

Measuring the internationalization of the wind energy industry

Jose M. Yusta^a, Roberto Lacal-Arántegui^{b,*}

^a Department of Electrical Engineering, Universidad de Zaragoza, María de Luna 3, 50018, Zaragoza, Spain

^b European Commission, Joint Research Centre, Westerduinweg 3, Petten, 1755 LE, the Netherlands



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ABSTRACT

Wind energy has grown from less than 20 gigawatts (GW) in 2000 to 590 GW by the end of 2018 and already provides 6% of the electricity consumed in the world. During this period, the wind energy technology industry has evolved from a local to a global business. To illustrate the globalization of this sector, this research assesses the effectiveness of the firms' international strategies based on empirical indicators. The intensity, the speed of internationalization, the geographic extensity and diversification are calculated and analyzed. The results indicate that the most successful firms are the market leaders Vestas and Siemens Gamesa Renewable Energy, and they are characterized by leading in both the depth (sales abroad/total sales) and width (number of countries) of internationalization as well as in geographic diversification. These companies are closely followed by four European and American firms: Enercon, Nordex, General Electric and Senvion. To date, Chinese firms, leaders in the largest market (China), are in general unable to internationalize as effectively as firms from other constituencies. Our results reveal that strong rivalry pressure in the domestic market is not a guarantee for the international competitiveness of its best-performing firms in the case of the wind energy industry – unless there are special characteristics in that domestic market.

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1. Introduction

Many theories about the process of firm internationalization can be found in the literature. Among the best known is the Uppsala model, which presents growth in the international activities of a company as a gradual process of expansion into new markets [1,2]. This expansion occurs through a series of successive stages that result in an increasing degree of international operations. A second approach explains internationalization as a process of learning or the development of company capabilities to recognize opportunities in international markets [3]. Researchers have focused on the importance of establishing relationships [2,4]; firm growth is seen as a dynamic process, strongly dependent not only on a competitive product or service but also on the opening and strengthening of relations with players in other markets. Research has also focused on technical know-how, location [5] and international entrepreneurship [6], in which both emerging and consolidated companies can create value based on the use of their entrepreneurial skills in their internationalization processes.

Time is a key factor of competitive advantage, as the first company entering a new country positions itself better in this market. Management of time in terms of the order, timing and speed of the process is an essential aspect of a firm's international expansion [7]. The speed of internationalization is therefore a matter of interest in the study of business globalization, and most studies analyze the process only until the moment the company starts to internationalize [8,9]. However, some works have argued that it is necessary to consider not only the time a company takes to establish its business in the first foreign market but also the time that elapses until it consolidates its international activity [10,11]. Furthermore, some studies have suggested that speed does not always positively influence performance [12]. Finally, firm size, firm age and other factors influence the success, measured in terms of profitability, of the international activity of a firm [13].

In the case of the wind industry, there are hardly any references that address how the international expansion processes of the companies occurred [14]. In this sector, there have been asymmetric developments in different regions, mainly depending on specific political support and the economic and industrial background. On the one hand, Europe has led technological development for 40 years, using first the local market for wind energy deployment and later expanding to other regions based on the

* Corresponding author.

E-mail addresses: jmyusta@unizar.es (J.M. Yusta), roberto.lacal-arantegui@ec.europa.eu (R. Lacal-Arántegui).

experience gained. Innovation has been, and still is, a key factor in the growth of companies beyond their national borders. On the other hand, China has become an important player in recent years, capturing almost half of the new capacity installed annually, which has allowed the technological and business growth of local companies.

The wind industry is relatively young, since it has only reached a significant size during the last 20 years; in terms of its main indicator, cumulative installed capacity in gigawatts (GW), it has grown from less than 20 GW in 2000 to 590 GW by the end of 2018 [15]. By considering this deployment as well as the unit costs from, for example, IEA Wind [16,17], Bloomberg New Energy Finance [18] and Joint Research Centre [19], we estimate that the approximate equivalent cumulative investment reached \$50 billion by 2000 and \$1370 billion by 2018.

Some research papers have confirmed that the creation of a domestic market in renewable energies has been decisive for the competitiveness and internationalization of companies [20–23]. This impact of the local market is particularly true in the case of companies in Europe and the USA, whereas the large Chinese market has not been decisive for its companies to actively participate in the global industry, at least until now [14].

Indicators for measuring the degree of internationalization of firms include the transnationality index [24], the network spread index [25], the Herfindahl-Hirschman index and other indices. Those indicators have been used to measure the degree of internationalization intensity, geographic extensity or geographic concentration of the firm's international activity, respectively [26] (cited by Ref. [27]).

However, there is little research on the internationalization of the wind energy industry in general and of wind turbine manufacture in particular, and none of this research used internationalization indices. Yet, quantitative assessment is necessary to enable robust, unbiased research to identify the international strategies of wind companies and to increase the understanding of the historical evolution and current trends.

The objective of this paper is to select the appropriate indices for assessing the globalization of the main wind turbine manufacturers worldwide. In this way, we address the internationalization effectiveness of these companies that eventually result in the global deployment of wind energy.

The novel contributions of this paper are (a) the proposal of a set of indicators to measure the degree of internationalization of wind turbine manufacturers, which combine structural indicators with indices for measuring the speed of internationalization, and (b) their application to data of the installed capacity by the 15 major manufacturers in 112 countries and territories over the past 40 years.

Section 2 presents and discusses the methodology used. Indicators such as the intensity and speed of internationalization, geographic extensity and diversification are described, and the results of modeling of these indicators are presented in Section 3. A discussion follows in Section 4 along with the ranking of the firms. Finally, Section 5 presents the conclusions.

2. Methodology

The indicators to assess the internationalization of enterprises that have been proposed in the scientific literature can be classified as structural, performance-based and attitudinal [27]. Composite indices have been created with the individual indicators [25]. Of these types, structural indicators are the most widely used. Performance indicators represent the economic results and market success of the company brought about by its international expansion. The indicators of attitude refer to the management styles and

the decision-making processes leading to the globalization of the company.

Structural indicators are the preferred measures of the degree of internationalization, perhaps because they rely on numerical values to provide an empirical view, and for this reason, they are used in this research. As there is not an individual indicator that satisfactorily measures the overall degree of the internationalization of a firm [27], we propose the use of several structural indices that help with assessment, lead to a useful analysis and together present a meaningful picture of the process.

One of the most popular indicators is the transnationality index (TNI), which was introduced by a United Nations report (World Investment Report 1995. Transnational Corporations and Competitiveness) at the United Nations Conference on Trade and Development in 1995 [24]. The TNI is a composite indicator calculated as the average of three ratios: foreign assets to total assets, foreign sales to total sales and foreign employment to total employment. This index belongs to the group of measures of internationalization intensity, focusing on the intensity of foreign activities in relation to the quantity of domestic activities.

However, other interesting dimensions can be provided for the assessment [28]. Geographic extensity indices consider the number of countries and operations to calculate the spread of a firm, while geographic diversification indices estimate the degree of concentration or diversification of a firm's business among different countries. As a third dimension, measuring the speed of internationalization could help to explain not only the success but also the different nature of firms' strategies [29–32].

