# A Cluster Analysis of the Global Wind Power Industry

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# A cluster analysis of the global wind power industry: Insights for renewable energy business stakeholders and environmental policy decision makers

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## Abstract

In light of an ongoing climate change and an increasing fragility of fossil energy supply due to global political tensions, the adoption of renewable energy sources is of utmost importance for economic and social prosperity. This study targets to endeavor major value chain configurations within the global wind power industry network based on a data set of 326 relationships established by the 10 globally leading wind turbine firms covering a time span of 15 years. We discuss the demand side and provide an overview of the main wind power investment target countries and compare the importance of different regions. On the supply side, we analyze and identify eight important firm clusters within the global wind power business network. Concerning our sample, we elaborate horizontal and vertical relationship links, their collaboration patterns, regional partner preferences, and their value chain competences, thus providing valuable insights into the competitive structures of the wind power industry. By doing so, we open the debate on appropriate and efficient firm strategies within renewable industries. As consequence, we provide robust empirical evidence on global wind power industry architectures and corresponding competitive firm forces for the future. As we found that the industry is currently divided into eight main global industry clusters, our study delivers valuable industry network insights addressing managerial, political, and socioeconomic decision makers in order to secure future ecological and economic prosperity in a challenging world.

**KEYWORDS**

cluster analysis, environmental policy, renewable energy, value chain connections, wind power industry network

## 1 | INTRODUCTION

In 2015, the UN General Assembly adopted the 2030 *Agenda for Sustainable Development and its Sustainable Development Goals* (SDGs), where *SDG 7* is related to energy supply. SDG 7 targets a dedicated vision on energy, calling to ensure access to affordable, reliable, sustainable, and modern energy for all people. Energy also lies at the heart of both the 2030 *Agenda for Sustainable Development* and the *Paris Agreement on Climate Change* (United Nations, 2022). In parallel, sustainable development goals set by the *World Trade Organisation* (WTO) outline targets to be met by 2030 in the areas of poverty reduction, health, education, and the environment (WTO, 2018).

In light of aforementioned global climate change initiatives, we undertake this study, as renewable energy generation is of particular and urgent importance helping to reduce carbon fossils emissions (Meschi & Norheim-Hansen, 2020; Snyder, 2019; Stalmokaitė et al., 2022; van Tulder, 2018). As the renewable energy industry (such as global wind power) is relatively young compared to conventional fossil industries such as carbon, oil, and gas, the research on its value chain networks remains scarce (Ahuja, 2000; Feller et al., 2006). Therefore, a better understanding of the renewable industry, its competitive structure, and relationship dynamics is of critical importance for a number of reasons described as follows.

The adoption of locally supplied renewable energy resources is of utmost importance to ensure steady supply availability and environmental sustainability (Aslani & Mohaghar, 2013; United Nations, 2022; WTO, 2018). While the adoption of renewables helps in combating global warming (van Tulder, 2018), their adoption also bears positive economic outcomes. Renewable industries will play an essential role in job creation, increasing future employment capacities of the local markets and contribute to the welfare of the countries and better quality of life of its citizens (Baker, 2015; w3.windmesse.de, 2021). The establishment of wind power project parks for example requires fine-grained supply and transportation logistics where firm relationships are important. The development of wind power projects is not possible without state-of-the-art engineering, research and development, and capacity planning where different project stakeholders need to cooperate (Stalmokaitė et al., 2022). Thus, the development of wind power energy requires intense institutional relationships as they have a significant effect on high-value employment generation and, consequently, the prosperity of local economies involved in wind power generation.

Previous industry network research often focused on manufacturing (Ritter et al., 2004; Verdu et al., 2012) and high-technology industries (Li et al., 2000; Salavisa et al., 2012), while studies focusing on renewable energy networks remain scarce (Gosens et al., 2017; Hsueh et al., 2010; Nguyen & Ha-Duong, 2016). As we see, the current literature only delivers limited insights concerning inter-organizational firm relationships and relevant developments concerning international wind power industry clusters that would help predicting firm strategies and global competitive forces (Meschi & Norheim-Hansen, 2020; Snyder, 2019).

While existing renewables research often contrasts the changing competitive power of two regions (e.g., China vs. Europe), it tends to fall short of the value chain analysis and the discussion of important relationship dynamics between renewable energy firms' global networks (Reisach, 2017). This resulted in calls for more empirical studies on the evolution of industry networks (Bembom & Schwens, 2018), the role of relationships in the development of wind energy clusters, and the global competitive relationship dynamics of western versus emerging Chinese wind power firms (Bauwens et al., 2016). Moreover, existing research in the field often focused on spotlight analysis through a single firm case study and/or within a limited time frame, with calls to study industry network formations over an extended time frame (Bembom & Schwens, 2018; Humphrey & Schmitz, 2002). Furthermore, Cano-Kollmann et al. (2016, p. 259) call for "bridging the dualism of location- and firm-centric views." They ask for contrasting firms and regions, which is especially relevant from the perpective of regional partner selection preferences within international industry networks.

