The Market Challenge of Wind Turbine Industry-
Renewable Energy in PR China and Germany

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Abstract

This paper presents the role of global Industry 4.0 technology management in the growth of the wind turbine industry. The article begins with a brief overview of the Industry 4.0 wind turbine industry development, focusing on factors shaping this development. The legal policies are identified as one of the significant factors, especially in PR China and Germany. A detailed secondary data analysis of the country-specific systems is presented, followed by the analysis of patents and companies in both countries to understand better how the development, management and transfer of technology affected the different factors and the global patterns. An effective approach of acquiring technology for local enterprises as well as market development entry mode for the foreign technology holding companies are both identified. Accessing technology through licensing, entering joint ventures, or acquiring knowledge-intensive companies can be identified as common and often successful industry approaches. To develop, obtain, or maintain competitive advantages in the wind turbine industry, we suggest that the governments issue relevant legislation and regulations to support the upgrading of the industry, and the enterprises can access and manage the technology through the approaches mentioned above.

Keywords: Wind turbine industry, Legal policies, Technology management, Industry 4.0, Market development entry mode, Renewable energy.

1. Introduction

Nowadays, Industry 4.0 goes beyond automation affecting all types of energy systems, including wind energy. Based on the Global Wind Energy Council (GWEC)'s report in 2019, wind energy has increased its popularity in the last 20 years, despite numerous successes and failures, providing clean energy at a competitive cost worldwide. The trend towards environmental sustainability, however, accelerates the transformation of traditional manufacturing. Recent studies (e.g., Fargani et al., 2018) demonstrate that three main factors affect sustainable manufacturing development such as (1) government regulations, (2) customer expectation, and (3) cost savings. As an essential part of sustainable manufacturing, the wind power industry has grown fast in recent decades, mostly because of substantial technological improvements. The market for wind power has seen rapid growth in efficiency and reliability, contributing to an essential aspect of Industry 4.0 since it is a crucial energy source.

However, not everyone now understands whether and how Industry 4.0 affects them. Moreover, not everyone knows what Industry 4.0 is and when it appears. According to UNIDO (2017), Industry 4.0 comes in the face of global challenges such as climate change, food insecurity, lack of access to energy, water scarcity, environmental degradation, loss of biodiversity, population growth, urbanization and mass migration, as well as new and ongoing conflicts and global crises. These challenges are planned to be overcome by the use of smart technologies, including cloud computing, Big Data, augmented reality, robotics, sensors, Artificial Intelligence, the Internet of Things (IoT), and cyber-physical systems (Solar Magazine, 2019).

It is considered that factories operating or those that will be established in the coming years will become "smarter" and have a cyber-physical system that will monitor physical processes by establishing co-operation and communication through the Internet of Things (IoT). By switching Industry 4.0 in the green energy industry, society is acquiring smart energy networks, thereby avoiding developing a dependency on a new path (Solar Magazine, 2019). The wind turbines allow decentralization as the energy is produced locally and users can manage and control their energy consumption.

In addition, while the long-term relationship between the wind power industry and Industry 4.0 has already been established, it is clear that in the future, they will become even stronger and closer as manufacturers, energy suppliers, consumers and grid operators benefit directly from approaches closely related to Industry 4.0. Thus, not only the whole wind power industry and, in particular, wind turbines, but all its components, both physical and communication-oriented, are closely linked to and are affected by Industry 4.0.

Therefore, this research investigates the history of the wind turbine industry and its development, focusing on the factors that make up this development. The structure of this article is as follows: Section 1 briefly describes the history of the wind power industry, then addresses the wind power markets in PR China and Germany. Section 2 sets out factors affecting the wind turbine industry. Section 3 focuses on the legal policies of PR China and Germany and their development over the years. Section 4 refers to technology management in the wind turbine industry. Then, section 5 turns to Siemens' portfolio of patent applications to understand how a Western company managed its knowledge in the different phases of the industry, whereas the final section gives conclusions and discussions about the future works. This paper provides a better understanding of the current wind turbine industry and its relationship with Industry 4.0. By investigating the influencing factors and the development, management, and transfer of technology, we suggest that the government should issue relevant legislation, regulations, and development plans to support the upgrading of the domestic wind turbine industry and establish a comprehensive industrial system. The local enterprises can also access and manage the technology through licensing, entering joint ventures, or acquiring knowledge-intensive companies.

1.1. Brief History of the Wind Power Industry

The wind power industry hit it off like a NASA project in the mid-1970s to develop large scale wind turbines (NASA, 2007). The conducted research pioneered the industry and the technologies developed are still in use today. In the late 1980s, wind power growth in the US slowed due to ending tax incentives in the US. However, the market continued to grow in Europe together with Vestas, Enercon and General Electric (GE) supporting this initiative. This was followed by the Wind Energy Foundation, established in 1991 (Wind Energy Foundation, 2016). The leading technological development was taking place in Europe during the 1990s. At the end of the 1990s, PR China began to establish its wind power industry market and gain market shares. Once established, the market has been growing rapidly to provide an impetus for Industry 4.0 development in China.

According to GWEC (2020), China, the US, United Kingdom, India and Spain represent 70 percent of the offshore wind power installation in 2018. However, by the end of 2019, the top five markets consist of China, the US, Germany, India and Spain. Thus, this paper mainly focuses on two of the leading countries by comparing both the wind power markets and legal policies in PR China and Germany.

Nowadays, the development of the wind industry provides 300,000 jobs in Europe and contributes €37 billion to EU GDP every year (WindEurope, 2020). Additionally, each new turbine installed in Europe generates, on average, €10 million of economic activity, demonstrating the commercial potential of wind power. Therefore, it is key to create a deeper, more nuanced understanding of the industry and its long-term sustainability, which is consistent with the focus of GWEC (2019).

1.2. The wind power market in PR China

During the last decade, PR China's economy has been growing quickly, and as a result, the energy demand has increased at a fast pace (Figure 1). The installed wind capacity was relatively low and considered as a new industry until 2005-2006.

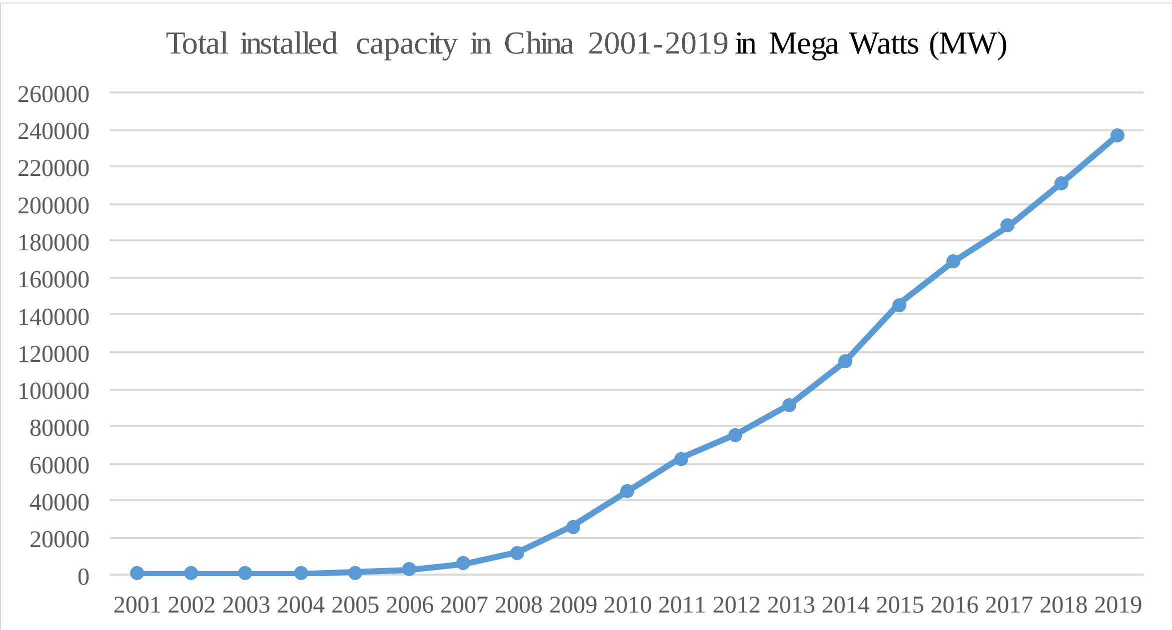

Fig. 1: Total installed capacity in China 2001-2019. (Data source: Global Wind Energy Council, 2016; GWEC, 2018; GWEC, 2019; Wind Energy Installation, 2020)

However, the Chinese government decided to be highly involved in developing the industry and the Chinese wind power concession system, which has improved gradually as the obstacles and problems have been identified. In 2005, the National Development and Reform Commission of PR China published a requirement of a minimum of 70 percent domestically produced equipment within wind power projects, thereby increasing the domestic manufacturing capabilities in PR China (Yuan et al., 2015; Global Wind Energy Council, 2008). This period can be considered the beginning of PR China's wind power industry, as shown in Figure 2.

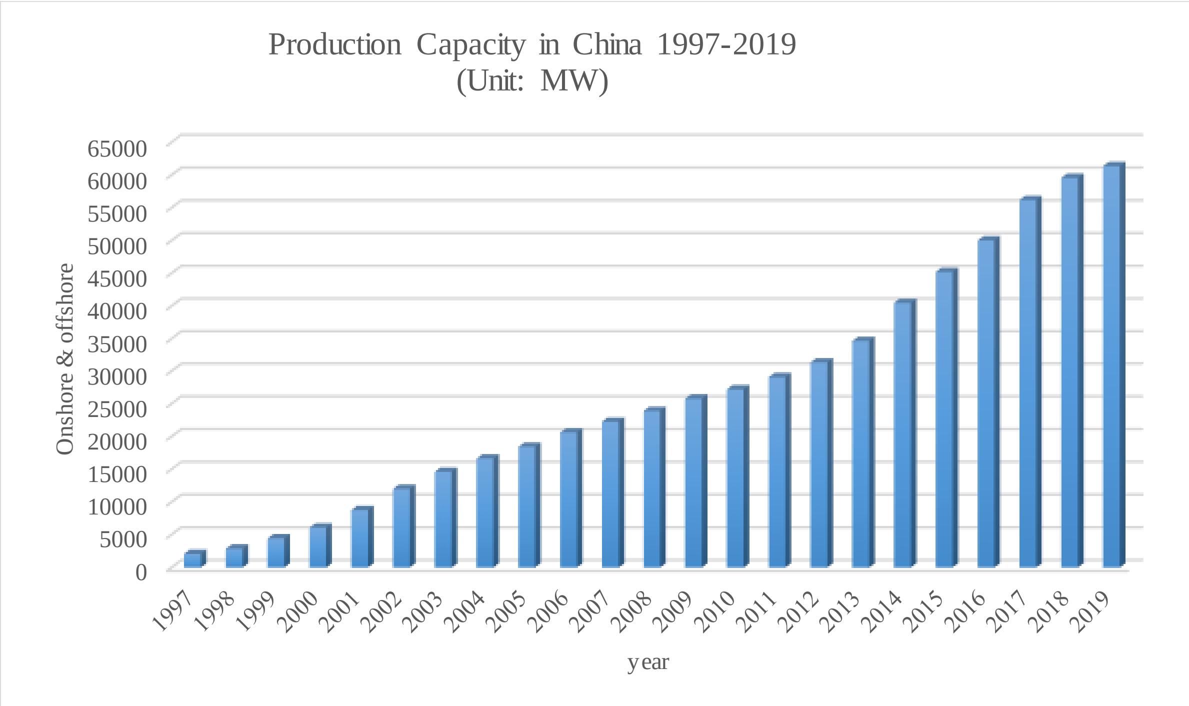

Fig. 2: Total production capacity in China 1997-2019. (Data source: The Wind Power, 2019)

While the Chinese wind power industry is still moving towards maturity, they lack experience maintaining and operating wind turbines over extended time-periods. PR China is behind in crucial design technology and is dependent on the industry leaders in the US and Europe. As of 2009, the technology created domestically was still at an early stage in development (Global Wind Energy Council, 2010). Domestic manufacturing development in PR China has been of great importance in reducing overall costs and increasing the scales and volumes of the domestic market. In 2007, the import policy in China was changed, which led to the Value-Added Tax (VAT) exemptions for importing materials for wind turbine manufacturing (Yuan et al., 2015). In 2007, the domestic wind turbine market share was 56 percent, and by 2010, this number had increased to 90 percent (Liao et al., 2010).

