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Trade Complementarity of Sino-US Wind Energy Products: based on UN Comtrade Data

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Abstract – *China and the United States are both major countries in the world in the production of and trade in wind energy products, and they are also important trading partners. Therefore, it is of great practical significance to analyze and evaluate the Sino-US bilateral wind power complementarity for re-examining their respective comparative advantages and re-understanding the benefits that trade liberalization brings to both countries, in an attempt to strengthen the trade relations between China and the United States and enhance trade complementarities in wind energy products under the global circumstances of fierce competition. In this paper, based on the trade data from the UN Comtrade database in 2007-2016, a quantitative analysis was conducted on the complementarity of Sino-US wind energy products, by adopting the quantitative research methods of trade combination degree index (TCD), export similarity index (SI) and trade complementarity index (TCI). The results shows that: i) the total trade volume of wind energy products between China and the United States has increased rapidly, and the trade surplus between China and the United States has been expanding year by year; ii) the overall trade balance of wind energy products trade between the two countries is generally stable, and the dependence of China's wind energy products on the United States is much higher than that of the U.S wind energy products on China; iii) the Sino-US wind energy products between China and the United States are highly competitive in the international market; iv) Sino-US wind energy products have different degrees of complementarity in bilateral trade. Finally, this paper proposed policy implications based on the findings of this study.*

Keywords – *wind energy products, international trade, complementarity, China, United States.*

1. INTRODUCTION

Under the huge pressure of the global challenges, such as the energy resource shortage, environmental degradation and climate change, energy-saving, emissions reduction and low-carbon economy have begun to rise and been widely promoted in various countries in recent years. Therefore, the vigorous development of renewable energy or clean energy has become an important basis to ensure energy security, social and economic stability, and to meet the daily needs of the people.

At present, the main approach to develop renewable energy is to achieve energy conversion through power generation. As one of the important clean energy sources, wind energy has drawn attention to more and more countries throughout the world. China and the United States are both the major producers and traders of wind energy products, and the two countries have close trade relations in wind energy products. China is the largest overseas market for US wind energy products, and the United States is also an important export market and import source for China's wind energy products.

Indeed, China and the United States have formed important trading partners for wind energy products. Therefore, trade imbalance has inevitably become the core issue of trade disputes between wind energy products in China and the United States. According to estimation results based on data retrieved from the UN Comtrade database, in 2016, the total wind energy trade volume between the two countries reached 5,614 million US dollars, of which China exported 4,459 million US dollars to the United States and the United States exported 1,155 million US dollars to China. This fact shows that the trade imbalance does exist between China and the United States. However, what are the causes for this imbalance? What are the specific wind energy products causing this imbalance? This paper will focus on these research questions.

The research literature on this issue includes the following aspects:

i. Research on the wind energy trade between China and the United States. Wu and Li [1] concluded that China's dominant share of the wind energy market forces its wind energy companies to innovate. Pinson [2] pointed out that wind energy as an environment-friendly energy source and it is necessary to analyze the predictability of wind energy. Jiang et al. [3] used combining the integration of empirical mode decomposition to predict the wind speed, and argued that the way will reduce the cost of generating wind power and achieve the economic and social benefits of wind power management. Labordena and Lilliestama [4] studied Sino-US cooperation in renewable energy technologies will increase the amount of renewable energy. Gosens [5] analyzed that China and the United States have lower-quality natural resources but occupy a relatively high market share of wind

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power or photovoltaic power generation.

ii. Discussion on the competitiveness of Sino-US wind energy products in the international market. Jiang and Li [6] analyzed the predicament of Sino-US cooperation in the development and transfer of wind energy technologies due to the advantages of China's wind energy industry in the international market, and proposed the use of "game equilibrium" to promote Sino-US new energy cooperation. Du [7] analyzed the allegation that the United States argued that China's relevant measures caused a serious impediment to its wind energy industry, but the progress of wind energy in China has benefited from the implementation of its domestic clean development mechanism. Huang [8] and Shen [9] all used the "Sino-US Wind Energy Subsidy Case" to illustrate the legal issues of the Sino-US renewable energy products trade friction, reflecting the Sino-US global game in renewable energy. Zheng *et al.* [10] pointed out that the cooperation and conflict coexistence between China and the United States in renewable energy field while the differences in the perception of energy security between China and the US is the major obstacle to cooperation between the two countries Hughes, Llewelyn and Meekling, Jonas [11] confirmed that China and the United States have made important contributions to the renewable energy industry, and concluded that the domestic policy of renewable energy trade may lead to conflicts between the two countries.