The data about the installed capacity, in megawatts (MW), from each of the 15 primary wind turbine manufacturers in 112 countries and territories worldwide from 1978 to 2017 was used for the purpose of this study [33]. The database is nearly complete, as it includes a total of 517.7 GW of wind turbines installed or commissioned during this period, including old turbines that have already been decommissioned. This figure is 96% of the most accurate estimate of the worldwide installed capacity, 539.6 GW, by the Global Wind Energy Council [34]. The main gaps in the database correspond with Chinese installations; for example, a total of 32.6 GW of installations were assigned to Goldwind of China, whereas its actual installations were 42.7 GW in China [35] plus 1.3 GW abroad. The installed capacity by the top 15 turbine manufacturers, also called original equipment manufacturers (OEMs), in the database was 458.5 GW, or about 85% of the worldwide installed capacity by the end of 2018.

The consideration of what constitutes the "home country" required a methodological decision. The history of the wind energy sector includes many mergers and acquisitions between OEMs, and, in some cases, the result is an OEM with a large installed base in several countries, such as the merge of Siemens Wind Power and Gamesa into Siemens Gamesa Renewable Energy (SGRE) in 2016. Siemens Wind Power was, in turn, the acquisition of the Danish company Bonus by German Siemens in 2004. Assuming that SGRE (now a Spanish company with Siemens as a majority German stakeholder) has Spain as a single home country is incorrect; it is more accurate to assume that SGRE has three home countries (DK, ES and DE).

In the same way, General Electric (GE) is mostly the result of the acquisition of the U.S. companies Zond and Kenetech and the German company Tacke (see Fig. 1), and thus it was assigned two home countries (DE and US). Although GE acquired the Swedish company ScanWind, the contribution of this firm was not significant, and Sweden was thus not considered a home country for GE. Following this criterion, Nordex was assigned Spain and Germany as home countries, but Goldwind was not assigned Germany (following the acquisition of 70% of Vensys) as a home country.

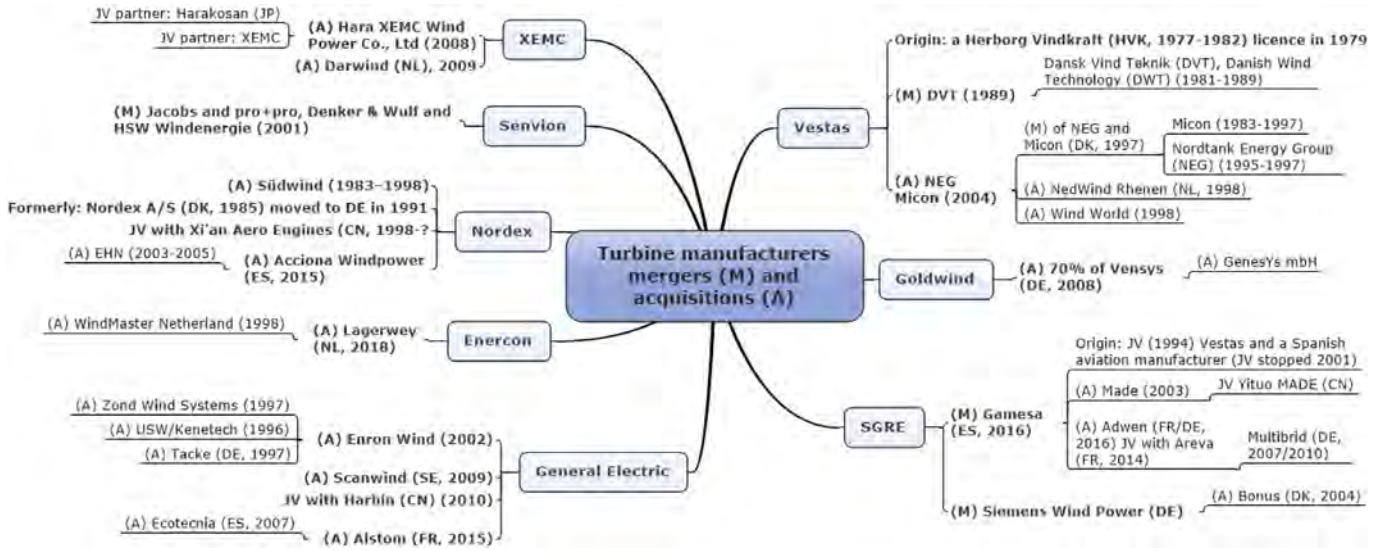


Fig. 1. The most significant mergers and acquisitions among wind turbine manufacturers.

Fig. 1 lists the most significant mergers and acquisitions among wind turbine manufacturers.

After having worked with wind installation databases from five different industrial intelligence suppliers since 2009, we found that the MAKE database is the most complete in terms of the number of installations (in MW) that are allocated to each turbine manufacturer. However, the database still retained some elements that had to be refined. This refining work consisted of screening the initial installations in the database against the company’s history on either its website or wind energy-related books of the 1990s [36,37] and against some of the other databases from industrial intelligence suppliers [38–41].

The data therefore allows the assessment of certain structural measures of the internationalization of these wind firms. The indicators aid in understanding the evolution of market dynamics, firm expansion and the influence of the domestic renewable policy on boosting a firm’s global activity. Hence, we selected and applied the following structural indices to the analysis of wind turbine manufacturer internationalization.

2.1. Internationalization intensity

For a measure of the intensity of internationalization, we focused on the ratio of the installed wind turbine capacity abroad (“exports”) to the company’s total installed capacity (“total sales”). This index is one of the three that constitute the TNI [24], and it is one for which the available data allows full research. This index can effectively measure the *depth* of the foreign expansion for each firm.

First, we calculated this index for each year in the sample, from 1978 to 2017. Then, the intensity index I_{firm} was obtained for the total amount of the installed capacity by each firm in all 112 countries and territories. In addition, a second indicator \bar{I}_{firm} was calculated, averaging the annual intensity index.

$$I_{firm} = \frac{\sum_{yr} \sum_{co \in foreign} P_{firm, co, yr}}{\sum_{yr} \sum_{co} P_{firm, co, yr}} \quad (1)$$

$$\bar{I}_{firm} = \frac{1}{40} \sum_{yr=1978}^{yr=2017} \frac{\sum_{co \in foreign} P_{firm, co, yr}}{\sum_{co} P_{firm, co, yr}} \quad (2)$$

Where $\sum_{yr} \sum_{co \in foreign} P_{firm, co, yr}$ is the installed capacity abroad by each wind turbine *firm*, in each country *co*, in each year *yr*, while $\sum_{yr} \sum_{co} P_{firm, co, yr}$ is the total installed capacity by each wind turbine *firm*, in each country *co*, in each year *yr*, including the domestic and foreign capacity.

2.2. Geographic extensity

The number of foreign countries and territories in which each company has installed wind turbines is the relative spread of each firm worldwide [25]. This spread is directly related to what can be called the *width* of internationalization of a company, which is measured by the network spread index (NSI), a ratio for each firm of the absolute number of foreign countries where the firm ever deployed wind turbines to the similar figure for the firm that installed turbines in more foreign countries [42].

$$NSI_{firm} = \frac{N_{countries_{firm}}}{\max_{1 \leq firm \leq 15} (N_{countries_{firm}})} \quad (3)$$

Where $N_{countries_{firm}}$ is the absolute number of different foreign countries that a firm has ever done business with.