In course of our study, we aim to answer three major research questions. As firms are embedded in clusters facilitating innovation transfer, the analysis of networks can offer important insights into potential collaboration opportunities. Therefore, we ask (1) *whether wind turbine manufacturers of our sample form separate global wind power clusters*. This aims at discovering the collaboration patterns of the firms in question and their vertical and horizontal relationship preferences and possible patterns of divergence. We also explore (2) *how the firm's network position within the global wind energy industry influence the firms' competitive progress*. We discuss a firm's network position in terms of its horizontal and vertical relationships to other actors of the global wind power industry network. Finally, we consider the collaboration patterns of regional clusters and ask (3) *whether firms in Africa, America, Asia, and Europe interact within and between in clusters*. This strategy would foster the collaboration in terms of increased business opportunities and mutual innovation capacities, while the lack of such collaboration would cause further divergence of different regions in terms of innovation capacity and would inhibit learning across international wind energy clusters. Addressing the identified research gaps, we perform our study within the following research design.

As called by several scholars, in light of an increasing global value chain complexity, empirical research concerning industry network formations should cover a more extended period of time (Bembom & Schwens, 2018; Humphrey & Schmitz, 2002). Therefore, our sample consists of leading wind turbine firms across countries and 326 organizational relationships between them based on the data spanning 15 years period of 2007–2021.

The importance of the wind turbine industry is exemplified by its size. The wind turbine supply market is an example of oligopolistic business-to-business markets. Wind turbine manufacturers named Vestas, Siemens-Gamesa, and General Electric Renewable Energy hold more than half of the global market shares in 2020 (En:former.com, 2021; Sánchez, 2017). It is expected that they will increase their market shares to more than 60% (which equals 48 GW) by 2028. It is forecasted that together with the emerging Chinese firms named Goldwind and Dongfang Electric (En:former, 2021), these five firms will hold around two thirds of the global market shares within the next 10 years (w3.windmesse.de, 2021). Thus, considering the importance of European and Chinese firms, we focus on the comparative analysis of China versus Europe.

By employing this analysis, our research is one of a few to shed light on supply chain clusters in the wind power industry, their competitive dynamics, collaboration preferences, and the role of relationships. We contribute to the literature by revealing how the wind power energy industry clusters have developed during the last 15 years, which also helps predicting future competitive forces. As to our knowledge, our study demonstrates a premier research because

there is no equivalent renewable industries study in terms of data richness and longitudinally currently available in the literature. It also offers managerial implications as we outline opportunities for strengthening the renewable energy firms' industry network positioning in the global markets. This study also bears social relevance as we work towards combating the global climate change while ensuring economic prosperity, welfare, and job creation.

## 2 | LITERATURE REVIEW

Analyzing the wind energy research, project planning, manufacturing, supply, and distribution chains through firm relationship lens helps to better understand global supply and demand configurations and to predict future competitive forces of the involved actors (Zhao et al., 2014). Therefore, our study focuses on inter-organizational horizontal and vertical relationships between business actors and their industry network clusters within the wind power industry. Horizontal relationships involve competitor ties, whereas vertical relationships involve, for instance, relationships to a wind energy distributor, research laboratories, universities, wind turbine manufacturer, or electricity sales company. These relationships form clusters within the wind power industry (Agndal & Chetty, 2007).

Because of high levels of interaction frequency, intense firm relationships serve as excellent conduits for exchanging specific resources such as privileged market knowledge, which is not easily accessible from the perspective of industry cluster outsiders. Therefore, cluster structures allow for the development of efficient collective knowledge-sharing routines and joint learning channels, helping involved firms to gain competitive advantages concerning their market entry and market penetration strategies (Larsson et al., 1998). In addition, inter-organizational firm relationships enhance common understanding and knowledge sharing between suppliers and customers and limits incentives for behaving opportunistically (Vanhaverbeke et al., 2012).

While the importance of network relationships as valuable knowledge vehicles is widely agreed among scholars (Fritsch & Kauffeld-Monz, 2008; Powel, 1999), more empirical research is required concerning renewable industry cluster formations over a longer time period (Bembom & Schwens, 2018). As industry network literature focused mainly on manufacturing (Ritter et al., 2004; Verdu

**TABLE 1** Current research on the wind power industry

| Article | Countries | Sector | Main focus |
|---|---|---|---|
| Wang et al. (2012) | China | Wind power | The role of government policies in the adoption of wind power technology. |
| Zhao et al. (2014) | China | Wind power | The evaluation of the wind power industry in terms of supply chain, technology chain, and value chain. |
| Gosens et al. (2017) | China | Renewable energies | Review of government policies supporting wind and photovoltaic. |
| Lam et al. (2017) | China | Wind industry | Evaluation of China's wind industry. |
| Sahu (2018) | China | Wind industry | Evaluation of China's wind industry and policy implications. |
| Kim and Kim (2015) | 16 countries & 14 countries | Solar photovoltaic & wind power | The role of the government policies in the domestic diffusion and international competitiveness of the solar photovoltaic and wind power technologies. |
| Bauwens et al. (2016) | Denmark, Germany, Belgium, & the UK | Wind power cooperatives | The factors fostering citizen and community participation in wind power cooperatives |
| Brunekreeft et al. (2016) | Germany | Hydro power, biomass, onshore and offshore wind, solar | The structure of the renewable electricity supply industry – the changing dynamics between incumbents and third parties -competitive forces on Germany's domestic electricity market. |
| Kelsey and Meckling (2018) | EU & US | Wind and solar photovoltaic | Cross-national comparison of renewable energy ownership. |
| Lema et al. (2016) | China, India, & Denmark, Germany | Wind power | Comparison of wind power innovation paths in Europe and Asia. |
| Poulsen and Lema (2017) | China, Europe | Offshore Wind industry | Comparison of the offshore wind supply chain in Europe and China. |
| Pan et al. (2017) | Leading wind manufacturers in China, Europe | Wind turbines | Comparison of innovation strategies (patents) of Chinese and European turbine firms. |

et al., 2012) and high-technology industries (Li et al., 2000; Salavisa et al., 2012), analyses of renewable energy networks remain comparatively rare (Gosens et al., 2017; Hsueh et al., 2010; Nguyen & Ha-Duong, 2016). Table 1 summarizes important publications in the field of wind energy.

