control technologies. The product line of Vestas, the global Danish leader, is currently divided into two groups: large offshore turbines and medium –size onshore turbines. Vestas onshore turbines range from 2 MW to 3 MW. Within this category, the models most relevant to our discussion are those that mount the "GridStreamer technologies". Basically these models are an upgrade of the best-selling Vestas turbines (V80 e V90) and are designed to increase their compatibility with grids. The key differences with previous models are a permanent magnet generator and a full scale converter which, as we saw before, are key elements for grid integration. The product line of Goldwind is narrower and is composed of two models of onshore turbines: the 1.5 MW DDPM[18] and the 2.5 MW

[18] Direct-drive permanent magnet

DDPM. So far, the bulk of installations of the company came from the 1.5 DDPM MW model since the 2.5 MW has been released only in 2010. The newer model, which represents a significant increase in size if compared to the previous ones, has just exited the testing phase, during which 5 prototypes of the 2.5 MW were installed in Xinjiang, Beijing, Jiangsu and Germany, and it has now entered the commercial phase (Goldwin, annual report 2011). According to the company data the 2.5 model is equipped with full power converter, a permanent magnet generator and, as Vestas' model, has power electronics elements. The capacity of the turbine to provide flexibility and to meet grid connection requirements is well stressed in the product characteristics which claim the turbine can *"...meet the most stringent grid requirements; provide curtailment and ramp-rate control, reactive power as well as low-voltage and zero-voltage ride through capabilities*[19]". As such, both Vestas and Goldwind onshore turbines seem to be equipped with similar technologies. Nevertheless, it would be interesting to see the two models standing the tests of international markets. Unfortunately, as we saw, the 2.5 MW models is a new release from Goldwind and only few Goldwind turbines have been installed outside China[20]. Furthermore, a closer scrutiny of these sales reveals that often the buyer of the Goldwind technology is a Chinese company. More precisely the 19.5 megawatt wind farm build by Goldwind in Australia was sold to CGN Wind Energy, which stands for China Guangdong Nuclear Wind Power Co. While the 4.5 MW Uilk project Minnesota, where the manufacturer sold three 1.5 MW direct-drive turbines, is structured as an individual limited liability corporation (LLC), where the project company, namely TianRun Uilk LLC is 75% owned by TianRunUSA, a Goldwind subsidiary and the remaining 25% is split between small local developers like Dakota Wind (10%) and an entity called Horizon Wind (15%)[21]. Additionally, Goldwind signed an agreement with the Export-Import Bank of China covers credit loans and guarantees. Credit loans will be granted to Goldwind for foreign projects. Therefore, these sales cannot maybe defined as "the first commercial success outside of the China" but the fact that the company is installing turbines in foreign markets means that, even if the technology might not be fully ready, surely is quickly approaching the ability to compete with European and American manufacturers outside China. As such, it is possible to argue that the Chinese industry, or at least the main domestic manufacturer, is very close to (if not already have) catch-up with the technological frontier for onshore turbines. Finally, it is worth to remember that Goldwin is a not a mere imitator but also an innovator whose ability has been recently recognized by the Technology Review, a journal published by the MIT. The Journal recently nominated the Chinese company as one of "The 50 Most Innovative Companies in 2012" because of its ability to optimize wind farms in China, using its specially designed turbines that are specially adapted for the high altitudes and low wind speeds that characterize Chinese wind resources[22].

[19] Goldwin America, Brochure for the Permanent Magnetic Direct-Drive 2.5 MW win turbine

[20] Currently the main market for wind turbines is China. However, the ageing electricity grid struggles to absorb new capacity and according to the China Wind Energy Association, as much as 27 per cent of turbines were standing idle at the end of last year. As such, it is not possible to argue that the Chinese market has technical requirements as stringent as EU or US.

[21] http://www.windpowermonthly.com/news/965995/Power-contract-Chinese-turbines/?DCMP=ILC-SEARCH

[22] http://www.technologyreview.com/tr50/goldwind/

3 Two Sectoral Innovation Systems

In the following pages the key constituting elements of the two systems will be described. While the Danish experience with commercial wind turbine is long and it can be dated back to the 1980, the Chinese industry started to develop later and first experiments with wind turbine technology dates back to the 1990.

3.1 Danish Sectoral Innovation system

3.1.1 Danish Firms

During the early stage of the wind turbine industry ('80), Danish manufacturers[23] were usually firms with a background in agricultural machines and leveraged a core group of skilled workers, technicians and few engineers. This background was visible in most of the industry leaders as NEG Micon (originally a manufacturer of road tanks for oil industry), Vestas (a former producer of hydraulic cranes and agricultural machines) or Bonus (company manufacturing accessories for the agriculture sector). The approach to problem resolution of Danish firms was initially focused on facing problems that had to do with operational reliability and structural dynamics and only later specific technical elements like aerodynamic efficiency emerged as key design concern (Garaud, 2003). Lacking theoretical knowledge on turbine aerodynamics, engineers started a learning process by deploying and redesigning components that failed but could be further improved. The focus on reliability of these firms (instead of complex technical designs) proved winning as testified by the large share of Danish turbines (around 50%) that were installed in California during the so called "Wind rush" (Vestergaard et al, 2004).

In the early '90 a process of M&A begun and it culminated when large conglomerates (GE, Siemens[24]) entered the industry. This was a period of rapid transformation in the sector and that marked the passage to a more mature industry. The case of Vestas is exemplificative of the evolution of the whole industry. Vestas diversified in the turbine industry as early as the' 80 and took part in Californian wind rush. During the '90, it began transitioning to being a globalised firm. In 2004, it merged with NEG-Micon (2004) becoming one the top turbine manufacturers while undergoing an intense restructuring of the innovation process (Pedersen T., 2009). Overtime, Vestas become the only large size Danish turbine manufacturer and signalling the passage from a sector characterised by several small firms to a consolidated industry.

[23] A critical contribution of these sections derives from: Garud R. & Karnoe P.; " Bricolage versus breakthrough: distributed and embedded agency in technology entrepreneurship", Research Policy 32, 2003. Additional relevant references for the interested reader: are (i)Van Est R., "Winds of Change: A Comparative Study of the Politics of Wind Energy Innovation in California and Denmark", International Books, 1999. (ii) Kamp L. M.: Ruud E. H. M. ;"Notions on learning applied to wind turbine development in the Netherlands and Denmark"; Energy Policy, volume 32, issue 14, 2004. (iii) Buen J.; "Danish and Norwegian wind industry: The relationship between policy instruments, innovation and diffusion", Energy policy, volume 34, issue 18, 2006.

[24] Siemens acquisition of Bonus, GE of acquired Enron Wind

3.1.2 Danish Users and Suppliers

The initial customers of Danish firms were individual users and cooperatives that bought small turbines. These started to organise "wind meetings" several times a year[25] where they shared knowledge and created a network of users. Concerned about their investments in wind turbines, early owner-users mobilised to form the Danish Wind Mill Owners' Association in 1978. The goal of the association was to encourage turbine manufactures to enhance the safety and reliability of wind turbines (Kamp, 2004). Additionally, in 1980 the Wind Mill Owners' Association began publishing a monthly magazine containing reliability and performance data on many turbine models. The increased market transparency due to the publications forced manufactures to compete on evaluation criteria defined by the market (Van Est R, 1999) but also enhanced the learning by using of turbine manufacturers. Based on the association's suggestions, Danish manufacturers incorporated several features[26]. Even if these associations are still present nowadays, they lost part of their importance because of the globalisation of the turbine industry and because digital technology allows manufacturers to gather directly information on the functioning of their machines. As such, this continuous flow of user generated information to manufacturers has strongly decreased.