2.3. Geographic diversification

A firm whose foreign activity is diversified does business in each market in a balanced way. This balance protects the firm against the ups and downs of individual markets. This protection is unlike a firm whose business mostly depends on a few of its export markets. We propose the use of a geographic diversification index GD_{firm} to measure how the activity is split among those countries.

First, for every firm and year, we calculated the ratio of the installed capacity in each country ($P_{firm, co, yr}$) to its total installed capacity. Second, we used the well-known Herfindahl-Hirschman

index (HHI) [43] to obtain a measure of the diversification of the firm activity for each year $GD_{firm, yr}$. Finally, we computed the mean of the annual HHI values to obtain an average value of the geographic diversification index of each company in the whole period \overline{GD}_{firm} . This average index can also be calculated for a different number of years.

$$GD_{firm, yr} = \sum_{co=1}^{112} \left(\frac{P_{firm, co, yr}}{\sum_{co=1}^{112} P_{firm, co, yr}} \right)^2 \quad (4)$$

$$\overline{GD}_{firm} = \frac{1}{40} \sum_{yr=1978}^{yr=2017} \left[\sum_{co=1}^{112} \left(\frac{P_{firm, co, yr}}{\sum_{co=1}^{112} P_{firm, co, yr}} \right)^2 \right] \quad (5)$$

The index varies between 0 and 10,000, where 10,000 indicates that the company concentrates its sales in a single country, while values closer to zero indicate greater international diversification.

2.4. Speed of internationalization

Internationalization studies using structural indicators do not usually include a measure of speed. However, this speed is an important issue and a key aspect of a firm's international strategy [7,10]. Hence, we discuss here a set of indicators based on proposals in the literature that quantify the average speed at which the company has expanded internationally.

Hilmersson et al. [19,20] have suggested several possible indices to measure the speed of internationalization: the mean number of markets exported per year since inception, the ratio of exports to total sales and the share of the firm's assets abroad. Concerning the first index, Mohr [21] has proposed a variation as the average number of foreign markets divided by the number of years since the firm's first international expansion. Using the date of the first international expansion fits better with the wind industry than the date of inception since sales abroad started after a long period of technology development.

The ratio of exports to total sales is the internationalization intensity defined in Section 2.1. How this element evolved over time can be a useful indicator for the assessment of the internationalization dynamics of a firm. In the case of wind turbine manufacturers, the indicator is defined as the percentage of the foreign against the total rated capacity (in MW) of the turbines installed.

Speed could also refer to the length of time until a certain milestone is achieved. The literature suggests using between 10% and 20% of the total number of countries and territories exported to for this indicator [32,44,45]. After analyzing the historical data series from the database, we propose this milestone to be 20%, as this figure reflects a significant number of exports for most companies in the sample.

Therefore, the selected indicators to measure the speed of the internationalization of wind turbine firms are the following:

- The average number of new markets entered per year since the firm's first international expansion
- The number of years between the first year of the internationalization of the firm to the year when it reached the milestone of 20% of its final number of foreign markets; thus, for example, if a firm had exported to a total of 30 countries by the end of 2017, the figure in this indicator would be the years until it reached six foreign markets.
- Internationalization intensity over time

3. Results

The results indicate that some of the companies in the sector have had an international focus almost since their inception, while others have based their growth on meeting the needs of their home country. Fig. 2 depicts the 2017 market shares of the world's 15 leading wind turbine manufacturers, in which European companies continue to retain a significant quota: Vestas, SGRE, Enercon, Nordex and Senvion accounted for 56% of the 2017 market share of the 15 largest companies. Chinese companies reached a 30% share of the top 15, due to the strong momentum of wind power in their home country and the nature of a state-managed economy that favors national champions and state-owned companies [46]. In total, those 15 leading companies installed 45.5 GW in 2017, with a minimum contribution from Sinovel and XEMC.

3.1. Internationalization intensity

Table 1 summarizes the results of some indicators of the degree of internationalization as discussed in Section 2. First, it should be highlighted that the international activity of wind turbine companies has accounted for as much as 51% of the total installed capacity worldwide until 2017: 235,800 MW of 458,500 MW. Moreover, the first four companies reach 63% of the total installed capacity and 85% of the foreign installed capacity.

The I_{firm} indicator relates the installed capacity abroad to the total capacity installed by the firm, according to the formula of Equation (1). The indicator reveals that European companies have carried out most of their business in the international field throughout the history of the wind sector. Furthermore, Fig. 3 graphically illustrates these results: two companies, Vestas and SGRE, have captured most of the international wind energy business. However, Fig. 4 shows that Vestas and SGRE reached that position in very different way: Vestas was very international from the beginning whereas SGRE reached Vestas in 2011 and between this year and 2017 both accounted for roughly equal share of international sales, 47 GW Vestas vs. 45 GW SGRE. Table 1 indicates that these two companies have accounted for an overall 64% of the installed capacity abroad.

The results of the index \bar{I}_{firm} offer a historical perspective of the international activity of the companies, since the average of the annual index I_{firm} was calculated. Vestas appears to be the only

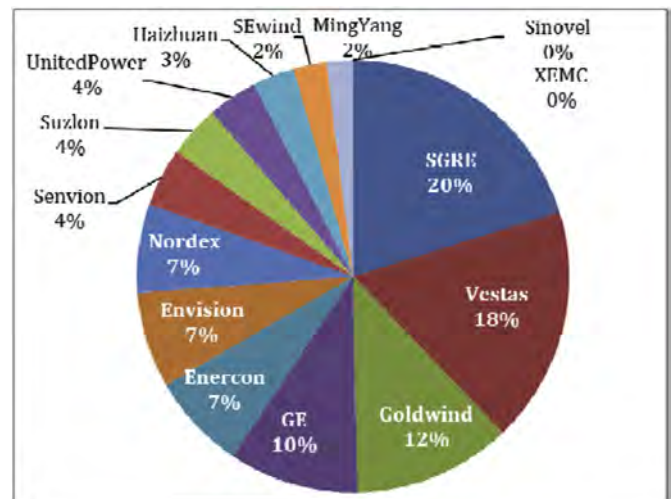


Fig. 2. Wind turbine market share in 2017 of the 15 leading OEMs in this study. Installations by other OEMs have been disregarded. Source: MAKE database [33].

Table 1
Results of the indicators of intensity of the degree of internationalization.