iii. Research on the complementarity of Sino-US wind energy products in the international market. Zhang *et al.* [12] analyzed the evolution of energy strategies in China and the United States, and argued that China should learn the diversified energy supply strategy from the United States Zhang [13] explained that the current trade friction between China and the United States did not affect the increase of trade complementarity between the two countries. Liao and Wu [14] estimated the elasticity of substitution between US imported wind energy products from China and US national products, and found that the current relationship between the two countries is complementary; but over the long term, the Sino-US wind energy trade relationship will shift from complementarity to competitiveness. Liu [15] analyzed the commodity structure of Sino-US and concluded that the bilateral trade structure shows complementary, but at the same time there is certain intra-industry competition in the field of mechanical and electrical products. Wang [16] pointed out that under the division of global value chains, China and the United States showed a very significant complementarity in their trade structure. Lewis [17] China and the United States through the establishment of Sino-US Clean Energy Research Center for technical cooperation, and this concern for the sustainability of clean energy technology and intellectual property issues can ultimately generate considerable global benefit. Wu and Hu [18] studied the development trajectories of seven renewable energy technologies, and found that major countries such as the United States, Japan, Germany, China, and South Korea have super-strong innovation ability in the renewable energy industry and China's renewable energy technology has surpassed developed Western countries.

iv. Research on Sino-US renewable energy policy. Yuan *et al.* [19] reviewed the policy evolution of China's wind power industry at different stages, and concluded that misleading industrial policies is the main obstacles for the sustainable development of the industry. Yu *et al.* [20] found that China and the United States have actively cooperated in the formulation of climate and energy policies. Tarek *et al.* [21] analyzed the role of carbon tariffs and renewable energy price subsidy policies in the promotion of renewable energy in 15 countries, such as the United States, China and the European Union and found that energy policies can become the driving force for the development of the energy market, especially when the current fossil fuel industry is under shock.

v. Studied on the significance of developing renewable energy between China and the United States. Li [22] argued that China and the United States have broad cooperation foundations in the development of renewable energy, such as responding to climate change, ensuring energy security, and transforming the mode of economic development. Zhang *et al.* [23] made a quantitative analysis of the cooperation between China and the United States in renewable energy, and found that it is beneficial to promoting the economic development and environmental improvement. Xue *et al.* [24] used the life cycle of wind power industry to demonstrate that the development of wind power can obtain more environmental benefits. Wang and Yang [25] conducted that exploring new clean energy has become an inevitable choice for adapting a rapid economic growth and strategy of sustainable development and mentioned that China's new energy resources are very rich and have achieved effective development.

From the above literature review, we understand that plenty of studies have been conducted in this field, but more scholars tend to analyze the overall Sino-US trade relations (competitive or complementary), the study of the energy policies of the two countries, the cooperation of renewable energy technologies and the significance of the development of renewable energy. To date, however, there have been only a few researches targeting the complementarity of Sino-US specific wind energy products trade in the recent decade, or taking one certain wind energy products as an example.

Therefore, in this paper, taking China and the United States as the research object, and by adopting the trade combination degree index (TCD), export similarity index (SI) and trade complementarity index (TCI), we have conducted a quantitative analysis of Sino-US trade complementarity for 19 wind energy products during

2007-2016, in an attempt to explore the complementarity of Sino-US wind energy trade and propose some policy recommendations for continued healthy development of Sino-US wind energy products trade.

2. THE PRESENT SITUATION OF SINO-US WIND ENERGY TRADE

China is one of the largest countries in the world for wind energy production and trade. According to the data retrieved from the UN Comtrade database and through calculations, China's wind energy trade has been increasing rapidly in the past decade, from 16,507 million US dollars in 2007 to 35,602 million US dollars in 2016, with an average annual growth rate of 8.88%. During this decade, China has been in a super-prominent position in Sino-US wind energy trade. China's trade surplus has been increasing year by year. By 2016, China's trade surplus hit 8,038 million US dollars (see Table 1 and Figure 1 for details).

Table 1. Overall trend of China's wind energy products trade.

Year	China's export	China's import	China total wind energy products trade	China's trade surplus	Annual growth rate, %
2007	641,695.30	1,009,064.68	1,650,759.98	(367,369.38)	-
2008	956,532.21	1,189,148.16	2,145,680.37	(232,615.95)	29.98
2009	827,508.08	1,134,593.94	1,962,102.02	(307,085.86)	-8.56
2010	1,151,887.56	1,452,286.97	2,604,174.53	(300,399.41)	32.72
2011	1,543,109.41	1,665,059.75	3,208,169.16	(121,950.34)	23.19
2012	1,720,781.02	1,430,850.86	3,151,631.88	289,930.16	-1.76
2013	1,840,012.03	1,429,832.91	3,269,844.94	410,179.12	3.75
2014	2,088,713.94	1,622,132.74	3,710,846.68	466,581.20	13.49
2015	2,138,551.09	1,423,861.26	3,562,412.35	714,689.83	-4.0
2016	2,182,029.42	1,378,223.17	3,560,252.59	803,806.25	-0.06

Notes: the Unit is ten thousand US dollars.
Sources calculated by the authors based on the UN Comtrade database, 2017.