The flourishing of the turbine industry led to development of a huge network of suppliers. Many of these firms also diversified from related industry and entered the Danish innovation systems. According to Andersen (2006) the industry mainly consists of many small firms and two-thirds of the firms generate less than half of their turnover from wind. As the industry matured and moved to a global scale, the Danish suppliers expanded internationally. According to the Danish wind manufacturers association, only 13% of components suppliers do not generate revenues from sales abroad. The expansion strategy is based both on simply shipping, JV or establishment of production facilities abroad according the nature of supplied components and strategic positioning of the company.

3.1.3 Other Organisations

An organisation that played an important role in shaping the Danish wind turbine industry was "The Engineers at the Danish Wind Turbine Test Station" (DWTS)[27] established at Risø[28]. Since its foundations (1978), the DWTS had a strong practical attitude toward how problems were addressed. Its role became crucial when the Danish government established that wind turbines had to undergo a compulsory approval system in order to be eligible for market stimulation mechanisms. The same decision assigned the role of testing centre to the DWTS (Karnoe, 2003). In order to define the criteria for the approval, the DWTS undertook an interaction process with early wind turbine manufacturers and users, integrating received suggestions into the DWTS's research agenda (Lundsager and Jensen, 1982). This further increased the process of collective knowledge generation. Other than because of the DWTS, the

[25] http://www.windpower.dk/articles/coop.html.

[26] like a double brake system that is still in use.

[27] The DWTS was established in 1978 to service the emerging wind turbine industry (Risø, 1988).

[28] Risø is the National Laboratory for Sustainable Energy at the Technical University of Denmark - DTU

RISOE played an important role in the technology evolution. Initially dedicated to nuclear power, the "wind practice" received early resources only for short period of time (from three to five years) and therefore their strategy was to immediately prove their utility to the wind turbine industry (Kamp L. M., 2004). This resulted in a focus on applied research and in strong ties with the industry.

As the technology matured and the system evolved, the RISOE has been able to maintain its role and becoming a worldwide renowned wind research hub. The strong ties to business world have been kept and even incorporated in the centre missions. In fact, RISOE operates through "*continuous dialogue with the business sector, the political system and the research community and our research is part of national and international networks…. Our research is furthermore the basis of customer-driven activities*[29]*"*. A sign of this intense collaboration is the R&D office opened within RISOE facilities by Vestas in order to facilitate knowledge transfer (Hanson, 2007).

3.1.4 Danish Policies and Instruments

A key merit of Danish policy makers has been the ability to "synchronise" the industrial policies and instruments with the technology evolution (EIA, 2005; Buen, 2006). The Danish government implemented several direct measures to support the infant industry. Initially, the focus was mainly on supporting R&D activities. Around 10% of the total energy research program funds from 1976 to 1995 was spent on wind energy projects (Olivecrona, 1995). The first "rush" toward wind energy began after the 1974 energy crisis, when the Wind Energy Committee of the Danish Academy of Technical Sciences concluded that wind power was economically feasible and received money to invest in R&D for the development of large-scale wind turbines. This led to the collection of several funds (around 35 DKK millions between 1977 and 1980) that were made available to the Risø National Laboratory and the Technical University of Denmark (Van Est, 1999). Later on, basic R&D support was coupled with demonstration projects like the Nibe A and Nibe B (Klassen, 2005). During these years, a further relevant policy instrument has been the establishment of the Wind Guarantee Company (1986) which served as export finance guarantee for manufacturers (Lauber V., 2005) by the end of the Californian golden rush.

Currently, the direct instruments seem to have two main focuses. First, there is still a support to abroad sales thanks to the EKF which basically took the place of the Wind Guarantee Company. In 2011 this fund guaranteed around 20 per cent of Danish wind turbine exports. Secondly, the focus on R&D activities has remained both in term of funds granted to public R&D centres and in terms of grant schemes for Wind offshore demonstration projects (e.g. Nysted Offshore Wind Farm, 2003).

Other than direct instruments, the industry was supported also by the several indirect measures such as the establishment of long term wind energy objectives. Few years later the Wind Energy Committee's conclusions, the first long-term targets for the industry were set by the Energiplan 81 (1981) which forecasted possible installations of 60,000 wind turbines by 2000 and increased the credibility of the actors associated with the emerging wind industry. In 1995, the ambitious goal (set by the Energiplan 2000) of satisfying 10% of the country electricity need through wind power by year 2000 was politically accepted (Karnoe, 2003). However, while the following energy plan (Energiplan 21, 1996) recognised the

[29] http://www.risoe.dk/About_risoe.aspx

role of the green industry as an engine for growth (and not only a tool for increased energy security), it is only after 2005 that according to Nygard it is possible to observe how green growth become a widely accepted topic among Danish policy makers (Nygard, 2011).

The definition of ambitious long-term objectives has remained a key feature of Danish energy policies. For instance, we find the 2011 "Energy Strategy for 2050" which establishes the long term horizon of a fossil fuel free economy by 2050 and the 2012 Energy Agreement which targeted an approximately 50% of electricity consumption supplied by wind power and more than 35% of final energy consumption supplied from renewable energy sources in 2020.

Finally, several measures were set in order to boost demand for turbines since early years of the industry. After the second energy crisis (1979) a considerable 30% investment subsidy for buyers of certified wind turbines was approved but this was gradually decreased and cancelled in 1989 (Karnoe, 2003; Buen, 2006). Later on, under political pressure, the utilities were forced to pay owner-users of wind turbines a price equal to the 70–85% of the prices they asked for power distributed through their grid. In December 1985, utilities accepted to install 100 MW in the next five years in return for a law that limited private investments in wind turbines (Kamp, 2004). The implemented regulation prevented a "Danish wind rush" that would have resulted in the installations of many small and relatively inefficient wind turbines and also created a demand for wind turbines which had collapsed after the end of the Californian wind rush (which suddenly abrupt in 1984). Finally feed-in tariffs have been formally established in 1993[30] and, constantly updated over time, are currently implemented.

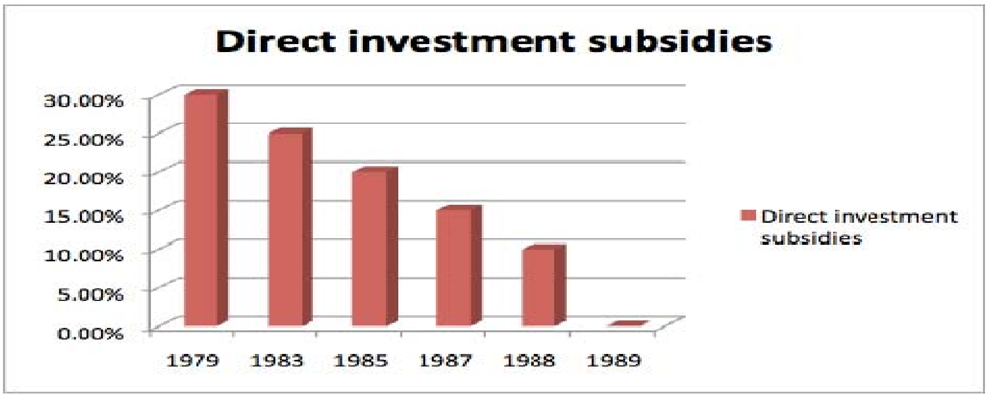


Figure 4*: **Decreasing Investment subsides in Denmark**. Source: Buen, 2006.*

3.1.5 Danish Institutions

Among Danish manufacturers to share knowledge was a common practise, as documented by several studies. For instance Andersen shows how "patenting" was rare and often considered as a "misbehaviour" (Andersen P.H.; Drejer I.; Waldstrøm C., 2006). When a complete supply chain industry started to emerge, the design and production of many components was managed in a collaborative

[30] Bolinger, Mark. "Community Wind Power Ownership Schemes in Europe and their Relevance to the United States." (Environmental Energy Technologies Division, Lawrence Berkeley National Laboratory, May 2001).

approach that resulted in the creation of a network characterised by interaction and “cross-learning” (Karnøe, 1991). Lawson underlines as a specific feature of the Danish network a strong sense of communality that allowed for an intense collaborative knowledge generation and learning process (Andersen et al., 2006). Karnoe argues that the wind turbine industry emerged “*using the traditional Danish collaborative “small and medium sized enterprise” (SME) industry structure. As part of such a SME structure, Danish wind turbine producers were able to benefit from the competencies of firms distributed across a range of suppliers in a network*”. As such, it is possible to argue that a key feature of Danish wind turbine industry was an open approach at innovation.