Company	Total installed capacity		Foreign installed capacity		Intensity	
	MW	%	MW	%	I_{firm} (MW foreign/MW total)	\bar{I}_{firm} Annual average
Vestas	91,168	19.9%	87,521	37.1%	96%	70%
SGRE	82,922	18.1%	62,460	26.5%	75%	42%
GE	63,180	13.8%	22,189	9.4%	35%	18%
Enercon	49,038	10.7%	27,170	11.5%	55%	35%
Goldwind	32,643	7.1%	1,310	0.6%	4%	2%
Nordex	23,896	5.2%	17,112	7.3%	72%	33%
United Power	18,082	3.9%	254	0.1%	1%	0%
Suzlon	17,634	3.8%	5,907	2.5%	33%	9%
Senvion	17,108	3.7%	11,120	4.7%	65%	32%
Sinovel	16,739	3.7%	350	0.1%	2%	3%
Envision	11,940	2.6%	30	0.0%	0%	0%
Ming Yang	11,501	2.5%	180	0.1%	2%	1%
SEwind	9,937	2.2%	0	0.0%	0%	0%
XEMC	6,616	1.4%	4	0.0%	0%	0%
Haizhuan	6,132	1.3%	32	0.0%	1%	1%
	458,536	100%	235,637	100%		

Table 2
Results of the indicators of geographic extensity.

FIRM	Geographic extensity	
	No. countries	NSI_{firm}
Vestas	73	1.00
SGRE	70	0.96
GE	40	0.55
Enercon	47	0.64
Goldwind	13	0.18
Nordex	41	0.56
United Power	2	0.03
Suzlon	16	0.22
Senvion	26	0.36
Sinovel	8	0.11
Envision	2	0.03
Ming Yang	3	0.04
SEwind	0	0.00
XEMC	1	0.01
Haizhuan	1	0.01

company maintaining international business activity superior to

the domestic business activity on an annual average, while the rest of the European companies reached desirable rates of foreign business of between 32% and 42% over time. The American company GE presents a lower \bar{I}_{firm} of 18%, whereas Chinese companies have hardly developed an international business.

Fig. 4 represents the installed capacity in foreign countries by each company and helps with understanding their historical evolution. In addition, a dashed line in the figure indicates the sum of the domestic installations up to 2008, which puts the foreign business into perspective.

Vestas, SGRE, GE and Nordex display continuous growth, while Enercon’s international business has been in decline since 2012. It is also interesting to note that Vestas first started a significant international expansion around 1995, while other companies did not start until the 21st century. However, during recent years and after the merge of Siemens and Gamesa, SGRE has caught up with Vestas in the international arena.

The figure reveals an interesting feature in 2012–2013: a general drop in foreign installations that is pronounced in the case of Siemens and Gamesa (SGRE). This drop is due to the fall of the U.S.

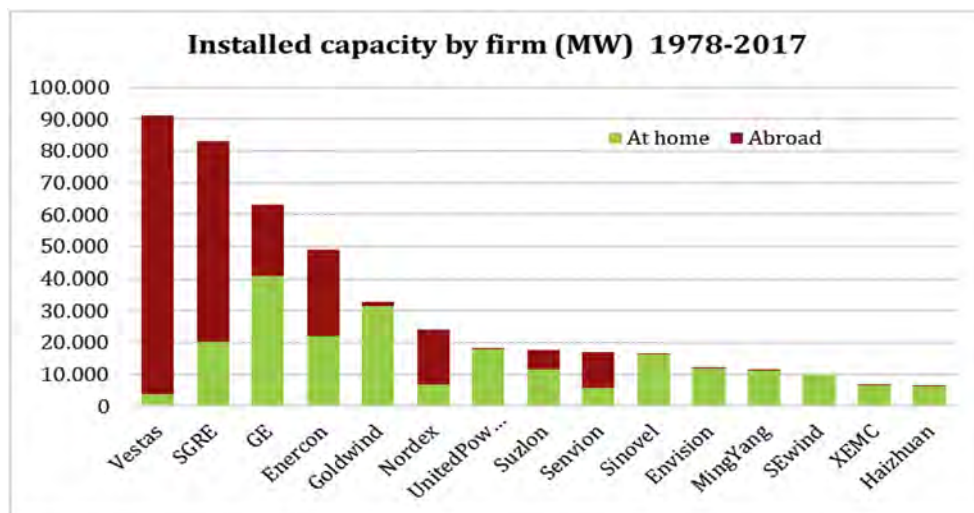


Fig. 3. The installed capacity by wind turbine manufacturers from 1978 to 2017, with a distinction of the capacity installed at home and abroad. Source: MAKE database [33].

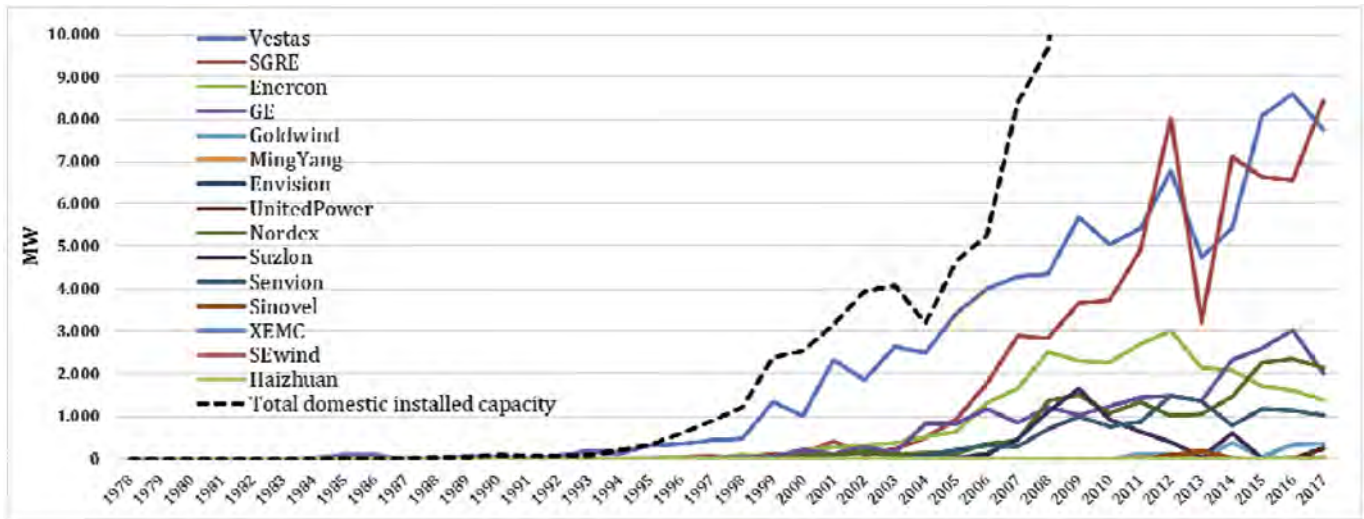


Fig. 4. The annual evolution of installed capacity abroad by firm and the total aggregate domestic installed capacity by all firms from 1978 to 2017. Source: MAKE database [33].

market, during which installing 13,124 MW in 2012 reduced to 1,084 MW in 2013 [47]. The data indicates that Siemens and Gamesa, two separate companies at that time, installed 3,875 MW in the US in 2012 and only 87 MW in 2013. Other companies suffered from the U.S. drop as well, primarily GE. However, the case of GE is not depicted in Fig. 4 because the US is GE's domestic market. The figure illustrates the lack of contribution from Chinese OEMs to internationalization as well as the retreat from foreign markets of Suzlon in 2012–2017.

