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China in global wind power development: Role, status and impact

Shijie Zhang [a], Jing Wei [b,*], Xi Chen [c], Yuhao Zhao [a]

[a] College of Mechanical Engineering, Chongqing University, Chongqing, 400044, PR China
[b] State Key Laboratory of Mechanical Transmission, Chongqing University, Chongqing, 400044, China
[c] Global R&D Center of Envision Energy, Shanghai, 200051, China

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ABSTRACT

China is the largest power producer and consumer and has the largest installed capacity of wind turbines (WTs) worldwide. In the last two decades, China's installed capacity of WTs has exploded, significantly impacting its wind power (WP) industry and promoting the development of the industry globally. This paper examines China as one part of the world and elucidates its role, status, and impact on global WP development from a global perspective. Research indicates that China has become the global leader in WP, its WP development has greatly promoted the growth rate of global WP, and it has become an indispensable force in global WP development. However, the comprehensive capability of China's WP generation is not only lower than that of other major WP countries but also lower than the global average. China's WTs have low global recognition and are difficult to export. In addition, the proportion of WP in China's power structure is lower than that of most other major WP countries. Fortunately, these gaps between China and other major WP countries are gradually narrowing. The goal of this paper is to help researchers and investors better understand China's situation and to provide a reference for the rational investment in and development of China's WP.

1. Introduction

Many countries have signed agreements to address global climate change, such as the Kyoto Protocol and the Paris Agreement, and these countries are striving to fulfill their commitments [1,2]. There is consensus on the need to reduce fossil energy and to accelerate the development and utilization of renewable energy among most countries, and they are engaging in concerted action [3,4]. As a source of clean energy with high storage, no pollution, and using mature technology, many countries are seeking to utilize wind energy [5] and consider wind power (WP) to be a promising energy [6]. China, a major energy-consuming carbon emission country, is one of many countries that have installed wind turbines (WTs) (as shown in Fig. 1). The Chinese government is actively supporting the development of clean energy through laws, regulations, finance, and taxation. With the strong support of the Chinese government, the country's WP has experienced explosive growth [7,8]. In 2018, the cumulative capacity of WP installed in China accounted for a record high of 35.7% of the total globally, ranking first.

China's WP development has attracted worldwide attention. To date, a high volume of literature has reported on country's WP status, development and policies. For instance, He et al. [9], Xu et al. [10], Zhao et al. [11], and others [12,13] studied the development of onshore/offshore WP in China. Kang et al. [14], Zhang et al. [15], Zhou et al. [16], Lu et al. [17], and others [18–21] analyzed China's WP policy, development and challenges. Lin et al. [22], Lam et al. [23], and Ru et al. [24] studied the innovation capabilities of China's WP industry and found that they are relatively low and that national policies, WP deployment and feed-in tariffs have a great impact on China's WP technological innovation. Dai et al. [25] performed a comprehensive assessment of the development of China's WP industry and found that it is still facing many challenges. McElroy et al. [26] studied the development potential of WP in China and found that the country's WP capacity will reach 640 GW. In addition, some studies have examined the globalization of China's WP. For example, Zhang et al. [27] and Tan et al. [28] studied the internationalization of China's WP. Zhao et al. [29] performed a comparative assessment of the performance of foreign and local WT manufacturers in China and identified their competitive advantages and disadvantages in the Chinese market. Additionally, Zhao et al. [30] studied the impact of international forces on the Chinese WP industry and found that the international cooperation subsystem, joint

Abbreviations: GWEC, Global Wind Energy Council; CWEA, Chinese Wind Energy Association; PTC, Production Tax Credit; WPIC, wind power installed capacity; GR, growth rate; MHI, Mitsubishi Heavy Industries; WT, wind turbine; WP, wind power.

* Corresponding author.
E-mail address: weijing_slmt@163.com (J. Wei).

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Units and nomenclature

MW	Megawatt
GW	Gigawatt
TWh	TeraWatt Hour

research and development and information sharing provide both finance and technologies for the entire Chinese WP industry. Lema et al. [31] and Zhou et al. [32] found that China's WP has a low level of innovation and technology through research on the innovation path of WP and quantitative analysis of the knowledge base of WP firms in Asia and Europe; however, they also noted that China is constantly improving its innovation ability through mergers with European enterprises. Lacal-Arntegui [33] found that the globalization of WP has greatly promoted the technological progress of Chinese WP enterprises. Lema et al. [34] studied China's impact on the global WP industry considering five categories of power, launching a new field focused on the WP industry to study the impact of China's rise on the changing global landscape. However, outside of this example, few studies focus on the role, status, and impact of China on the development of global WP. In particular, there is a lack of research on China's WP development from the perspective of globalization.

Therefore, this study focuses on the role, status and impact of China on global WP development. More importantly, as its major innovation, this study examines the role and impact of individuals on overall development from the perspective of globalization. By establishing a multifactor model and selecting several important factors for analysis, this study performs a comprehensive evaluation of China's role, status, and impact on global WP development. This study fills a research gap in this field and provides a reference for researchers and investors to better understand China's situation for the rational investment in and development of China's WP.

2. Research methodology

There are many factors that determine the international role and status of a country's WP (as shown in Fig. 2), and some of these factors are interrelated and mutually restricted. Therefore, it is difficult to establish a comprehensive analytical model to accurately analyze the international role and status of China's WP in the development process of global WP. To solve this problem, this paper analyzes the various factors that determine the international role and status of WP and the linkages and constraints among these factors. It selects several factors that have a great impact on the status of China's WP in the world for detailed study, such as China's import and export of WTs, the average generation by WTs in major WP countries and the comprehensive capability of WP generation in China.

Through public reports, scientific articles, news, microblogs, government policies, the annual reports of companies and other publicly available information, necessary data can be collected. Then, the data can be classified, screened, summarized, compared, analyzed and standardized. Finally, based on the comprehensive impact of various factors and examines China as one part of the world, the role, status and impact of China on the development of global WP can be elucidated and determined.

3. WP development in China and globally

Over the past two decades, as the energy crisis, environmental degradation and greenhouse gas emissions have intensified, the global development of clean energy has received increasing attention. Among the numerous clean energy sources, the development of WE has been particularly rapid, which is reflected not only in the installed capacity but also in the growth rate (GR), the maximum WT size and the average installed capacity of WTs.

3.1. Installed capacity of WP in China and globally

Although the Kyoto Protocol was adopted in December 1997, it entered into force in February 2005 [35]. During the period prior to

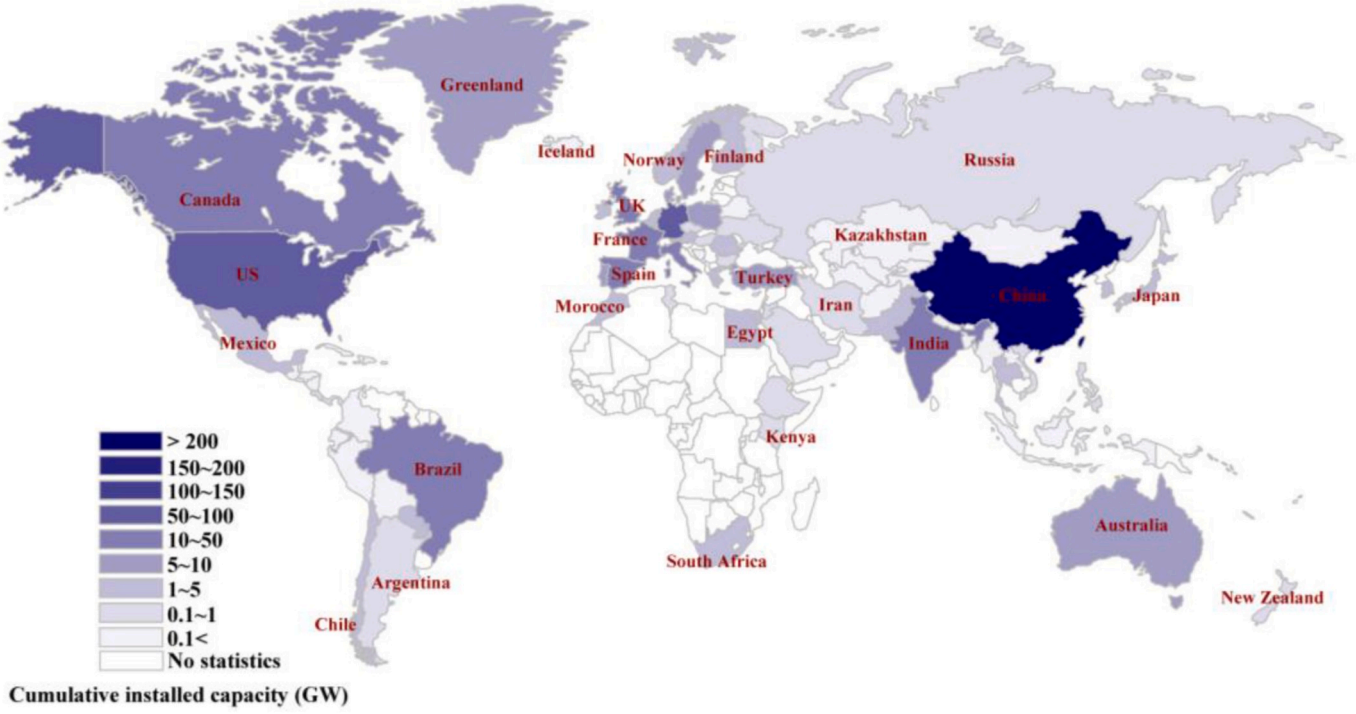


Fig. 1. Distribution of WP installed around the world.

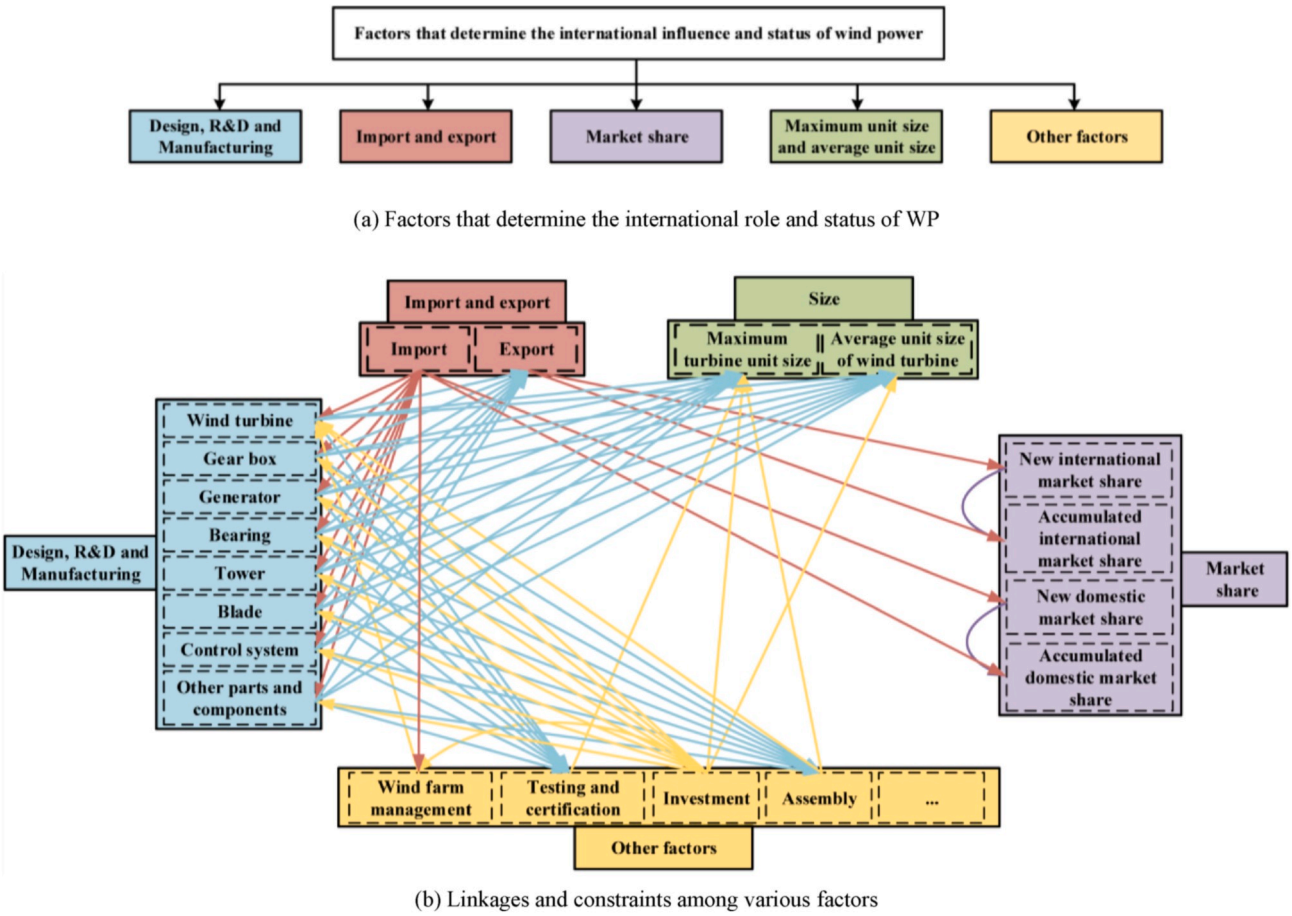


Fig. 2. Factors that determine the international role of WP and their interrelations.