The existing literature can be divided into three research streams. China emerged as a global leader of the wind power deployment supported by governmental policies. Today, Chinese wind turbine manufacturers use competitive cost structures to achieve economies of scale flanked by large-order volumes at its Chinese home market. Although Chinese firms strengthened their competitive global positionings, they still lack development capabilities of innovative technologies (Lam et al., 2017; Sahu, 2018). Consequently, wind power industry research focused to a large extend on the Chinese context (e.g., Gosens et al., 2017; Lam et al., 2017; Sahu, 2018; Wang et al., 2012; Zhao et al., 2014) as this research stream explored the role of the governmental policies in China in course of adoption of wind power technologies (Gosens et al., 2017; Sahu, 2018; Wang et al., 2012). The second literature stream focuses on the evaluation of the industry in terms of its technology and value chain processes (Lam et al., 2017; Zhao et al., 2014). While these two research streams were limited to China and were mainly descriptive, they shed light on the key barriers that threaten the competitiveness of the Chinese wind power industry, such as their technology adoption, innovative capacity, and the shortage of qualified project and product engineering.

The third research stream went beyond focusing on China and drew comparisons between European and Chinese firms in the wind turbine industry (Lema et al., 2016; Pan et al., 2017; Poulsen & Lema, 2017). These studies demonstrate that the innovation paths in Europe (e.g., Germany and Denmark) and Asia (China and India) show signs of convergence (Lema et al., 2016). However, the wind turbine firms in Europe still indicate a stronger competitive positioning as they lead in technology trajectories and offshore technologies, contrasted with China's technology drawbacks and its focus on the onshore technologies (Pan et al., 2017; Poulsen & Lema, 2017).

From this existing literature, it becomes evident that China has successfully expanded its wind generation industry capacities while the Chinese industry is still behind European firms in terms of innovation breakthroughs. This lack of innovation might is caused because of limited international collaboration relationships of Chinese firms targeting technological exploration (Pan et al., 2017).

Industry collaboration is essential for gaining and maintaining competitive advantage as the wind power project development involves a complex range of value-added activities covering project planning, engineering, and commercial businesses, including consulting, research and development, wind turbine manufacturing, electric grid infrastructure planning, regional turbine assembly, and supply and distribution (Poulsen & Lema, 2017; Wang et al., 2012). These value chain activities create specific industry eco-systems based on firm-to-firm relationships that finally form the wind power industry network (Alfaro et al., 2015).

The added value is created through mutual commitment in these business network relationships through institutionalized firm relationships (Blankenburg-Holm et al., 1999; Poulsen & Lema, 2017). Institutional relationship preferences (collaboration preferences) can be analyzed through industry network cluster analysis (Ronen & Shenkar, 2013). Business clusters represent areas of the industry network where firms are more closely linked to each other (e.g., through intense research and development activities) than other segments of the business network (Tichy et al., 1979).

As this study aims to elaborate on *how the firm's network position within the global wind energy industry influences the firms' competitive progress*, we conduct an industry cluster analysis. In order to capture corresponding value chain configurations, we apply the inter-organizational relationship model that focuses on a firm's position in its international wind energy business networks. These firm links are established through contractual relationships with other actors such as suppliers, clients, service providers, and competitors (Johanson & Mattsson, 1988; Mattsson & Johanson, 2006).

We apply the industry chain model as recommended by Zhao et al. (2014) aiming to discover important firm cluster structures based on inter-organizational firm relationships within relevant wind energy value-adding processes. According to the approach recommended by Turkina et al. (2020), we study horizontal relationship ties, wind turbine manufacturing firms usually establish to gain complementary knowledge within similar value chain activities (e.g., wind turbine component assembly). Vertical relationships in the wind energy industry are established to get access to research and development (e.g., upstream ties with universities and research laboratories) or distribution channels (downstream links with local electricity providers or infrastructure development entities). The evaluation of both relationship types is necessary to compute the global wind industry cluster. This cluster analysis helps us to understand preferential partner linking pattern (e.g., national or regional preferences) between groups of actors based on our firm sample analysis (Turkina et al., 2020).

In the wind energy industry, firm relationships are usually institutionalized through contracts addressing wind turbine unit sales or rather complex wind park project developments. On the seller side, there is the wind turbine manufacturer, and, on the buyer side, there is the local electricity distribution provider. In the case of complex wind park projects, the wind turbine manufacturer offers the equipment's installment and sells project planning and operations' maintenance services, which can have a time horizon of up to 20 years (Nghiem & Pineda, 2017).

The methodology of our study, aiming to fill above mentioned research gap, relies on data of organizational firm relationships of 10 globally leading wind turbine manufacturers, covers a time span of 15 years (2007–2021) as described in details in the following section.

## 3 | RESEARCH METHODOLOGY

### 3.1 | Research design

We decided to study the wind energy sector because wind power, together with solar photovoltaic and hydro energy, indicates the most prominent technologies within the renewable energy generation industry (van Tulder, 2018; Zhao et al., 2014).