3.2. Geographic extensity

The geographic scope, or extensity, of the wind turbine manufacturers is here assessed by means of the number of countries where they have expanded their businesses, depicted in Table 2 and Fig. 5. This information is accompanied by the calculation of the NSI, which allows a relative classification. Fig. 6 provides additional information on the historical evolution of the number of foreign markets per firm.

When comparing the trends displayed in Figs. 4 and 6, it is interesting to note how the world leaders, Vestas and SGRE, are also the manufacturers that have been present in many countries. However, their evolution was different: Vestas was consistently leading in both the number of countries and the installed capacity abroad, while SGRE lagged behind in both indicators until it reached Vestas around 2011. Since that year, Vestas installed in an average 33 countries per year and SGRE in 27.

Table 2 lists the high number of countries where Enercon, GE and Nordex have been present (47, 40 and 41, respectively). However, the share of those companies in the total foreign installed capacity (see Table 1: 12%, 9% and 7%) has not achieved a similar high level. In this regard, GE's and Nordex's NSI values are 0.55–0.56, lower than Enercon's 0.64. Senvion, Suzlon and Goldwind have been present in 26, 16 and 13 countries, respectively, but the volume of their activity abroad (Table 1) is different at 4.7%, 2.5% and 0.6% of the total foreign installed capacity.

Equally interesting a finding, the figures for Goldwind and other Chinese companies do not support the theory proposed by Porter in

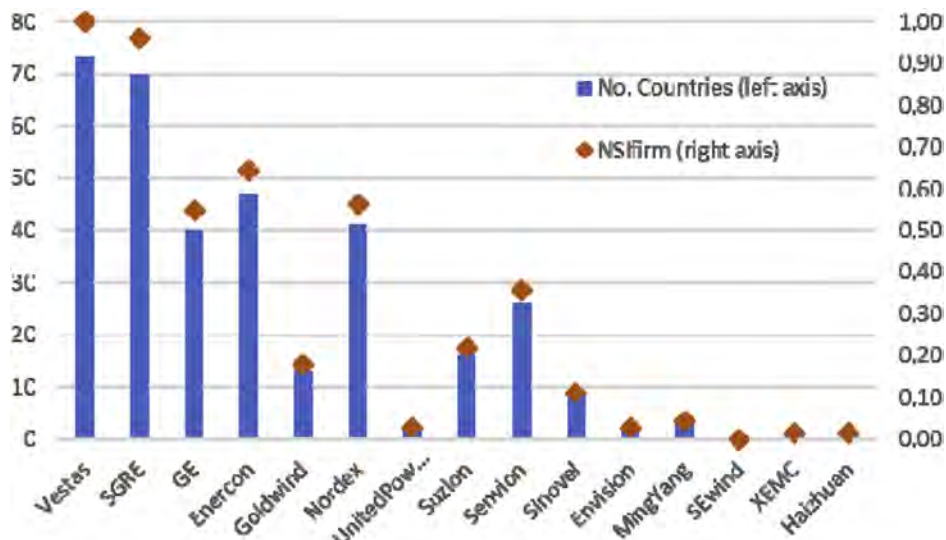


Fig. 5. Graphical representation of Table 2.

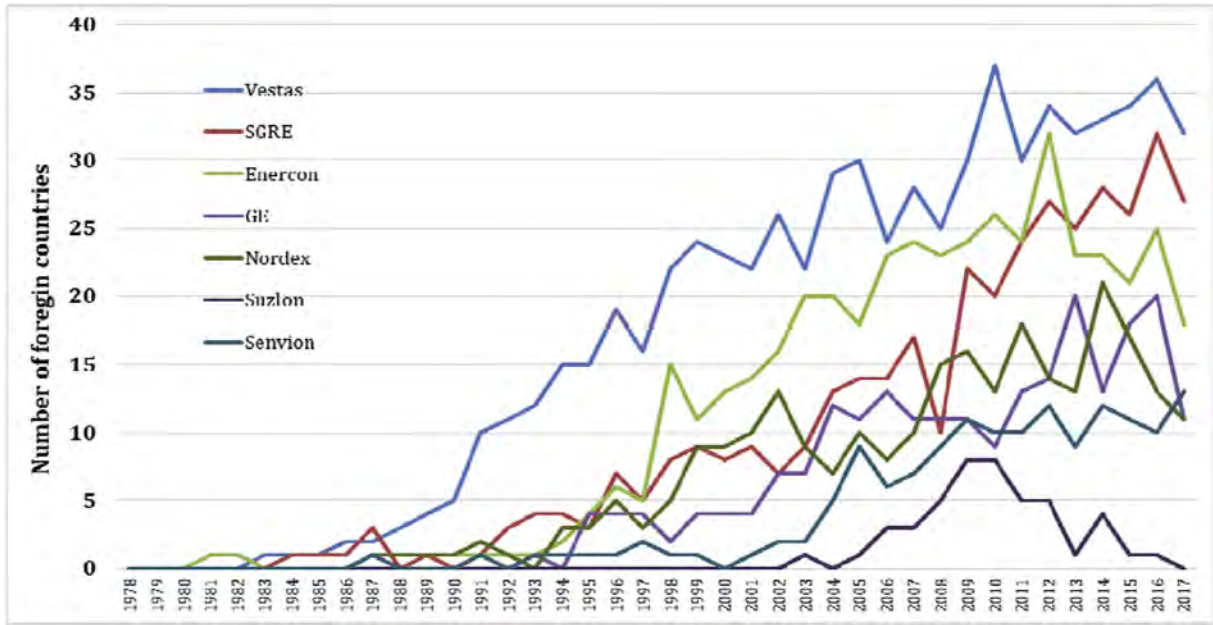


Fig. 6. Annual evolution of number of exported countries from 1978 to 2017 by firm (excluding Chinese companies). Source: MAKE database [33].

1990 that strong domestic pressure from rivals provides a competitive advantage for internationalization [48]. We think that this strong pressure is more theoretical than real in the Chinese case. With China as the leading country (189 GW installed by the end of 2017), the most international of the Chinese OEMs, Goldwind, has only installed between 3% and 4% of its business abroad, even though Goldwind has surpassed every other leading Chinese OEM in this respect.

3.3. Geographic diversification of companies

It was discussed previously that internationalization is different when it is balanced among countries rather than when one country (or a small handful of them) weighs heavily in the business portfolio of the company. In other words, the international diversification of each company is to be measured in relation to the size of its presence in each country, not only according to the number of countries where it is present. This indicator can be obtained by relating it to diversification indices based on the Herfindahl-Hirschman market concentration index.

Section 3.1 clarified that internationalization in the wind industry started, in practice, by 2000. For this reason, this indicator was applied to the period from 2000. Table 3 presents the average value \overline{GD}_{firm} of the annual GD_{firm} index between 2000 and 2017. This indicator reveals once more that Vestas has the most

diversified international activity with a \overline{GD}_{firm} value of 1,334. On the other hand, the \overline{GD}_{firm} index of Chinese companies takes a value close to 10,000 in all cases, thus indicating that they have virtually not expanded their activity outside their country. Fig. 7 depicts the annual values of the GD_{firm} for companies in the wind sector, excluding Chinese companies.