Over the years, the collective innovation setting seems to have been considerably weakened. An analysis of the Danish patenting propensity during the past decade shows an increasing trend (see chart below) which is a sign of a vanishing collective innovations setting. Another sign of this “vanishing approach” to innovation is brought by Andersen and Drejer (Andersen I. and Drejer P. H., 2006 and 2008). The authors, thanks to six cases study of six different Danish suppliers, point out how suppliers are currently showing two contrasting behaviour. On one side, some of them are actually becoming increasingly aware of the importance of Intellectual Property Rights; on the other side, many still consider the sharing of information as a sine qua non on for their business.

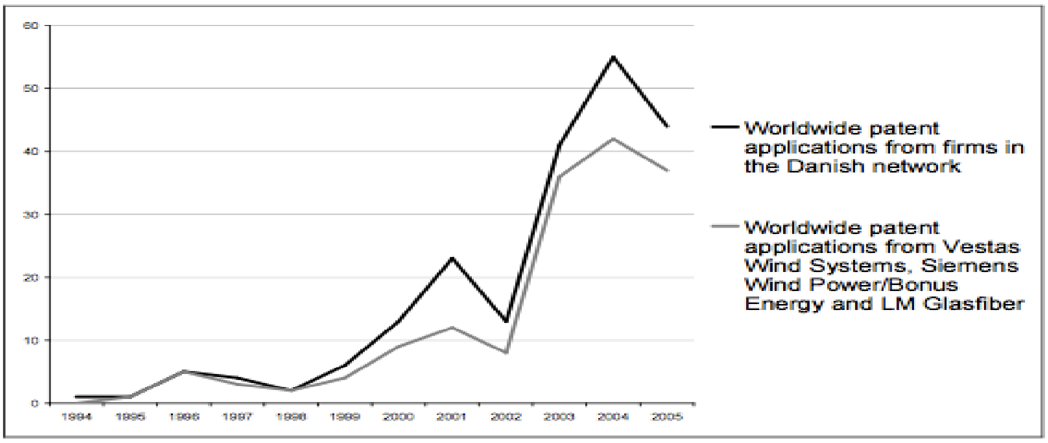


Figure 5: ***Danish and European patents in wind turbine industry***. *Source: Andersen P.H.; Drejer I.; Waldstrøm C (2006).:“In the eye of the storm”.*

3.1.6 Key elements of the Danish SIS

To summarise, the early years of Danish experience in the wind turbine industry were marked by a strong technology uncertainty, small users (cooperatives) and relatively small firms diversifying by the agricultural machine sectors. During this stage, the government direct support was mainly linked to R&D grants while energy policy had as main target energy security. As the technology evolved and the market become more mature, a process of M&A led to an industrial consolidation. At the same time, utilities become the main customers of Danish firms while policy supported evolved. Energy policy started to recognise the role played by wind energy as an industrial sector and not only as a tool to diversify energy sources. Contemporaneously, several measures like feed-in tariffs and export credits were implemented to sustain the industry. A remarkable similarity over the different decades is the role played by public R&D centre, not only as certification centre, but also as key players in the knowledge generating process.

3.2 The Chinese Sectoral Innovation System for Wind Turbine

3.2.1 Chinese Firms

The main players in the Chinese turbine[31] industry are SOE[32] or public companies with a majority of shares owned by the State (Liu and Kokko, 2010). Most of the firms currently active diversified in the industry at the beginning of this century and have their roots in sectors such as electric power generation equipment, aeronautics and heavy machinery equipment. During the first years of 2000, at the birth of the Chinese industry, their approach to innovation was mainly licensing technology from foreign companies. The foreign partnering companies were usually small companies that did not have the global scale to sell in distant markets so licensing was an effective method to generate revenues from remote locations. The list of Chinese companies that entered these kind of agreements is long: Goldwind began its operations based on licenses from German firms Jacobs and Repower; Sinovel, Dongfang, CSIC and Beijing Beizhong have benefited from licenses from Fuhrländer (Germany), REpower (Germany), Aerodyn (Germany) and DeWind (UK/USA); A-Power licensed technology from Norwin; CSIC acquired from Aerodyn; Beizhong acquired from DeWind, Windey acquired from REpower and Zhuzhou acquired from Windtec[33](Lewis, 2011). After this initial phase, the strategy of Chinese manufacturers become more aggressive and several M&A begun. For instance Goldwin, after the licensing agreement in 1999 for 600 kW wind turbines with Jacobs and the 2001 agreement with Vensys to produce a 1.2 MW direct drive turbine, acquired Vensys in 2008. A second example can be XEMC which acquired Darwind B.V in 2009. As we have seen, the number of operators in the industry is large (around 27 firms) but this group is likely to shrink in the near future because of economic and political push for consolidating[34]. As a final remark, it is interesting to note how firms diversifying in the industry were not small firms with few R&D skills as in the Danish case but large firms with some technical expertise. For instance, the mother company of Goldwind (established in 2001) was the Xinjiang Wind Energy Company (XWEC) which had been cumulating experience in wind technology since 1989 thanks funded granted by Danish and German government. Instead, Sinovel includes among its largest shareholders the DHI-DCW group which is a SOE operating in the heavy machinery sector.

3.2.2 Chinese Users and Suppliers

The bulk of investment in wind MW comes from the five main power generation companies. The group, referred sometime as the “big five”, accounts for almost 70% of the installed capacity (GWEC, 2010) and is the result of the decision taken in 2002 to break up the pre - existing monopolized State Power

[31] A critical contribution to this section derives from: Peng, (2012); Lewis, J.I., 2011, Liu,Y. and Kokko,A.(2010)

[32] State Owned Enterprise

[33] Similarly Suzlon began its wind turbine manufacturing with a license from German company Südwin.

[34] Nomura, “China Wind”, June 3, 2011. More details in the section dedicated to the Chinese policies

Corporation into seven SOE's: two grid companies (State grid and Southern Power) and five power generation companies (China Huaneng, China Datang, China Huadian, Guodian Power and China Power) (Liu Y. and Kokko A., 2010). The remaining share of turbines is owned by farm developers and by regional electricity companies.

With the investment boom in the wind power sector, the equipment industry has also rapidly developed. If around five years ago Chinese wind turbine manufacturers were almost entirely dependent on the import of bearings and electronic controls, nowadays a larger supplier base is available locally. For instance, China's nacelle assemblers can currently choose from over 250 domestically localised suppliers of main components, like: blades, gearboxes, generators, towers, large bearings. Furthermore, domestic industry leaders argue that between 90%-95% of the components are sourced locally while a sampling of the international companies — Vestas, Gamesa, GE, Suzlon and Nordex — returns values of 70% and above (Mayers, 2010). It is interesting to underline how also in the supply side of the industry a process of acquisition of past licensors has been undertaken. For instance, in September 2009, Huiteng Windpower Equipment acquired CT Holding B.V., a Dutch blade design firm and former partner of Huiteng.