This study is built on separate research phases. First, we conducted a semi-systematic (narrative) literature review addressing relevant topics such as ecology and climate change, sustainable energy generation, wind turbine, wind power value chains, and renewable industry network publications (Snyder, 2019). The semi-systematic review approach is suitable for topics that consider diverse disciplines of interest, as our research focuses on renewable energies, business relationships, and supplier-customer value chains. Moreover, studying global value chains in business networks is multifaceted and indicates a relatively high degree of literature complexity (Nell & Andersson, 2012).

Second, as we have not found appropriate quantitative data sets concerning wind energy value chains (Kim & Kim, 2015; Nguyen & Ha-Duong, 2016), we started a data collection process through empirical field research. The objective of this data collection was to work out institutionalized firm links between the wind turbine manufacturer and other business actors (Provan et al., 2007). As there is no single source of evidence concerning firm connections in the wind power industry existing, we have systematically collected and recorded information from various knowledge sources such as annual reports, renewable industry surveys, and press releases (Turkina et al., 2020; Yin, 2018). We collected the data addressing the following questions: (1) *Why was a bilateral relationship tie established (between our sample firm and another firm)?* This question addresses the relationship objective, e.g., sales of wind turbines.; (2) *what is the country of origin of the contract partner*?; and (3) *what is the corresponding year the contract between the wind turbine seller and its buyer is established?*

Third, we recorded and coded bilateral firm ties for each of our sample firms between 2007 and 2021. Through network analysis, we computed vertical and horizontal relationships within sub-clusters in the wind power industry network in order to better understand the industry configuration dynamics (Christensen & Hain, 2017). Table 2 provides an overview of the major contents concerning secondary and primary research phases of our study.

Wind power turbine manufacturers do the primary value-adding processing in the wind power industry chain (En:former, 2021). To develop and to sell their products and services, wind turbine manufacturers need to establish both vertical downstream relationships and vertical upstream relationships. The former involve vertical, contractual links with electricity transmission enterprises. The latter involve raw material and component suppliers, research laboratories, and universities, as well as infrastructure, project financing, and consulting services providers (Zhao et al., 2014). Our analysis also considers horizontal relationships (e.g., ties between competitors such as strategic alliances) established to strengthen their competitive positioning through mutual resource exchange in terms of market or technology knowledge (Birkinshaw, 2000; Blankenburg-Holm et al., 1999).

**TABLE 2** Primary and secondary research contents

| Research phase | Source of evidence |
|---|---|
| Secondary data search | • Semi-systematic (narrative) literature review addressing relevant topics such as ecology and climate change, sustainable energy generation, wind turbine, wind power value chains and renewable industry network publications<br>• Study of the United Nations sustainable development goals targeting energy supply and the threat of global climate change<br>• Evaluation of WTO Organization sustainable policy and recommended guidelines in light of economic outcomes of the global climate change<br>• Study of renewable industry surveys provided by external market research institutes, profit and non-profit organizations |
| Primary data search and analysis | • Selection of 10 globally leading wind power generation firms such as Vestas, General Electric Renewables, Siemens-Gamesa, Goldwind, Dongfang, Minyang, Envision, Enercon, Nordex and Vensys<br>• Study of annual reports, press releases, and company information of each sample firm targeting to figure when and why a new bilateral relationship was established with another firm, name and origin of the partner firm and geographical target market of the wind power project<br>• Data are recorded for the period 2007 until 2021 of each sample firm<br>• All together 326 bilateral bilateral firm ties of our sample were found, analyzed and recorded in an adjacency matrix<br>• Cluster analysis was done with UCINET network analysis software |

## 3.2 | The sample

We collected, recorded, and analyzed horizontal and vertical firm ties of globally leading wind turbine manufacturers (Turkina et al., 2020). To ensure the highest possible representativeness, our sample selection of the 10 leading wind turbine manufacturers was conducted based to the following criteria (Burgelman, 2011). First, because the wind turbine manufacturer is the most important actor within the wind power value chain (Pan et al., 2017), our sample firm generates value-adding activities in research and development, manufacturing, and local assembly of wind turbines. Second, we considered the wind turbine manufacturer's global market share (En:former, 2021).

Based on these criteria, our study sample consists of 10 globally leading wind turbine manufacturers, namely: Vestas (Denmark); General Electric Renewables (United States); Siemens-Gamesa (Germany-Spain); Goldwind, Dongfang, Minyang, and Envision (all China); and Enercon, Nordex, and Vensys (all Germany). These firms hold altogether more than 80% of the global wind power market shares (En:former, 2021); thus, highest possible representativeness of our sample is ensured.

As our sample firms are involved in various fields of renewable energy generation such as hydro energy, solar photovoltaic, synthetic gas, and others (e.g., General Electric Renewables), we separated and

analyzed bilateral relationships referring to the wind power industry only.

For the period between 2007 and 2021, we identified 402 "relationship" ties within our sample set. However, in the wind industry, the project customer (e.g., energy distributing firm and infrastructure project financier) sometimes does not want to be disclosed to the public (Vestas, 2021a). As a consequence, we have identified relevant contractual partners' unclear identifications, which amounted 76 ties. (This explains the difference between 402 relationships found and 326 suitable ties reported for coding in course of this research.) The undirected (symmetric) relationship ties are recorded and coded as 1 s in our adjacency matrix, while all others without a proven bilateral firm relationship are attributed and coded as 0 s (Prell, 2012). To discover relevant mutual wind industry communities, we conducted a cluster analysis using the network analysis software UCINET (Borgatti et al., 2002).