2005, WP development globally and in China did not show significant growth, but after 2005, it began to rapidly develop worldwide (Fig. 3). The new wind power installed capacity (WPIC) of global increased in all years except 2013, 2016, 2017 and 2018. In 2015, the new WPIC globally and in China reached a peak of 63.63 GW and 30.75 GW, respectively [36]. Subsequently, the new WPIC of global decreased for three consecutive years. In 2018, the new WPIC globally and in China was 51.32 GW and 23.00 GW [37], respectively, an increase of −2.24% and 16.99% over the 2017 level. By the end of 2018, the cumulative WPIC globally and in China reached 591.55 GW and 211.39 GW, respectively [37,38]. As a result, since 2000, the average annual GR of WP globally and in China has been 21.64% and 42.82%, respectively. The GR of WP in China is almost twice that of wind power worldwide.

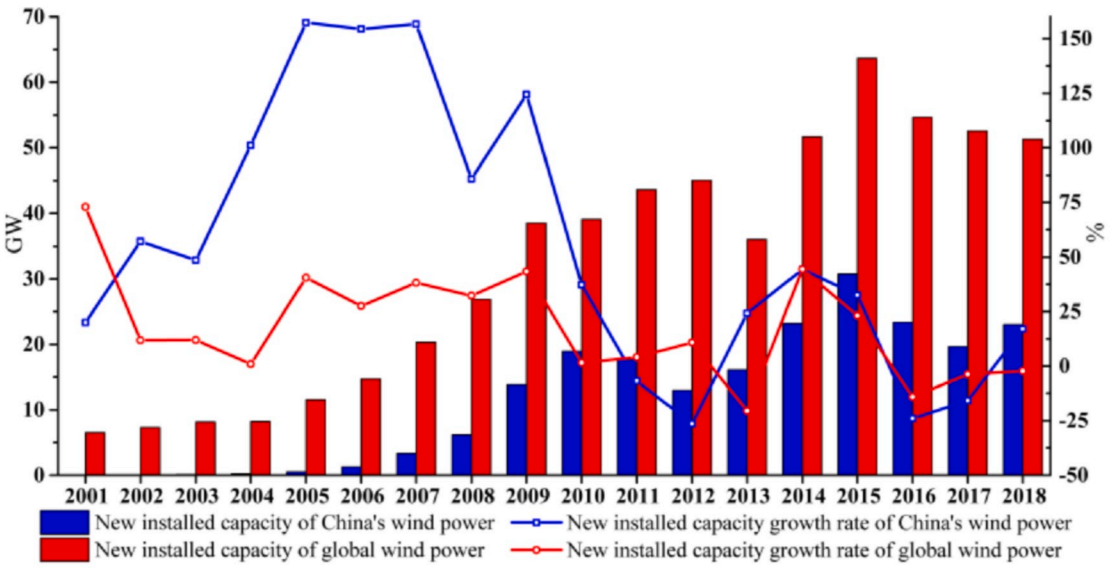
According to China Wind Energy Association (CWEA) data, China's WP has experienced explosive development. In the period under study, the GRs of both the new and cumulative installed capacity of China's WP were much higher than the global average. China's GR for new WPIC and total WPIC achieved maximum of 157% and 130%, respectively, whereas globally, these maximum GRs were only 43.3% and 31.8%, respectively. Due to the explosive development of China's WP industry, in 2010, China became the top ranked country globally for total WP capacity [53]. In the same year, China's new WPIC accounted for 48.5% of the global total, and in 2010, China abolished its localization policy to attract foreign investment [54]. Since China became the largest country in wind power installed capacity (WPIC) in 2010, the country's new and accumulated WPIC have consistently ranked first in the world, and 2018 was no exception (as shown in Fig. 4).

3.2. Maximum size of WTs in China and globally

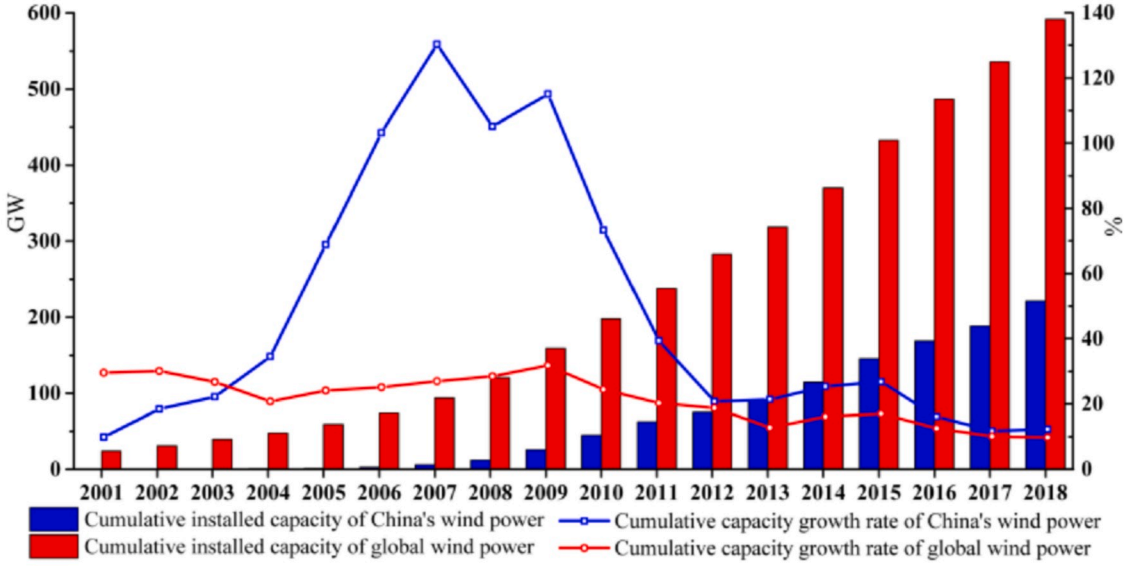
To reduce equipment costs, improve the utilization of land and obtain more wind energy, development is trending towards large-scale single-unit capacity WTs (as shown in Fig. 5). All major WP countries are competing to develop large-scale WTs, and to some extent, the maximum unit size of WTs reflects a country's WP technology level. At present, the maximum WT that has been installed or will be installed worldwide (agreement reached but not yet installed) is 9.5 MW [55], but the maximum WT that has been installed or will be installed in China is only 7.25 MW [56]. Although Goldwind has released 8 MW WT [57], they are still far from formal installation. Meanwhile, the 10 MW WT produced by MHI Vestas has obtained product quality certification and will be officially installed for commercial use in 2021 [58]. The prototype of the Haliade-X 12 MW WT developed by GE is undergoing pre-installation preparations at the Port of Rotterdam in the Netherlands [59]. From this perspective, there is still a large gap in the maximum WT unit size between China and other countries, although this gap has been gradually narrowing since 2000.

3.3. Average unit size of WTs in China and globally

In 2017, the average size of new installed WTs globally passed 2.5 MW for the first time [60], reaching 2.525 MW (Fig. 6). However, the average rated capacity of new turbines installed in China is only 2.111 MW, which is lower than the global average, only slightly higher than that of India, and lower than that of other major WP countries. Among the world's major WP countries, the average size of new installed WTs in the UK is the largest. The average unit size of WTs in three countries—China, the US and India—is lower than the global average, but the



(a) New installed capacity of WP



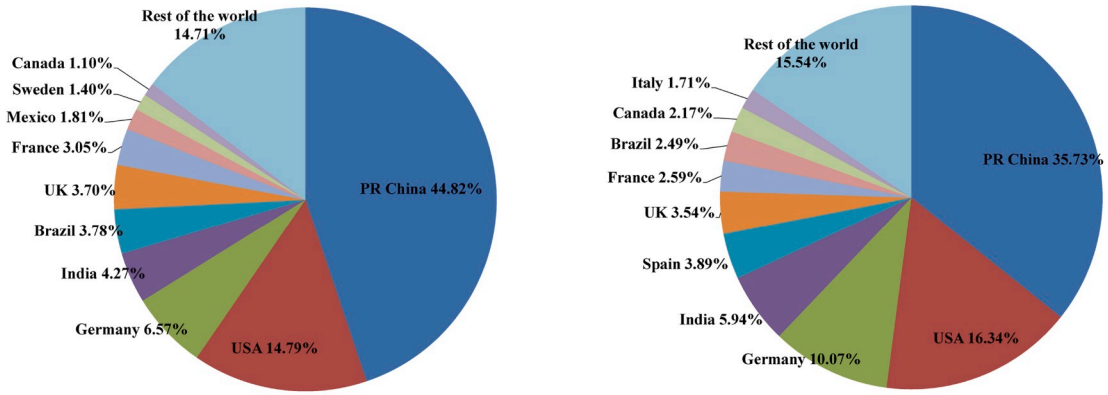
(b) Cumulative installed capacity of WP

Fig. 3. Installed capacity of WP in China and globally: 2001–2018.
Source: Based on data from [36–52].

total WPIC in these three countries accounts for a large proportion of the global total. Therefore, the average size of new installed WTs in China, the US, and India greatly reduces the global average unit size of new installed WTs. In 2018, the average rated capacity of new installed WTs in the US surpassed the global average, promoting an increase in the average size of new installed WTs worldwide. However, the average rated capacity of new installed WTs in China and India is still lower than the global average. Because the new installed capacity of WTs in China and India together accounts for 49.1% of global new installed turbines, it ultimately dropped the average size of new installed WTs globally to below 2.5 MW in 2018, 2.452 MW [61]. Among the world's major WP countries, the average size of new installed WTs in Germany, Denmark and the UK has surpassed 3.75 MW, and it is expected to reach 4 MW in 2019. In particular, the UK is likely to be the first country to break through 4 MW with regard to the average size of new installed WTs. Meanwhile, the average size of China's new installed WTs is only 55.5% that of the UK, representing a large gap.

4. The impact of China on the global WP growth rate

China's WP development is part of global WP development. Due to the strong support of the Chinese government, the proportion of China's WP in global WP is rising rapidly. The development of China's WP is inseparable from the development of global WP, and the rapid development of WP in China has also increased the GR of global WP.



(a) Share of new WPIC (b) Share of cumulative WPIC

Fig. 4. Top ten share of the global wind market by the end of 2018.
Source: Based on data from [38].

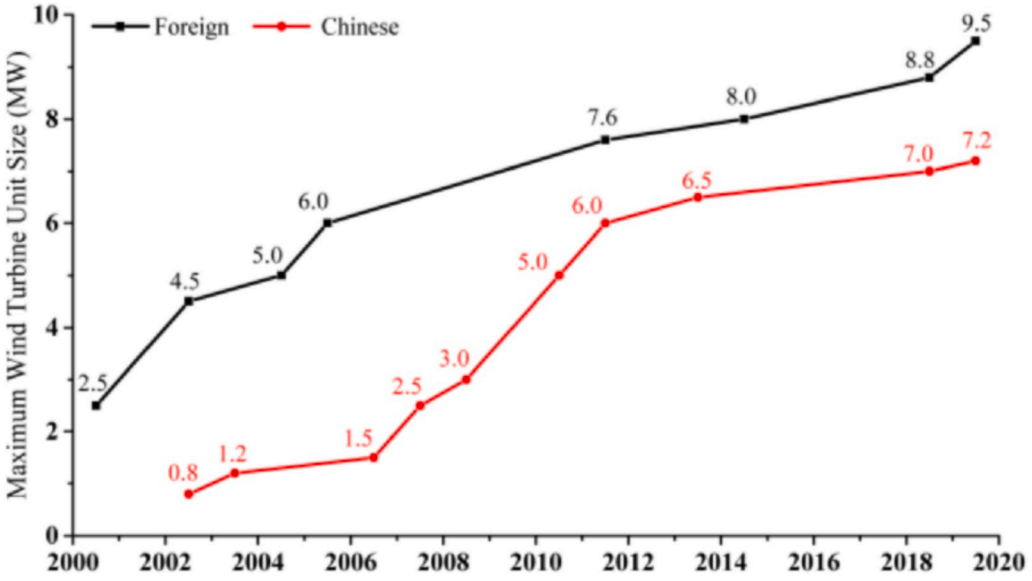


Fig. 5. Maximum WT unit size.