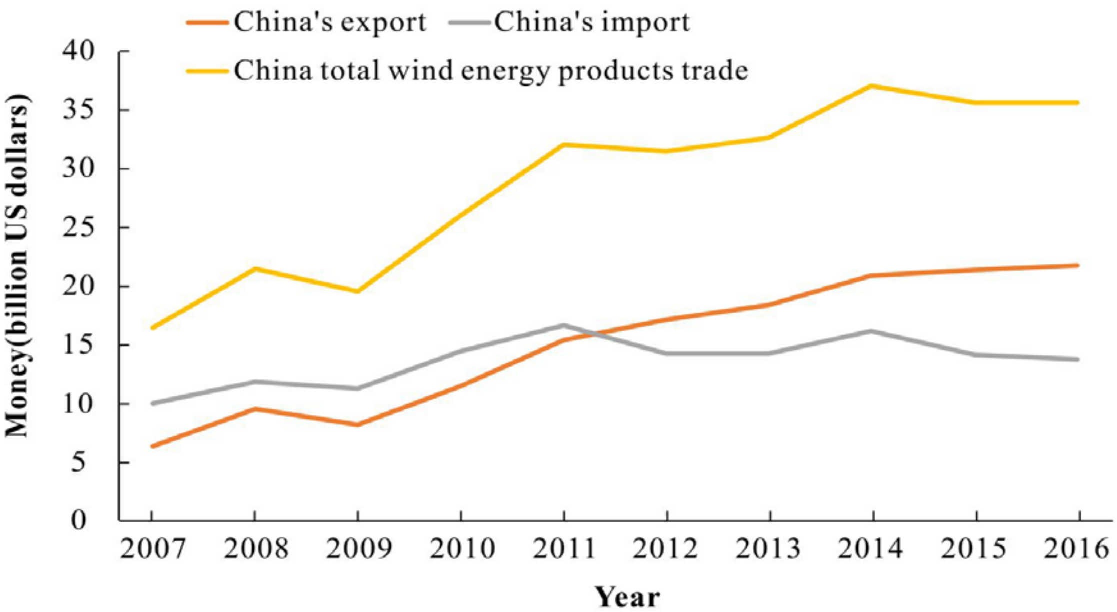

Fig. 1. Overall trend of China's wind energy products trade.

China and the United States have always been the important trade partners for wind energy products. In the period of 2007 and 2016, the Sino-US wind energy trade has been growing very rapidly, from 2,010.82 million US dollars in 2007 to 5,613.59 million US dollars in 2016, with an average annual growth rate of 12.27%, which is 2.79 times as much as in 2007, surpassing the trade volume of China's wind energy trade (8.88%) growth rate. Nevertheless, the development of Sino-US wind energy trade remains imbalanced. China's total wind energy products exports to the United States each year is 2-3 times as much as that of the US exports to

China. For example, in 2008, China's total wind energy exports to the United States reached 1,842 million US dollars, while US exports to China was only 912.45 million US dollars. In 2016, China's total wind energy products exports to the United States reached 4,458.73 million US dollars, while US exports to China was only 1,154.86 million US dollars. Over time, China has been in a super-prominent position in Sino-US wind energy trade, China's trade surplus has been increasing year by year. In 2007, China's trade surplus was 503.65 million US dollars, by 2016, China's trade surplus hit 3,303.87 million US dollars, which is an increase of 2.29 times, and with an average annual growth rate of 28.79% (see Table 2, Figure 2 and Figure 3 for details).

Table 2. Overall trend of Sino-US wind energy trade.