3.2.3 Other Organisations

The first researches on wind technology were carried out by the Hang Zhou Machine Design and Research Institute which produced a 200 kW wind turbine (Peng, 2012) in cooperation with Chinese firms in 1988. More than ten years after it is possible to find several R&D centres that focus on wind power. An important characteristic of these centres is the strong connection to the industry. In the Xinjiang region, where Goldwind was originally established[35], it has been founded the National Windpower Engineering Technology Research Center (NWTC). The NWTC is affiliated to Goldwind which covers most of its operational costs (Mah D., 2011). In Beijing, the State Grid Corporation of China (SGCC) established the State Grid Energy Research Institute that is a wholly-owned subsidiary dedicated to the study of energy & power related issues for sustainable development of economy and society. The centre is specially active in the power sector and on February 2010 started a project with Vestas to investigate the difficulties of large scale integration of wind power into the grid. In Shanghai, where Seawind (the wind branch of state-owned conglomerate Shanghai Electric Group) is headquartered, it has been established the Shanghai Clean Energy Research and Industry Promotion Center. This centre has been modeled as the US National Renewable Energy Laboratory (NREL) under a special collaboration arrangement between the Ministry of Science and Technology in Beijing and the local government. The SCEC is more sophisticated in its internal structure when compared with that of the NWTC (Mah D., 2011).

A key actor in the industry is Chinese national testing centre. The Ministry of Finance established that the China General Certification Centre (CGC) has the duty to certify if turbines meet the required criteria to access the support schemes. The presence of test centre for wind turbine since the beginning of the industry is one of the most evident similarity between the Danish and Chinese innovation system

[35] Goldwind is officially named Xinjiang Goldwind Science & Technology Company

Finally, another relevant group of actors is composed by the Chinese universities. According to China Wind Power Centre[36] (CWPC) there are more than 30 universities involved in Wind power technology. An interesting method to link academic research and the industry can be found in the Guadong province where the Enterprises' Science and Technology Commissioners Action Plan allows personnel from Chinese universities to spend one year in designated enterprises. During this period they are expected to carry out a broad variety of research and to establish long-term enterprise-university collaborations (Mah D., 2011).

3.2.4 Chinese policies and instruments

As in the Danish case, the development of the national industry built on both industrial and energy policies. During the early years of the Chinese industry (1986 - end of '90), industrial policy was mainly directed to support R&D activities. For instance, the Seventh (1986) and Eighth Five-year (1995) Plans funded 150 kW and 300 kW R&D (Pedersen, 2012). In 1996, the first program dedicated to installation of wind power was created. The program, named Ride the Wind, aimed at importing wind turbine technology and developing a domestic industry thanks to a 40% local content requirement and to support measure for JVs with Chinese companies (Allen and Overy, 2011). The most important outcome was the establishment of two joint ventures between two foreign enterprises, MADE (Spain) and Nordex (Germany), and two domestic firms handpicked by government, the Yituo and the Xi'an Aero Engine group, both operating in the aerospace industry (Wu, 2008). Another example is the Special Plan for Energy Development (2001) which supported the creation of large-scale demonstration wind farms. The support to R&D activities did not diminished as the technology progressed and, for instance, the Ministry of Science and Technology supported the development of megawatt-size wind turbines, including technologies for variable pitch rotors and variable speed generators, as part of the "863 Wind Program" under the Eleventh Five-Year Plan (Lewis ,2011). Additionally, the inflow and learning was also supported by a duty free policies and the establishment of a local content requirements policy to access incentive. Recently, the domestic content requirement has been dropped due to international lobbying but the early duty free policy on wind turbine imports has been restricted only to specific components for "advanced" turbine (above 2.5 MW) (Peng, 2011; CWPC). Another key element of current legislation is the more selective access criteria in order to prevent overcapacity in the industry. For instance, according to the new Guideline Catalogue for Industrial Structuring published by the National Development and Reform Commission (NDRC), China will not extend the preferential policies to companies that produce wind turbines with a capacity of less than 2.5MW nor wind turbine components/gearboxes of 2MW capacity or lower. According to the directive, the Government aims to reduce the number of turbine manufacturers to 3-5 competitive firms with R&D capability in the long term. (Nomura, 2011).

After the initial R&D support measures, several other measures were established. In 2000, the National Debt Wind Power Project (2000) which targeted to build an 80 MW market for domestic manufacturers thanks to discounted loans for the building of four wind farms and imposing a local content requirement

[36] CWPC is a platform for information on wind power in China supported by the Sino-German China Wind Power Project

was established. The establishment of a local industry was also sustained by other actions like the granting of favorable loans for the setting up of wind farms equipped with domestic turbines and a reduction of the value-added tax for wind turbines (Xia C. and Song Z., 2009; Han J. et al., 2009). In 2003, a new wave of favourable measures was approved. The Wind Power Concession Project (2003) granted several concessions for the construction of wind power farms. Each project included a PPA for the first 30,000 h of the project, financial support for both grid extension and access roads, and preferential tax and loan conditions (Lewis, 2011). From 2003 to 2007, five rounds of concessions had been pursued, with a 3,350 MW cumulative capacity installed (Peng, 2012). Projects were usually sized around 100 MW and were required to use wind turbines over 600 kW (Lewis J.I., 2011), a level that was relatively low if compared to turbines available in 2003 which hovered around 5000 kW (EWEA, 2007). Additionally, the local content requirement imposed to participate in the Concession projects was gradually increased (from 50% to 70%). Always in 2003, first feed-in tariffs were set which were, nevertheless, repeatedly modified over time. From 2003-2005 tariffs were determined either by tendering in the so-called 'concession projects' or by 'government approved' tariffs, depending on the size of the projects (less than 50 MW); during 2006 - 2008 tariffs were still determined by the two processes but government approved tariffs became more consistent. Finally, feed-in tariffs took the current shape in 2009 when four national feed-in tariffs were set based on the different wind resources of the considered areas (GWEC)[37].

The mirror image of the industrial policy and relative instruments is the establishment of forward-looking policies to promote RES. Among these, the Renewable Energy Law (2005, amended in 2009) is often considered as the key framework law to attract stakeholders' interest in the Chinese renewable energy sector and to signal the Chinese government's commitment to renewable energy development. Even if this Law does not promulgate binding renewable energy development targets or economic incentives, it designates responsible government authorities to draft renewable energy development plans as well as supporting legislation. Building on the provision of Renewable Energy Law, in 2007 the NDRC released the Medium and long-term Plan for Renewable Energy Development which set quantitative objectives for renewable energy development. The plan establishes a development target for wind power of 5 GW by 2010 and of 30 GW by 2020. Furthermore, the plan imposed to power producers owning a capacity larger than 5 GW to increase their portfolio of non-hydro renewables to 3% by 2010 and 8% by 2020. Long run targets objectives have been then reviewed by the 12th Five-Year Renewable Energy Development Plan which increased expected wind power generation to 70 GW by 2015 (Pedersen, 2012).

3.2.5 Chinese Institutions

According to the patent data from China's State Intellectual Property Office gathered by Peng (Peng, 2012), Chinese firms show a strong and increasing patenting propensity. In 2002 there were 522 patent applications that then rose to 1132 in 2008. Another important element of the Chinese turbine industry

---

[37] Tariff prices range from 0.51 Yuan/kWh for wind power in regions with the most wind resources, such as Inner Mongolia, to 0.61 Yuan/kWh for regions with the least wind resources (US cent 7.5–8.9/kWh).

is the role played by the guanxi ("social connections") which according to several international players are relevant also in the renewable energy industry (Hook, 2011).

3.2.6 Key elements of the Chinese SIS

The Chinese SIS underwent a fast development were the role played by the State is probably more evident that in the Danish case. During the early years of the catch-up process, industrial policies were mainly R&D grant scheme while the first firms to produce wind turbine via the participation in JV were handpicked by the government. As the locally knowledge improved, indirect measures were set up, like government tendering, FIT, local content requirements and long-term target for wind energy. Furthermore, as in the Danish case, it is possible to notice strong links between the industry and the academia and, specially, the presence of national certification centre. Another key difference is found in firms size since Danish firms progressively become larger while Chinese firms entering the industry were already big corporations.