4.1. Proportion of China's WP in global WP

Since entering the new century, the proportion of China's WP in global WP has increased annually (as shown in Fig. 7). Before 2003, China's WP represented a very small share of the global market, with both new and accumulated WPIC accounting for less than 2% of the global total. To promote the domestic WP manufacturing industry, the Chinese government implemented a localization policy for the concession project initiated in 2003 [27], and this policy stipulated that the localization rate of WP equipment in the construction of wind farms should not be less than 50%. This percentage was raised to 70% in the Notice on the relevant requirements of WP construction management issued by the National Development and Reform Commission in 2005 [62]. Meanwhile, to accelerate the development of renewable energy in China and to respond to the call for energy conservation and emission reduction in the Kyoto Protocol, the Chinese government promulgated the Renewable Energy Act in 2005, which came into force the following year [63]. Supported by a series of incentive policies from the Chinese government, China's WP has developed rapidly, China's WP technology has gradually matured, and China has realized the localization of WTs and the cost of production, manufacturing and transportation of WTs in China dropped significantly. Eventually, under the influence of many factors such as policies and the cost decrease, the proportions of China's new and accumulated WPIC in the global totals have rapidly increased.

The financial crisis of 2008 seriously affected the global economy and the development of WP in different countries to varying degrees [34]. Because China was less affected by the financial crisis and because it had the strong support from the Chinese government, its WP development was only slightly affected. In 2008, China's new WPIC ranked second worldwide [64]. In the following year, China exceeded the United States in new WPIC, becoming the country with the greatest new WPIC globally [53]. That same year, China's cumulative WPIC surpassed that of Germany, making it second only to the United States. China then surpassed the US in 2010, making it the country with the greatest cumulative WPIC globally [40], a position it holds today. In 2018, China's cumulative WPIC accounted for 35.73% of the global total, and it represented more than one-third of the global WPIC for four consecutive years. China has become an indispensable force in the development of global WP.

4.2. China's impact on the growth rate of global WP

In different periods of global WP development, China's WP has accounted for a varying proportion of global WP, and the impact of

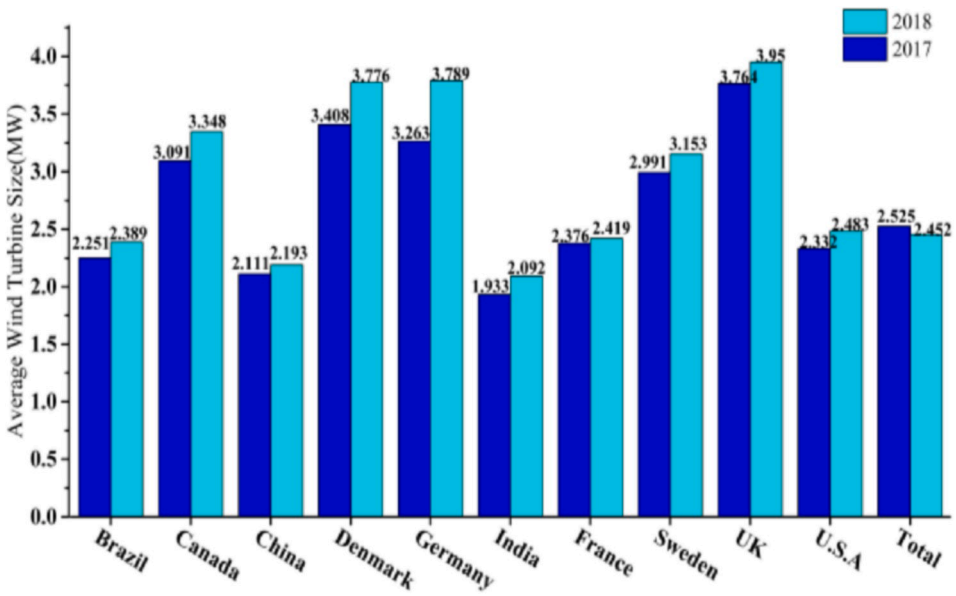


Fig. 6. Average size of new installed WTs.

China on global WP development has also varied. The difference between the proportion that China's cumulative WPIC and new WPIC represent in global totals reflects the impact of China on the GR of global WP at different stages, that is, whether it increases or decreases the GR of global WP. Additionally, the difference in the GR of global WP when including China and excluding China reflects the extent of China's impact on the GR of global WP (Fig. 8 a). Before 2003, China's cumulative WPIC accounted for a higher proportion of the global total than China's new WPIC accounted for in global new WPIC, and China lowered the global average GR. However, at that time, China's new WPIC accounted for a small proportion of the global total; thus, its impact on the GR of global WP was small. After China implemented the localization policy for wind farm construction in 2005, the proportion of China's new and cumulative WPIC in the respective global totals increased rapidly. However, the proportion of China's cumulative WPIC globally has increased at a slower rate than that of China's new WPIC globally, and the difference between the two is gradually increasing, which means that China is having a gradually increasing impact on the global GR of WP.

During the rapid development period of 2005–2010, the proportion of China's new WPIC in the global total increased from 4.4% in 2005 to 48.5% in 2010, and the proportion of China's accumulated WPIC in the global total increased from 2.1% in 2005 to 22.6% in 2010. The difference between the two increased gradually. In 2010, the difference between the proportion of China's new WPIC in the global total and that of China's cumulative WPIC in the global total reached a maximum of 25.9%, which means that the impact of China on the GR of global WP reached a peak (Fig. 8 b). China has increased the GR of global WP by 9.5% points, representing an increase of 63.1%. Due to the large-scale abandonment of WP caused by the power grid failure in 2011 [65], China's new installed WP capacity declined sharply, and China's contribution to global WP growth decreased accordingly. Meanwhile, the "price war" caused by overcapacity has also harmed China's WP industry: "There is no minimum, only lower" is a phrase that vividly portrays the price war at that time; thus, 2012 is called the "cold winter" of China's WP industry [66]. Nonetheless, China continued to contribute to the increase in the GR of global WP. In that year, the GR of global WP including China increased by 0.7% points more than the GR of global WP excluding China, with an overall increase of 3.9%. As the global cumulative WPIC increases, the GR of global WP decreases. The difference in the GR of global WP including China and that excluding China is also decreasing, but China still plays a significant role in promoting the growth of global WP.

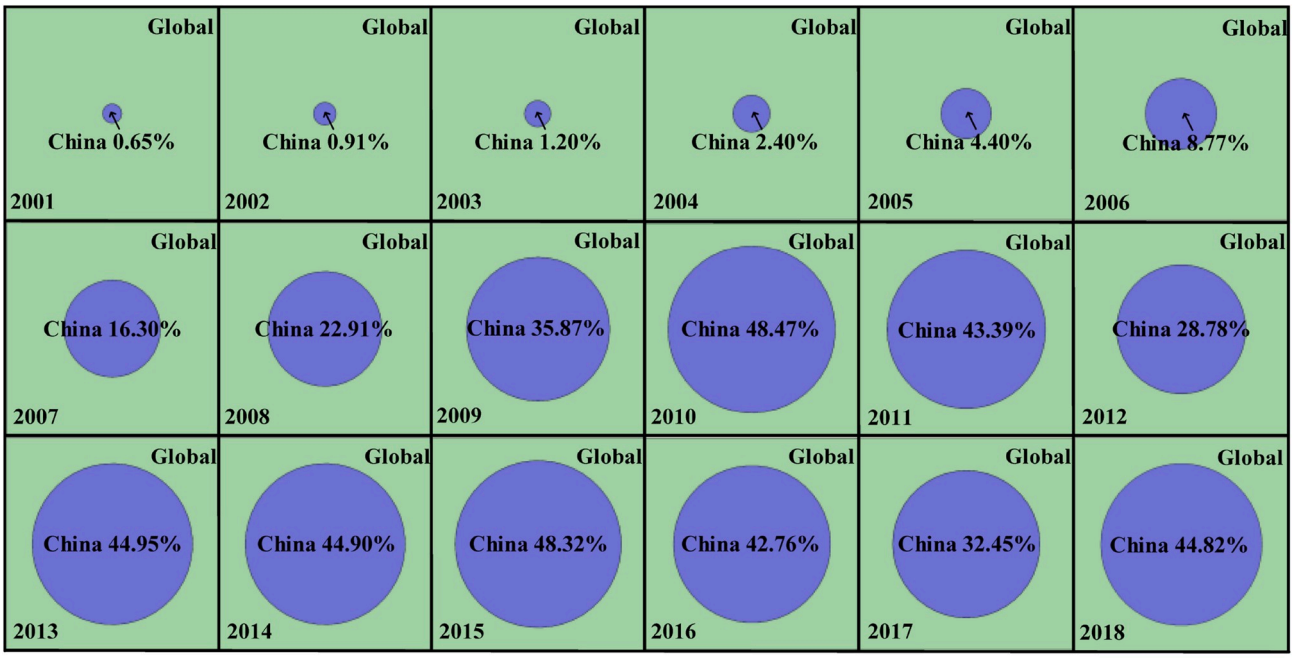
5. Import and export of WTs in China

China's WP market is large, and the import and export of WTs in China will have a great impact on global WT enterprises. The development of China's WP has undergone a transition from relying on imports to achieving continuous exports. Due to the low price and certified quality of China's WTs, it quickly occupied the local market and caused most foreign WT manufacturers to withdraw from the Chinese market. Meanwhile, with the increasing export scale of China's WTs, the impact of China's WP on the global market is growing.

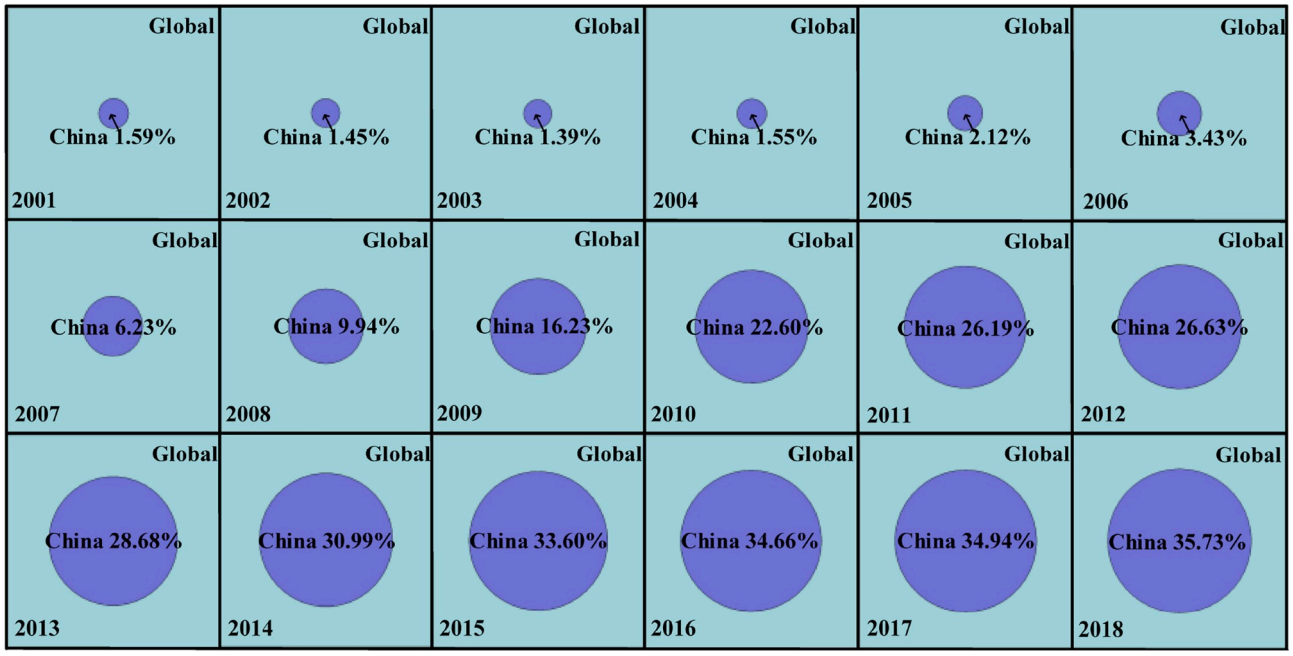
5.1. *The import of WTs in China*

The turbines used in the early stage of China's WP development were mostly imported. In 1985, China installed its first WT [67], and its WP industry began to develop. Prior to 2001, more than 90% of WTs in China were imported, but there was also only a small market for WP in China at that time, and the capacity of imported WTs in China was small. With the rapid development of China's WP industry, the capacity of imported WTs in China began to increase. However, China's WP imports did not experience explosive growth mirroring the development of China's WP industry because imports were hindered by China's localization policy and local WP companies began to emerge. Meanwhile, the share of imported WTs in the Chinese market declined sharply due to the large number of local WP enterprises emerging and seizing the market. In 2001, the shares of cumulative and new imported WTs in the Chinese market were 90.74% and 91.43%, respectively, but they fell 77.40% and 69.95% by 2005 (Fig. 9). Following the period of exponential development in China's WP industry (2005–2010), the shares of cumulative and new imported WTs in the Chinese market were only 17.50% and 8.47%, respectively, by the end of 2010. Thus, the incentive policy for WP development promulgated by the Chinese government benefited the development of local but not foreign WT enterprise development in China.