Year	China's export to the United States	China's import from the United States	Sino-US total wind energy products trade	China's trade surplus	Annual growth rate, %
2007	125,723.87	75,358.40	201,082.27	50,365.47	
2008	184,200.35	91,245.98	275,446.33	92,954.37	36.98
2009	142,801.66	88,194.19	230,995.85	54,607.47	-16.14
2010	211,577.96	98,883.54	310,461.50	112,694.42	34.4
2011	305,708.64	120,444.17	426,152.81	185,264.47	37.26
2012	377,673.05	125,713.28	503,386.33	251,959.77	18.12
2013	334,604.15	146,674.35	481,278.50	187,929.80	-4.39
2014	391,815.61	145,744.56	537,560.17	246,071.05	11.69
2015	444,143.98	138,478.47	582,622.45	305,665.51	8.38
2016	445,873.42	115,486.40	561,359.82	330,387.02	-3.65

Notes: the Unit is ten thousand US dollars.
Sources calculated by the authors based on the UN Comtrade database, 2017

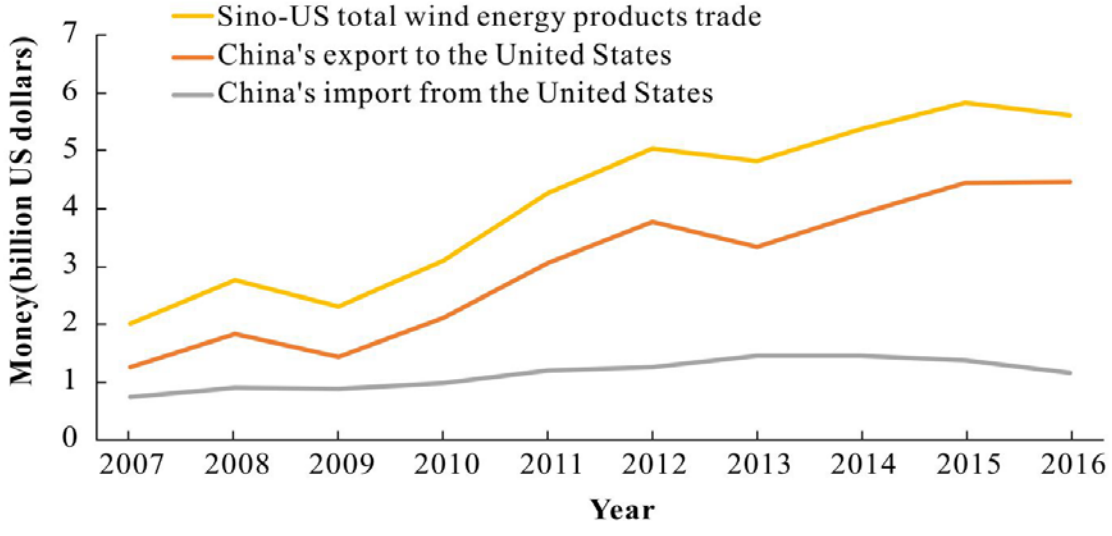

Fig. 2. Overall trend of Sino-US wind energy trade.

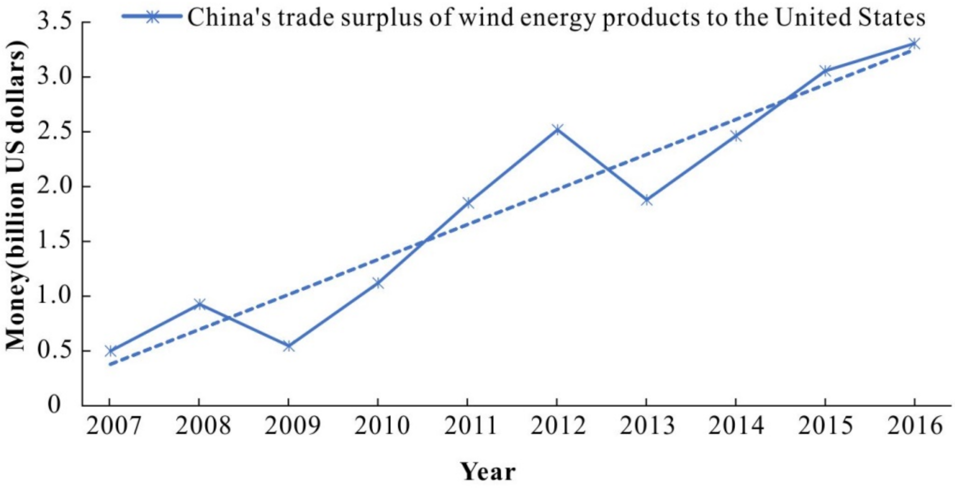

Fig. 3. China's trade surplus of wind energy products.