At the end of 2019, China had around 7 GW (Giga Watts) of offshore wind in their global installations, taking the third position after the UK and Germany (GWEC, 2020). So far, eight Chinese OEMs (Original Equipment Manufacturers) have launched offshore turbines above 5 MW (Mega Watts), six of which are included in the list of the top ten suppliers. In 2019, China also had achieved a new record in terms of installed offshore wind in a single year - more than 2.3 GW.

However, apart from purely economic and political facts, there is a list of related areas affected by the wind power industry, facilitating export, manufacturing, scientific studies on new algorithms, etc. These results also positively influence the global wind power industry. So, let's turn to a few examples, also focusing on some Industry 4.0 supporting examples.

Xia (2018) believes that as a typical discrete manufacturing project, the wind power intelligent factory should improve the workshop automation, manufacturing execution system, and operational intelligence and then integrate these systems. With the application of digital technology and human-machine collaboration, the equipment or devices can communicate with each other intelligently. The data from these devices can be converted into the most effective and suitable production instructions and manufacturing management. Moreover, high efficiency and on-time production are realized; logistics costs and storage costs are reduced (Xia, 2018).

Zhong Fu Lian Zhong (ZFLZ), China's largest manufacturer of blades for bulk export, found that the existing traditional production management of the enterprise performs unsatisfactorily with the overall production efficiency, on-time delivery rate, and customer pass rate. In order to improve the lean manufacturing level of the blade, from 2015 to 2017, the company established a full life cycle traceability mechanism of the blade with the support of information technologies. In this mechanism, the production process is transparent and can be continuously improved, the product quality can be controlled in real-time and the data can be traced fully (Qiao et al., 2018).

Maintenance of wind power equipment faces many challenges because wind farms are generally located in remote areas and places with a harsh environment. Moreover, most of the important components of the equipment are located on the top of the tower, which is hard to reach hence maintain. Currently, the main maintenance strategy of wind turbines in China has a mixture of regular inspection and breakdown maintenance, which is time-consuming (Xiao, 2015). Ding and Huang (2017) used the fault chain as the data basis to deal with the issue and adopted the Bayesian network method for intelligent fault diagnosis. The algorithms achieved a test accuracy of up to 90 percent.

To sum up, despite the difficulties and barriers, China is the biggest wind energy market so far (GWEC, 2020). It also demonstrated the most impressive new capacity, taking a leading position in the top five markets with 43.3 percent of the entire market.

1.3. The wind power market in Germany

During the past ten years, the development of the German wind power market is somewhat different from that of the Chinese one. After having had a pioneering role in wind power utilization for many years, there is already a lot of experience gained. The technological and economic successes are partly due to a continual policy of support from the German Government (Institute for Solar Energy Supply Technology, 2009). The German wind power market is growing at a steady pace. In 2005 there were 18,415 Mega Watts (MW) in total installed capacity compared to 250 MW for China in the same year. Over ten years, this number in Germany had grown and more than doubled to 44,947 MW in 2015 (Figure 3). However, it is more than three times worse than the results in China. Positive trends are observed in terms of production capacity as well (Figure 4).

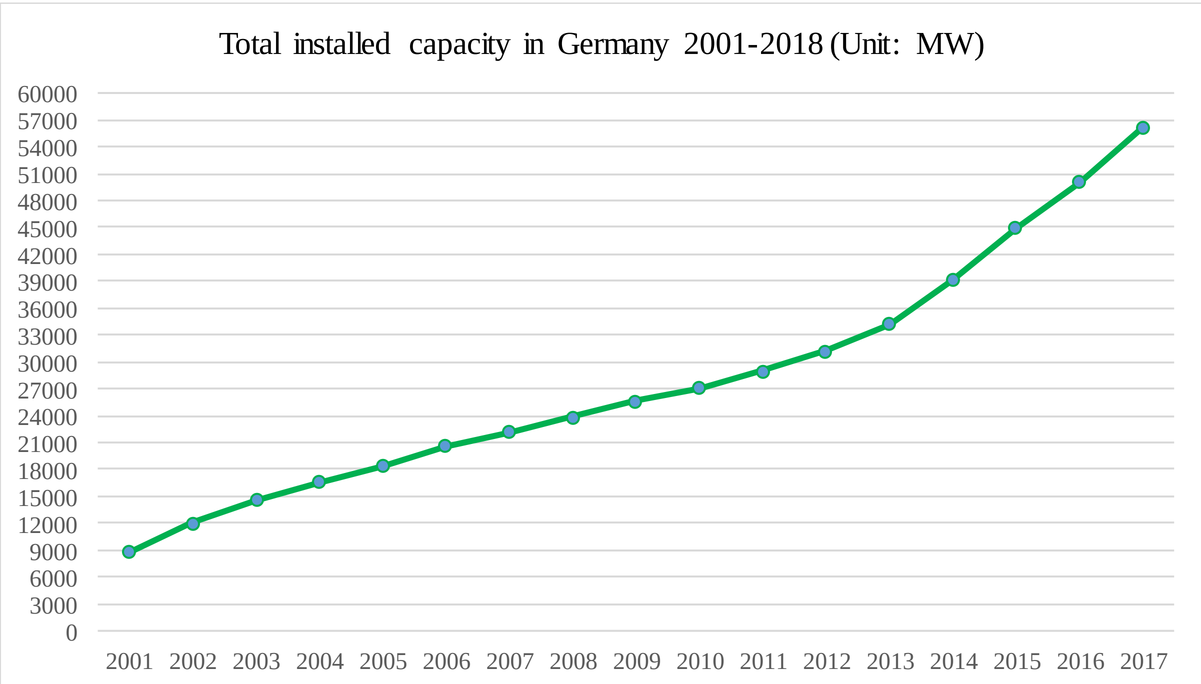

Fig. 3: Total installed capacity in Germany 2001-2018 (Data source: Global Wind Energy Council, 2016; GWEC, 2018; Wind Energy Installation, 2020)

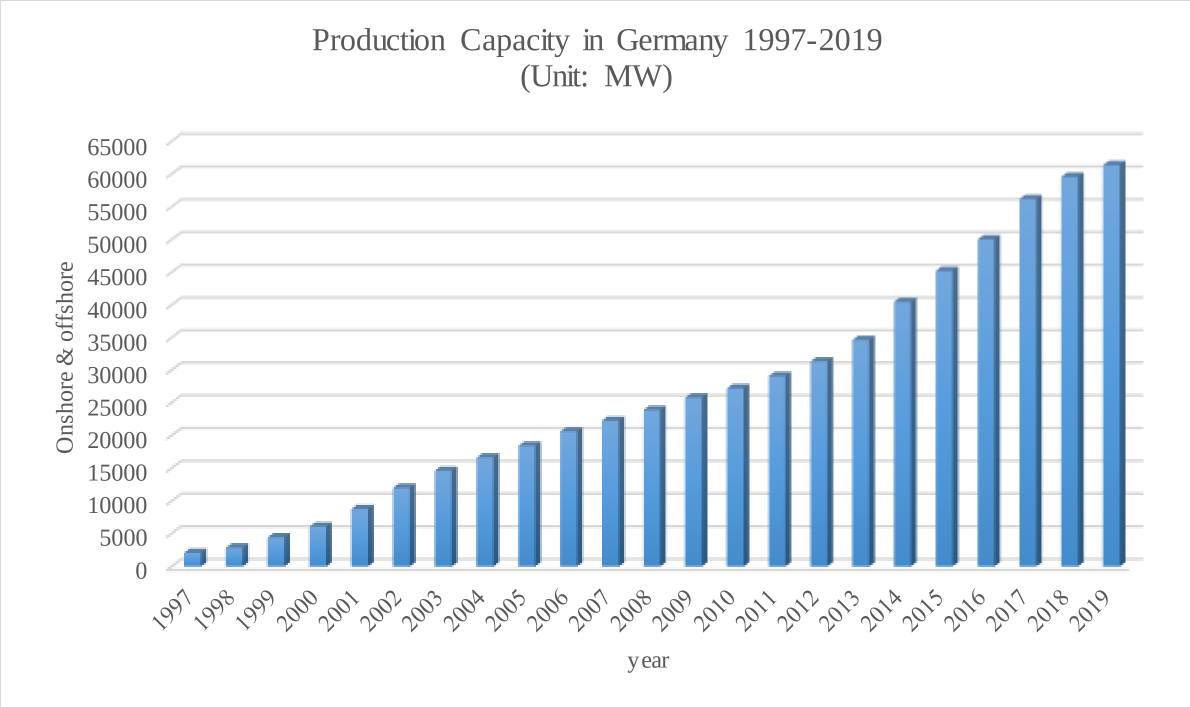

Fig. 4: Total production capacity in Germany 1997-2019. (Data source: The Wind Power, 2019)

In 2015, the average electricity cost of wind power had been reduced by 12 percent compared to 2011. This is a result of the progress made in optimizing technology and costs.

As of 2015, Germany is the number one country in Europe with the most wind power available, which is also the case in 2019 (Power Technology, 2019). Moreover, only two countries in the world are surpassing Germany - PR China and the US (Global Wind Energy Council, 2016, 2020). However, while keeping a steady growth rate, it is crucial to continue with system optimization and grid expansion. Lengthy planning procedures are not optimal when dealing with a highly uncertain market dependent on German and the EU regulations (Global Wind Energy Council, 2016).

Germany is also contributing to the world market with new technologies. For instance, in 2015, Beckhoff introduced a new wind software architecture named TwinCAT 3 Wind Framework. The framework provides manufacturers a ready-to-use application template so that they can reduce development time and costs and facilitate modular engineering design at the same time. (Beckhoff, 2015).