By the end of 2018, the cumulative capacity of imported WTs in China was 15.38 GW, and the share of cumulative imported WTs in the Chinese market was 7.28%; the capacity of new imported WTs in China was 0.975 GW, and the share of new imported WTs in the Chinese



(a) Scale diagram of the new installed capacity of WP



(b) Scale diagram of the total WP installed capacity

Fig. 7. The proportion of WP in China to that worldwide.

market was only 4.24%. The fierce competitive environment, price wars and the protection of local WP enterprises by the Chinese government forced many foreign WP enterprises, such as Suzlon, REpower and Zond, to withdraw from the Chinese market. At present, except for Vistas, GE and Siemens, it is very difficult for foreign WP enterprises to obtain orders in China, and the era of foreign WTs dominating the Chinese WP market has ended.

5.2. China's WT export

In 1999, the Chinese government initiated the "go international" strategy [32]. However, in the early stage before 2007, China's WP development was slow, and all of its WTs were used in the domestic market. In 2007, Huayi Wind Energy exported three WTs to Chile [68], with a total export capacity of 2.34 MW, marking the first step in Chinese WT export. However, the export of Chinese WTs did not grow as rapidly as the development of China's WP. In contrast, it has been very difficult for China to export WTs, and the share of Chinese WT exports in the global market (excluding China) is very small. Before 2010, the annual export capacity of Chinese WTs was less than 0.15% of the global market (excluding China), and the total exported capacity was less than 0.4% of the global market (excluding China). It was not until 2011 that Chinese WTs export capacity surged, reaching 692 MW in 2013 [45] and accounting for 3.51% of the global market (Fig. 10). In the three years

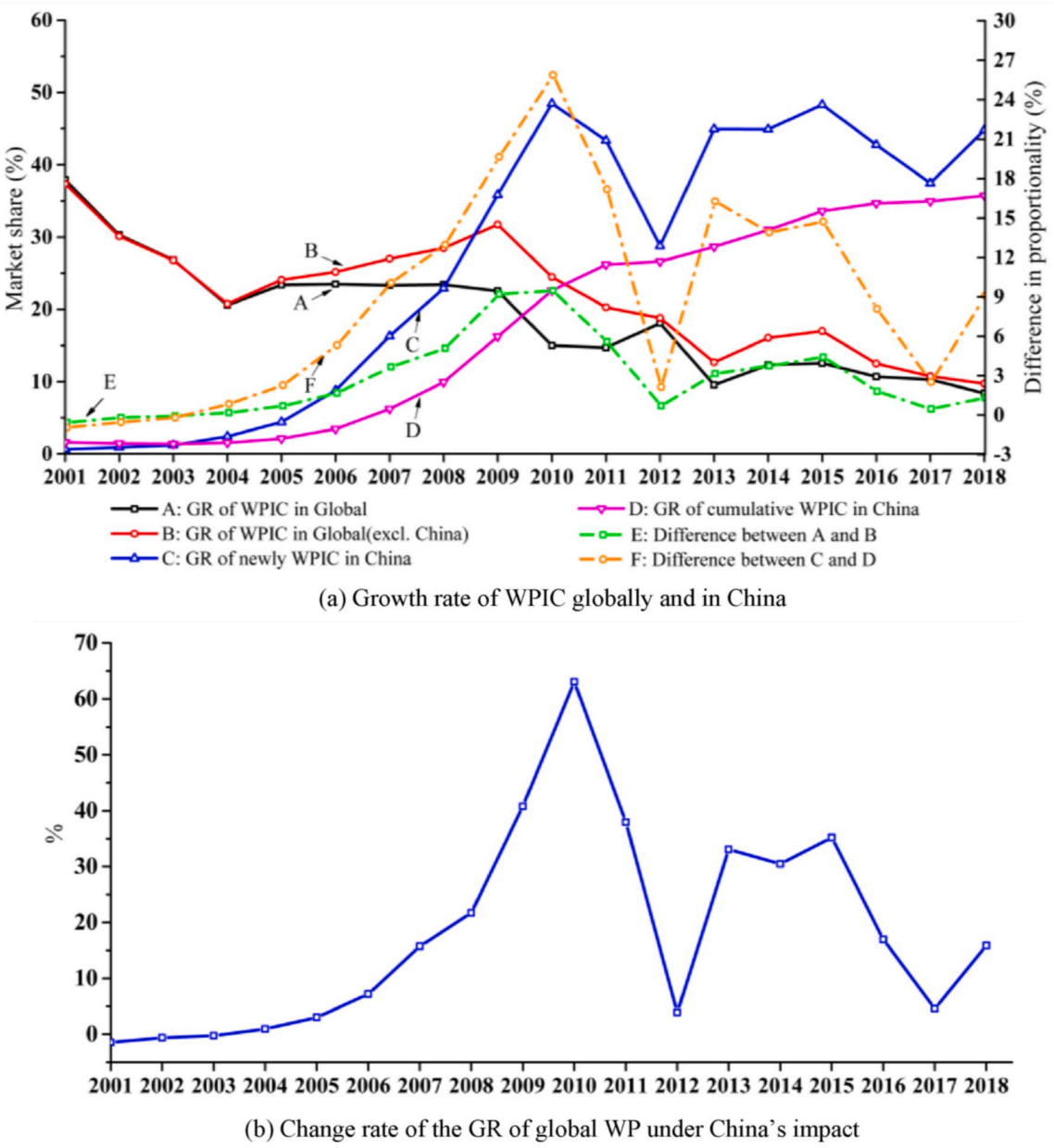


Fig. 8. The curve of China's impact on global WP.

from 2011 to 2013, the export capacity of Chinese WTs showed a rapid growth trend; thus, 2011 represents the commencement of the internationalization of Chinese WT manufacturers [69]. However, this boom period did not last long, and the export capacity of Chinese WTs dropped sharply after 2013. Although it increased later, to date, the peak capacity of Chinese WT exports remains at 692 MW. By the end of 2018, China's total exported WP capacity was only 3.58 GW [37], which is less than 1% of the global market (excluding China).

Although the export capacity of Chinese WTs is small, the export markets for Chinese WTs are increasing rapidly. Chinese WTs exported to only 1 country in 2007 but exported to 19 countries in 2011. By the end of 2018, the export market of Chinese WTs reached 34 countries (as shown in Table 1). Among them, the United States is the largest export market for Chinese WTs, with a cumulative capacity of 552 MW, accounting for 15.38% of China's cumulative WP export capacity. Additionally, Australia and Pakistan account for 14.31% and 11.9% of China's WP cumulative export capacity, respectively. Unlike the situation of Chinese WTs in the global market, the share of Chinese WTs in different export markets varies. Take the United States, Australia, Pakistan, India and South Africa as examples. The share of Chinese WTs in the US market is less than 1%, only 0.57% (in 2018, the cumulative installed capacity of WP in the United States was 96.67 GW [37]); similarly, the share of Chinese WTs in the Indian market is also small, only 0.32% (in 2018, the cumulative installed capacity of WP in India was 35.13 GW [37]). However, compared with China's market share in the United States and India, Chinese WTs accounted for a larger share of the market in Australia, South Africa and Pakistan, at 9.58%, 14.34% and 59.14%, respectively. Notably, the installed capacity of WP in these countries is small: the total capacity of WP in Australia, South Africa and Pakistan is 5.36 GW, 2.09 GW and 0.72 GW, respectively.

Clearly, Chinese WTs have not been recognized in major WP countries around the world, their market share in major WP countries is extremely small, and their influence is extremely limited. However, Chinese WTs have a higher market share and a greater influence in some countries with a small WPIC, which may be related to the relatively low cost of Chinese WTs and the smaller demand for WTs in these countries.

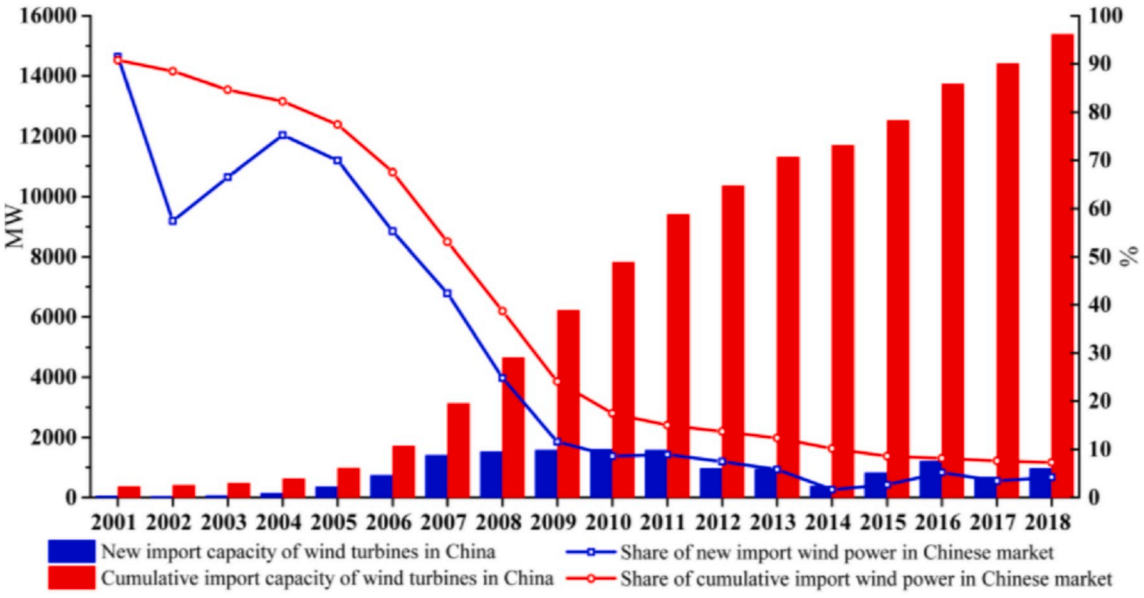


Fig. 9. Capacity of imported WTs in China and their share in the Chinese market: 2001–2018.

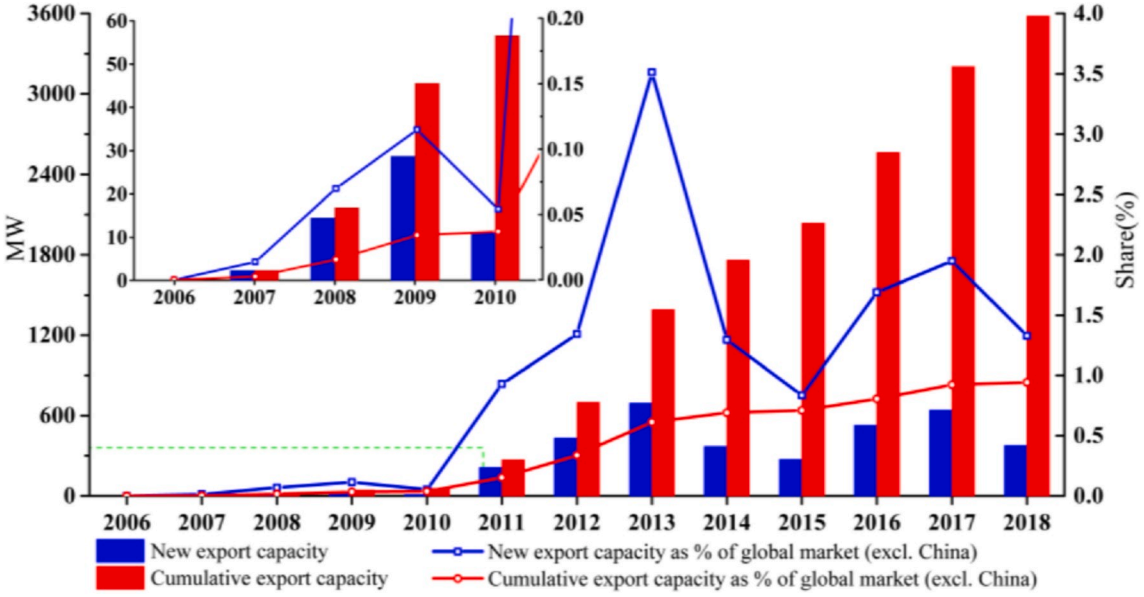


Fig. 10. China's WT export capacity and its share in the global market.