	Denmark		China
Technological stage	**Infancy stage**	**Mature technology ('90 and after)**	**Mature technology**
Firm	Small firms diversifying from agriculture sector	Large manufactures	Firms diversifying from aeronautics and power generation equipment
Users	Small users	Utilities	Utilities
Other organization	Certification centre Public R&D Centre Links between academia and industry	Certification centre Public R&D Centre Links between academia and industry	Certification centre Public R&D Centre Links between academia and industry
Institutions	Strong knowledge sharing	Patenting	Patenting
Government policies and instr.			
- Local content req.	No	No	Yes
- Financial and tax incentives	Yes	Yes	Yes
- Favorable custom duties	No	No	Yes
- Export credits	No	Yes	Yes
- Quality certification	Yes	Yes	Yes
- R&D Support	Yes	Yes	Yes
- Feed-in tariffs	No	Yes	Yes
- Renewable Energy targets	Yes	Yes	Yes

Table 4: Country comparison of SIS. Source: Author's elaboration.

4 A comparative analysis

In the previous pages, we described the key constituting elements of the two sectoral systems and how the technology evolved over time. More precisely, the analysis allows to compare the configuration of the two innovation systems within three different cases. The analysis of the Danish SIS provides us with insights on the case when both the technology and the domestic sector are novel (Case A) and on the case of a both mature technology and a mature national industry (case C). Instead, the Chinese SIS provides insights on the case when the domestic sector is novel but the technology is already mature (Case B). In a more formal manner, it is possible to argue that we can describe the features of competitive green innovation systems within three different settings. First, within a Schumpeter Mark I scenario where the industry is characterized by small firms and by an unstable technology (Case A – early years of Danish System); secondly within a catch-up scenario (Case B - Chinese SIS) and finally within a Schumpeter mark II scenario which, characterized by large firms and a strong cumulative knowledge base, is represented by the current situation of the Danish industry (Case C). The fourth combination allowed by the considered variables, which is a scenario where a mature domestic sector is confronted with a new to the world technology, can be framed as a case of a disruptive technology and it is not investigated in this paper. Our argument is that the relative importance of the functions and how they are activated should be different in the three cases identified. In order to more easily discuss the differences and similarities, we leverage the functions of innovation systems approach as previously discussed. However, this approach has a weakness that lies in the strong interactions among the different functions and elements. Therefore, in the following pages the different elements of the SIS are linked to the functions that they contributed the most to activate but this has not to be considered as a univocal correspondence.

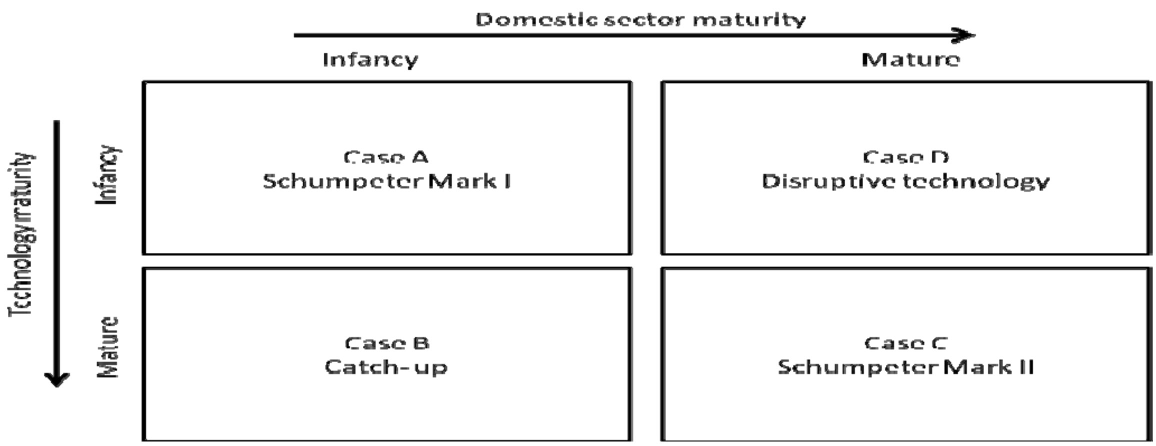


Figure 6: Features of SI and Technology Stage. Source: Author's elaboration.

4.1.1 Developing a new sectoral green innovation system (Case A)

When the technology paradigm has not yet emerged and the domestic firms embedded in the given sector have no experience with the underlying technology, the **function of knowledge creation and diffusion** is of crucial importance to the system. As we have seen, this function has been performed in Denmark thanks to numerous firms operating in the industry with strong links between academia and public R&D centre. From this standpoint, it is interesting to note how several scholars point out that one of the reasons of the poor performance of the US innovation system was that the US centre for wind turbine (NREL[38]) did not manage to develop relations with the wind turbine industry as broad and continuous as those developed by RISOE[39]. Nevertheless, it is important to underline once more that the collectively knowledge generating process engaged by Danish firms cannot be expected to be easily found in other regions. In the literature it is possible to identify specific technologies where this approach to innovation is advisable. Nelson and Merges argue that the impact of the intellectual property rights regime on the rate of innovation depends strictly on the nature of the technology. In case of cumulative technology, defined as technologies "consisting of a number of interrelated components and in which current improvements are tightly related to previous innovations", strong intellectual properties might hinder the innovation process over the long-run. The number of components and interrelations in wind turbines is extremely high: the machines can be composed up to 8000 components. As put by Devux, a turbine is "a complex system working in a complex environment... It is composed of subsystems working in a tightly coupled way". If we would like to refer to the Kauffaman's model, then we would say that this system is characterised by a high level of "N" and "K". If the technology of the green SIS shows these features, then the policy maker might be interested in favouring a more "collective approach" to innovation.

A remarkable feature of the Danish System is the role played by users in **guiding the direction of research.** In fact, they increased competition among producers thanks to a clear comparison of the performance of the different turbines and drove the development of the industry highlighting the performance elements they valued the most. It is possible to argue that these practises, jointly with the testing of turbines performed at RISOE, led Danish firms to quickly indentify buyers decisions drivers and therefore allowed them to select earlier the winning technology trajectory. However, it would not be fair to not underline a specific merit of the Danish government. In fact, policies implemented by Copenhagen have often been praised for their ability to quickly adapt to the evolution of the technology. For instance, the switch from a support based on investment incentives to incentives to production (FIT) has correctly framed buyers' incentives who were then interested in having a machine that effectively produced electricity (the mere installations of wind turbines might have been beneficial during the initial rollout of the technology in order to facilitate learning by doing of firms). These elements suggest that when a new technology is under development, firms should be able to follow the

[38] Funded as the Solar Energy Research Institute, it was later renamed as the National Renewable Energy Laboratory. The birth of NREL can be tracked back to US government's support of small-scale wind turbine R&D in 1977.

[39] Karnøe, P., Garud, R., 2003.

trajectory they consider optimal while market signals should be made as strong as possible in order to highlight what features of the technology the users value the most. Within this context, government policies should be set in order to not twist buyers' incentives.