## 4 | FINDINGS AND DISCUSSION

In what follows, we discuss the findings of the wind power industry cluster analysis. First, we discuss the demand side and provide an overview of the main wind power investment target countries and compare the importance of different regions. Second, we discuss the supply side and identify eight important clusters within the global wind power business networks. We elaborate horizontal and vertical relationship links, collaboration patterns, and partner preferences within each of the clusters, thus providing insights into the relationship structure of the industry.

### 4.1 | Demand side

Our industry network analysis shows that wind power energy capacities have been increasing during the last decade on all continents. In Europe, particularly, the Scandinavian countries, as well as Turkey, Ireland, Italy, Netherlands, France, Portugal, Spain, and the United Kingdom, have strengthened their wind turbine installment investments. In addition, Brazil, Chile, Ethiopia, Kenia, and Vietnam serve as emerging wind power generation markets in recent years. Table 3 provides an overview of the main wind power investment target countries across geographical regions between 2007 and 2021.

**TABLE 3** Main wind power investment target countries (2007–2021)

| Region | Country |
|---|---|
| Europe | Belgium, Bulgaria, Denmark, France, Germany, Greece, Italy, Ireland, Lithuania, Netherlands, Norway, Poland, Portugal, Spain, Sweden, Turkey, Ukraine, United Kingdom |
| America | Argentina, Brazil, Canada, Chile, Mexico, USA |
| Asia | China, India, Kazakhstan, Pakistan, South Korea, Vietnam |
| Africa | Ethiopia, Kenya, Morocco, South Africa |
| Oceania | Australia |

Concerning wind power lead markets, our study shows that Denmark and Germany were the first movers in the wind industry as they developed a strategic advantage that led to a leading positioning of Danish and German firms in the industry worldwide. Our research outcomes are consistent with previous research (Brunekreeft et al., 2016; Lema et al., 2016). Denmark and Germany remain as technological lead markets for the wind power energy industry. They are a widely accepted as benchmark models for developing policies and technologies that support the expansion and development of the wind energy industry (Brunekreeft et al., 2016; Lema et al., 2016).

Our analysis also shows that over the past decade, the United States and China have become important players within the wind power supply chains and corresponding sales markets. In China, the continuously increasing energy demand and resulting worsening of the air and water quality brought concerns over China's economic development modes (Gippner & Torney, 2017). As a result, particularly in recent years, Chinese wind turbine manufacturers have enjoyed political and financial support aimed at helping to boost their renewables capacities (Gosens et al., 2017). Consequently, China has developed into one of the most important wind power installation markets. Chinese firms including DongFang, Goldwin, Guodian, Envision, and Minyang gained competitive power thanks to the economies of scale due to a high number of orders for their home market (Kejun & Woetzel, 2017; Poulsen & Bay Hasager, 2017; Sahu, 2018).

The selection of target markets by Chinese firms has been heavily influenced by governmental initiatives compared to firm-centered objectives of the Western firms. China often combines renewable energy supply with its new silk road initiative as Chinese wind turbine manufacturers launch their wind farms in Kazakhstan and Pakistan. These countries are involved in the *One Belt–One Road* project. Therefore, what differentiates the Chinese wind power firms from those in Europe and the US is that they select their target markets, among other reasons, within a much broader geo-political framework, set by the Chinese government, rather than exclusively following firm-centric motives for market entry as rather typical for western firms (Sahu, 2018; Wang et al., 2012).

### 4.2 | Supply side

Our wind power industry cluster analysis reveals firms that are mutually connected in dense industry grid architectures. Dense relationships' structures serve as efficient mutual knowledge transfer platforms (Fritsch & Kauffeld-Monz, 2008). Project planning capabilities and maintenance service, which is more complex in the wind power industry than in photovoltaic, play an important role in selling wind power farms. Offering sophisticated products and services requires qualified engineering and managerial knowledge. Our study identifies eight important clusters within the global wind power business networks. Out of eight, two clusters are driven by Chinese firms; one cluster by a global Anglo-Saxon community and five clusters are led by European wind turbine manufacturers. The Table 4 provides an