Table 1
Export countries and cumulative export capacity of Chinese WTs through 2018 [38].

N	Country	Accumulated (MW)	% Share	N	Country	Accumulated (MW)	% Share	N	Country	Accumulated (MW)	% Share
1	USA	552	15.38	13	Chile	77	2.15	25	Ecuador	17	0.47
2	Australia	513.5	14.31	14	Mexico	70	1.95	26	Belarus	9	0.25
3	Pakistan	427	11.90	15	Bulgaria	52	1.45	27	Kazakhstan	7	0.20
4	South Africa	299	8.33	16	Brazil	51.5	1.44	28	Finland	5	0.14
5	Panama	270	7.52	17	Romania	50	1.39	29	Cuba	5	0.14
6	Ethiopia	224	6.24	18	Iran	50	1.39	30	Morocco	4	0.11
7	Turkey	141.7	3.95	19	Montenegro	46	1.28	31	UK	4	0.11
8	Sweden	134	3.73	20	Philippines	40	1.11	32	Denmark	4	0.11
9	Thailand	122	3.40	21	France	37	1.03	33	Bolivia	3	0.084
10	India	111	3.09	22	Spain	36	1.00	34	Uzbekistan	1	0.028
11	Italy	92	2.56	23	Russia	35	0.98	Total		3581	100
12	Argentina	78.4	2.19	24	Cyprus	20	0.56				

Considering the number of exporting countries, the export markets and international influence of Chinese WTs are increasing. However, judging from the export capacity of Chinese WTs, the internationalization of Chinese WTs is still far many years away. The proportion of Chinese WTs in the global WP market (excluding China) is still small, and the market shares of Chinese WTs in major WP countries are also small. In other words, Chinese WTs have limited international influence in global and major WP countries but have a greater influence in a few countries with a small WPIC. However, in the long run, with the further improvement of the quality of China's wind turbines, its export capacity will increase, and the prices of global wind power will be reduced by that time.

5.3. Domestic sales rate and share in the domestic market of Chinese WTs

The accumulated market share of Chinese local WP enterprises was less than 20% before 2005, but this proportion began to increase with the implementation of a series of Chinese government policies to encourage the development of local WP enterprises. At the end of 2010, local Chinese enterprises held 91.4% market share for new WPIC and 82.5% market share for accumulated WPIC (Fig. 11). In 2010, the new WPIC in China was 37.34 times that in 2005. In just six years, the total WPIC in China reached 43.468 GW, of which Chinese local enterprises represented an installed capacity of 36.622 GW, with a market share of 84.25%. Since then, the share of local WTs in the Chinese market has remained high, and the market share of local WTs in new installed WTs has remained above 90% every year, reaching a maximum of 98.35%. By the end of 2018, local WTs accounted for 92.72% of the cumulative WPIC in China, holding a dominant position. Among China's local wind turbine manufacturers, seven large wind turbine manufacturers—Goldwind, United Power, Mingyang, Huarui, Envision, Dongfang Electric and ShangHai Electric—account for 68% of the domestic market [38]. Goldwind ranks first, with 23.65% of the domestic cumulative WP market.

This enormous installed capacity in the domestic market has enabled China to accumulate rich experience in the production, manufacture, and installation of WTs, but it has not increased export orders. Since the first export in 2007, the export capacity of Chinese WTs has remained relatively small. In other words, most WTs produced by Chinese local manufacturers are installed domestically. Approximately 98% of the WTs manufactured annually by Chinese manufacturers are used in the domestic market, and the utilization rate of local Chinese WTs was the lowest in 2013 (95.63%). By the end of 2018, 98.23% of the cumulative WTs produced by Chinese manufacturers were used in the domestic market. Therefore, we have reason to believe that China is a country that is dependent on its domestic market and that Chinese WT manufacturers are regional rather than international enterprises. Although more than half of the top 15 WT manufacturers worldwide were from China in 2018 [60] (as shown in Table 2), they have benefited from China's huge domestic market but have not changed the status quo for Chinese WT manufacturers, which find it difficult to sell outside of China. According to a CWEA report [38], only four Chinese WT manufacturers achieved exports in 2018, Goldwind, Envision, Dongfang Electric and Sinovel, with a total export capacity of 376 MW. Among them, Goldwind's installed capacity of WTs in 2018 was 6707.2 MW, ranking second in the global market and first in the Chinese market, but the export capacity of its WTs was only 274 MW, which means that 95.91% of the WTs produced by Goldwind were used in the domestic market. Similarly, the installed capacity of Envision's WTs was 4180.5 MW in 2018, ranking fifth in the global market and second in the Chinese market, but its export capacity was only 75 MW, and 98.21% of WTs produced by this manufacturer were used in the domestic market. Other Chinese WT manufacturers that entered the top 15 of the global market in 2018 have not achieved exports, and all of the WTs they produce are used in the domestic market.

From the first WT export to the end of 2018, a 12-year period, the

Table 2
Top 15 WT manufacturers globally and their market share in 2018 [60].

Market share ranking	Manufacturer	Country	Share (%)
1	Vestas	Denmark	20.3
2	Goldwind	China	13.8
3	Siemens Gamesa	Spain	12.3
4	GE Renewable Energy	USA	10.0
5	Envision	China	8.4
6	Enercon	Germany	5.5
7	Mingyang	China	5.2
8	Nordex Acciona	Spain	5.0
9	United Power	China	2.5
10	Sewind	China	2.3
11	Suzion	India	1.8
12	Senvion	Germany	1.8
13	Windey	China	1.7
14	CSIC Haizhuang	China	1.6
15	XEME	China	1.1
Total of top 15			93.3

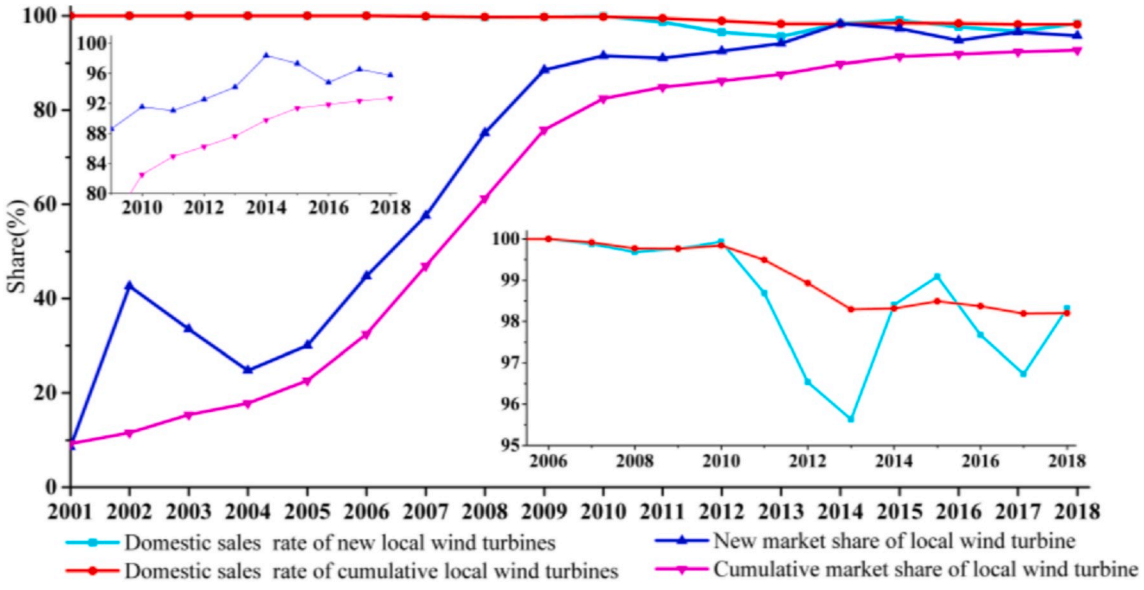


Fig. 11. Domestic sales rate and domestic market share of Chinese WTs.

total capacity of export WTs was 3.58 GW, indicating the difficulty in exporting them. The fierce competition, price war and the local protectionism in the Chinese WP market decreased the market share of foreign WT enterprises in China. Meanwhile, Chinese WTs have poor reliability and low recognition globally, ultimately creating a situation in which "Chinese enterprises find it difficult to go out, and foreign enterprises find it more difficult to enter". However, the international market cannot be circumvented [70], and a single target market is not conducive to the development of WP manufacturing. Chinese WP enterprises face many problems and shortcomings, such as high supply chain costs, long capital cycles, and overcapacity. In 2018, the National Energy Administration issued a notice on "Configuring and Determining the Electricity Price through Competition" [71], which indicates that China will soon realize the same price for WP and thermal power. The promulgation of this policy will force Chinese WP enterprises to reduce WP costs in a relatively short time; otherwise, they will find it difficult to survive. Currently, Chinese WT manufacturers are actively seizing the market and maximizing their market share, but increasing domestic competition has forced domestic WT manufacturers to expand overseas.

6. The level of WP generation

By analyzing the WP generation capacity, the proportion of WP in the power consumption and the average power generation capacity of WTs in a country, the development potential of WP and the comprehensive capacity of WP generation in that country can be obtained, which is conducive to guiding the development of WP.

6.1. Power generation and WP generation in major WP countries

In the development of modern society, all countries attach great importance to the development of electric power. According to the "BP Statistical Review of World Energy June 2019" report, in 2018, global electricity production reached 26614.8 TWh [72]. Meanwhile, the proportion of WP in the global power structure is still low, representing only 1270.0 TWh in 2018 and accounting for 4.77% of the global total, less than 5%. To promote the development of the new energy industry, many countries have formulated policies: the New Tax Reform Act in the US retains the "Production Tax Credit" to reduce the tax credit for WP [73,74]; Germany approved a plan to reform renewable energy laws to facilitate bidding and to increase WP deployment in 2016 [75,76]; the Spanish government is encouraging foreign companies to transfer their production bases to Spain and provides financial subsidies for localized WP projects [76,77]; and Denmark provides long-term financing and guaranteed loans for projects using Danish WTs and low-interest loans for WT technology research [78,79]. As the largest country in terms of WPIC, China has also implemented a series of policies to encourage and support the development of its WP industry, such as the National Strategic Emerging Industries Development Plan of the 13th Five-Year Plan [80], the 13th Five-Year Plan for Renewable Energy Development [81], the 13th Five-Year Plan for WP Development [82], the Notice on the Establishment and Improvement of the Renewable Energy Power Consumption Guarantee Mechanism [83], the Notice on Improving the WP On-grid Price Policy [84], the Notice on the Green Industry Guidance Catalogue [85], and others [86–88]. The implementation of these policies is gradually improving and promoting the development of WP in China.

Currently, China is the world's largest producer of electricity and of WP. In 2017, China's electricity production reached 6495.1 TWh [89], accounting for 25.4% of the global total (Fig. 12), and China's WP production reached 286.1 TWh [90], accounting for 25.5% of the global total (Fig. 13). This marks the first time that the global proportion of China's WP production exceeded the global proportion of China's electricity production, and both represent more than a quarter of the global total. In 2018, China's electricity production reached 7111.8 TWh [72], representing an increase of 7% over 2017, and accounting for 26.72% of the global total, while China's WP production reached 366.0 TWh [72], representing an increase of 24.1% over 2017 and accounting for 28.8% of the global total. As shown in Figs. 11 and 12, the proportion of China's power generation in the global total has increased steadily, and the proportion of China's WP generation in the global total has increased rapidly with the increase in its cumulative WPIC.