3.DATA AND METHODS

3.1 Methods

3.1.1 Trade Combination Degree (TCD)

The concept of trade combination degree (TCD) was first proposed by economist Brown in 1947. After the improvement of Kiyoshi Kojima and Yamazawa, the concept of TCD was refined and its significance in statistics and economics was clarified. The formula is as follows:

$$TCD_{ab} = \left(X_{ab} \ / \ X_a\right) / \left(M_b \ / \ M_w\right) \qquad (1)$$

where, TCD_{ab} represents the trade combination degree of country a to country b, X means export, and M means import. $\left(X_{ab} \ / \ X_a\right)$ represents the ratio of the exporting of country a to country b in the total exports of country a, $\left(M_b \ / \ M_w\right)$ represents the ratio of the import of country b from country a in the total world imports in country b. The trade combination degree is based on 1, if the value is greater than 1, it indicates that there is a close trade relationship between the two countries; if the value is smaller than 1, it implies that there is a distant trade relationship between the two countries.

3.1.2 Similarity Index (SI)

The export similarity index is used to measure the similarity of exported products between the two countries or two groups of countries in the third market or in the world market. It was first proposed by Finger and Kreinin and calculated as:

$$SI\left(ab, n\right) = \left[\sum_k \min\left(\frac{X_{an}^k}{X_{an}}, \frac{X_{bn}^k}{X_{bn}}\right)\right] \times 100 \qquad (2)$$

where, $SI\left(ab, n\right)$ represents the product similarity index of the exports of country a and country b to the market n, $\frac{X_{an}^k}{X_{an}}$ represents the ratio of the commodity k exported by the country a to the country n to the total exports of country a to country n, $\frac{X_{bn}^k}{X_{bn}}$ is the ratio of the commodity k exported by the country b to country n in the total exports of the country b to country n. The value of this index ranges from 0 to 100. If the two countries export exactly the same products to the third market, the index is 100; and if they export completely different products, then the index is 0. It is important to note that if this index continues to grow, the two countries are becoming more competitive in the third market. On the contrary, it shows that the division of labor in exporting trade between the two countries in the third market has risen and the complementarity of trade between the two countries is gradually increasing.

3.1.3 Trade Complementarity Index (TCI)

The trade complementarity index was first proposed by Japanese scholar Kiyoshi Kojima and later refined by economist Peter Drysdale in 1967. The trade complementarity index is often used to measure how well a country's exports of one product match those of another. The formula is as follows:

$$TCI_{ij}^k = RCA_{xi}^k \times RCA_{mj}^k \qquad (3)$$

where, TCI_{ij}^k represents the trade complementarity index of product k between country i and country j. RCA is the Revealed Comparative Advantage index proposed by Balassa (1965). RCA_{xi}^k denotes the comparative advantage of country i in product k measured by exports. RCA_{mj}^{k} refers to the comparative disadvantage of country j in product k measured by imports. The formula is as follows:

$$RCA_{xi}^{k} = \left(X_i^k / X_i\right) / \left(X_w^k / X_w\right) \qquad (4)$$

$$RCA_{mj}^{k} = \left(M_j^k / M_j\right) / \left(X_w^k / X_w\right) \qquad (5)$$

where, X_i^k and X_w^k are exports of product k from country a and world respectively; X_i and X_w are the total exports of country i and the world respectively. M_j^k is the import of product k of country j, M_j is the total imports of country j.

In general, the larger the value of RCA_{xi}^{k}, the stronger the comparative advantage of country i in product k. The larger the value of RCA_{mj}^{k}, then the stronger the comparative disadvantage of country i in product k. If country i has a strong comparative advantage in k product, and country j has a strong comparative disadvantage. In the trade of product k, the export of country i is complementary to the import of country j, and the size of their complementarity is measured by TCI_{ij}^{k}. When $TCI_{ij}^{k} > 1$, it indicates that the product of the two countries are highly complementary to each other. The greater the value, the stronger the complementarity. When $TCI_{ij}^{k} < 1$, it indicates that products of the two countries have weak trade complementarity. The smaller the value, the weaker the complementarity.

3.2 Data

All the data used for this research were retrieved from the UN Comtrade database. According to the HS code classifications for trade commodities, we retrieved and downloaded the data involving 19 categories of wind energy products for China and the United States from the database. In this paper, the trade combination degree (TCD), export similarity index (SI) and trade complementarity index (TCI) are used to analyze Sino-US wind energy trade relationship during 2007-2016, it is expected to find the characteristics and trends of the complementarity of Sino-US wind energy trade in the past decade.

4. RESULTS AND ANALYSIS

4.1 Trade Combination Degrees Index of Sino-US Wind Energy Products

In this paper, where a represents country China and b represents country the United States. According to the above research method, we have measured the TCD between the two countries during 2007-2016 from two aspects: exports from China to the United States and exports from the United States to China. The results show that (see Table 3 and Figure 4):

Table 3. TCD of Sino-US wind energy trade.