Another solution drawing attention is BirdVision developing a camera system with the support of artificial intelligence in 2018. This system aims to solve one of the barriers to the construction of wind turbines in Germany in recent years. This solution aims at combating danger causing by huge leaves endanger the birds flying nearby, protecting both birds and leaves simultaneously. The system detects and tracks birds that may be harmed by wind turbines and shut down the turbines to protect the birds as soon as they approach the turbines. The "BirdVision" camera system uses neural deep learning networks to detect birds through intelligent tracking, which has been tested on eight wind turbines and has achieved a satisfying detection rate (Jungblut, 2020). Additionally, the servers are established in the wind turbine tower and can directly use power generated by the turbine. At the moment, it is difficult to draw any conclusions on how this solution affects the attitude of German citizens towards wind turbines. However, it is known that Germany has been competitive enough in the wind industry over the last years.

2. Factors influencing the Wind Turbine Industry – PR China and Germany

In recent years, PR China and Germany are the main competitors in the wind power industry, wherein in 2019, China is the leading market in terms of new and cumulative installations. Germany holds the third position in cumulative installations but is number one in Europe. Therefore, it is essential to determine the factors that have the greatest impact on the wind turbine industry by relying on these two countries. Our findings are based mainly on the observations and experience gained during the study and a comprehensive literature review, underlying some common trends. The factors that shaped a significant expansion of the wind turbine industry can be classified into institutional, political, environmental, financial, etc. The most crucial and relevant factors are listed and briefly described as follows:

1. <u>The global installed capacity and the production</u> from renewable technologies have increased substantially, and environmental policies have continued to spread to more and more countries worldwide.
2. <u>A more significant focus</u> has risen on the mitigation of climate change and the rapid exploitation of many renewable energy technologies.
3. <u>The increasing market demand</u> for green products has led to advancements in technology and economies of scale, setting the basis for the expansion of a promising market.
4. <u>Declining costs</u> as some of the renewable energy technologies are cost-competitive, which is also the case for wind power, making it one of the most affordable forms of electricity. It offers lower costs than any other possible resource (American Wind

Energy Association, 2013). This considerable decrease has been made possible thanks to advanced technologies, improved positioning techniques and learning across all sectors. Figure 5 shows a significant decline in costs of more than 90 percent from the early 80s (see Figure 6). Moreover, Levelized Cost of Energy (LCOE) is not considered a focus anymore (GWEC, 2020). Rather, it has been focusing more on Industry 4.0 and the digitization of manufacturing. The evolution of global policies, which captivate investments and creating markets that sustain economies of scale and boost technology, has made it possible to benefit from lower costs and to guarantee a steady growth of the sector. In this process, Pioneers have been mainly Germany, Denmark, the US and Spain, which first set up the innovation policies that have been taken into account (e.g., Germany is committed to the "Energiewende" program).

5. Green policies that also developed and fostered from a local point of view: the commitment of municipalities, local governments, etc.
6. Institutional policies such as REN21, the Renewable Energy Policy Network, are for the 21st Century.

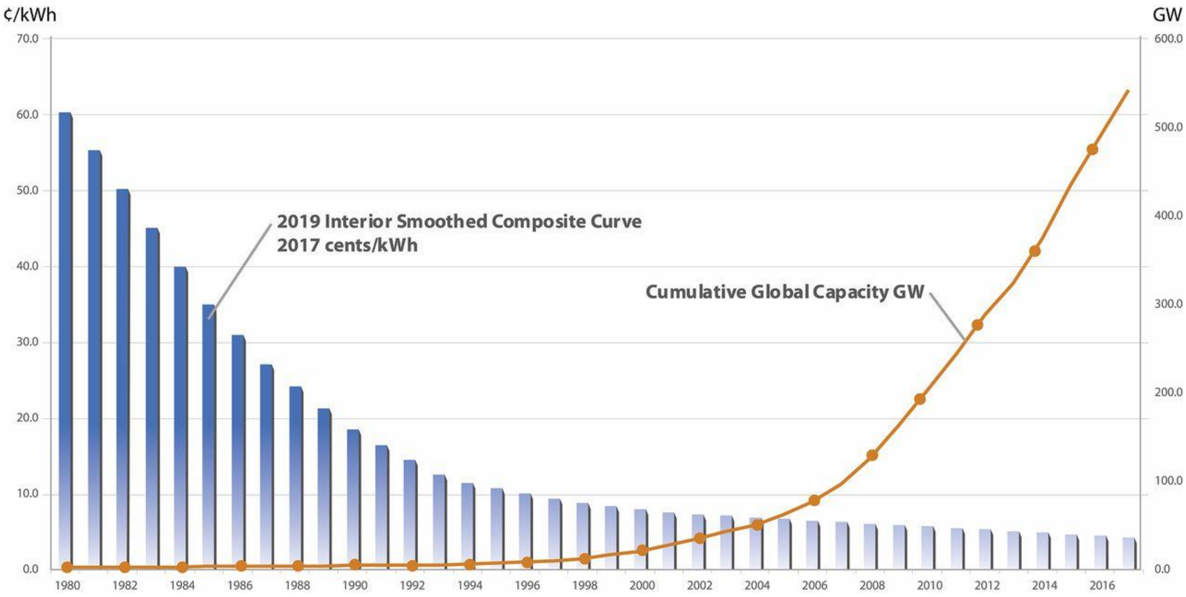

Fig. 5: Annual Installed Wind Capacity and Levelized Cost of Energy (LCOE) 1980-2016. (Veers et al., 2019)

GWEC (2020) highlight the most powerful factors contributing to the price drop that significantly affects wind energy development. These factors are technological developments, restructuring the equipment supply chain, and enabling of procurement negotiations globally. In other words, the wind turbine industry is becoming as close to Industry 4.0 as possible.

PR China has developed a vast wind power industry that continues to grow at a steady pace. However, the industry faces several challenges and issues due to the complex environment in the Chinese market. In the book *"Renewable and Sustainable Energy Review"* by a few Chinese engineers (Wang et al., 2015), the authors identified a framework of nineteen factors, including strengths and weaknesses, and opportunities and threats, to examine the competitiveness of the Chinese market.

The most influential factors in China are highlighted below. First, PR China can brag about an abundance of wind energy resources that can be fostered and boosted.

Second, in general, renewable energy can conduct several environmental advantages, such as the reduction of greenhouse gas emissions, the reinforcement of the supply's diversity, and the improvement of security. These are some of the environmental advantages that make wind power generation promising.

A third important aspect is the competitiveness of renewable energy with mature technologies and the potential for large-scale developments. Indeed, Wind power helps fulfill energy demand, enhance the energy industry structure, decrease pollution, and promote economic growth. The last strength analyzed is the rapid outgrowth of the wind power equipment manufacturing sector, mainly thanks to the domestic, foreign and joint venture wind manufacturers. PR China has promoted the development of this industry in its territory and has now achieved the local capability to produce significant components of wind turbine units (Yuan et al., 2015).

However, the factors of weakness should be seriously considered. For instance, the high price of wind power electricity is a significant obstacle to its commercialization. Almost all the total investment in wind farm projects in China is spent on equipment purchase and installation, which is one of the reasons why PR China used to rely on imported wind power equipment in the past. Indeed, the manufacturing capacity of domestic wind turbine manufacturers lags behind the world's leading manufacturers. The lack of high quality and reliability is another major flaw of this type of structure, while the production of prototype turbine must respect several steps, including certification and tests, to highlight potential issues and improve it before moving to the large-scale commercialization stage. Typically, it requires at least three years for prudent testings before it is commercialized. In the case of significant defects associated with product quality, the business of the wind turbine manufacturers would be severely impacted (Zhao et al., 2013). Lastly, it is the issue of absorption. The majority of wind resources are located in some inner regions in China where economic development speed is very slow and the energy demand is low. Therefore, it results in a significant waste of wind power resources, especially in those resource-rich areas where the grid structure is not strong enough to transfer capacity to the load centers efficiently.

For the industrial situation in Europe, Germany has become one of the world's leading wind energy producers (Bruns and Ohlhorst, 2011) over the past twenty years. There is a list of determinants of such colossal expansion, from the legislative norms to the administrative regulations, sociological responses, as well as unforeseen events (Renewable Energy Policy Network for the 21st Century, 2015, 2020). Thanks to its long mechanical and electronic engineering tradition, it not only at the forefront of technological development, but it also can leverage these strengths to consolidate its dominant position. Germany's central location makes it an ideal place for European onshore and offshore markets alike. It has enormous potential for offshore wind energy and is demonstrated by developing a new prototype of 5 MW or giant wind turbines that can make full use of the possibility of wind power at sea. This makes it possible for offshore wind farms to perform more cost-effectively once the issues related to the application of the new technologies have been resolved (German Trade & Invest, 2016, 2020). One more critical aspect is the support of the German Federal Government. In 2010, Germany embraced the so-called "*Energiewende*" policy, which is no other than the transition to renewable "clean and green" energy, emphasizing wind power, raising the public awareness of such matters even more. Other significant institutional and political aspects and factors affecting the wind turbine industry in general, specifically in PR China and Germany, will be analyzed and presented in the next section.

3. Legal Policies on the Wind Turbine Industry Development

3.1. Regulatory Policies in PR China

The legal development of the wind turbine industry in PR China, starting from scratch to mass production, can be divided into the following policy dimensions: legislation, planning, taxation and electrovalence policies. These policies positively contributed to the increase of the Chinese wind turbine installation capacity, wind power output and sustained growth rate. The early wind turbine development (1994-2005) was fostered mainly by the superior Chinese design and government financial support. In contrast, legislation and industry-specific preferential policies came at a later stage (2005-2011) characterized by tremendous growth. During the industrial exploration period in the 1990s, the Chinese Ministry of Science and Technology established the National 863 Project. It focused on digesting and absorbing foreign wind power technology through industry research. In 1995, the Ministry of Electric Power Industry formulated the *Administrative Regulations of Wind Power Grid Operations* stating that wind turbines were allowed to be built associated to the grid and assured a full supply of electricity and decided to apportion the cost of electricity consumption above average to the entire State Grid (Sun, 2005). Moreover, in 1996, the former Economic and Trade Commission implemented several double–processing projects and introduced the public financing and debt program (Sun. 2005). Therefore, these policies encouraged finances to start developing wind turbines while also protecting the interests of investors. Consequently, the newly installed capacity of a wind turbine in PR China began to expand.