**TABLE 4** Main industry cluster of the global wind power industry (status 2021)

| Cluster group | Cluster members (country code) | Cluster characteristics |
|---|---|---|
| 1 | DongFang (CHN), Goldwin (CHN), Envision (CHN), Vensys (GER), RePower (CHE), American Superconductor Corp. (AMSC) (US), KSK Energy (IND), Cimatron (ISR), DEIF (GER), Ethiopian Electric Power (ETH), The Switch (FIN), Ulanotech Research Centre (RUS), Infineon (GER), Columbia University (US), Brown University (US), HS Saarbruecken (GER), TU Delft (NLD), DTU Copenhagen (DNK), HEC Lausanne (CHN), UNSW (AUS), Shanghai Investigation Design & Research, ReGen Power Tech Ltd. (IND), IMPSA Wind (ARG), A.O.I. Arab Organisation for Industrialization (EGY), DHL (GER), Aisha Wind Farm (ETH), Continental (GER), CNEEC (CHN), China Power (CHN), Yucel (TUR), ACT Wind (PAK), Viotia Project (GRC), REIPPPP (ZAF), Velocita Energies (FRA), Sprng Energy (IND), Vive Energia (MEX), Vientos Del Secano (ARG), Oekowind (AUT), Getproject (GER) | Cluster driven by Chinese wind turbine manufacturers Influential horizontal tie to Europe controlled by Chinese (Goldwin – Vensys) Various upstream relationships to Western universities (research and development knowledge) A broad range of international downstream links with local electricity providers or infrastructure development entities all around the world (e.g., Africa, America, Asia, and Europe) |
| 2 | General Electric (US), Harbin Power (CHN), Scanwind (NOR), Wind Tower Systems (US), Alstom Power (FRA), LM Wind (DNK), Microsoft (IRE), RES (AUS), Dogger Bank (UK), Luxcara (SWE), ONL (US), NREnergy Lab (US), Oersted (US), Invenergy (US), Leeward (US), EDF (FRA), Pattern Energy (US), PowerChina (CHN), Allete (US), Veolia NAmerica (US), Azora (ESP), EurEnergy (DNK), Soft Bank (JPN), Merkur Offshore (GER), Mitsui (JPN), Turkerler (TUR), RWE (GER), LM Wind Power (NLD), Fina Enerji (TUR), Sanko Enerji (TUR), Phuong Mai (VNM), EDF-SITAC (IND), OX2 (FIN), HECIC (CHN), Huaneng (CHN), Shenzhen Energy (CHN), Kipeto (KEN), Potegowo Mashav (PL), Enerfin (SPN), Long Wing (UKR), ReNew Power (IND), Engie (BRA) | Anglo-Saxon cluster led by General Electric (belongs to top three as global market leaders) with downstream links to local electricity providers or infrastructure development entities in America, Asia and Europe<br>Vertical upstream ties to Western research labs<br>Chinese firms are less represented in the cluster except of various downstream links to Chinese electricity providers |
| 3 | Guodian (CHN), Minyang (CHN), Aerodyn (GER), Inner Mongolia First Machinery (CHN), Tidal Power (KOR), Zhejiang University (CHN), Tsinghua University (CHN), Henkel (GER), DOW Chemical (US), Nimschu-Iskudow (CAN), Revolution Energy Solutions (US), Harbor Wind (US), Guoxin Jiangsu New Energy + Yinjia Yangzhong (CHN), Guodian Weifang Wind Power Generation (CHN), Longyuan Power (CHN), Shenhua Group (CHN), Huaneng Renewables (CHN), Reliance Group (IND), W Power EOOD (BGR), State University in Raleigh (US), Beijing University of Aeronautics and Astronautics (CHN), South China University of Technology (CHN), China Guangdong Nuclear Power Holding (CHN), CGN Wind Energy Limited (CHN), Shenzhen Energy Group Co. Ltd (CHN), State Power Investment Corp (CHN), RenEnergy (UK) | Cluster driven by Chinese wind turbine manufacturers<br>Various upstream relationships to Chinese universities (research and development knowledge) China represents the major sales market (economies of scale at its home market to be used as cost advantages when entering global markets outside China) Vertical upstream ties to Western chemical suppliers |
| 4 | Nordex (GER), Acciona Windpower (ESP), Plambeck (SSP Technology) (GER), Vestavind Kraft (NOR), Jaemtkraft (FIN), Acciona Windpower (ESP), Den Tol Exploitatie (NLD), Enel (ITA), Eksim (TUR), Sancak Enerji (TUR), Vattenfall (NLD), RWE Renewable (SWE), TODA Energia (BRA), UKA (GER), Enlight (ESP), VSB Group (FIN), ABO Wind (FIN), Vattenfall (UK), Voltalia (BRA), Ningxia Electric Power Group (CHN) | European cluster<br>Strong horizonal tie inside Europe (Nordex-Acciona) Downstream links to local electricity providers or infrastructure development entities mainly in Europe |
| 5 | Vestas (DNK), Upwind Solutions (DNK), Windlab (AUS), Availon United Wind Services (GER), E2i (ITA), Hanas (CHN), Enercity (GER), China State Power (CHN), MSPL Limited (IND), Finerge (PRT), Swifterwin (NLD), Eolica Tecnologia (BRA), Mitsubishi (JPN) | European Cluster led by Vestas (belongs to top three as global market leaders) Strong horizontal tie: Vestas-Mitsubishi International sales (downstream links) to local electricity providers or infrastructure development entities all around the world |
| 6 | Enercon (GER), Generg, Eneland, EDP (PRT) Wobben R&D GmbH (GER), Polat Enerji (TUR), EWE (GER), Corani S.A. (BOL), Fraunhofer-Institute (GER), Metafor (TUR), Petrobras (BRA), ERG (ITA), EIP (SWE), EWE (GER), Rosatom (RUS) | European Cluster led by Enercon<br>Upstream relationships to European research and development knowledge (Frauenhofer) |

(Continues)

**TABLE 4** (Continued)

| Cluster group | Cluster members (country code) | Cluster characteristics |
|---|---|---|
| 7 | Siemens Gamesa (ESP/GER), AREVA (FRA), Rabbalshede (SWE), CrossWind (NL), EDF (FRA), Tekniska (SWE), Aela Energia (CHL), Berkshire (CAN), Orsted (US), European Energy (SWE), Hanbaram (VNM), Engie (BRA) | European Cluster led by Siemens-Gamesa (belongs to the top three of global market leaders) International downstream links with local electricity providers or infrastructure development entities in America and Europe Makes use of Siemens organizational structure, its global business activities and financial power (in-house network) |
| 8 | Leitwind (ITA), Shriram epc (IND), B. Ventus (GER), EOLE Association (FRA) | Niche cluster targeting Europe and India It becomes less important compared to other industry clusters due to its smaller size in terms of its participating firms |

overview of all participating wind power network actors and their cluster memberships.