Among the major WP countries and major electricity producers, the United States, Germany, and Spain have a higher proportion of global WP production than of global electricity production. Thus, in these countries, WP has played an important role in promoting electricity production and increasing the proportion of their electricity production globally. However, the global share of WP generation in Germany and Spain is declining sharply. In particular, the global share of WP generation in Spain fell from 20.34% in 2005 to 4.01% in 2018. Thus, it appears that something is hindering the development of WP in Germany and Spain. Although Russia and Japan rank among the top five worldwide in terms of electricity generation, WP in these two countries accounts for a small proportion of the global total, less than 1%, which

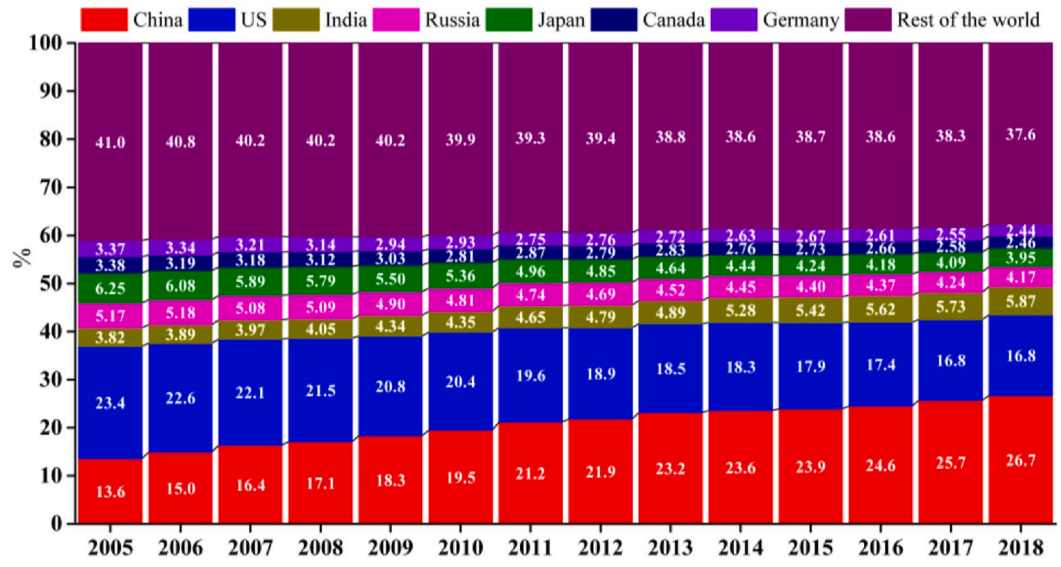


Fig. 12. Proportion of electricity production in major countries.

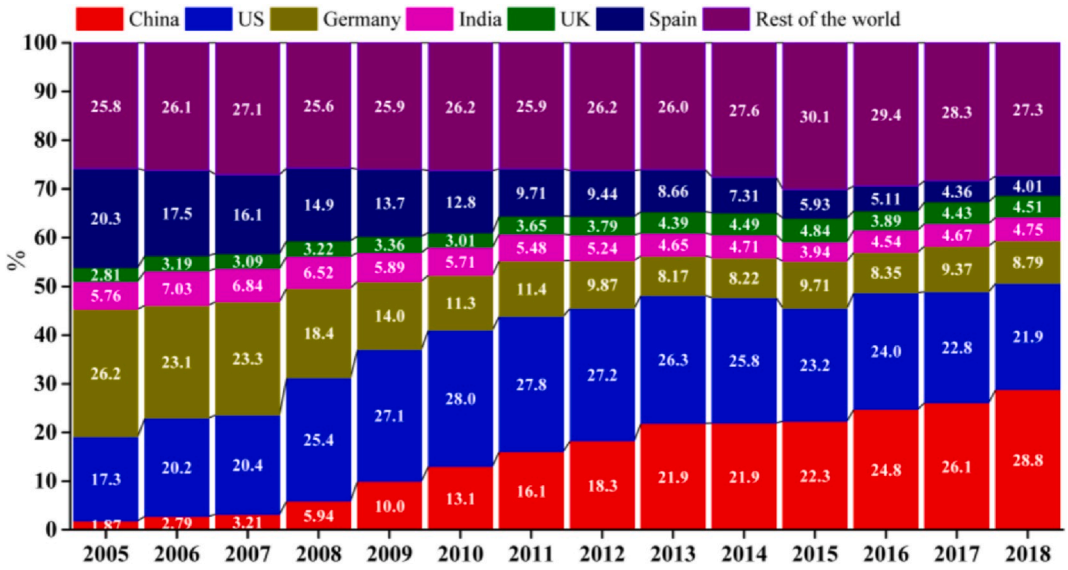


Fig. 13. Proportion of WP production in major WP countries.

shows that WP is developing slowly in these two countries. However, Russia and Japan rank among the top five worldwide in terms of WP patents, far surpassing China. In particular, Japan has the largest number of WP patents in the world [6].

6.2. Proportion of WP in the electricity structure of major countries

Although China is the world's largest producer of WP, the proportion of Chinese WP in its electricity structure is relatively low (Fig. 14). This proportion was below the global average prior to 2017, reached the global average in 2017 and slightly exceeded the global average in 2018. Among the major WP countries, Denmark has the highest proportion of WP in its power structure, and it is much higher than that in other countries, followed by Spain, Germany and the UK. In 2017, the proportion of WP in Denmark's total power generation was 43.6%, which is a record high [91]; in 2018, this proportion dropped to 41% [92]. The proportion of WP in Spain's power structure is relatively stable, and in 2010–2018, it remained at 15%–20%. The proportion of WP in the power structure of the United Kingdom and Germany increased rapidly in 2010, reaching 6.08% and 2.69%, respectively, but increasing to 17.20% and 17.10% by 2018. Apart from these countries, the proportion of WP in the electricity structure of other major WP countries is less than 10%, and in China, this proportion was only 5.15%. According to the analysis and forecast of the International Energy Agency, the proportion of WP in Denmark's power structure will exceed 50% by 2020; the proportion of WP in Spain's power structure will peak at approximately 20%, and the proportion of WP in Germany's power structure will surpass 20% [93]. According to the US Department of Energy, WP will account for 10% of US total by 2020 [94]. The goal of China's 13th Five-Year Plan for WP Development is for the proportion of WP in China's power structure to reach 6% by 2020 [82]. In the proportion of WP in the power structure, there is a large gap between China and other major WP countries. However, this gap also indicates that China's WP has much room for development compared to other major WP countries.

6.3. The average power generation of WTs in major WP countries

The average power generation of WTs is determined by numerous factors, such as wind resources, WT quality, wind farm management and grid infrastructure, and these are a direct reflection of the

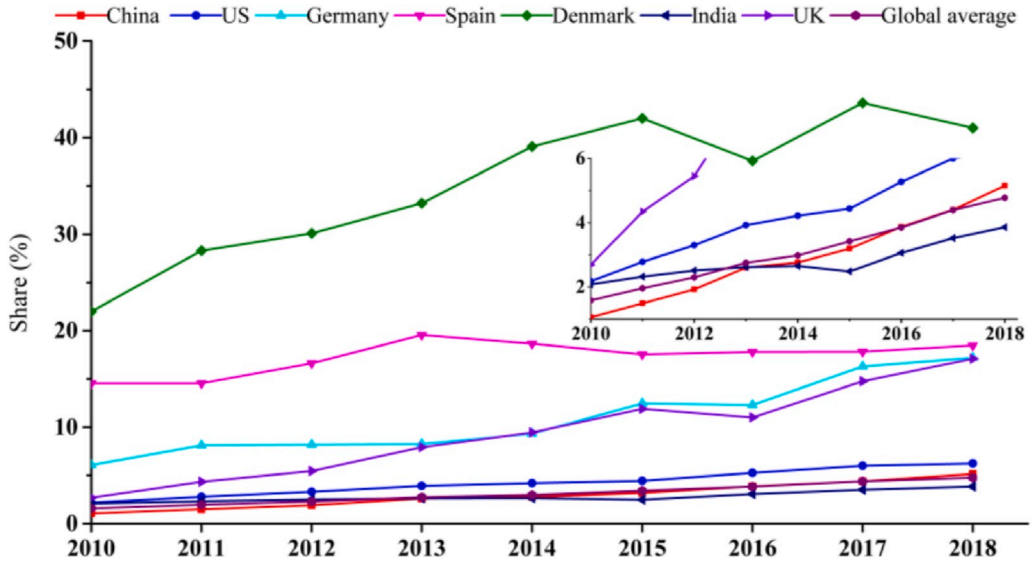


Fig. 14. Share of WP generation in the power structures of major WP countries.

comprehensive capacity of WP generation in a country. The larger the average power generation of WTs is, the higher the comprehensive capacity of WP generation in a country. With the development of the global WP industry, the average power generation of WTs in the world is constantly improving (as shown in Fig. 15). Among the major WP countries, Denmark, the United States and the United Kingdom have consistently held the leading position in the average power generation of WTs, which is far higher than the global average. This once again demonstrates that in terms of the comprehensive capacity for WP generation, Denmark, the United States and the United Kingdom are the global leaders. However, the average power generation of WTs in China is low, being lower than not only the global average but also the averages of all other major WP countries. Thus, the comprehensive capacity of WP generation in China is very low, and the total amount of electricity produced by a WT in China is supported by the huge installed capacity of WTs. At present, China's WP generation is still in the stage of winning by "quantity" rather than "quality". Strong WP countries such as the United States not only have the advantage of "quantity" but also have higher "quality" WP generation. However, although strong WP countries such as Denmark and the UK do not have a huge installed capacity of WP, they do have a higher comprehensive capacity of WP generation. Thus, it becomes clear that judging whether a country is a powerful WP country or not is more concerned with the "quality" than with the "quantity" of WP generation. Therefore, China must improve its comprehensive capacity for WP generation to become a strong WP country and not just a large WP country.

The low average capacity of WP generation in China is the result of a combination of factors. For example, with the backward technology and high failure rate of China's WTs, the average downtime of domestic WTs is longer than that of WTs produced by strong WP countries; China's "Three North" region is rich in wind resources, and many wind farms have been developed and constructed. However, the economic development of the "Three North" region is backward, and the power consumption capacity is insufficient. At the same time, the grid's capacity to accept WP is insufficient, and the cross-regional transmission capacity is poor. To prevent large-scale power failure and to ensure the stability of the grid, WP must be reduced in large quantities. Notably, however, China is actively encouraging the development of distributed WP and offshore WP. At the same time, China is also boosting grid construction and improving the load-bearing and transmission capacity of the grid, and these measures will be more conducive to improving the average capacity of China's WP.

Fortunately, the gap between China and other major WP countries is gradually narrowing. As shown in Fig. 16, based on the average power generation of WTs in China, the per unit (p.u.) average power generation of WTs in other major WP countries is obtained, where China's p.u. average power generation of WTs is 1. The p.u. average power generation of WTs in other major WP countries is continually approaching 1, which means that the gap in the average power generation of WTs between China and other major WP countries is decreasing and that the gap in the comprehensive level of WP generation between China and other major WP countries is also decreasing. The function fitting of p.u. values for the average power generation of WTs in major WP countries shows that the average power generation of WTs in China will reach the global average level as soon as 2025 based on the current development trend in WP. However, China still has a large gap with strong WP countries. By 2038, the average power generation of WTs in China will be equal to that of the United States, but it will still fall short of the average power generation of WTs in Denmark and the UK. Therefore, China still has a long way to go before becoming a strong WP country.

7. Future prospects of WP in China

After more than 30 years of development, China's WP has gradually matured, and China has become one of the leaders in the development of global WP. At present, the development of WP in China and globally mainly involves onshore WP. However, with the increasing restrictions on onshore WP and the increasing requirements on the efficiency of WTs, WP is developing towards large-scale offshore WP.

Compared with onshore WP, the offshore wind speed is 15%–40% higher, the annual operating hours can reach more than 4000, and the wind stability is relatively good. Therefore, WTs can output high power in a stable manner and can generate 50%–70% more power [95]. However, the offshore environment is more complex, and more factors need to be considered in the development of offshore WP, such as the impact of waves on WTs [96,97], the erosion of blades in the offshore salt fog environment [98,99], the distribution and classification of offshore wind resources [100,101], the wind energy storage of the China Sea [102,103] and the offshore wind farm management [104,105], among others. These are urgent problems in the development of offshore

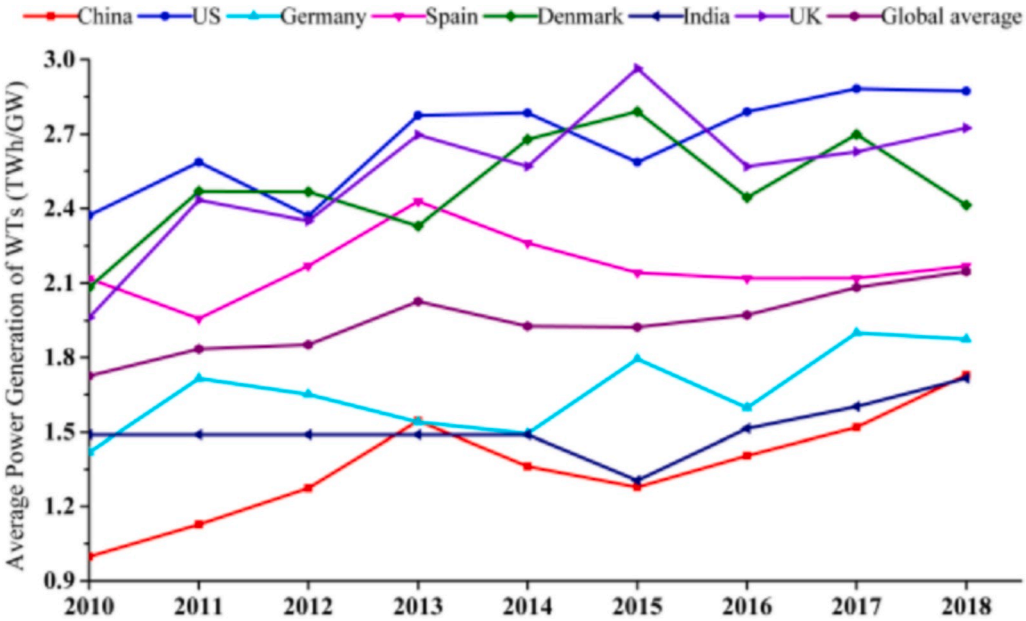


Fig. 15. Average power generation of WTs (TWh/GW).