The next phase (2005-2011) in the Chinese wind turbine industry was the fast growth period with increased competitiveness of local Chinese firms accompanied by a more comprehensive regulatory system. In 2005, the National People's Congress enacted the *Renewable Energy Law*, which established a stable cost-sharing system that rapidly increased the local wind power equipment manufacturing capacity scale. Meanwhile, the Chinese National Development and Reform Commission delegated the approval authority to sub-provinces regarding projects below 50,000 kilowatts (kW). In order to strengthen the development of the local wind power industry, it is stipulated that at least 70 percent of wind power projects have to be contracted to domestic manufacturers. It was then followed by another *Memorandum on Promoting Wind Turbine Industry* and a detailed *Eleventh Five-Year Plan for Renewable Energy Development* (Shi, 2013). Apart from these macro-policies that chartered the course of local wind turbine industry development, the Chinese Ministry of Finance introduced the *Regulations of Special Funds for Industrialization of Wind Power Generation Facilities* in 2008, which subsidized as per the criteria of 600 CNY/kW to the first 50 turbine units of wind power equipment manufacturing enterprises. This subsidy was equivalent to approximately 10 percent of the total cost. Additionally, the Chinese State Administration of Taxation enacted the *Catalogue of Preferential Corporate Income Tax Treatment for Green Public Infrastructure Projects (2008 Edition)*. They pointed out that for the first three years, wind turbine enterprises could be exempted from corporate income tax and for the next three years, the corporate tax can also be reduced to half (Shi, 2013). Additionally, in the same year, the Tax Administration introduced a 50 percent tax refund to enterprises that harness wind power to generate electricity.

With an increasingly improved legal system and supportive policy enhancement, the domestic wind turbine industry witnessed an unprecedented rapid development stage. The reason is that the manufacturing capacity of wind power turbines significantly improved and Chinese manufacturers with over three megawatts have achieved their production scale. By the end of

2011, for the first time, the market share of Chinese domestic-funded enterprises exceeded foreign-funded ones, ranking the first globally (Li et al., 2012).

In recent years, the Chinese wind turbine industry development from 2012 onwards could be characterized by steady quality growth and adjustment. On the legal front, in 2012, the Chinese State Council promulgated the *12th Five-Year Plan for the Development of PR China's Strategic Emerging Industries* that requested relevant departments to guide, supervise and improve wind power consumption capacity. Simultaneously, the Chinese National Energy Administration also tightened up the authority approval of wind turbine projects to slow down and reshuffle the industry. The Chinese National Development and Reform Commission increased the on-grid electricity tariff of offshore wind turbine operations from 0.85 CNY/(kW·h) to 1.5 CNY/(kW·h) to shift the corporate focus from quantity to quality.

To further enhance the quality, the Chinese National Energy Administration issued the *Public Notice on Requirements for Regulating Market Order of Wind Power Equipment* in 2014 (Wang et al., 2015). These policies restrained the overheating in the Chinese wind turbine industry and successfully transformed the industry from focusing on "*heavy size, heavy speed and heavy loading*" to "*high efficiency, high quality and high consumption*." The wind turbine industry then entered a steady growth stage and was expected to increase by 20 percent in the following few years (Wang et al., 2015).

In general, the relevant legislation, regulations, development plans issued by the various Chinese governmental organizations have strongly supported the prosperity and upgrading of the domestic wind turbine industry. They have been instrumental in strengthening innovation and establishing a comprehensive industrial system. As a result, in 2015, China alone implemented more wind capacity than in other European countries such as Denmark, France and the UK, which was also accounted for about half of the world's total capacity. However, in 2019, China was in the third position after the UK and Germany, and became a leader for offshore turbines (GWEC, 2020).

The most recent report states that the regulation of 2018 stipulates that offshore projects approved in 2019 and 2020 will be subject to competitive auctions. However, beginning of 2020, PR China announced that it would entirely suspend offshore wind subsidies starting from 2022, while subsidies allocated by provincial governments are incited to ensure continuity of support (GWEC, 2020). This means that all newly accepted onshore wind energy projects will reach grid parity from January 2021. The wind power price can be at the same level as the regulated price for coal power without any supporting policies. (GWEC, 2020).

3.2. Regulatory Policies in Germany

As in PR China, direct and indirect policy supports can characterize the German wind turbine industry. Direct policy support includes a government policy plan, legislation. In contrast, indirect policy support covers supply-side incentives for manufacturers and investors, demand-side incentives for grid enterprises, and Research & Development (R&D) investment, including educational investment.

According to Kong and Guo (2012), in the period of wind turbine industry development from the 1970s to 2000s, the German Federal Government provided massive financial support and preferential electricity tariff policy to boost the industry. For example, from 1974 to 2003 German government invested heavily 6 trillion USD in wind power R&D and the total volume was second only next to the US. However, the German government funding level lacked continuity and intermittency between years, which could negatively impact developmental cycles.

By the turn of the 1990s, the German Ministry of Research and Technology fully initiated the *Wind Power Demonstration Projects* by providing subsidies in tax returns starting from the 100-megawatt scale and later expanding to the 250-megawatt scale. Additionally, the German government also introduced a 10-year *Tax Rebate Program* to the turbine manufacturers, requiring owners of these turbines to pass the national testing assessment, thereby improving overall technical standards. It enabled turbine manufacturers to sell equipment at a premium and allowed for extra margin for investment in their own internal R&D activities.

The domestic market's success was fostered by the government’s preferential policies on the domestic equipment over foreign ones, as exemplified by the *100MW/250MW Tax Rebate Scheme*, which provided an additional 6 pfg/kWh - 16.52 pfg/kWh coupon to German domestic turbine manufacturers. Besides, the design requirement of the turbine surface leaned towards local producers, which was further proof of supporting the German industry from the regional perspective (Szarka and Blühdorn, 2006).

In terms of indirect policy support, the earliest success of the German wind turbine industry could be attributed to the national preferential program on the supply side and a steady internal tax program on the demand side. The *Electricity Feed-in Law (EFL) Act*, implemented in January 1991, required operating entities to include wind power generation in the system by paying at least 90 percent of retail sales (excluding 15% tax) for electricity. It also outlined the principles of *compulsory access to the grid*, *full purchase* and *clear stipulation of electricity tariff*. In order to decrease regional disparities due to fluctuations in electricity prices and resource availability, the Act was revised in 1997 to limit renewable energy generation up to 5 percent of total local power generation capacity from 2000 onwards (International Energy Agency, 2015).

On the supply side, the *German Renewable Energy Law (RWL)* came into force in April 2000, aiming to supply 10 percent of the total electricity supply from renewable sources by 2010. The law also introduced the *tax return policy* as compensation for the traditional electricity market to make renewable energy more economically attractive. The *EFL Act* was further reinforced in this law, stating that the power operators must unconditionally pay the protective price set by the government for electricity generated by renewable sources and sell with a price ceiling. Moreover, the RWL abolished the 5 percent ceiling rule established in 1997, and expenditures on renewable energy were allocated to all electricity suppliers based on total sales volume (Ydersbond and Korsnes, 2014).

Besides, in 2009, the German Federal Parliament enacted the *Amendment to Renewable Energy Law*, which revised the purchase price and wind turbine technicality. The wind turbine generators were required to meet the technical specifications of transmission and medium-voltage grids. The ones that had been connected to the grid but were not up to the requirements would be subject to the alteration within time. Furthermore, the German government also initiated market promotion to support renewable wind energy into the market with easier access to public funds and less reliant on government subsidies from 2010 onwards. Thus, in July 2014, the *German Renewable Energy Law 2014* (EEG, 2014) was promulgated and came into effect one month later. This new policy required that all new projects exceeding 500 kW would have to be sold directly to the electricity market while also lowering government subsidies. This policy strengthened various means for financing and increased both the newly installed capacity and cumulative capacity to 6,013 MW and 44,947 MW, respectively, in 2015 (Global Wind Energy Council, 2016). Since 2017, the government has been holding "subsidy-free" offshore wind auctions, which were criticized by GWEC to emphasize institutional weaknesses (GWEC, 2020).

According to GWEC (2020), after several revisions to the EEG for offshore wind power projects, the 2017 EEG Reform made the tariff-based auction mandatory. While in 2017, guaranteed support schemes moved to an auction-based system, Germany had two zero-subsidy tenders before 2018 and there was no allocation plan for offshore wind projects for 2019-2020. From 2021, Germany intends to have a centralized auction model to limit project financing risk, with annual volume caps of 700-900 MW for bids.

In summary, the success of the German wind turbine industry development could mainly be attributed to government investments, preferential tax policy reforms, and a stable market environment. The difference with the Chinese wind turbine industry is that Germany focused more on accuracy and quality at an earlier stage with consistent improvement. Moreover, government subsidies have been intentionally lowered at a later stage, thus making full use of market mechanisms to increase funding and smooth operation.

4. Technology Management in the Wind Turbine Industry

In order to analyze how technology is managed in the wind turbine industry, this paper aims to answer the following questions starting at a global industry level, then focusing on the company level:

1. Where has the basic knowledge and technology been developed?

2. How has it been managed and improved in the following industry development?

3. How have new entrants, especially from PR China, gained their technological knowledge?

Some interesting patterns can be detected through patent data. Therefore, three company cases are analyzed to show how they gained and managed knowledge and related technologies. For the patent analysis, the WIPO (World Intellectual Property Organization) database and our own database were created and used. Our own database is based on all patent applications in the IPC Class F03D and the relevant subclasses for the time frame (from 01.01.1990 up to 31.12.2015). "F" in F03D represents machines and engines in general, and its subclass F03D describes wind motors, more specific mechanisms for converting wind energy into useful mechanical power, and the transmission of such power to its point of use (World Intellectual Property Organization, 2017). In total, 70,683 patent applications were segmented depending on their title, jurisdiction, publication date, IPC classes, applicant, and inventor.

4.1. Where has the basic knowledge and technology been developed?

First, we looked at the overall number of patent applications and their geographical distribution. A similar pattern corresponding to the aforementioned in terms of industry growth was identified. Until 2006, patent applications were growing moderately and were regionally focused on developed countries such as Germany, Japan and the US (Figures 6 & 7). In the following years, emerging markets like Brazil and PR China gained importance and the country with the highest share of patent applications in 2010 was PR China. Comparing PR China and Germany, we found that the German jurisdiction patent applications were higher until 2004 (Figure 8), with 23 percent in 2000 to only 11 percent in 2010 for Germany, and 6 percent in

2000 to 24 percent in 2010 for China (Figures 6 and 7). Then PR China gained relevance and the number of patent applications started to grow massively (Figure 8).