Year	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
China exports to US	2.62	2.51	2.22	2.70	2.74	2.50	1.77	2.09	2.14	2.44
US exports to China	1.05	0.92	1.00	0.69	0.60	0.51	0.58	0.51	0.48	0.43

Notes: sources calculated by the authors based on the UN Comtrade database, 2017.

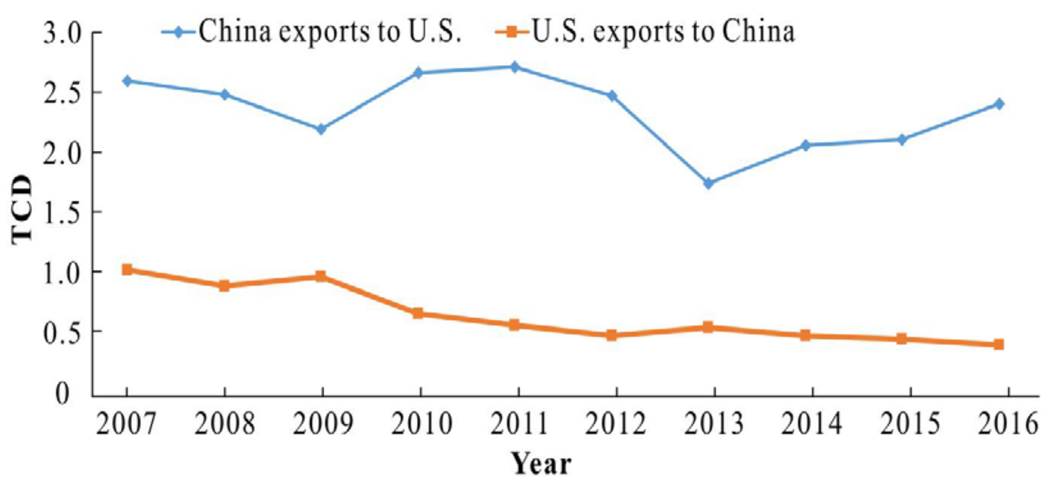

Fig. 4. TCD of Sino-US wind energy trade.

The TCD of Sino-US wind energy trade remains steadily in general terms, the dependence of China's wind energy trade on the United States is much higher than that of the US on China. It can be seen from Table 3 that China's TCD to the United States were generally greater than 2 during 2007-2016, with TCD smaller than 2 only in 2013; However, US' TCD to China were smaller than 1 in general terms. This result indicates that China's wind energy products rely more on the US market, while the US wind energy products do not rely on the China market. As more and more countries paying attention to clean energy, wind energy products have grown explosively under the promotion of the Chinese government. Nevertheless, due to the fact that wind energy products are not easy to store, it has caused the surplus of wind energy products in China. The development of wind power products has been affected by the issue of the continuity of PTC (The Wind Energy Production Tax Credit) policies and wind power has become a stable energy supply to the United States, which makes it impossible for the United States to import high quality and inexpensive wind energy products from China.

4.2 Similarity Index of Sino-US Wind Energy Products

In this paper, we also calculated the similarity index (SI) between the two countries during 2007-2016. In this study, *a* represents country China, *b* represents country the United States, *n* represents the world market, *x* represents exports and *k* represents 19 categories of wind energy products for China and the United States from the database, such as: iron steel structure (730820), engine parts (848210), ball bearings (848210), tapered roller bearings (848220), spherical roller bearings (848230), needle roller bearings (848240), cylindrical roller bearings (848250), other ball or roller bearings (848280), gears and gearing (848340), electric generating sets (850231), electric motors and generators parts (850300), other electric control devices (for a voltage not exceeding 1000 volts) (853710), other electric control devices (for a voltage exceeding 1000 volts) (853720), other floating structures (890790), electricity supply or production meters (902830), oscilloscopes and oscillographs (903020), multimeters (903031), instruments and apparatus (903039), regulating or controlling instruments and apparatus (903289). The results are shown in Figure 5:

Sino-US wind energy products are fiercely competitive in the international market. By comparing the SI of 19 categories of wind energy products between China and the United States in the international market, we can easily see that the SI index ranges from 72 to 79. The SI of Sino-US wind energy trade is at a high level, which means that the wind energy products of China and the United States are fiercely competitive and the industrial division of labor in the international market is not evident. Due to the increasing importance of clean energy supply in the United States and the benefits of investment and employment in wind energy industry, a series of policies have been formulated to promote exports, the real economy and high-tech industries. At the same time, the Chinese government believes that the development of strategic emerging industries is of great significance in terms of maintaining long-term and steady economic growth, and the strategic industries include energy-saving and environmental protection, new energy and new-energy vehicles. So, the wind energy industry is greatly valued and promoted by the government. This increase the degree of similarity in the trade structure and development policies between China and the United States, which will intensify the competitiveness of the wind energy product trade between the two countries.