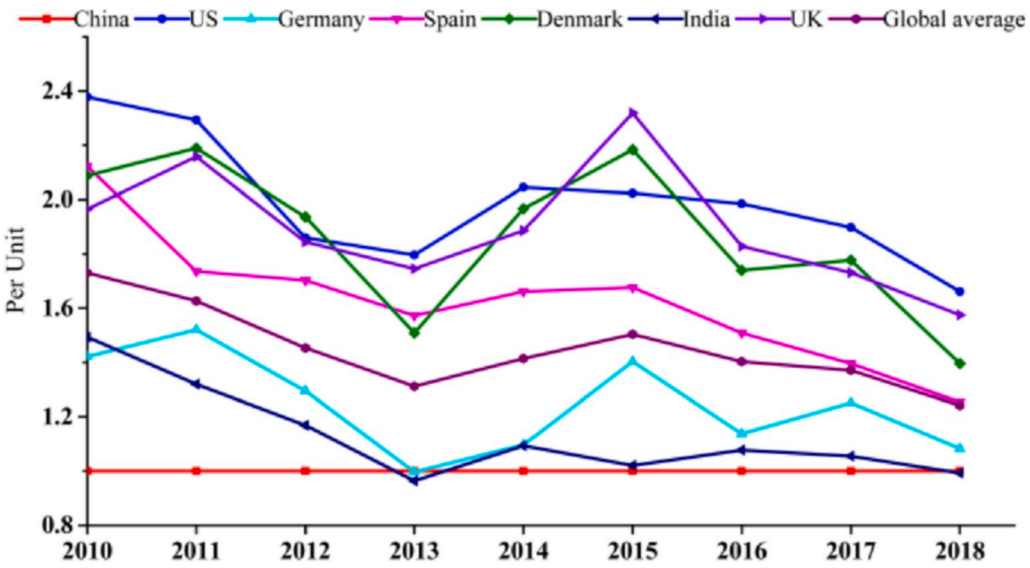


Fig. 16. Per unit average generation of WTs in major WP countries.

WP. The researches conducted by Zheng et al. [96,106,107] are important for the development of offshore WP in China, and these researches will provide reference for the wind power plant location and will be helpful to study the influence of wave impact on offshore wind turbine foundation. Unfortunately, current research on offshore WP in China still lags behind that in Europe (such as Denmark and Germany); thus, China must accelerate research on offshore wind resources, the marine environment and other factors to better develop the country's offshore WP.

Compared with WP related technology research, the installed capacity of offshore WP in China is growing rapidly. Before 2010, almost all offshore WP projects were located in Europe; even in 2015, 91.1% of the global installed capacity of offshore WP was in Europe, with the UK having the largest offshore WPIC, followed by Germany and Denmark [48]. By the end of 2018, the market share of the cumulative installed capacity of European offshore WP had fallen to 79.5% worldwide and for the first time it was below 80%. Meanwhile, the global market share of the cumulative installed capacity of China's offshore WP increased from 8.38% in 2015 to 19.32% in 2018, and the cumulative installed capacity reached 4443 MW. The new installed capacity of China's offshore WP in 2018 accounted for 38.04% of the global total, reaching 1655 MW [37]. Since 2010, China's new offshore WPIC has increased at a compound annual GR of 36.7% and the cumulative installed capacity is increasing at a compound annual GR of 52.6%. China has become one of the fastest-growing countries in offshore WP development. The development of WP in China is also moving in the direction of large-scale WTs. The future of China's WP will also be offshore WP. After China becomes the leader in WPIC, it is expected that China will become the leader in offshore WP technology.

8. Conclusions

This paper treated China's WP as part of global WP to elucidate China's role, status and impact on global WP development. It found that China's role, status and impact on global WP development have undergone tremendous changes with the development of WP globally and in China. After the Kyoto Protocol entered into force, WP, both globally and in China entered a rapid development period. However, the development of WP in China has been faster than that globally. The proportion of China's accumulated WPIC in global WP increased from 1.59% in 2001 to 35.7% in 2018, and the total installed capacity and new installed capacity rank first. China has transitioned from a small WP country to an indispensable force in WP development.

The rapid development of WP in China has spawned a large number of local WP enterprises, which have seized much of the domestic market, forcing many foreign WP enterprises to withdraw from the Chinese market. China's WP has realized the transformation from relying on imports to achieving continuous exports. Unfortunately, China's WTs have low recognition globally, and the share of Chinese WTs in the international market is less than 1%. Therefore, at present, the impact of China's WP on the global WP market is very limited. However, the development of WP in China has greatly promoted the growth of WP worldwide. Under the influence of China, the GR of global WP has increased by a maximum of 9.5% points, for an increase of 63.1%. The rapid development of WP in China has given confidence to the global WP industry and triggered a wave of WP development in more countries. It is believed that with the expansion of China's WT export scale, the impact of China's WP on the global WP market will increase, causing the global WP price to drop due to the low price of China's WTs.

At present, China's WP is still in the stage of winning by "quantity" rather than "quality". The maximum WT unit size of China is small, the average rated capacity of new turbines installed in China is below the global average, and the average power generation of WTs in China is lower than that in other major WP countries. Compared to the world's major WP countries, the technology level of China's WP technology is lower. Fortunately, the gap between China's WP and that of other major WP countries is gradually narrowing. After more than ten years of development, China has become a large WP country and a global WP leader. Currently, China is striving to meet the goal of becoming a strong WP country. If China can overtake at a bend in the development of offshore WP, then it will truly become a strong WP country, it will have a greater impact on the development of global WP, and the development of global WP will follow China's lead. However, before this happens, the development of WP in China will face more difficulties and challenges. Nonetheless, we should have full confidence in China's ability to face these issues.

In summary, China's WP development has matured, and China has become one of the global leaders in WP. Meanwhile, the rapid development of China's WP has increased the average GR of global WP. Although the installed capacity of China's WP ranks first in global, China's WP is still in the "quantity" victory stage, and the quality of China's WP needs to be improved. Due to the low price of Chinese WTs, China's WP has had a huge impact on foreign WT manufacturers and greatly squeezed the share of foreign manufacturers in the local market. With Chinese WTs getting more and more recognition worldwide, China's WP will have an increasing impact on the international WP

market.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

[1] Arantegui Roberto Lacal, Jäger-Waldau Arnulf. Photovoltaics and wind status in the European union after the Paris agreement. Renew Sustain Energy Rev 2018; 81:2460–71.
[2] Fan Xiaochao, Wang Weiqing. Spatial patterns and influencing factors of China's wind turbine manufacturing industry: a review. Renew Sustain Energy Rev 2016; 54:482–96.
[3] Dong Yang, liu Jingru, Yang Jianxin, Ding Ning. Carbon footprint of wind turbine by life cycle assessment. Acta Sci Circumstantiae 2015;35:927–34 [in Chinese].
[4] Li Lingyue, Ren Xiaoqing, Yang Yanli, Zhang Peidong, Chen Xiao. Analysis and recommendations for onshore wind power policies in China. Renew Sustain Energy Rev 2018;82:156–67.
[5] Duan Hongbo. Emissions and temperature benefits: the role of wind power in China. Environ Res 2017;152:342–50.
[6] Yi Feng, Lin Heyun, Ho SL, Yan Jianhu, Dong Jianning, Fang Shuhua, et al. Overview of wind power generation in China: status and development. Renew Sustain Energy Rev 2015;50:847–58.
[7] Lu Zeyu, Li Wenhua, Xie Baichen, Shang Lifeng. Study on China's wind power development path based on the target for 2030. Renew Sustain Energy Rev 2015; 51:197–208.
[8] Lema Rasmus, Nordensvärd Johan, Urban Frauke, Lutkenhorst Wilfried. Technological trajectories for climate change mitigation in Europe, China and India. Wind energy in Europe. GDI Working Paper. Bonn, Germany: German Development Institute; 2014.
[9] He ZhengXia, Xu ShiChun, Shen WenXing, Zhang Hui, Long Ruyin, He Yang, et al. Review of factors affecting China's offshore wind power industry. Renew Sustain Energy Rev 2016;56:1372–86.
[10] Xu Lei, Pang Mingyue, Zhang Lixiao, Roger Poganietz Witold, Marathe Sheetal Dattatraya. Life cycle assessment of onshore wind power systems in China. Resour Conserv Recycl 2018;132:361–8.
[11] Zhao Xingang, Ren Lingzhi. Focus on the development of offshore wind power in China: has the golden period come? Renew Energy 2015;81:644–57.
[12] Liu Changyi, Wang Yang, Zhu Rong. Assessment of the economic potential of China's onshore wind electricity. Resour Conserv Recycl 2017;121:33–9.
[13] Wu Jie, Wang Zhixin, Wang Guoqiang. The key technologies and development of offshore wind farm in China. Renew Sustain Energy Rev 2014;32:453–62.
[14] Kang Junjie, Yuan Jiahai, Hu Zhaoguang, Xu Yan. Review on wind power development and relevant renewable policies in China during the 11th Five-Year-Plan period. Renew Sustain Energy Rev 2012;16:1907–15.
[15] Zhang Sufang, Li Xingmei. Large scale wind power integration in China: analysis from a policy perspective. Renew Sustain Energy Rev 2012;16:1110–5.
[16] Zhou Yuan, Xu Guannan, Minshall Tim. A policy dimension required for technology roadmapping: learning from the development of emerging wind energy industry in China. PICMET 2011, P.S. University, Portland.
[17] Lu Xi, McElroy Michael B, Peng Wei, Liu Shiyang, Nielsen Chris P, Wang Haikun. Challenges faced by China compared with the US in developing wind power. Nat Energy 2016;61:1–6.
[18] Lema Rasmus, Zhou Yuan. Wind energy development in China. World Energy Monitor 2012;4:5–16.
[19] Zhao Xiaoli, Li Shujie, Zhang Sufang, Yang Rui, Liu Suwei. The effectiveness of China's wind power policy: an empirical analysis. Energy Pol 2016;95:269–79.
[20] Kumar Sahu Bikash. Wind energy developments and policies in China: a short review. Renew Sustain Energy Rev 2018;81:1393–405.
[21] Zhang Sufang, Andrews-Speed Philip, Zhao Xiaoli. Political and institutional analysis of the successes and failures of China's wind power policy. Energy Pol 2013;56:331–40.
[22] Lin Boqiang, Chen Yufang. Impacts of policies on innovation in wind power technologies in China. Appl Energy 2019;247:682–91.
[23] Lam Long T, Lee Branstetter, Azevedo Inês ML. China's wind industry: leading in deployment, lagging in innovation. Energy Pol 2017;106:588–99.
[24] Peng Ru, Zhi Qiang, Zhang Fang, Zhong Xiaotian, Li Jiangqiang, Su Jun. Behind the development of technology: the transition of innovation modes in China's wind turbine manufacturing industry. Energy Pol 2012;43:58–69.
[25] Dai Juchuan, Yang Xin, Wen Li. Development of wind power industry in China: a comprehensive assessment. Renew Sustain Energy Rev 2018;97:156–64.
[26] McElroy Michael B, Lu Xi, Nielsen Chris P, Wang Yuxuan. Potential for wind-generated electricity in China. Science 2009;325:1378–80.
[27] Zhang Sufang, Wang Wei, Wang Lu, Zhao Xiaoli. Review of China's wind power firms internationalization: status quo, determinants, prospects and policy implications. Renew Sustain Energy Rev 2015;43:1333–42.
[28] Tan Hao, John A, Mathews. Accelerated internationalization and resource leverage strategizing: the case of Chinese wind turbine manufacturers. J World Bus 2015;50:417–27.
[29] Zhao Zhenyu, Ling Wenjun, George Zillante, Zuo Jian. Comparative assessment of performance of foreign and local wind turbine manufacturers in China. Renew Energy 2012;39:424–32.
[30] Zhao Zhenyu, Sun Guangzheng, Zuo Jian, George Zillante. The impact of international forces on the Chinese wind power industry. Renew Sustain Energy Rev 2013;24:131–41.
[31] Lema Rasmus, Sagar Ambuj, Zhou Yuan. Convergence or divergence? Wind power innovation paths in Europe and Asia. Sci Publ Pol 2015;43:400–13.
[32] Zhou Yuan, Li Xin, Lema Rasmus, Urban Frauke. Comparing the knowledge bases of wind turbine firms in Asia and Europe: patent trajectories, networks, and globalisation. Sci Publ Pol 2015;43:476–91.
[33] Lacal-Arántegui Roberto. Globalization in the wind energy industry: contribution and economic impact of European companies. Renew Energy 2019;134:612–28.
[34] Lema Rasmus, Berger Axel, Schmitz Hubert. China's impact on the global wind power industry. J Curr Chines Aff 2013;42:37–69.
[35] Kyoto IPCC. Protocol of united nations framework convention on climate change. 1997. Tokyo, Japan.
[36] Global Wind Energy Council. Global wind report, annual market update 2014. 2015. Brussels, Belgium.
[37] Global Wind Energy Council. Global wind report, annual market update 2018. 2019. Brussels, Belgium.
[38] China Wind Energy Association. Statistics of China's installed capacity of wind power. 2018. Beijing, China. 2019 [in Chinese].
[39] China Wind Energy Association. Statistics of China's installed capacity of wind power. 2010. Beijing, China. 2011 [in Chinese].
[40] Global Wind Energy Council. Global wind report, annual market update 2010. 2011. Brussels, Belgium.
[41] China Wind Energy Association. Statistics of China's installed capacity of wind power. 2011. Beijing, China. 2012 [in Chinese].
[42] Global Wind Energy Council. Global wind report, annual market update 2011. 2012. Brussels, Belgium.
[43] China Wind Energy Association. Statistics of China's installed capacity of wind power. 2012. Beijing, China. 2013 [in Chinese].
[44] Global Wind Energy Council. Global wind report, annual market update 2012. 2013. Brussels, Belgium.
[45] China Wind Energy Association. Statistics of China's installed capacity of wind power. 2013. Beijing, China. 2014 [in Chinese].
[46] Global Wind Energy Council. Global wind report, annual market update 2013. 2014. Brussels, Belgium.
[47] China Wind Energy Association. Statistics of China's installed capacity of wind power. 2015. Beijing, China. 2016 [in Chinese].
[48] Global Wind Energy Council. Global wind report, annual market update 2015. 2016. Brussels, Belgium.
[49] China Wind Energy Association. Statistics of China's installed capacity of wind power. 2016. Beijing, China. 2017 [in Chinese].
[50] Global Wind Energy Council. Global wind report, annual market update 2016. 2017. Brussels, Belgium.
[51] China Wind Energy Association. Statistics of China's installed capacity of wind power. 2017. Beijing, China. 2018 [in Chinese].
[52] Global Wind Energy Council. Global wind report, annual market update 2017. 2018. Brussels, Belgium.
[53] Global Wind Energy Council. Global wind report, annual market update 2009. 2010. Brussels, Belgium.
[54] National Development, Reform Commission. Notice on canceling the localization rate of procurement equipment for wind power project [in Chinese], https://www.ndrc.gov.cn/xxgk/zcfb/tz/201010/t20101014_965220.html. [Accessed March 2019].
[55] CNELC. The world's first batch of 9.5MW offshore wind turbines, manufactured by Mitsubishi Vistas are confirmed to be installed in Belgium [in Chinese], http://www.cnelc.com/text/1/181119/AD100871410_1.html. [Accessed December 2018].
[56] ESCN. China's largest offshore wind turbine has been successfully hoisted in Guangdong Province [in Chinese], http://www.escn.com.cn/news/show-712215.html. [Accessed March 2019].
[57] GOLDWIND [in Chinese], http://www.sohu.com/a/270217399_656637. [Accessed March 2019].
[58] MHI VESTAS OFFSHORE WIND. Products: Turbines & Innovations. http://www.mhivestasoffshore.com/innovations/; [accessed Mar. 2019].
[59] BJX. Brazil's first sea breeze project will adopt the Haliade-X 12MW developed by GE [in Chinese], http://news.bjx.com.cn/html/20190515/980424.shtml. [Accessed May 2019].
[60] China Wind News. Top 15 wind turbine suppliers in annual global market in 2017. 2018 [in Chinese], . [Accessed August 2018].
[61] Global Wind Energy Council. Global wind market development-supply side data 2018. 2019. Brussels, Belgium.
[62] National Development, Reform Commission. Notice on the relevant requirements of wind power construction management. https://www.ndrc.gov.cn/xxgk/zcfb/tz/200508/t20050816_965833.html. [Accessed May 2019].