The first *Chinese cluster* is led by the wind turbine manufacturers named DongFang, Goldwin and Envision. Through its major shareholding of Goldwin at Vensys, the Chinese cluster maintains an influential horizontal tie to Germany and its European markets (Windpower Monthly, 2009). The cluster holds various vertical upstream relationships with Western universities to gain and exchange research and development knowledge. Furthermore, they have established a broad range of international downstream links within its value chain to local electricity providers and project infrastructure development entities worldwide (e.g., Africa, America, Asia, and Europe).

Guodian and Minyang lead the second *Chinese cluster*. Interestingly, this cluster mainly concentrates on the Chinese market. Firms embedded in this cluster prefer vertical upstream relationships to Chinese universities (joint research and development knowledge exchange) and vertical downstream links to various Chinese electricity distributors. Because China represents the major sales market for this cluster, there are economies of scale opportunities generated at home when intensifying their market entry activities outside China, which can be used as a cost advantage. The cluster also maintains valuable vertical upstream ties to western chemical firms, which serve as important suppliers (e.g., surface material and chemical ingredients of electronics components).

General Electric, which leads the *Anglo-Saxon cluster*, belongs together with Vestas and Siemens-Gamesa to the top three wind power turbine manufacturers based on their global market shares (evwind.es, 2021). This Anglo-Saxon cluster indicates vertical downstream links to local electricity providers and project development firms not only in America but also in Asia and Europe. In addition, the value chain analysis reveals vertical upstream ties to Western research laboratories. Chinese firms tend to be less represented in this cluster. However, some downstream links to Chinese electricity firms gained importance in recent years due to sharply increasing investments in the wind power industry in China.

The first *European cluster* is led by Vestas (Denmark), which represents the global market leader with the most extended firm history in wind power generation, compared to other sample firms of our study (En:former, 2021; Vestas, 2021b). The cluster relies on vertical downstream links to local electricity providers and infrastructure development entities all around the world. Vestas and the Japanese firm Mitsubishi have the strongest horizontal tie within the cluster. The relationship was initially established as a joint venture aiming to develop the offshore wind business and targets mutual support in course of entering new markets of the joint venture partners. Meanwhile, Vestas took over the lead and integrated the former venture operations with Mitsubishi into its firm hierarchy (Seelos, 2020).

Siemens-Gamesa (German-Spanish firm origin) leads another powerful *European cluster*. This cluster is characterized by international vertical downstream links with local electricity providers as well as with wind park infrastructure development entities, mainly located in America and Europe.

The third *European cluster* is headed by Nordex (Germany). There are value chain downstream links to local electricity providers and infrastructure development entities in Europe which serves as its major target market. This cluster is characterized by a strong horizontal tie between former competitors Nordex and Acciona (Spain). In 2016, Nordex acquired Acciona Windpower, while the Acciona conglomerate (e.g., construction and real estate business) remains major shareholder of Nordex (Nordex SE, 2021; Völkl, 2020). German wind turbine manufacturers on the one hand such as Siemens and Nordex and Spanish firms on the other hand (e.g., Gamesa and Acciona) prefer each other when seeking intense bilateral relationship engagements.

Enercon leads the fourth, comparatively smaller *European cluster*. This cluster focuses on the European market (vertical downstream ties to local electricity providers). There are some limited upstream relationships to European research and development institutions (e.g., Frauenhofer research institute).

The last and smallest *European wind power cluster* is led by Leitwind (Italy). This sub-network community launches a niche strategy mainly focusing on vertical downstream relationships to electricity distributors in Europe and maintains very limited relationships in India.

Above discussed cluster characteristics based on vertical and horizontal relationships of our wind power energy industry sample for the period 2007–2021 are illustrated in Figure 1.