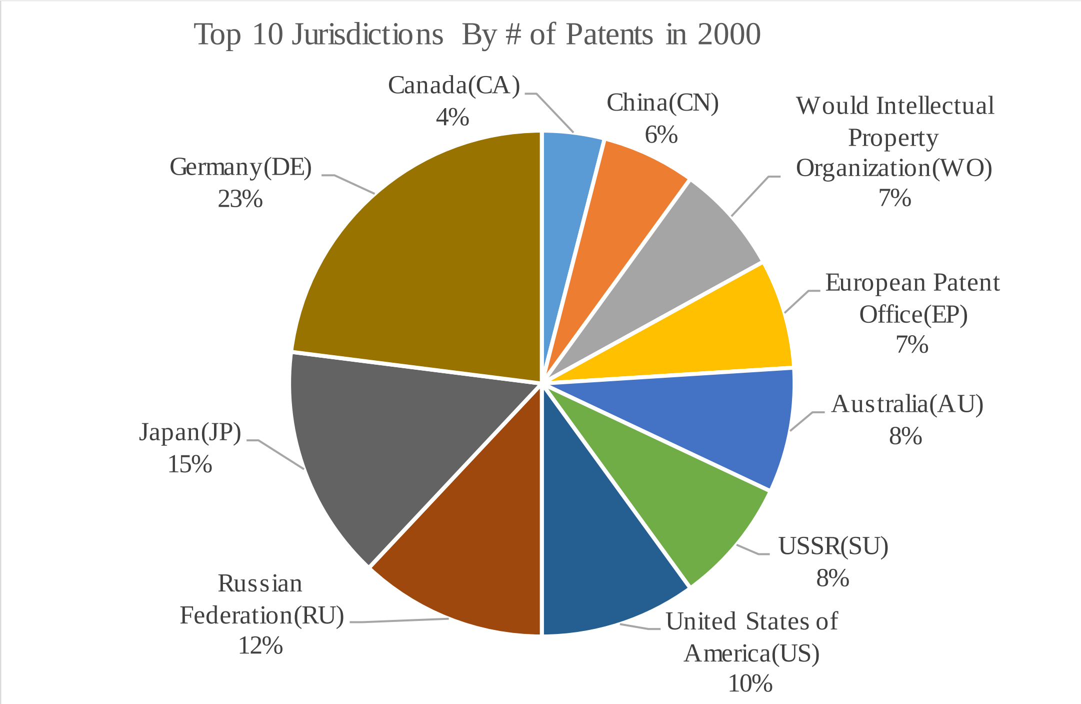

Fig. 6: Top 10 Jurisdictions 2000

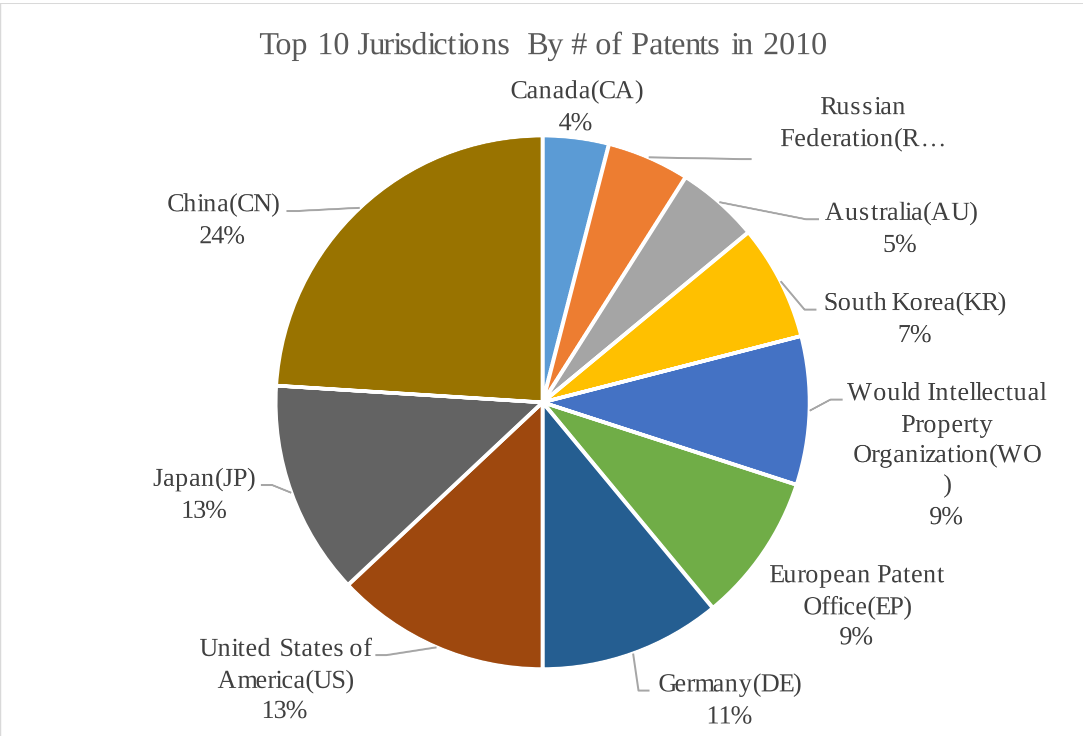

Fig. 7: Top 10 Jurisdictions 2010

Possible reasons for these observations can be found in the related market sizes of these regions. Filing a patent in a particular jurisdiction makes sense if the chances that competitors will try to copy and monetize the underlying invention in that specific market are increasing. Exchanges with a high or growing volume attract competitors and could be necessary for patent applications. The biggest markets until 2006 were Germany, the US, Spain and Brazil, as shown above. The legal studies show that in the following years, the Chinese government and industry supported wind energy projects and the Chinese market grew to the biggest market in the world by far. Thus, the patenting pattern and the market development seem to correlate, although more in-depth analysis is necessary to argue for a causality.

An appealing deduction at this stage would be to argue that the basic knowledge and technology were developed in countries like Germany, Japan and the US (as they had the highest shares of patent applications in the early years). The PR China overtook these countries further on, hence by 2010, China became a leader in the development of advanced technologies. However, this deduction does not account for an essential detail about the patent application in different jurisdictions. Companies, regardless of their origin, patent simultaneously in various jurisdictions around the world. Considering this, the growing amount of patents in PR China does not necessarily need to reflect the knowledge development in Chinese companies or other local organizations.

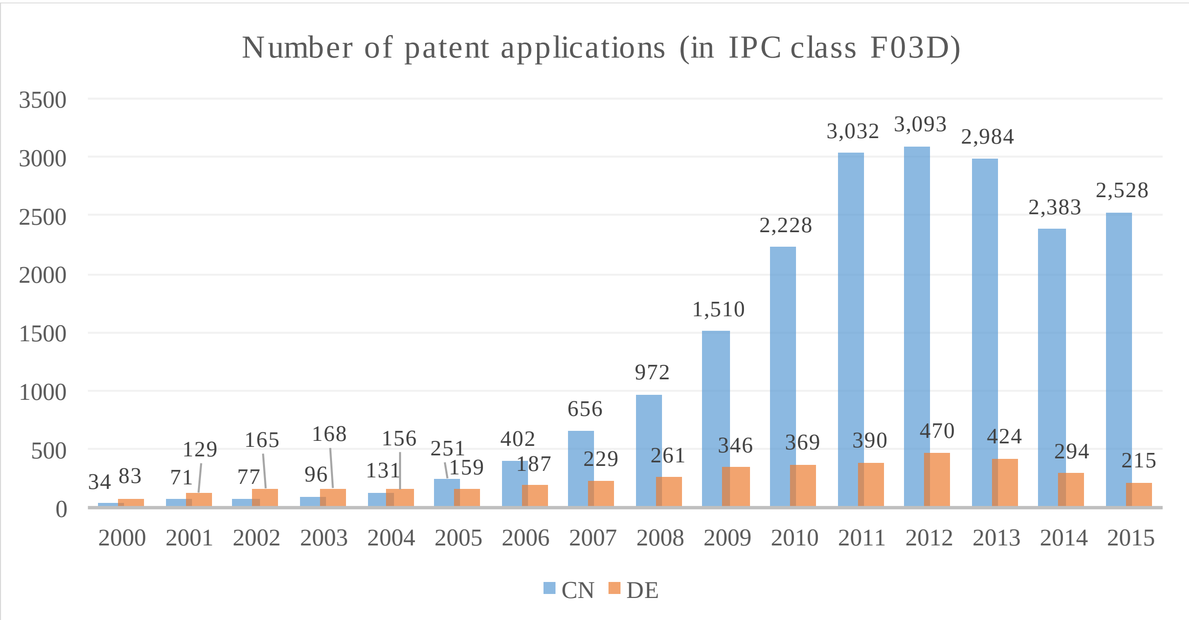

Fig. 8: Number of patent applications PR China (CN) and Germany (DE)

Therefore, to detect the origin of the first knowledge and the basic technology, analyzing the leading pioneers in the wind power industry and their patenting behavior is the next step. The top ten companies sorted by the number of patent applications for the year 2000 are highlighted in Figure 9. Some examples are Micon A/S, Bonus A/S, LM Glasfiber (Denmark), Enercon, Aerodyn, Siemens (Germany), Zond Energy, US Windpower, United Technologies (US) and Mitsubishi (Japan).

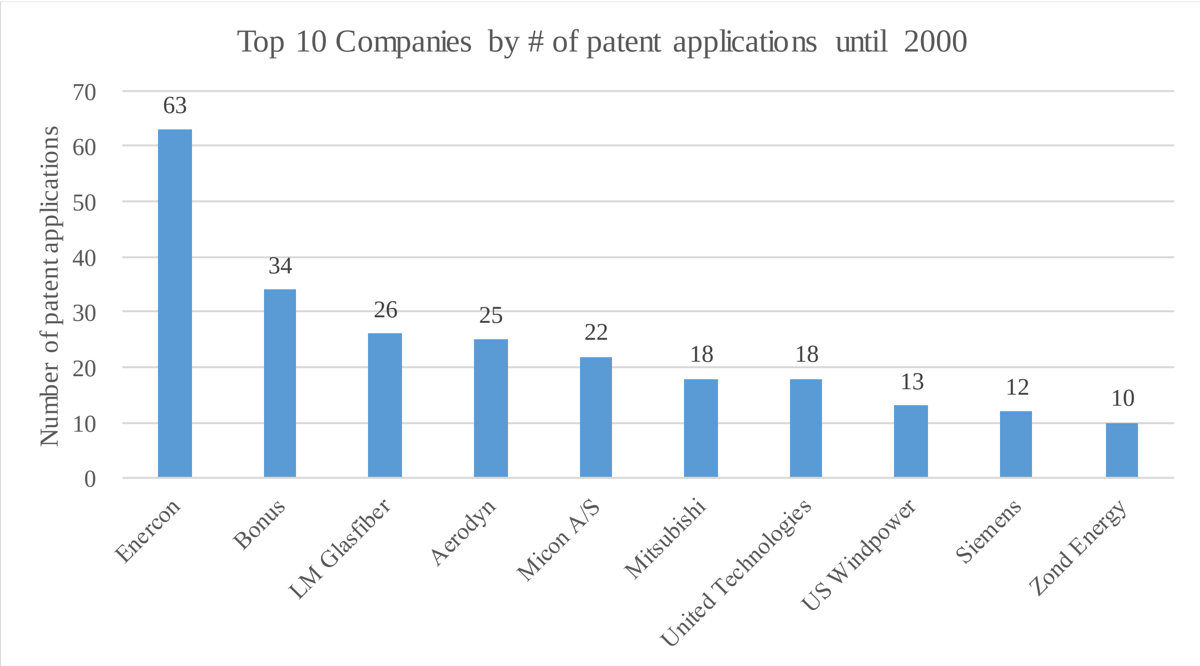

Fig. 9: Top 10 Companies by number of patents in 2000

Together with the above data, these observations show that the origins of the first knowledge and the basic technology originated in developed countries such as Germany, the US, and Japan, which can now be supported by further data.