The comparison between the results of two companies illustrates the contribution of this index to assessing the different character of internationalization from a country diversification point of view. Firms can be present in a similar number of countries yet have different structures of diversification. Both GE and Nordex are present in a similar number of foreign countries (40 and 41, respectively; see Table 2). However, the \overline{GD}_{firm} index reveals that Nordex ($\overline{GD}_{firm} = 2,156$) has more geographically diverse business, while GE ($\overline{GD}_{firm} = 4,123$) concentrates its business more in some countries, led by its home market, the US.

The \overline{GD}_{firm} figures include the respective acquisitions of Acciona by Nordex and Alstom by GE in 2016. Interestingly, these acquisitions were presented as complementary in terms of country diversification by both acquiring OEMs. For example, in the case of Nordex-Acciona, the press release noted that “the two wind turbine manufacturers have complementary technologies and market footprints, with Nordex’s strong presence in Europe a good match for ACCIONA Windpower’s established position in North and South

Table 3 Results of the indicator of geographic diversification \overline{GD}_{firm} .

Geographic diversification			
Firm	\overline{GD}_{firm} (>YR 2000)	Firm	\overline{GD}_{firm} (>YR 2000)
Vestas	1,334	Senvion	4,042
SGRE	2,420	Sinovel	9,556
GE	4,123	Envision	9,955
Enercon	3,021	Ming Yang	9,630
Goldwind	9,276	SEwind	10,000
Nordex	2,156	XEMC	9,991
United Power	9,745	Haizhuan	9,520
Suzlon	7,234		

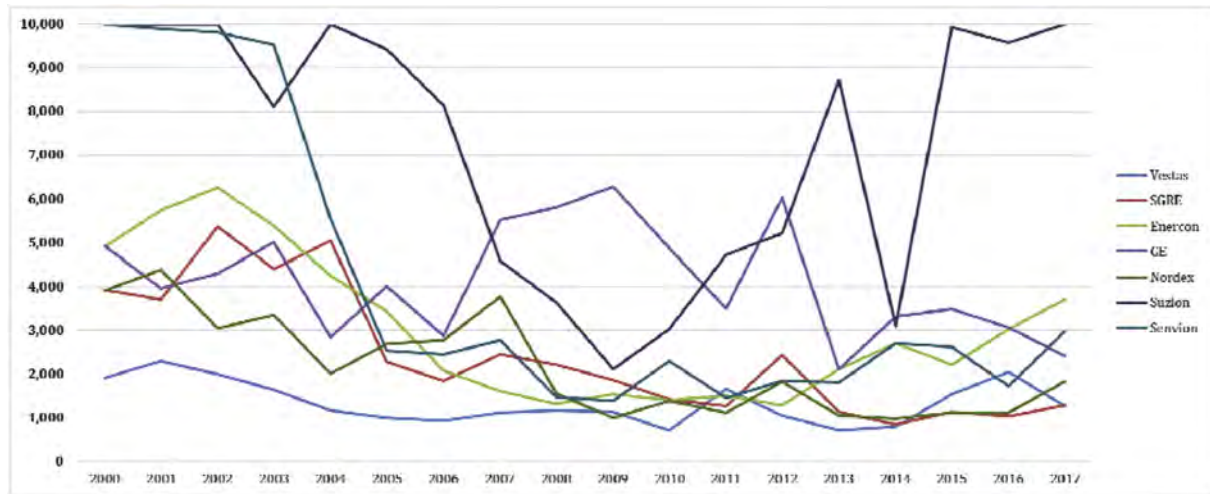


Fig. 7. Geographic diversification index GD_{firm} from 2000 to 2017 by firm excluding Chinese companies.

Table 4

Wind turbine installations of Acciona and Nordex for the period up to 2015, main markets.

Country	Nordex	Acciona	Country	Nordex	Acciona
Australia	1	239	Italy	626	65
Belgium	39		Japan	70	
Brazil		303	Lithuania	70	
Canada	26	177	Mexico		607
Chile		105	Netherlands	252	
China	724		Norway	148	
Colombia	20		Pakistan	150	
Costa Rica		50	Poland	271	183
Croatia		30	Portugal	411	
Czech Republic	13		Romania	100	
Denmark	135		South Africa	182	138
Egypt	63		South Korea		65
Estonia	18		Spain	203	1,730
Finland	247		Sweden	435	
France	1,402	39	Turkey	1,122	59
Germany	3,204		United Kingdom	1,122	36
Greece	111	6	United States	902	1,373
India	54		Uruguay	167	
Ireland	391		Total	12,696	5,202

America" [49].

This statement matches data in the MAKE database, as presented in Table 4. Only in the US, Poland and South Africa were both companies about equally active in the number of installations, whereas in 28 of the 37 countries, only one of them was present or both were present but one had only a symbolic presence of less than 10 MW.

Fig. 7 reveals that the overall trend of the index \overline{GD}_{firm} between 2000 and 2017 is slightly decreasing, which indicates greater diversification of the sector international activity. The trend can possibly be split into two clearer periods: from 2000 to 2011, all companies experienced an increase in diversification, whereas the period 2012–2017 introduced a slight reversing trend that was more severe in the cases of Suzlon and Enercon. Suzlon has experienced a deep crisis since 2011 that caused it to retreat to its home market of India after about seven years of significant international expansion. Enercon's evolution since 2012 was likely influenced by the boom of its home market, Germany, where it is the leading OEM (see figures in Table 5).

An even finer focus on the two more diversified companies, Vestas and SGRE for recent years (2014–2017) shows that SGRE

Table 5

Onshore wind installations, in MW, which boomed in Germany between 2010 and 2017 and contributions by Enercon. Global installations by Enercon. Sources: German Wind Energy Association, MAKE database [33]. Note that Enercon does not make offshore wind turbines, thus only onshore figures are relevant here.

Year	2010	2011	2012	2013	2014	2015	2016	2017
Germany (DE)	1,453	2,012	2,217	2,786	4,571	3,731	5,002	5,334
Enercon DE	926	1,213	1,304	1,496	2,043	1,329	1,782	1,915
Enercon global	3,197	3,920	4,310	3,636	4,107	3,023	3,343	3,264

became the most diversified company during that period, with an average \overline{GD}_{firm} for the period of 1,068 vs. 1,407 Vestas. Even, during this period, Nordex with a \overline{GD}_{firm} of 1,254 performed better than Vestas.

3.4. Speed of internationalization

Three indicators were used in this research to study the pace at which companies have expanded their operations abroad: the mean number of new markets entered per year since internationalization, the years passed from the first year of internationalization until reaching 20% of the total number of countries exported and the relationship between the exports and total sales over time.

Table 6 presents key figures used for the calculation and the results obtained for the first two indicators. In general, companies had an early internationalization led by Vestas and SGRE in the 1980s, and they were soon followed by the European companies Nordex, Enercon and Senvion and GE of the US. Chinese companies have not been included here because they have barely developed international activity.

The average number of new markets per year since the firm's first international foray is also presented in Table 6. This indicator reveals how the speed of internationalization of SGRE and Vestas has been faster than the rest of the companies, whereas Suzlon and Senvion have significantly lower ratios that make them lag behind the others.