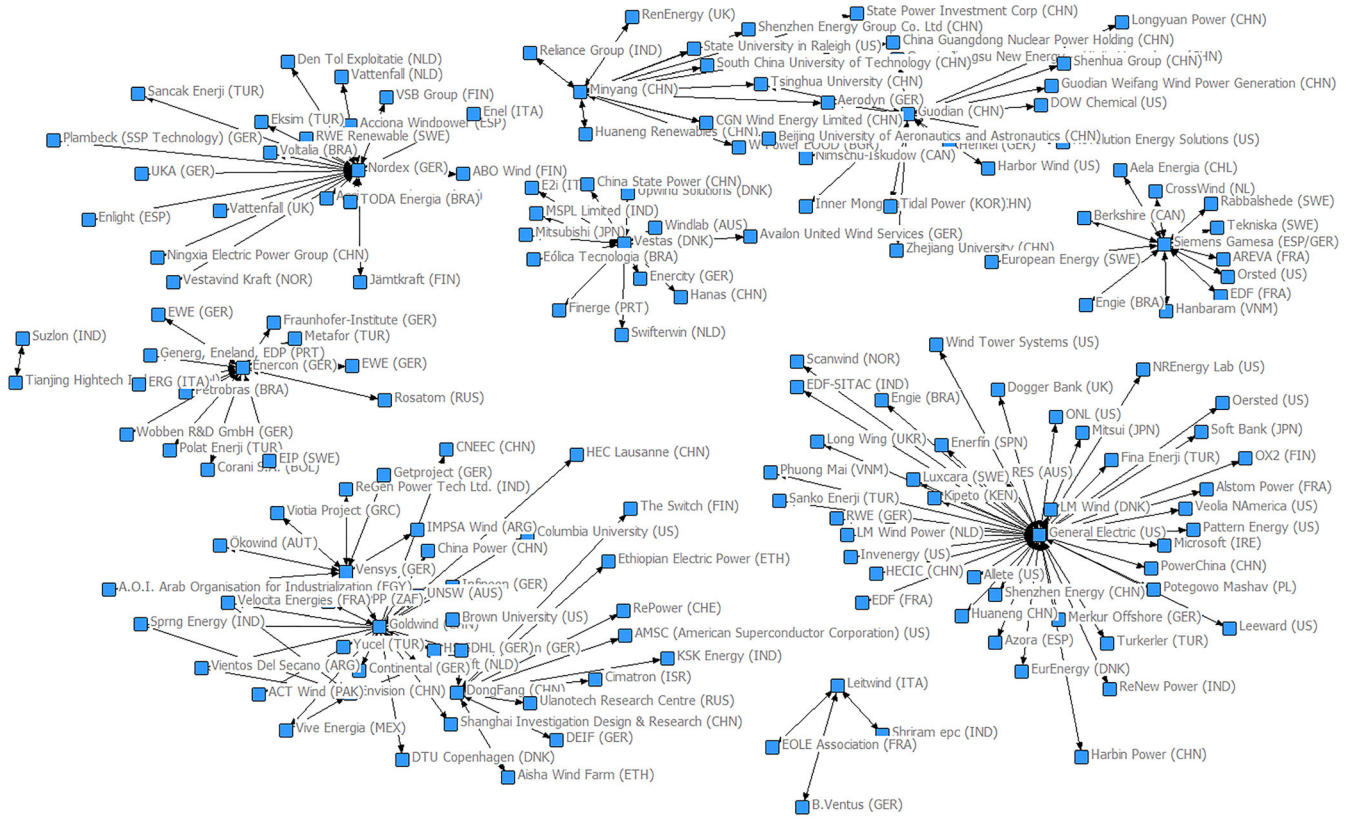


**FIGURE 1** Vertical and horizontal bilateral relationships of main actors of the wind power energy industry for the period 2007–2021

## 5 | STUDY CONTRIBUTIONS AND FUTURE OUTLOOK

The widespread adoption of renewable energy resources such as wind power is of vital importance for securing stable energy supply and promising economic outcomes, employment, local prosperity, and wellbeing. The increasing urgency to combat the climate change and accelerated fossil energy costs resulted in multiple calls to study the competitive structure and relationship dynamics of the renewable industry. In particular, researchers called for the value chain analysis and the discussion of the relationship dynamics of the industry and the evolution of industry networks (Bauwens et al., 2016; Bembom & Schwens, 2018; Cano-Kollmann et al., 2016; Reisach, 2017). Pursuing this study, the understanding of inter-organizational relationships and relevant developments in wind power industry clusters indicate a key for predicting future global competitive forces.

We contribute to the literature as our research responds to the call for more robust empirical evidence on the evolution of industry networks (Bembom & Schwens, 2018). Our study delivers a fine-grained cluster value chain analysis securing upmost generalizability and representativeness of the global wind power network. Due to its data richness and longitudinal approach, our study goes far beyond existing renewable industry network research as currently available in the literature.

More specifically, we identify eight industry clusters and discuss the firms' strategic collaboration patterns involving key horizontal and vertical relationships within the cluster. We list up, discuss, and compare collaboration motives (e.g., market entry, research, and development) and partner preferences of the actors in each cluster across different regions. This allows us to discover predictors of firm relationship patterns and opportunities for developing mutual innovation and regional market entry capacities. Therefore, we contribute filling a current research gap bridging country location and firm relationship perspectives as called by Cano-Kollmann et al. (2016).

In addition, our study helps identifying strategic opportunities for figuring out and consequently strengthening a firm's network positionings and, thus, delivers essential insights for managerial and policy decision makers concerning renewable industries.

We found that wind turbine manufacturers often cooperate with research laboratories and universities over a longer period of time (upstream links) and often place orders with the same electricity distributors but for different projects (e.g., wind farms). Thus, we prove that partnership experience through long-lasting relationships plays an important role in the wind energy industry.

Our industry network study provides empirical evidence of growing wind power energy capacities during the last decade on all continents and thus provides valuable information for business executives concerning attractive renewable energy markets.

As we also show, competition will become more complex and intensifies, as the Chinese strategy is different from western firms as it tries to achieve synergy through combining its renewable energy

supply with other governmental initiatives such as its new silk road initiative.

We collected the sample data to the best of our knowledge. However, network research is complex, and global relationship configurations rapidly tend to change over time. Some of the firms' relationships are not opened to the public, which may result in missing some important contractual relationships in our analysis. Further limitations of our research address the fact that we have considered only formal relationships which are institutionalized through contractual agreements, officially communicated in the firm's annual reports, press releases, and industry surveys available to the public. We are aware that informal (social) relationships of the operating management to suppliers, clients, policymakers, lobbyists, and other stakeholders vitally influence a firm's international business success as well. Studies of informal relations tend to be difficult, but these are not out of consideration for continued future research, for example, through an in-depth case study and (anonymous) field interviews.

We understand our study as a door opener for further network research regarding other renewable industries such as solar photovoltaic and hydro-energy. As from our point of view, the development of renewable industries is of vital interest to fight the global warming while at the same time it creates interesting business opportunities and, thus, contributes to economic prosperity for a better life on earth.

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## CONFLICT OF INTEREST

There is no conflict of interest.

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