However, Denmark could be added to the list of innovative countries in the wind turbine industry since three of the top five companies by the number of patents in 2000 were from Denmark. Although this analysis is not complete enough to answer the question of knowledge origin as a too broad concept, it is a good indicator assuming that it accounts for the source of most of the first knowledge in the wind turbine industry. This concept is also backed by similar findings in academic papers (e.g., Lema and Lema, 2013; Urban et al., 2015; Lewis, 2007).

4.2. How has the knowledge been managed and improved in the following industry development?

Based on these observations, the next step is to analyze how the companies could defend and improve the knowledge base, thereby defending their leading positions. One feasible way of finding out if the early technology leaders were able to monetize their technology, which would also give us an indicator of the quality and utilization of these first technologies, is to analyze the market shares in the wind turbine industry. Although assuming that technological advantages lead to market success does not consider other success factors, such as product design and manufacturing competence, but it is still a good indicator.

The top 10 companies by market share in 2005 are shown in Figure 10. This list contains some of the earlier identified technology leaders, such as Enercon, Siemens and Mitsubishi, which had significant market shares in the previous years of the wind turbine industry. This allows concluding that these companies had precious knowledge, technologies, and marketing capabilities to successfully bring it to the market. However, at the same time, a great number of our early-technology leaders seemed to have no economic and or financial success.

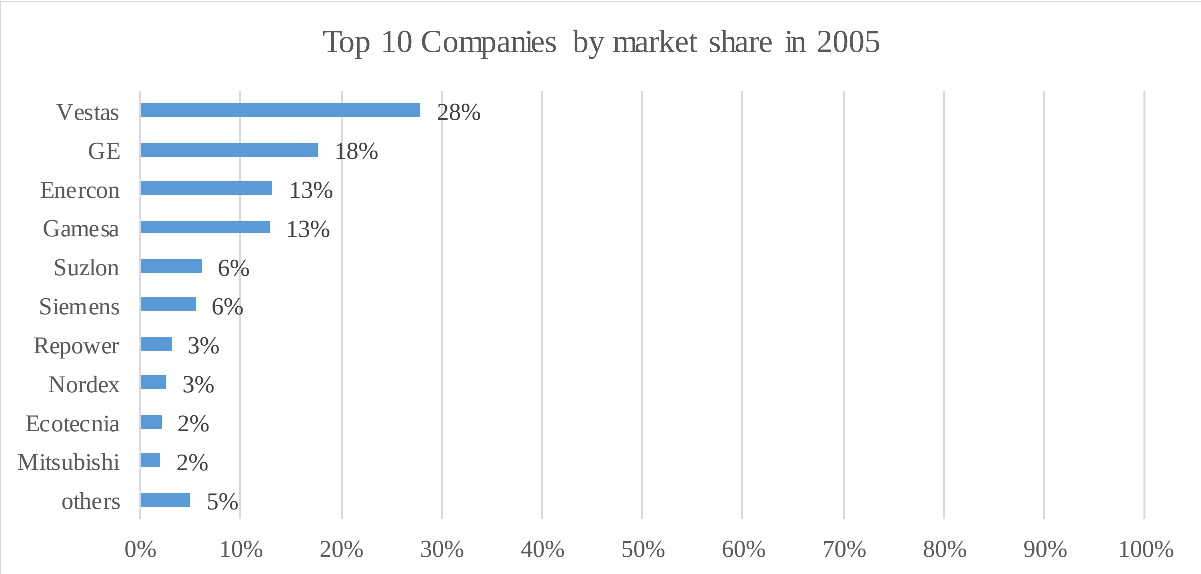

Fig. 10: Top 10 Companies by market share 2005

Even more, this is the case for the Danish and American firms (Micon A/S, Bonus A/S, Zond Energy, US Windpower, United Technologies) that are not present. Despite this fact, the two companies with the highest market share (Vestas and General Electric) are Danish and American, which is not a coincidence. Micon A/S was acquired by Vestas and build up their knowledge base in 2004. General Electric's strong market position can be explained by the acquisition of Zond Energy (through Enron Corporation). To sum up, some of the new technology leaders who remained independent could transfer their technological know-how to the market. At the same time, larger companies acquired large parts of other companies from the same region to support and strengthen their knowledge base.

Either way, most of the leading companies in 2005, both by market share and technological knowledge, are based in developed countries. Here Germany, having several substantial worldwide firms, i.e., four of the top ten by market share, should be mentioned. Most of the firms conduct their R&D in-house. At the same time, some acquired knowledge-leading companies to improve their own R&D. From a global viewpoint, technology transfer was regionally limited, and new technology was intensely developed in clusters in Germany and Denmark (Lewis, 2007).

One exception was an Indian company Suzlon, in which R&D departments are based in Germany, Denmark and the Netherlands since 2003. A high number of the first engineers were hired from an early German innovator called Südwind GmbH (Lewis, 2007). This captive outsourcing is an excellent example of how a firm can tap into regional knowledge clusters and source their technology outside of their home country. However, this setup of the industry changed radically when the Chinese market started its dense growth. Chinese firms were entering the market and profiting from the gigantic domestic wind projects. This way, half of the top ten companies by market share in 2015 were Chinese (in red), with Goldwind as a leader with 12.5 percent of market share, while other companies have 3.4 to 11.8 percent shares (Figure 11).

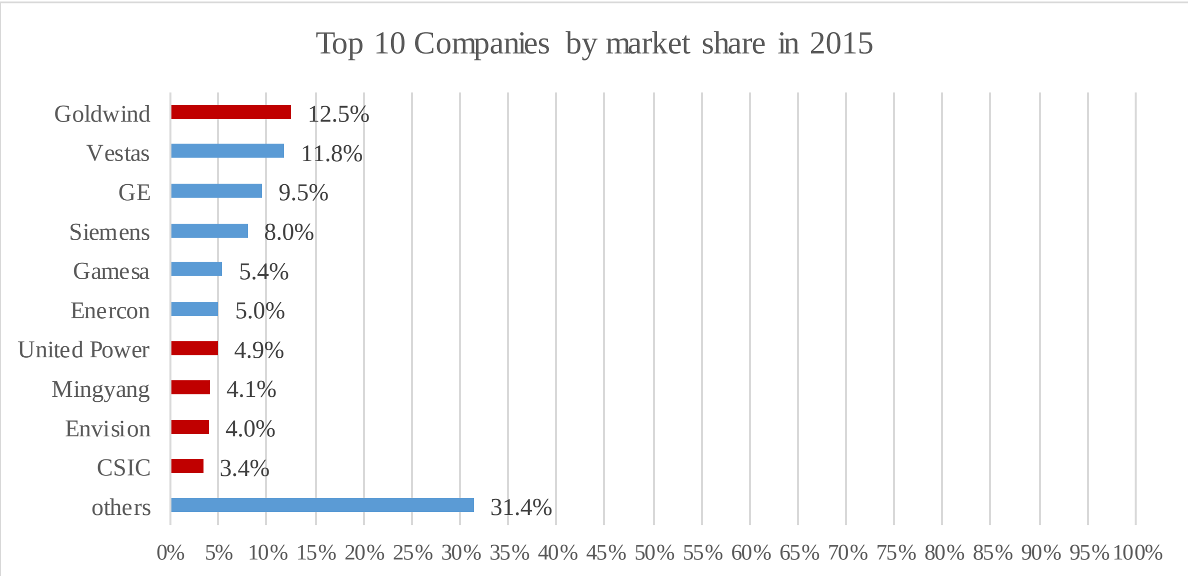

Fig. 11: Top 10 Companies by market share 2015

Aside from the size of the Chinese market, the significant market share was boosted by the protectionist Chinese policy, which affected the way technology was managed (Lema and

Lema, 2013). From the aspect of the established industry leaders from Western countries like Vestas, Siemens, GE, and Enercon, in order to secure their leading position in the global market, they had to transfer significant parts of their manufacturing, assembling, and thereby the inherent technological knowledge to PR China as they could not directly sell their turbines in PR China. (Bradsher, 2010). Managing and evaluating the connected risks and costs was a major task highlighting different strategies. Gamesa, a Spanish wind turbine manufacturer, Vestas and GE decided to enter the Chinese market and build factories. However, until 2015 the results were only achieving minor market shares – 2.7 percent of the Chinese market in total (Global Wind Energy Council, 2016). Other companies like Enercon decided to stay out of the Chinese market instead of coping with the strict policy and risking the knowledge drain. Another strategy is to enter via co-operations or joint ventures, which for example, Siemens, Nordex and several smaller firms did. Despite these different strategies, one common way of protecting and defending the technological advantages was to increase patent, especially in the Chinese jurisdiction (Figure 8). By matching the number of patents of the top ten companies in 2010 and 2015, a substantial increase in the number of patents per company is identified (Figure 12) compared to 2005.

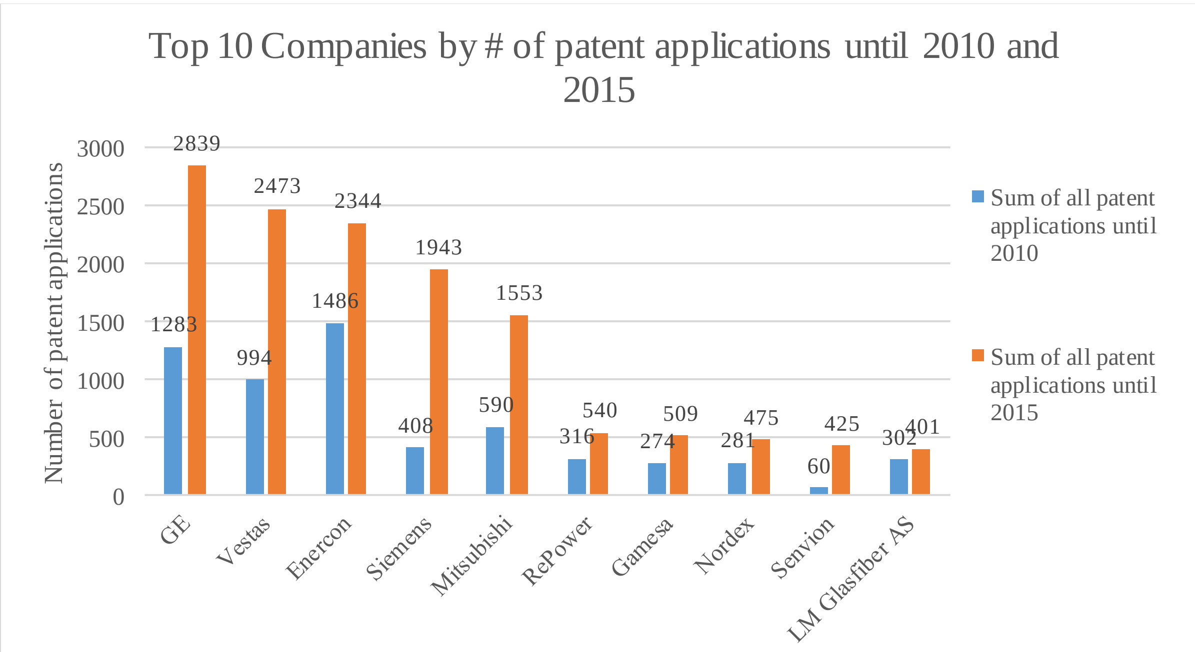

Fig. 12: Top 10 Companies by the number of patents between 2010 and 2015

4.3. How have new entrants gained their technological knowledge?

Despite the dominating market shares of Chinese companies, no Chinese firms were among the top ten companies with the most patents in 2010 or 2015. Simultaneously, when there were the most patents in China in 2010 and 2015, there were no Chinese firms under the top ten. This leads us to the last question: *how have new entrants, especially the recent market leaders from PR China, gained their technological knowledge?*

A more in-depth analysis of the technology behind the leading Chinese companies' wind turbines reveals a clear and homogeneous picture. Four of the five Chinese companies in the top ten by market share in 2015 have a similar strategy for accessing technology. All these firms are sourcing their technology either by (a) licensing or (b) co-developing in joint ventures with European, mainly German, firms. Some papers with a broader analysis also show additional examples with the same approach (e.g., Urban et al., 2015).