As mentioned in Section 2 and according to the literature, it is worth calculating the number of years between the start of internationalization until the year when a firm achieved 20% of the final number of foreign countries exported. The companies that have the best ratios here are Suzlon, GE, Enercon, Senvion and Nordex. Conversely, SGRE and Vestas did not reach 20% of sales abroad until

Table 6
Results of the speed of internationalization indicators (excluding Chinese companies).

Firm	Company funding year	Start internationalization	Year > 20% countries exp.	Firm age (years)	Firm exp. age (years)	No. countries	Mean no. new markets entered per year since internationalization	No. years until 20% countries exp.
Vestas	1978	1981	1993	39	36	73	1.97	12
SGRE	1978	1984	1996	39	33	70	2.12	12
Enercon	1984	1992	1997	33	25	40	1.77	5
GE	1983	1993	1997	34	24	47	1.64	4
Nordex	1987	1991	1998	30	26	41	1.59	7
Suzlon	1996	2003	2006	21	14	16	1.07	3
Senvion	1988	1993	1999	29	24	26	1.00	6

12 years after starting exports.

Thus, Vestas and SGRE took longer to reach the 20% milestone, but they were also the first companies both founded and initiating exports; they were the pioneers and their work facilitated faster development of the global market. The data indicates that late entrants such as Suzlon were faster to reach the milestone, which was due to the greater maturity of the markets.

The third indicator selected to measure the speed of internationalization was the relationship between the exports and total sales over time. Fig. 8 represents the percentage of foreign versus total installed capacity by selected companies from 2000 to 2017 for clearer visualization of the historical data. The difference between some companies that began their international development early (Vestas and SGRE in 1981–1984) compared to others that have accelerated in recent years is relevant. Suzlon has not been considered in this figure because the effect of its deep crisis would introduce noise into the analysis.

4. Discussion

The indicators proposed in this research to assess the internationalization of the wind industry reveal the different levels of success of the firms' foreign expansion as well as the evolution that allows the understanding of the current market situation. Thus, by comparing the results of the top 15 companies in Figs. 2 and 3, it is observed that Vestas and SGRE have led the market during the past 40 years and still maintain their leading positions.

These two companies also present the best results for internationalization. Table 7 lists the summary of the internationalization indicators obtained in this research, in which it is observed that Vestas and SGRE achieved the highest values both in the intensity of internationalization and in the geographic spread of their

activity. When the \bar{I}_{firm} index is considered, which presents the average value of the evolution of the international activity of the companies, a ranking similar to that of the I_{firm} index is observed for all companies except for Suzlon, which drastically drops from $I_{firm} = 33\%$ to $\bar{I}_{firm} = 9\%$. This reduction means that Suzlon's international activity has been prominent but also concentrated in a few years. These results justify deepening the study of the historical evolution of the overseas expansion of the companies and of the speed of that process.

Significant internationalization of the wind industry did not start until the beginning of the 21st century, except in the case of Vestas, which began its noteworthy activity abroad around 1993 (see Fig. 4 and Table 3). Among the companies that started to expand their business abroad later, SGRE has stood out in recent years, even at times surpassing the annual volume of Vestas's international activity.

Other than Vestas, the information in Fig. 4 allows companies to be classified into three groups:

- Enercon, SGRE and GE began to gain significant foreign sales volume in 2004, after the three companies had already reached an international presence in at least 20% of the countries exported to around 1997 (Table 6).
- Another group of companies (Nordex, Senvion and Suzlon) have accelerated their international activity since 2007, but these companies have subsequently experienced a different evolution. Nordex has consolidated its internationalization more than Senvion, whereas Suzlon has seen its internationalization shrank to nearly zero.
- Chinese companies have barely developed activity abroad, as can also be seen in the results summarized in Table 7. Among

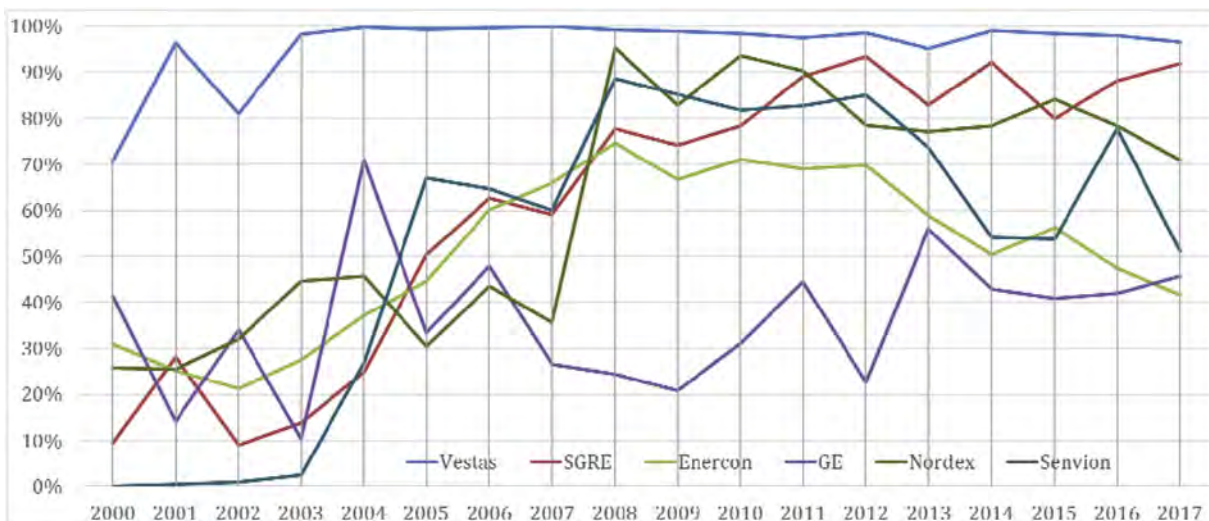


Fig. 8. The relationship between foreign and total installed capacity from 2000 to 2017 by firm, excluding Chinese companies and Suzlon.

Table 7
The results of the indicators of the degree of internationalization.

Company	Total installed capacity		Foreign installed capacity		Intensity		Geographic extensity		Geographic concentration
	MW	%	MW	%	I_{firm} (MW foreign/MW total)	\bar{I}_{firm} Annual average	No. countries	NSI_{firm}	GD_{firm} (>yr 2000)
Vestas	91,168	19.9%	87,521	37.1%	96%	70%	73	1.00	1,334
SGRE	82,922	18.1%	62,460	26.5%	75%	42%	70	0.96	2,420
GE	63,180	13.8%	22,189	9.4%	35%	18%	40	0.55	4,123
Enercon	49,038	10.7%	27,170	11.5%	55%	35%	47	0.64	3,021
Goldwind	32,643	7.1%	1,310	0.6%	4%	2%	13	0.18	9,276
Nordex	23,896	5.2%	17,112	7.3%	72%	33%	41	0.56	2,156
United Power	18,082	3.9%	254	0.1%	1%	0%	2	0.03	9,745
Suzlon	17,634	3.8%	5,907	2.5%	33%	9%	16	0.22	7,234
Senvion	17,108	3.7%	11,120	4.7%	65%	32%	26	0.36	4,042
Sinovel	16,739	3.7%	350	0.1%	2%	3%	8	0.11	9,556
Envision	11,940	2.6%	30	0.0%	0%	0%	2	0.03	9,955
Ming Yang	11,501	2.5%	180	0.1%	2%	1%	3	0.04	9,630
SEwind	9,937	2.2%	0	0.0%	0%	0%	0	0.00	10,000
XEMC	6,616	1.4%	4	0.0%	0%	0%	1	0.01	9,991
Haizhuan	6,132	1.3%	32	0.0%	1%	1%	1	0.01	9,520
	458,536	100%	235,637	100%					

them, Goldwind and Sinovel have been present in 13 and eight foreign markets, respectively.