The ability to **mobilise the required resources** for a system is crucial in order to avoid bottlenecks. In the Danish case, the government provided large amount of funding during the establishment of the industry. For instance, when the Danish Academy for Technical Sciences (1975) concluded that Denmark was abundant in wind resources, then several funds (around 35 DKK millions between 1977 and 1980) were made available to the Risø National Laboratory and the Technical University of Denmark (Van Est, 1999) in order to speed the development of this technology. Then, several funds were also devoted to demonstration projects (Nibe A, Nibe B, etc.). These elements obviously played an important role also **in the function of knowledge creation and diffusion.**

The **function of market formation** is extremely intertwined with the **function of legitimization** since legitimizing a technology eases its entrance in the market. By clearly stating its objectives for wind energy the Danish government legitimized the technology and created clear perspectives for investors. For instance, in 1981 the National Energy Plan set the goal for 1000 megawatts of wind energy by 2000 and later on (1999), the goal was increased to 5500 MW by 2030 thanks to the Government's Action Plan for Energy (Energy 21). Another significant tool in the process of market creation (and legitimation) has been the creation of test centres to verify if turbines were eligible to the support measures. This certification lowered the risk of the investment allowing for an easier market acceptance (and also avoided that State incentives were spread across not efficient machines). Finally, the Danish case shows how the function of market creation has to be carefully managed in order to avoid a excessively quick diffusion of a technology (with associated risks of lock-in in inferior technologies) but at the same time that it can be a useful tool to protect expertise cumulated in case of sudden demand shock (as in the case of the end of the Californian wind rush).

The last function that an innovation system should be able to perform is the "**the development of positive externalities**". This function is defined as "*the presence of networks and relevant institutions that create positive external economies in the form of an exchange of information, knowledge and visions*". As above underlined, the Danish collaborative approach to innovation has surely allowed for a high level of positive externalities which have probably decreased over time by the adoption of a more "traditional approach to innovation". Other than the knowledge sharing process, the creation of research centre dedicated to wind energy and the huge network of suppliers suggest the importance of this function.

4.1.2 Competing within a mature technology (Case C)

As the industry and the technology matured (around '90), functions in the Danish system started to show remarkably differences. For instance, the process of M&A that took place in Denmark during early 2000 surely impacted the **function of knowledge creation** since it reduced the heterogeneity among actors. Nevertheless, this transformation is advisable when economies of scale become more relevant and knowledge cumulative or, otherwise said, when we enter a Schumpeter mark II type of sector. Nevertheless, along the same function we find that the role of university and academia has remained constant (if not increased). For instance, Vestas opened an R&D office within RISOE facilities in order to facilitate knowledge transfer (Hanson, 2007). Instead, a remarkable difference is the probable weakening of the function "**guiding the direction of research**" since Danish users lost their role in the industry. However, this is not necessarily a limitation since, as the technology matures, the technology trajectory become clearer and innovation mainly incremental. Therefore, a very strong function of guidance is lees relevant. Finally, the function of **entrepreneurial experimentation** weakened as well due the same above mentioned reasons .

The **function of market creation** (and **legitimation**) shows both similarities and divergences compared to the original setting. The focus on the external market has surely increased, also because of the small size of the Danish country. However, this increased attention to foreign harbours is matched by a continuing support for local demand thanks to FIT tariffs. Furthermore, the recently approved Energy Strategy continued the established tradition of providing long term objectives to the industry and constitutes another significant tool in the process of market creation (and legitimation).

The **functions of the development of positive externalities** and **resources mobilization** are activated thanks to the same mechanisms previously tested. For instance, it is possible to observe the persistence of the strong ties between Vestas and its suppliers, built thanks to programmes aiming at promoting long-term relations, while the government contributes to provide relevant resources thanks to several R&D grant schemes. However, as previously discussed, the open knowledge sharing setting has been strongly re-dimensioned. While the debate of the reason behind this shift are not part of this paper, it is possible to guess that the role played by increasing foreign competition, globalisation of production, risks of uncontrolled spillovers and the possibility to use patent as a tool to attract potential international customers (e.g. licensing to Chinese firms) has been surely important.

4.1.3 Catching up in green innovation systems (Case B)

The analysis of the **function of knowledge creation** in China suggests that this function was slightly twisted and adapted to the technological context. In fact, domestic manufacturers seemed more focused on a process of knowledge absorption and diffusion (or technological catch-up) based on learning than on proper knowledge creation. For instance, this is clear if we consider that "wind turbine technology" made its entrance in China thanks to JV agreements between local and foreign firms. The extent and speed of the knowledge learning performed by Chinese firms has been probably eased by the nature of firms that entered these JV agreements. In fact, these companies were large company and, as underlined in the literature, knowledge transfer is eased if the "learning firm" has knowledge absorptive capabilities which usually reside within larger firms with R&D capacity (Malerba F., Nelson R., 2011).

In the case of the Chinese system, the main role of **guiding the direction of research** was played by the government. For instance, the five years plans gradually funded R&D for larger turbines while the local content requirements forced foreign companies to establish production facilities in the country creating positive spill-overs for the economy. The role of the Chinese government is visible also in more recent decisions, like the decision to extend preferential policies only to companies that produce wind turbines with a capacity of more than 2.5 MW or the new import regulation. The weak role played by users was probably compensated by the maturity of the technology and therefore the simple need to progress along an established trajectory. In fact if the technology trajectory is known, then the strongest argument against State intervention in R&D activities, which is that it might lead to select a suboptimal design option, decays since no technological selection is involved. Nevertheless, it is possible to identify at least a "risk" for the firms embedded in this system as they progress along the technology trajectory. More precisely, the continuing strong government guidance on the direction of research is likely to endanger the process of knowledge creation and of entrepreneurial experimentation which might be required once firms start to operate close to the technological frontier.

The **functions of market formation and legitimization have** been activated in very similar ways by the two systems. In fact, also during the Chinese catch-up a key element was the strong political endorsement of objectives for wind energy. For instance, the 2001 Special Plan of Energy Development (10th Five- year Plan) aimed at creating a 500 MW market for wind (Peng, 2011), a goal that was increased by the Medium and long-term Plan for Renewable Energy Development and later on by the newly approved 12th Five-Year plan. Within the legitimation and market formation process is interesting to notice how also in China a test centre has been set up in order to verify compliance with State standards. Finally, the Chinese Government can be also praised for having quickly implemented subsidies like feed-in tariffs.

Also along the function "**mobilising required resources**", the similarities between the two systems are remarkable. For instance, the Chinese government provided large amount of funding during the establishment of the industry through R&D funds and demonstration projects as well. Furthermore, Chinese universities and research centre accompanied the development of a successful industry elaborating programs to support the industry and providing competent human capital. The study of the Chinese system confirms also the importance of having strong connections between the academic world and the industry, like the Goldwind's relation to the NWTC or the university-industry program implemented in the Guadong province.

The last function that an innovation system should be able to perform is the "**the development of positive externalities**". The analysis suggests how the PRC can also leverage an extensive network made of several universities with strong ties to the industry and a large network of suppliers. Additionally, the fact that Chinese companies licensed western technology has probably resulted in the development of a technology that is very close to that of western firms and therefore allows to tap in the current supply chain of components without requiring for excessive customization of supplied parts.

4.2 Discussion

The comparative analysis shows that the configuration of system functions is not constant over time. More precisely, we find out that the functions most related to the technology stage, namely "*knowledge creation"* and "*guidance on the direction of research"*, should be performed differently according to state of the art of the technology and to the maturity of the relevant domestic green sectoral system.

In fact, while both systems show a remarkable analogy in the strong ties between firms and academia, the other elements characterising the functions of knowledge creation and of guidance on research present numerous differences. In Denmark, innovation was undertaken by firms in a collaborative fashion while users were increasing competition among manufacturers and providing relevant feed-backs to the industry. The presence of numerous firms, as in the Danish case, is the most effective option to explore an unknown technological space where several technological trajectories are possible. Within this context, the heterogeneity of trajectories that can be pursued by the different firms has to be preserved by intelligent policies that should be as possible technologically neutral. To this aim, the Danish case suggests the importance of promoting policies that allow markets to guide the direction of research during the infancy of a technology. Within the case considered, this was performed by continuous feedback from users to producers which resulted in a reduced information asymmetry and allowed firms to quickly identify drivers of buyers' selection. Within this perspective, it is extremely important to select support measures (if any is required) that do not twist buyers incentives (e.g. FIT tariffs for the production of energy instead of "simple" investment subsidies). Later on, once the technological paradigm has emerged and we enter a case C scenario, then the analysis suggests that the function of guiding the direction of research is less important. As the skills required to innovate evolve, the SIS should be able to consolidate its industry in order to move to an innovation setting characterized by Schumpeter mark II features. However, openness to innovation should be maintained in order to continue to progress along the selected technological trajectory and to avoid to be caught unprepared by disruptive technology.