Two examples of the top Chinese companies are analyzed below. The first case is Guodian United Power (on the top 10 as United Power), taking 7th place on the top 10 in 2015. Guodian United Power was founded in 2007 with prior knowledge in energy distribution and transmission from the parent company, but it had no experience in developing and manufacturing wind turbines. In order to overcome this weakness of knowledge lacking, they decided to license the technology and access the wisdom of Aerodyn Energiesysteme, a German company with wind turbine engineering experience since 1983 and are licensing or co-developing with at least five other Chinese firms (Urban et al., 2015). Even in 2015, this technology co-operation between Guodian and Aerodyn was still essential. Being number seven globally by market share, Guodian United Power has only filed 83 patents based on the patent base for the class F03D in 2015. This example highlights that the leading Chinese firms relied on licenses and co-development with small European firms to gain the necessary knowledge and technology in the first place. These results are also confirmed by several academic papers (e.g., Lema and Lema, 2013; Urban et al., 2015). Patent evidence led us to assume that although technology is transferred within this co-development, Chinese companies are still struggling to draw level with European firms in patent numbers and originality of the used technology. At the same time, small engineering-focused firms from Europe used the circumstances in PR China to enter the booming wind turbine industry and are now earning significant revenues as technology suppliers.

The second company – Goldwind being a market share leader and the world's largest wind turbine manufacturer in 2015, shows a similar picture. Goldwind was founded in 1998, but its roots go back to China XWEC, one of the earliest wind turbine developers in PR China. This company has also licensed wind turbine technology from a German company, later known as REpower (Lewis, 2007; Urban et al., 2015). In their first few years, Goldwind continued this strategy, and by 2001 they acquired and licensed knowledge from the German company Vensys

(Lewis, 2013). After co-developing and sourcing expertise for several years, Goldwind finally gained 70 percent of Versys' technology. In 2015 both firms had joint R&D centers and Goldwind is still licensing a considerable share of their technology from Versys. Based on previous German knowledge, today, Goldwind owns over 3,500 Chinese patent applications (including 2,000 inventions), more than 650 software copyright registrations, and more than 400 overseas patent applications. As a result, there is a clear evidence for global knowledge transfer based on initial licensing and later acquisitions and co-development. This is also in line with other studies that have found similar results (e.g., in Lewis, 2013).

4.4. Summary

While referring to the three initial questions of this study, the analysis demonstrates that the initial knowledge and underlying technology were developed in companies from industrialized countries such as Germany, Denmark and the US.

While some early innovators grew over time and were able to successfully market their technology, other companies were acquired by larger corporations to serve as a base for their future technology. Some of the largest Western firms (e.g., GE and Vestas) of the industry accessed knowledge in this way.

With the rise of the Chinese market, the industry and technology management changed dramatically. In order to enter the Chinese market, Western companies launched joint ventures, founded subsidiaries, and cooperated with local suppliers. However, until 2015, this resulted only in minor market shares. More successful was the strategy of several smaller European companies, e.g., Aerodyn, Vensys, REpower, etc., who took advantage of the protectionist Chinese policy by licensing to the fast-growing Chinese corporations. Despite their economic benefits, this resulted in knowledge and technology transfer from Western countries to PR China. Nevertheless, until 2015, the most significant share of patents was still filed by Western companies and R&D clusters.

In the next section, a closer look at Siemens and its patent portfolio will be made to understand how a Western company managed its knowledge in the different phases of the industry.

5. Siemens Patent Application Portfolio

This study focuses on the patent application activity of Siemens, which was ranked number 4 in market share in 2015. A closer look at the patent activity is made within the IPC-class F03D, which is the focus of this report. A summary of Siemens' patent applications for their respective patent classification in the year 2000 demonstrates that almost half of Siemens' patent application falls within subgroup "H - Electricity" (Siemens, 2017a) (Figure 13). Even though "C-Chemistry, Metallurgy," which is represented by the yellow area in Figure 13, may seem insignificant, it is essential to note that Siemens applied for a patent within this area on average every working day for the entire year of 2000. As for other subgroups, A refers to "Human Necessities", B – "Performing Operations; Transportation", C – "Chemistry, Metallurgy", D – "Textiles, Paper", E – "Fixed Constructions", F – "Mechanical Engineering, Lighting, Heating, Weapons, Blasting", G – "Physics", H – "Electricity".

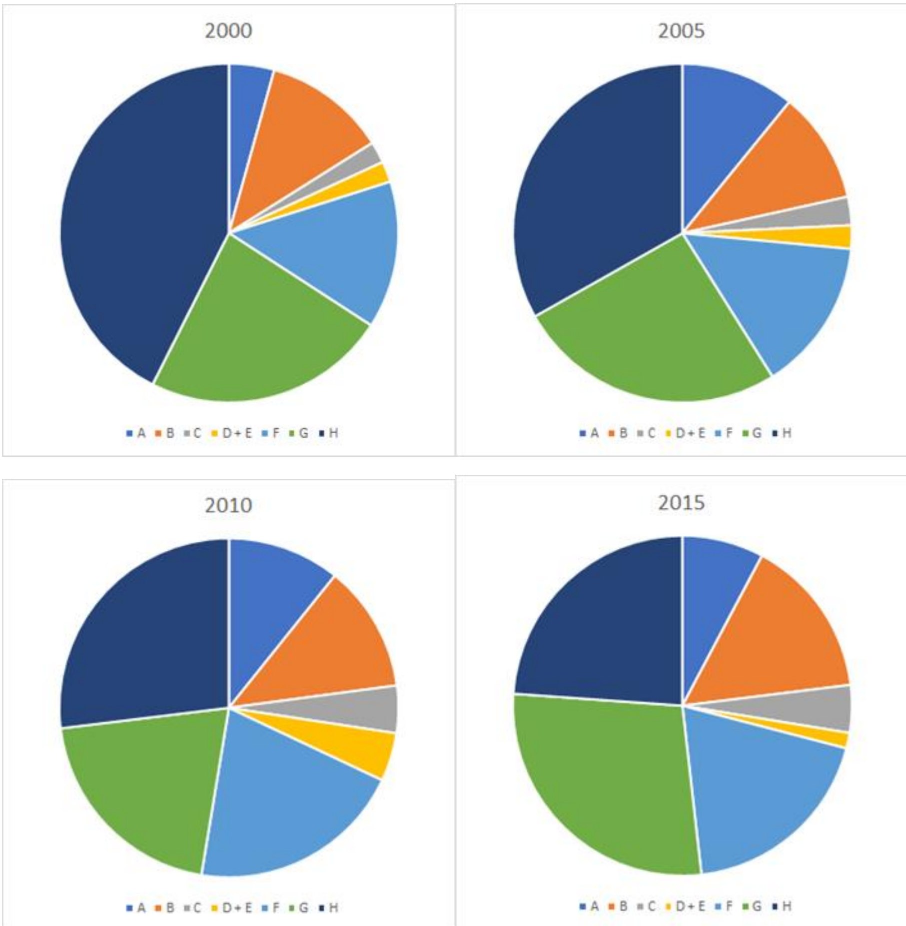

Fig. 13: The Development of Siemens patent application portfolio 2000-2015 (A-H representing the different basic IPC classes as described in the text above)

A more balanced portfolio was found when looking at the division of patent applications in 2010 and 2015 (Figure 13, charts #3 and #4). Subclasses "F - Mechanical Engineering, Lighting, Heating, Weapons, Blasting", "G - Physics," and "B - Performing Operations; Transportation " are now sharing the space in favor of "H - Electricity," which was the dominant subclass ten years earlier. When mapping the significant investments and divestments made by Siemens during the same period, some coherences were highlighted between the strategic/financial decisions made and the patent application output. During 2005-2007, Siemens made five acquisitions within healthcare and in 2008, Siemens' specific corporate strategy was to grow and compete within energy, industry and healthcare (Siemens, 2014). During the same period, Siemens made two investments and eight divestments within businesses that would generally fall under the classification "H - Electricity" (Figure 14 and Figure 15). This strategic portfolio management might partially explain the steadily decreasing number of patent applications within the same area during that period.