Table 4. Similarity index of Sino-US wind energy trade.

Year	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
SI	72.80	76.53	78.35	76.28	76.83	77.73	76.48	75.60	77.08	75.54

Notes: sources calculated by the authors based on the UN Comtrade database, 2017.

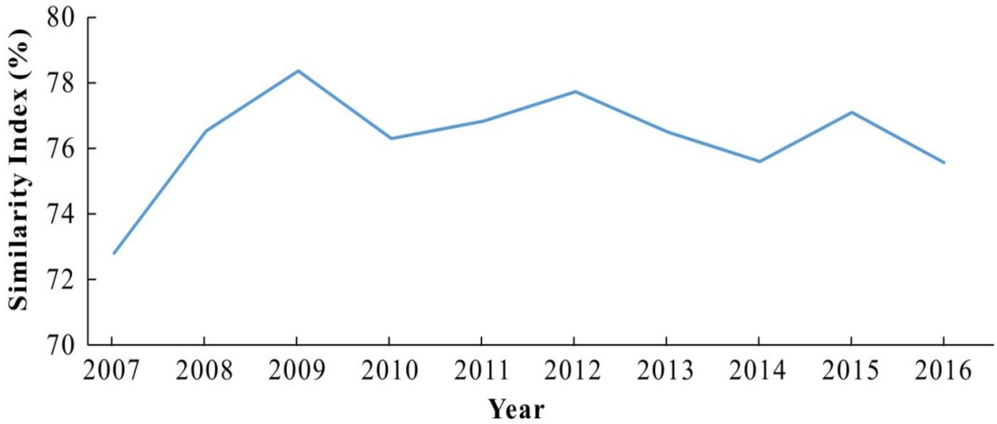

Fig. 5. SI of Sino-US wind energy trade.

4.3 Trade Complementarity Index of Sino-US Wind Energy Products

In this paper, we have measured the Trade Complementarity Index (TCI) of Sino-US wind energy trade during 2007-2016 from two aspects: exports from China to the United States and exports from the United States to China. Where i represent country China and j represent country the United States, the formula (6) represents the trade complementarity index of product k based on China as an exporter. When the United States as an exporter, the formula is:

$$C_{ji}^{k} = RCA_{xj}^{k} \times RCA_{mi}^{k} \tag{6}$$

The results exhibit that (see Table 5, Table 6 and Figure 6 and Figure 7):

4.3.1 Major Wind Energy Products in China and the United States Strong Trade Complementarity

From the perspective of the United States as an exporter, in 2016, the TCI of the following products are greater than 1: needle roller bearings (848240), cylindrical roller bearings (848250), oscilloscopes and oscillograph (903020), instruments and apparatus (903039), regulating or controlling instruments and apparatus (903289), the complementarity index of these products in 2016 were respectively 5.62, 2.33, 5.77, 4.76 and 2.76. In terms of China as an exporter, those products with the TCI greater than 1 in the same year are iron and steel structure (730820), engines parts (841290), electric motors and generators parts (850300), electricity supply or production meters (902830) and multimeters (903031), and the complementarity index of these products in 2016 were respectively: 1.63, 2.28, 1.43, 9.57 and 1.94. With the increase in similarity between the trade structure and development policies of the two countries, trade friction will intensify and complementarity will decline. However, there is still a strong trade mutual demand between China and the United States, according to the data retrieved from the UN Comtrade database and from the definition of complementarity. It indicates that the trade relationship between the two countries is getting closer under the circumstances of economic globalization.

Table 5. Wind energy products in HS code.