Different considerations can be made on the functions of knowledge creation and guidance in case of a catch-up process. In Denmark firms were collaboratively innovating while buyers contributed to increase competition among manufacturers and provided continuous feed-backs. Instead, in China the State intervention has been clearly stronger. This dissimilarity is likely to be due to the "features of a centrally planned economy" but also it is possible to link it to the different technological stage. In fact, the argument against strong State intervention in R&D activities is that it might lead to select a suboptimal design option. However, when the Chinese innovation race begun the technology trajectory was already known and therefore it was only a matter of quickly progressing through it. Thus, it is possible to argue that the function of knowledge creation should be performed by firms under the guidance of users, as in the Danish case, during the infancy of a technology. Instead, if the technological trajectory is already understood and a process of technological catch up is in progress then a stronger State intervention might prove to be positive. Furthermore, the licensing approach followed by Chinese firms confirms the finding of previous research that "*firm learning [in the catching up process] almost always requires access to knowledge of how things are done in leading countries*" (Malerba F., Nelson R., 2011). To this aim, another element that contributes to explain the success of Chinese firms is their large. In fact, in case of Schumpeter mark II sector (a sector characterized by economy of scale and cumulative knowledge), bigger firms are often considered more likely to catch up (Malerba F., Nelson R., 2011).

While the functions of knowledge creation and diffusion seems to be most related to the different technology stage and to domestic sector maturity, other functions seem more "*technological invariant*".

The focus on foreign markets has been a key feature of the Danish system (function of market creation), a characteristic strengthened by the need to protect domestic cumulated knowledge after the end of the Californian rush and also by the small size of the domestic market. However, recently also Chinese firms seem to have started investigation into the possibility of entering new markets. As such, it is possible to argue that this focus is a natural evolution of competitive green SIS and also a tool to nurture it. Given these elements, relevant policies should always be implemented. Supportive of the process of market formation has also been the definition of clear long run objectives to allow for the required investments in R&D. For instance, the Danish government has set its target for 2000 as far as 20 years before and has already prepared a strategy for 2050. A similar pattern can be found also in China where in 2007 targets for the next 12 years were identified by Beijing. Another significant analogy in the process of market creation (and legitimation) has been the creation of test centres to verify if turbines were eligible to the support measures. This certification lowered the risk of the investment allowing for an easier market acceptance. It is however import to underline how the certification process has to be designed in order to avoid that it constitutes a barrier to new technologies or new entrants.

The ability to mobilise not only financial resources but to create human capital proved to be fundamental both for the catch-up and the development of the Danish industry. The Risoe has strong ties to the industry as the research centres in China do. From this standpoint, it is interesting to note how several scholars point out that one of the reasons of the poor performance of the US innovation system was that the US centre for wind turbine (NREL) did not manage to develop relations with the wind turbine industry as broad and continuous as those developed by RISOE. The result of the analysis strengthens the hypothesis that the ability to connect academic research with the industry is another relevant feature to build a successful (green) industry and to sensibly strengthen the function of knowledge creation and diffusion. The last but not least consideration is instead related to the evolution of the policies targets. Both in the case of a catch-up and of developing a totally new technology, the cases underline how competitive SISs firstly focused on creating a local knowledge base and only later started to support the creation of markets. A strategy that avoids that the benefits generated by national incentives are gathered by foreign firms.

5 Conclusions

The aim of this paper is to gather relevant inputs from the evolution of the Danish and the Chinese wind turbine industry in order to provide insights to policy maker interested in creating a domestic green industry. The comparative analysis shows that the features that make a sectoral innovation system successful are not constant over time. We argue that the stage of technological evolution and maturity of local industry are some of the main explanatory variables that allow understanding which *functions (*and how*)* should be activated over time in order to sustain the development of local green SIS. More precisely, we find out that the functions most related to the technology stage, namely "*knowledge creation"* and "*guidance on the direction of research"*, should be performed differently according to state of the art of the technology and to the maturity of the relevant domestic green Sectoral system. Furthermore, the analysis of the other functions allows to identify several common elements which are possible candidate to be best practices, like the establishment of test centers, long run policies targets and strong links between academia and industry.

A compelling limitation of our research is that is based on two case studies within a single industry and therefore any generalisation of the results needs to be carefully considered. Nevertheless, the cases analysed opens up new interesting venues of research. It would interesting to very if the hypothesis on the elements characterising an healthy SIS advanced in this paper hold also in different settings as, for instance, other countries that developed a wind turbine industry (like India or Germany) or if they apply also to different technology (like solar). Furthermore, given the increasing focus (and need) of a greener growth, another interesting field of research would be to observe the evolution of green SIS not related to energy production and try to see if the nature of the technology varies the importance of some functions or their configuration.

6 References

Allen & Overy, (2011). “The Changing Landscape of the U.S. Energy Market - Is China taking over the world? The case of China’s entry into the U.S. wind power sector”, Allen & Overy 2011

Andersen P.H.; Drejer I.; Waldstrøm C. (2006).“In the eye of the storm – knowledge appropriation and the globalization of regional competencies in the wind turbine industry”, Druid summer conference paper 2006.

Altın M, Gő̆ksu O., Teodorescu R., Rodriguez P., Jensen B., Helle L.(2010). “Overview of Recent Grid Codes for

Wind Power Integration”. International Conference on Optimization of Electrical and Electronic Equipment, OPTIM 2010

Bergek, A. & Jacobsson, S. (2003). “The emergence of a growth industry: a comparative analysis of the German, Dutch and Swedish wind turbine industries”. In: Metcalfe, S. & Cantner, U. (Eds): Change, Transformation and Development. Physica/Springer, Heidelberg, 2003, pp. 197-228.

Bergek A., Jacobsson S., Carlsson B., Lindmark S., Rickne A., (2008). “Analyzing the functional dynamics of technological innovation systems: A scheme of analysis”, Research Policy 37 (2008) 407-429.

Blaabjerg F., Chen Z., Teodorescu R., Iov F. ,(2006). “Power Electronics in Wind Turbine Systems”, Power Electronics and Motion Control Conference.

Bolinger, Mark. (2001). “Community Wind Power Ownership Schemes in Europe and their Relevance to the United States”, Environmental Energy Technologies Division, Lawrence Berkeley National Laboratory, May 2001

BTM Consulting, Global Market updates 2006 and 2011

Buen J, (2006). “Danish and Norwegian wind industry: The relationship between policy instruments, innovation and diffusion”, Energy policy, volume 34, issue 18, 2006.

Chen Z., Hansen J.C., Wu Q.Hansen A.D., Bak-JensenB., (2011). “Research Developments on Power System Integration of Wind Power”, DTU working paper,2011

Cooke, P., Gomez Uranga, M. and Etxebarria, G. (1997) “Regional systems of Innovation: Institutional and Organisational Dimensions”, Research Policy, 26, 1997: 475 – 491.

del Río P., Bleda M., (2012). Comparing the innovation effects of support schemes for renewable electricity technologies: A function of innovation approach. Energy Policy, Volume 50, November 2012, Pages 272–282

EWEA (2005). “Wind Energy – The facts: Part II – Grid Integration”, EWEA.

EWEA,(2010). “Powering Europe: wind energy and the electricity grid” November 2010

Freeman, C. (1987). Technology policy and economic performance: lessons from Japan. London: Pinter.