The indicators represent the relationship between the number of countries where companies have expanded their activity and the volume of their international business. By jointly analyzing the results of the indicators \bar{I}_{firm} and \overline{GD}_{firm} in Table 7, it is confirmed that Vestas is the company that has historically extended its international activity more, demonstrating the highest intensity values of the degree of internationalization, $I_{firm} = 96\%$ and $\bar{I}_{firm} = 70\%$. In addition, Vestas is the company that has the most balanced international business between countries, with the lowest value of $\overline{GD}_{firm} = 1,334$; all the other companies present a higher concentration of their foreign business in a smaller number of markets.

Considering the historical evolution in Figs. 6 and 7, since 2009, the global wind energy market has increased remarkably, and companies are diversifying, except for GE, which has been significantly focused on meeting the high demand in its home country. Two companies, Enercon and Senvion, have reduced their diversification since 2013 (see Fig. 7), although Senvion maintains a presence in a relatively high number of countries but concentrates its activity in a few of them. Finally, it is interesting to observe how most companies evolved in 2017, decreasing their presence in some countries (Fig. 6) and concentrating their business more (Fig. 7), a

situation that reveals the maturity of some markets and pressures companies toward higher market diversification.

One of the main results of this research is the inclusion of some measures of the speed of internationalization in the assessment of company effectiveness. When analyzing the indicator of the average number of new markets exported per year since the firm's first international expansion (Table 7), it is possible to group the companies into three different sets:

- Vestas and SGRE present the highest value, near or above 2
- Enercon, GE and Nordex present values between 1.59 and 1.77
- Suzlon and Senvion present values at or just above 1.

These numerical values reflect the different paces of expansion of the international activity of these companies, highlighting Vestas and SGRE as more global companies, followed by GE, Enercon and Nordex.

The result of the individual indicators offers the opportunity to rank companies' internationalization, and this ranking is listed in Table 8. Overall, Vestas is leading in nearly all indicators, while SGRE follows, then a group of four Western companies ahead of the Asian companies, which are headed by Suzlon.

5. Conclusions

The wind energy technology manufacturing industry, as best

Table 8
Internationalization ranking of wind turbine manufacturers.

Ranking/indicator	Intensity	Geographic diversification	Geographic extensity	Speed (Avg. markets/yr)	Overall ranking
Vestas	1	1	1	2	1
SGRE	2	3	2	1	2
Enercon	3	4	3	3	3
Nordex	4	2	4	5	4
GE	6	6	5	4	5
Senvion	5	5	6	8	6
Suzlon	7	7	7	7	7
Goldwind	9	8	8	6	8
Sinovel	8	10	9	9	9
Ming Yang	11	11	10	10	10
United Power	12	12	11	10	11
Haizhuan	10	9	13	14	12
Envision	13	13	11	10	13
XEMC	14	14	13	13	14
SEwind	15	15	15	15	15

represented by wind turbine manufacturers, is an industry with a very limited number of key players: the top 15 manufacturers accounted for more than 85% of worldwide installed capacity by the end of 2018. This level of concentration enabled the researchers to perform a very thorough assessment of the different business internationalization models.

For the first time, this research has applied business internationalization indicators to analyze the internationalization effectiveness of the wind energy technology industry. Moreover, with the novelty of including an indicator of speed, this research combined four indicators in a way to shed additional light on the process.

An intensity indicator provided evidence of how much the different companies have internationalized related to their total activity and the evolution of each firm's international business relative to each other's and to the global domestic business. The geographic extensity indicator revealed the range of countries that the companies expanded to and how apparently similar firms (in terms of depth of internationalization) focus the range of their international business differently. The geographic diversification index exposed the quality of internationalization and demonstrated that some firms narrowly focus their business on a limited number of countries, whereas the market leaders have a more balanced portfolio of sales per country. Finally, the speed indicator proved that first movers were slow in internationalizing, but they paved the way for other companies to internationalize at a much faster pace.

One company, Vestas, has led the internationalization of this industry since the beginning, both in terms of depth (96% of sales abroad, as measured by the intensity indicator I_{firm}) and width (73 countries entered). Vestas has also led in the quality of internationalization, as it is the company with the lowest dependency on a small number of markets, as presented by the geographic diversification index with a \overline{GD}_{firm} value of 1,334. Close to Vestas, SGRE, the company resulting from the merge of Siemens Wind Power and Gamesa, currently presents similar figures in all these indicators (75% intensity, 70 countries and $\overline{GD}_{firm} = 2,420$) after trailing behind during most of the growth period of the industry. Moreover, since 2011, SGRE has reached Vestas in the depth of internationalization (sales of 45 GW vs. 47 GW respectively) but not in the annual number of countries, with 27 and 33 countries respectively. Since 2014, SGRE has presented best-in-industry quality of internationalization with an average $\overline{GD}_{firm} = 1,068$, closely followed by Nordex (1,254) and Vestas (1,407).

Chinese companies, relative newcomers, are yet to enter foreign markets, although they are starting to do this and are led by Goldwind (\overline{GD}_{firm} 7,334 in the 2014–2017 period). These companies demonstrate that, in the wind energy sector at least, a strong rivalry pressure in the domestic market is not a guarantee for the international competitiveness of its highest performing firms. The findings suggest that other elements different from competitive forces highly influence the Chinese domestic market.

The openness of the wind energy sector, in terms of international reach, suggests that one of the important questions for future research is whether the arrival of foreign companies in a country with incumbents increases competition and how it occurs.

Disclaimer

The views expressed in this paper are purely those of the authors and may not in any circumstances be regarded as stating an official position of the European Commission. The authors declare not to have any significant competing financial, professional or

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Declaration of competing interest

None.

CRediT authorship contribution statement

Jose M. Yusta: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data curation, Writing - original draft, Writing - review & editing, Visualization, Supervision, Project administration, Funding acquisition. **Roberto Lacal-Arántegui:** Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data curation, Writing - original draft, Writing - review & editing, Visualization, Supervision, Project administration, Funding acquisition.

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Appendix A. Supplementary data

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Abbreviations

- GE: General Electric
 GW: gigawatt (= 1 billion Watts)
 HHI: Herfindahl-Hirschman index
 IEAWind: International Energy Agency Wind Technology Collaboration
 JRC: Joint Research Centre of the European Commission
 MW: megawatt (= 1 million Watts)
 NSI: network spread index
 OEM: original equipment manufacturer, in this report OEM refers to the turbine manufacturer
 SGRE: Siemens Gamesa Renewable Energy
 TNI: transnationality index