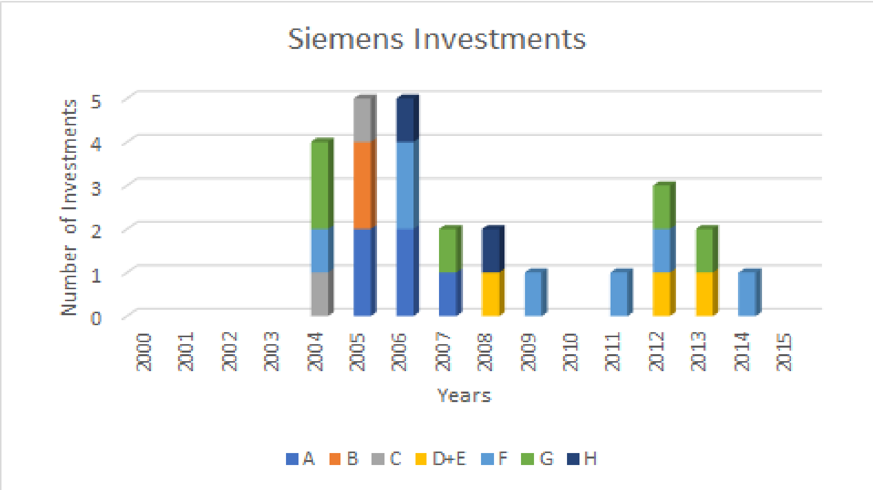

Fig. 14: Siemens company investments 2000-2015

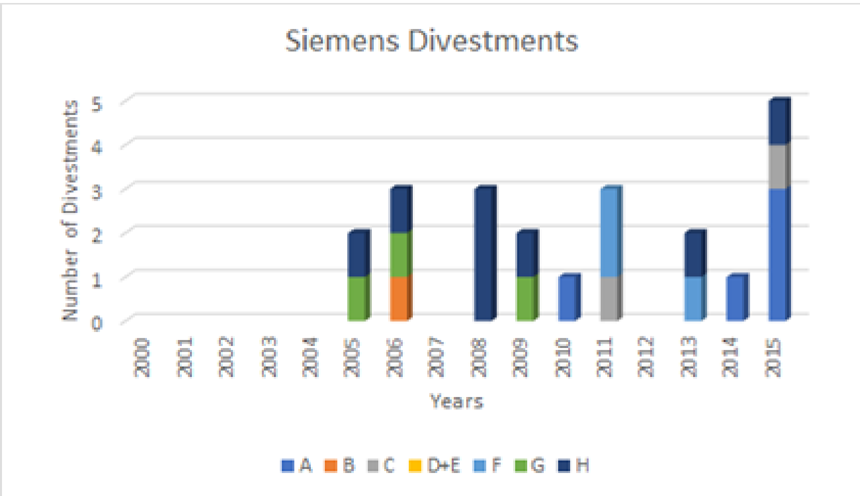

Fig. 15: Siemens company divestments 2000-2015

5.1. Siemens patent applications in the wind turbine industry

As previously described on a macro-level in this report, focusing on the wind turbine industry led us to an investigation into Siemens' patent applications in the F03D IPC subclass. This was achieved through the same previously described outputs by analyzing two databases. Figure 16 illustrates the number of F03D patent applications by Siemens compared to their total patent application output since the year 2000. Figure 17, however, shows Siemens F03D applications concerning all F03D applications globally during the same period. By 2007, F03D patent applications did not represent even 1 percent of Siemens's total patent application portfolio. The percentage of patent applications within the F03D subclass reaches its peak in 2011, where 4 percent of Siemens' full patent applications were categorized as F03D and Siemens owned 5 percent of all the patent applications within this subclass worldwide. The growth between 2006 and 2011 was almost exponential. This increase could partially be explained by the acquisition of Bonus Energy A/S in 2004. Back then, Siemens only filed for six patent applications within the F03D IPC subclass during the entire year of 2006. Six years later, this number had increased to over 300 applications and Siemens had become a dominant player within the wind turbine industry. During this acquisition, an inventor called Henrik Stiesdal started working at Siemens, as he prior had been at Bonus Energy A/S. As of 2016, he has applied for 614 patents with Siemens registered as the owner. This further shows the importance of Merger and Acquisition (M&A) when it comes to future patenting activity.

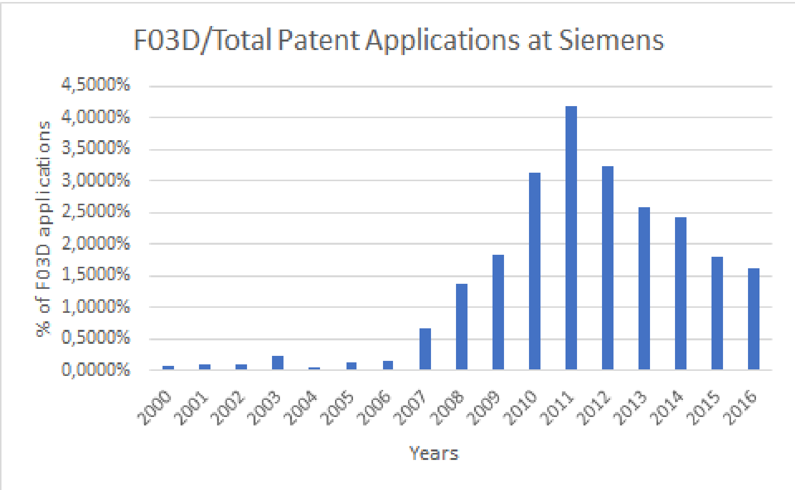

Fig. 16: F03D Applications/All Applications

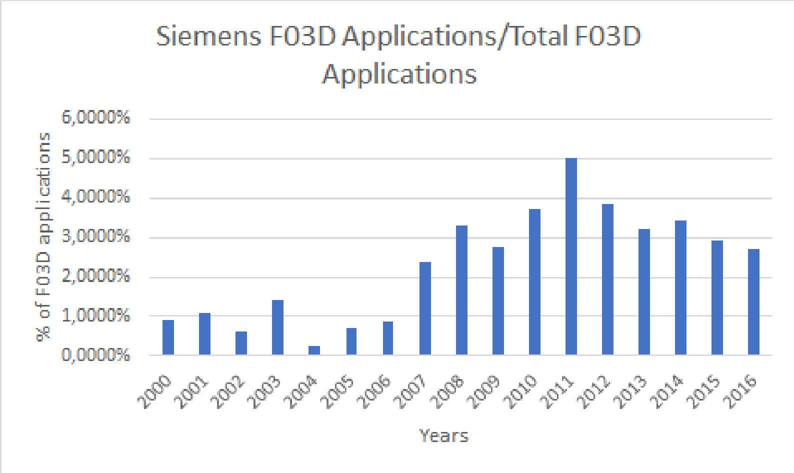

Fig. 17: Siemens F03D/All F03D

Since 2011, the number of patent applications within this field has declined internally and compared to the global market. One reason for the decline in F03D patent applications might be that the technology (wind turbine industry) reaches a mature stage in the S-shape curve. If this were the case, the patenting activity would generally decrease and a skew from product patenting to process patenting would be identified (Tidd, Bessant and Pavitt, 2005). This could affect the rate of F03D patent applications in comparison to Siemens' total patent applications as process innovations might be patented in a different subclass.

Additionally, the wind turbine market has seen a decrease since 2012, which would further explain why F03D applications have decreased concerning the total number of patent applications during the same period. In order to explain why Siemens F03D applications have seen a decrease in comparison to the market, one reason might be that there were more players in the industry in 2015 (Figure 10) than that in 2005 (Figure 9). The combined market share of companies outside the top 10 has increased from 5 percent to more than 30 percent of the market shares as the most prominent company. For example, Vestas lost 16.1 percent of its market shares during the period. More companies competing in the industry could imply that more patents are applied. Although outside the scope of this report, this topic would need to be further investigated to draw accurate conclusions.

Additionally, companies from PR China have become more prominent players in the wind turbine market and mainly compete on price. This could mean that Siemens might have to focus more on price-reduction rather than innovation to stay competitive and not lose too much market share. Siemens “2020 Vision” states that the company is focusing on electrification, automation and digitalization. Given that R&D efforts within the wind turbine business have suffered since 2011, the merger with Gamesa that was made earlier that year could have been a strategic step toward regaining strength in the industry. As stated by the Chief Executive Officer of Siemens - Joe Kaeser, "*With the new wind power company, we've created a global market leader in the area of renewable energies*" (Siemens, 2017b).

Time shows this assumption is true, as in the coming years, the Siemens-Gamesa's 10MW turbine is scheduled to be released, while the original plan was to release it by 2022 (GWEC, 2019). However, COVID-19 will likely have a negative impact on that date. Additionally, recent studies (GWEC, 2020) demonstrate that at the end of 2019, Siemens was the largest offshore developer in the US with a backlog of 4,366 MW and the next are GE Renewable Energy (1220 MW) and MHI Vestas (804 MW). The current Siemens strategy is to provide solutions for both communications in wind turbines and the networking of wind farms and energy suppliers. This also means that it would be possible to obtain new findings and observations in the coming years by analyzing Siemens' work trends and performance, which will complement the data and findings provided in this paper.

6. Conclusions

After an introduction and overview of the history of the wind turbine industry, with particular attention to the expansion that occurred in PR China and Germany, and a preliminary description of the factors and institutional policies that mostly affected such huge and significant outgrowth, the main purpose of the research was to focus primarily on the technology and knowledge management within this consolidating and expanding industry. As a vital part of Industry 4.0 development, the availability of vast and clean energy sources became strategically crucial for the growth in PR China and Germany. It is particularly true for PR China since maintaining both economic development and environmental conservation was essential. This research demonstrated that global and national policies, laws and regulations could strongly affect and support the industry trend over the years. The German wind turbine industry, for instance, had strongly benefited from government investments and subsidies during all stages of the industry development. Similarly, the wind industry in PR China was fertilized and heavily supported by the protectionist regulations and huge environmental efforts based on legislation, planning, taxation and electrovalence policies. Under these circumstances, a shift in the way technology was developed and managed in the industry was detected. This included a young industry where knowledge and technology were solely developed in western firms and only locally sourced and transferred. It also included a global industry with different sourcing strategies and managing technology with a significant West-East technology transfer. Accessing technology through licensing, entering joint ventures, or acquiring knowledge-intensive companies can be identified as a common and often successful industry approach. One could explain this by the legal premises and the west-east differences in technology and market base for Industry 4.0 development.

Additionally, by analyzing the patent portfolio of Siemens, some evidence can be identified on the company level to justify these external ways of accessing technology. The analysis of Siemens patents showed that strategic management decisions such as investments and divestments, e.g., in the form of acquisitions, can have a strong influence on knowledge and technology development. During Industry 4.0 development, wind power is an important energy source as it is clean and renewable. As an essential part of wind energy, wind turbine energy development is significant to Industry 4.0.

6.1 Theoretical and Managerial Contributions

This paper provides the combined theoretical and managerial contributions as follows. First, our work improves the understanding of the current wind turbine industry and its relationship with Industry 4.0. Management has a deeper understanding and also can foresee its rising significance due to the need to generate more energy, particularly green and reusable energy, to protect the environment. Scholars can understand the rapid development of PR China and also how Europe, such as Germany, can manage its stable growth. Second, we consolidate references and present holistic views and strategies towards the adoption of wind turbine energy by taking PR China and Germany as the two examples. Therefore, the summary of our insights can provide recommendations and suggestions for both government, companies and scholars to develop, obtain, or maintain competitive advantages in the wind turbine industry. This allows them to prepare adoption better and understand rising issues if considering wind turbine technologies.

From the prospects of the government, this paper suggests that relevant legislation, regulations and development plans should be issued to support the upgrading of the domestic wind turbine industry and establish a comprehensive industrial system. From the prospects of the local enterprises, the technology can be accessed or managed through licensing, entering joint ventures, or acquiring knowledge-intensive companies. Similarly, the technology holding enterprises can use a similar approach to enter foreign countries of strong market potential by initially licensing, then partnering with local companies by joint ventures, and finally establishing a whole-own company if that is the most beneficial mode of doing business for the company.

6.2 Limitations and Future Research

This paper also has limitations. Due to time constraints, the scope of our research is broad, but the depth may not be deep enough. In the future, we may select the aspect of the legal policies or technology management in the wind turbine industry and then conduct detailed research for these issues.

Although the wind turbine offers significant advantages recognized by society, some of the population may not accept it because it has been seen as another type of pollution such as destroying the landscape, making noise, etc. Therefore, there are rooms for the manufacturers to improve the product and installation, for the government to establish relevant policies, and for the marketers to improve their communication with the local population about their concerns.

As the analysis and findings of this research focused on PR China and Germany, it would be interesting to conduct future research investigating how the industry will continue to develop in the upcoming years in these countries with Industry 4.0 development in Wind Turbine and clean energy industry. Legal policies and governmental support are under discussion. As Chinese firms have accessed an extensive knowledge base, future research might investigate if Asian companies are reliable or even lead in knowledge and technology development in the wind turbine industry.

Acknowledgment

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