Frost and Sullivan (2008). “Advances in wind turbine design”, Frost and Sullivan, 2008.

Garud R.; Karnoe P.; (2003). “ Bricolage versus breakthrough: distributed and embedded agency in technology entrepreneurship”, Research Policy 32, 2003.

Gwec, The Development of Wind Power Tariffs in China

Gwec,2010. Global Wind Report. Gwec, 2010.

Gwec,2011. Global Wind Report. Gwec, 2011.

Han J., Mol A.P.J., Lu Y. and Zhang L. (2009): Onshore wind power development in China: Challenges behind a successful story. Energy Policy, Vol. 37.

Hansen A.D.; (2009); "Grid integration impacts on wind turbine design and development"; IEEE PowerTech, 2009

Hansen A.D., Cutululis N. A., Markou H., Sorensen P., Iov F.; (2010); "Grid faults and design basis for wind turbines – Final report". Risoe R-Report, January 2010.

Hansson F., Brenneche N T,, Mønsted M., Fransson T, (2007). "Success: Benchmarking Successful Models of Collaboration", Pilot project for cooperation between European Institutes of Technology, EU sponsored Research, 2007.

Hekkert, M.P., Suurs, R.A.A., Negro, S.O., Smits, R.E.H.M., Kuhlmann, S., (2007). Functions of Innovation Systems: A new approach for analyzing technological change. Technological Forecasting and Social Change 74, 413-432.

Hau, E. (2000) Wind turbines: fundamentals, technologies, application, economics. Berlin: Springer, 2000.

Hook L., Crooks E. (2011). China's rush into renewables: The way the world turns; Financial Times November 28, 2011

IHS, (2011). "Global Wind Turbine Markets and Strategies: 2011–2025", August 2011, Market Study Excerpt

Jacobsson, S., Johnson, A., (2000). "The Diffusion of Renewable Energy Technology: An Analytical Framework and Key Issues for Research". Energy Policy 28, 625-640.

Jacobsson A., A. Bergek A.(2011). "Innovation system analyses and sustainability transitions: Contributions and suggestions for research". Environmental Innovation and Societal Transitions 1, 2011.

Johnson A. (2003) "The emergence of a growth industry: a comparative analysis of the German, Dutch and Swedish wind turbine industries",In: Metcalfe, S. & Cantner, U. (Eds): Change, Transformation and Development. Physica/Springer, Heidelberg, 2003, pp. 197-228.

Kamp L. M.: Ruud E. H. M. (2004). "Notions on learning applied to wind turbine development in the Netherlands and Denmark"; Energy Policy, volume 32, issue 14, 2004.

Karnøe, P , (1993)."Approaches to innovation in modern wind energy technology: technology policies, science, engineers and craft traditions". Centre for Economic Policy Research, Publication # 334, Stanford, CA, 1993.

Karnøe, P., Jorgensen, U., (1995). "The Danish wind turbine story: technical solutions to political visions?' In: Tip, A, Misa, T.J. & Schot, J. (eds) Managing technology in society (p57-p82). London: Pinter Publishers, 1995.

Karnøe, P., Garud, R., (2003). "Bricolage versus breakthrough: distributed and embedded agency in technology entrepreneurship", Energy Policy n. 32, 2003.

Klaassen G., Miketa A., Larsen K., Sundqvist T.,(2005). The impact of R&D on innovation for wind energy in Denmark, Germany and the United Kingdom, Technological Change and the Environment — Technological Change; Volume 54, Issues 2–3, August 2005.

Koefoed, A.L.; (1999).“The Case of Danish Wind Power Integration and Wind Industry Development”, in “Eikeland, P.O., Christiansen, A.C., Koefoed, A.L., Midttun, A., Tangen, K., (Eds.), Green Energy-Industrial Innovation: A Comparative Study of Green Energy Transformations in Northern Europe”, FNI-Report, 1999

Lee I., Hon A., (2011). “Prefer quality component plays with unique bargaining power in the crowded space”, Nomura equity research, 06/2011

Lubaer V.(2005). Switching To Renewable Power: A Framework For The 21st Century, EarthScan.

Lewis, J.I., 2011. Building a national wind turbine industry: experiences from China, India and South Korea. International Journal of Technology and Globalisation 5 (3/4), 281–305.

Liu, X. and White, S. (2001). Comparing innovation systems: a framework and application to China's transitional context. Research Policy, 30(7), 1091-1114.

Liu,Y. and Kokko,A.(2010): Wind power in China: Policy and development challenges. Energy Policy, 38, 5520-5529

Lundvall, B-Å. (1992) (ed.). National Systems of Innovation: Towards a Theory of Innovation and Interactive

learning, London: Pinter.

Mah D., Hills P. (2011) R&D Collaboration for Wind energy in China: local diversity, achievement and limits. University of Hong Kong Working Paper 12.

Malerba, F., (1993). “Italy”, In: Nelson, R. (Ed.), National Innovation Systems. Oxford University Press, Oxford 1993.

Malerba F, Breschi S., (2001). “The geography of innovation and economic clustering: some introductory notes”, Industrial and Corporate Change,v.10 n. 4, pp. 817-833 , 2001.

Malerba, F. (2005). “Innovation and the evolution of the industries”, Cambridge Univer. Press, Cambridge, 2005.

Malerba F., Nelson R. N. (2012), “Innovation and Learning for Economic Development: The Evolution of Sectoral Systems”, Edward Elgar Publishing, May 2012

Maltha J.; (2005). “The evolution of the worldwide wind turbine industry 1975-2005:“Explaining the Danish industrial leadership”; Master thesis at Eindhoven University of Technology (TU/e) September 2005

Mayer S., (2010). Relaxing the rules of supply” Windpower monthly, 10/2010.

Negro S., Hekkert M., Smits R.E.,(2007). Explaining the failure of the Dutch innovation system for biomass digestion—A functional analysis, Energy Policy, Volume 35, Issue 2, February 2007, Pages 925–938

Nelson, R. R. (1993) (ed.). National Innovation Systems: A Comparative Study, Oxford: Oxford University Press.

Nilson M., Norén S. (2011). “Powerful winds from the east Explaining the fast development of the Chinese wind turbine industry”. Master of Science Thesis at the Chalmers University of Technology.

Nygård J. R., 2011. Denmark Country case analysis – Berkely Round table on in the international economy. June 15

2011

Olivecrona C., (1995). “Wind energy in Denmark” in Green budget reform, Earthscan Publications, London ,1995.

Pedersen J. L, Xinxin X. (2012). “The importance of basic research for inventions and innovations in wind energy: Some experiences from Denmark and China 1973 – 2011”. International Schumpeter Society, 14th ISS conference.

Pedersen T.; (2009). “Vestas Wind Systems A/S - Exploiting Gloabl R&D e synergies”; Ivey Management Service, 2009.

Peng R., Zhi Q., Zhang F., Zhong, Li j., Su J. (2012). "Behind the Development of Technology: The Transition of Innovation Modes in China's Wind Turbine Manufacturing Industry" Energy Policy, volume 43.

OECD, 2011. “Energy Policies of IEA Countries: Denmark, 2011Review”.

Tellis GJ, (1981). An evolutionary approach to product growth theory, Journal of Marketing, 45, pp. 125–132.

Van Est R.,(1999). “Winds of Change: A Comparative Study of the Politics of Wind Energy Innovation in California and Denmark”, International Books, 1999

Wu D., 2008. “Powering China’s Green Leap Forward: The Central Role of Wind Energy“, UNCTAD, 2008

Wu Q., Xu Z., Østergaard J., (2010),Grid Integration Issues for Large Scale Wind Power Plants (WPPs). IEEE.

Xia C. and Song Z. (2009): Wind energy in China: Current scenario and future perspectives. Renewable and Sustainable Energy Reviews, Vol. 13, pp. 1966–1974.