[63] The National People's Congress. Renewable energy law of the People's Republic of China [in Chinese], http://www.china.com.cn/chinese/law/798072.htm. [Accessed April 2019].
[64] Brussels Belgium. Global wind 2008 report. Brussels, Belgium: Global Wind Energy Council; 2009.
[65] Zhang Sufang. International competitiveness of China's wind turbine manufacturing industry and implications for future development. Renew Sustain Energy Rev 2012;16:3903–9.
[66] Wind Daily. The price war of the wind turbines has to start again?. 2018. http://new_energy.in-en.com/html/newenergy-2318010.shtml. . [Accessed October 2018] [in Chinese].
[67] Jin Xin, Rong Yiming, Xiang Zhong. Wind turbine manufacturing industry in China: current situation and problems. Renew Sustain Energy Rev 2014;33:729–35.
[68] Ma Mai. China wind power is setting sail. Wind Energy 2011;4:25–30 [in Chinese].
[69] Li XiaoMei. Internationalization of wind power equipment industry in China is accelerating but facing not small barriers. China Energy 2011;10:17 [in Chinese].
[70] Why can't China's wind turbines go out?. 2017 [in Chinese], https://chuansongme.com/n/1825653148932. [Accessed May 2018].
[71] National Energy Administration. Notice on the requirements for wind power construction and management [in Chinese], http://zfxxgk.nea.gov.cn/auto87/201805/t20180524_3184.htm. [Accessed October 2018].
[72] BP. BP statistical Review of world energy June 2019.
[73] Lange Marcus Page, Glenn Cummins Valerie. Governance challenges of marine renewable energy developments in the U.S. – creating the enabling conditions for successful project development. Mar Pol 2018;90:37–46.
[74] deCastro M, Salvador S, Gómez-Gesteira M, Costoya X, Carvalho D, Sanz-Larruga FJ, et al. Europe, China and the United States: three different approaches to the development of offshore wind energy. Renew Sustain Energy Rev 2019;109:55–70.
[75] Böhringer Christoph, Landis Florian, Reaños Miguel Angel Tovar. Economic impacts of renewable energy promotion in Germany. Energy J 2017;38:189–209.
[76] Jan Abrell, Kosch Mirjam, Rausch Sebastian. Carbon abatement with renewables: evaluating wind and solar subsidies in Germany and Spain. J Publ Econ 2019;169:172–202.
[77] Lacal Arantegui Roberto, Jäger-Waldau Arnulf. Photovoltaics and wind status in the European union after the Paris agreement. Renew Sustain Energy Rev 2018;81:2460–71.
[78] Johansen Katinka, Paul Upham. The post-normal politics and science of wind power planning: evidence from a Danish near-shore wind farm tender. Energy Research & Social Science 2019;53:182–93.
[79] Gavard Claire. Carbon price and wind power support in Denmark. Energy Pol 2016;92:455–67.
[80] The State Council, Cabinet China's. Emerging sectors of strategic importance during the 13th Five-Year Plan period. 2017 [in Chinese], http://www.sohu.com/a/154770898805678. [Accessed October 2018].
[81] National Development, Reform Commission. China. 13th five-year plan for renewable energy development [in Chinese], https://www.ndrc.gov.cn/xxgk/zcfb/ghwb/201612/t20161216_962211.html. [Accessed March 2020].
[82] National Development, Reform Commission, China. Wind power development plan during 13th five-year plan period [in Chinese], http://www.gov.cn/xinwen/2016-11/30/content_5140637.htm. [Accessed March 2020].
[83] National Development and Reform Commission, National Energy Administration, China. Notice on the establishment and improvement of the renewable energy power consumption guarantee mechanism [in Chinese], http://www.gov.cn/xinwen/2019-05/16/content_5392082.htm. [Accessed March 2020].
[84] National Development and Reform Commission. Notice on improving the wind power on-grid price policy [in Chinese], http://www.gov.cn/xinwen/2019-05/25/content_5394615.htm. [Accessed March 2020].
[85] National Development and Reform Commission. Ministry of natural resources, ministry of housing and urban-rural development. Notice on the green industry guidance Catalogue. 2019 [in Chinese], https://www.ndrc.gov.cn/gzdt/201903/t20190305_930083.html. [Accessed March 2020].
[86] The State Council, Cabinet China's. Strategic action plan for energy development (2014-2020). accessed [in Chinese], http://www.gov.cn/zhengce/content/2014-11/19/content_9222.htm. [Accessed March 2020].
[87] National Development and Reform Commission, National Energy Administration, China. Energy planning during the 13th five-year plan period [in Chinese], https://www.ndrc.gov.cn/xxgk/zcfb/tz/201701/t20170117_962873.html. [Accessed March 2020].
[88] National Development, Reform Commission. China. 13th five-year plan for energy technology innovation [in Chinese], https://www.ndrc.gov.cn/xxgk/zcfb/tz/201606/t20160601_963080.html. [Accessed March 2020].
[89] BP. BP statistical Review of world energy June 2018.
[90] Renewables REN21. Global status Report , REN21. 2018. 2018.
[91] In 2017. Denmark's wind power installed capacity was 5.3 GW, and wind power generation accounted for 43.6%, of Denmark's total power generation, recorded a high point [in Chinese], http://newenergy.in-en.com/html/newenergy-2307868.shtml. [Accessed September 2018].
[92] The European Wind Energy Association. Wind energy in Europe in 2018- trends and statistics. 2019. Brussels, Belgium.
[93] What is the highest proportion of wind power and photovoltaic power in each country in 2020? [in Chinese], http://www.chinapower.com.cn/guoji/20160909/53280.html. [Accessed April 2018].
[94] ENERGY EFFICIENCY & RENEWABLE ENERGY OFFICE. Wind vision: a new era for wind power in the United States. 2015.
[95] Offshore Wind Power Still Faces Multiple Challenges: Vigilance Against Disorderly Development Leading to Wind Abandonment and Power Abandonment. Science and technology daily. http://www.nea.gov.cn/2019-08/02/c_138278568.htm. [Accessed August 2019].
[96] Zheng Chongwei, Li Chongyin. Variation of the wave energy and significant wave height in the China Sea and adjacent waters. Renew Sustain Energy Rev 2015;43:381–7.
[97] Zheng Chongwei, Wang Qing, Li Chongyin. An overview of medium-to long-term predictions of global wave energy resources. Renew Sustain Energy Rev 2017;79:1492–502.
[98] Valaker EA, Armada S, Wilson S. Droplet erosion protection coatings for offshore wind turbine blades. Energy Procedia 2015;80:263–75.
[99] Slot HM, Gelinck ERM, Rentrop C, van der Heide E. Leading edge erosion of coated wind turbine blades: review of coating life models. Renew Energy 2015;80:837–48.
[100] Zheng Chongwei, Xiao Ziniu, Peng Yuehua, Li Chongyin, Du Zhibo. Rezoning global offshore wind energy resources. Renew Energy 2018;129:1–11.
[101] Zheng Chongwei, Li Chongyin, Pan Jing, Liu MingYang, Xia LinLin. An overview of global ocean wind energy resource evaluations. Renew Sustain Energy Rev 2016;53:1240–51.
[102] Liu Yichao, Chen Daoyi, Li Sunwei, Chan PW. Discerning the spatial variations in offshore wind resources along the coast of China via dynamic downscaling. Energy 2018;160:582–96.
[103] Zheng Chongwei, Li Xueyan, Luo Xia, Chen Xuan, Qian Yuhao, et al. Projection of future global offshore wind energy resources using CMIP data. Atmos-Ocean 2019;57(2):134–48.
[104] Wu Jie, Wang Zhi-Xin, Wang Guo-Qiang. The key technologies and development of offshore wind farm in China. Renew Sustain Energy Rev 2014;34:453–62.
[105] Wang Zhixin, Jiang Chuanwen, Qian Ai, Wang Chengmin. The key technology of offshore wind farm and its new development in China. Renew Sustain Energy Rev 2009;13:216–22.
[106] Zheng Chongwei, Pan Jing, Li Chongyin. Global oceanic wind speed trends. Ocean Coast Manag 2016;129:15–24.
[107] Zheng Chongwei, Pan Jing, Li Jiaxun. Assessing the China Sea wind energy and wave energy resources from 1988 to 2009. Ocean Eng 2013;65:39–48.