HS code	Description
730820	Iron or steel; structures and parts thereof, towers and lattice masts
841290	Engines; parts, for engines and motors of heading no. 8412
848210	Ball bearings
848220	Bearings; tapered roller bearings, including cone and tapered roller assemblies
848230	Bearings; spherical roller bearings
848240	Bearings; needle roller bearings
848250	Bearings; cylindrical roller bearings n. e. s. in heading no. 8482
848280	Bearings; n. e. s. in heading no. 8482, including combined ball/roller
848340	Gears and gearing; (not toothed wheels, chain sprockets and other transmission elements presented separately); ball screws; gear boxes and other speed changers, including torque converters
850231	Electric generating sets; wind-powered, (excluding those with spark-ignition or compression-ignition internal combustion piston engines)
850300	Electric motors and generators; parts suitable for use solely or principally with the machines of heading no. 8501 or 8502
853710	Boards, panels, consoles, desks and other bases; for electric control or the distribution of electricity, (other than switching apparatus of heading no. 8517), for a voltage not exceeding 1000 volts
853720	Boards, panels, consoles, desks and other bases; for electric control or the distribution of electricity, (other than switching apparatus of heading no. 8517), for a voltage exceeding 1000 volts
890790	Floating structures; tanks, coffer-dams, landing stages, buoys and beacons
902830	Meters; electricity supply or production meters, including calibrating meters thereof
903020	Oscilloscopes and oscillographs
903031	Multimeters; for measuring or checking voltage, current, resistance or power, without a recording device
903039	Instruments and apparatus; for measuring or checking voltage, current, resistance or power, without a recording device (excluding multimeters)
903289	Regulating or controlling instruments and apparatus; automatic, other than hydraulic or pneumatic

Notes: sources calculated by the authors based on the UN Comtrade database, 2017.

4.3.2 TCI Trends of the Major Wind Energy Products Difference between China and the United States

Products with an upward trend are: tapered roller bearings (up from 0.44 in 2007 to 1.13 in 2016), needle roller bearings (up from 3.28 in 2007 to 5.62 in 2016), cylindrical rollers bearings (up from 1.08 in 2007 to 2.33 in 2016), other ball bearings (up from 1.02 in 2007 to 1.16 in 2016), other electric control devices (for a voltage exceeding 1000 volts) (up from 1.10 in 2007 to 1.17 in 2016), instruments and apparatus (up from 3.73 in 2007 to 4.76 in 2007), regulating or controlling instruments and apparatus (up from 1.77 in 2007 to 2.76 in 2016), electric motors and generators parts (up from 0.91 in 2007 to 1.43 in 2016) and electricity supply or production meters (up from 3.97 in 2007 to 9.57 in 2016). Those with a downward trend are: iron and steel structure (down from 5.28 in 2007 to 1.63 in 2016), engine parts (down from 2.61 in 2007 to 2.28 in 2016), oscilloscopes and oscillographs (down from 2.67 in 2007 to 1.44 in 2007) and multimeters (down from 2.67 in 2007 to 1.44 in 2016). This also reflects from another aspect that although there is a certain degree of competitiveness in the wind energy products trade between China and the United States, complementarity remains its main melody. Therefore, the Sino-US wind energy trade can show various complementary indices

Table 6. TCI of wind energy products (China as an exporter).

HS code	Year									
	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
730820	5.28	3.51	1.82	1.29	0.85	1.65	0.39	1.13	1.56	1.63
841290	2.61	2.81	1.86	1.25	1.77	2.90	1.74	1.93	2.15	2.28
848210	0.78	0.64	0.64	0.72	0.80	0.79	0.89	0.83	0.77	0.75
848220	0.49	0.58	0.46	0.66	0.82	0.68	0.61	0.60	0.60	0.59
848230	0.23	0.23	0.23	0.25	0.34	0.33	0.36	0.54	0.52	0.43
848240	1.91	1.78	2.25	3.84	3.05	4.53	5.22	3.57	3.33	2.57
848250	0.16	0.27	0.29	0.36	0.43	0.44	0.43	0.60	0.50	0.39
848280	0.04	0.05	0.02	0.04	0.05	0.06	0.07	0.09	0.09	0.11
848340	0.55	0.56	0.63	0.70	0.74	0.75	0.77	0.78	0.86	0.83
850231	1.17	1.64	1.39	0.23	0.97	0.45	0.01	0.04	0.05	0.06
850300	0.91	0.76	0.69	0.74	0.82	0.88	1.07	1.24	1.27	1.43
853710	0.97	1.06	1.12	1.31	1.10	1.10	1.31	1.20	1.17	1.10
853720	0.35	0.34	0.32	0.33	0.34	0.31	0.35	0.39	0.37	0.40
890790	0.11	0.09	0.75	0.37	0.30	0.51	0.47	0.18	0.33	0.84
902830	3.97	5.33	10.1	9.12	14.9	13.7	5.87	6.94	5.11	9.57
903020	2.67	3.66	1.51	1.86	2.82	2.34	3.35	2.52	1.81	1.44
903031	2.88	1.31	1.70	2.21	1.78	1.48	2.57	2.41	2.18	1.93
903039	0.05	0.06	0.06	0.06	0.08	0.06	0.12	0.18	0.25	0.24
903289	0.69	0.76	0.82	0.97	0.84	0.69	0.79	0.76	0.76	0.69

Notes: sources calculated by the authors based on the UN Comtrade database, 2017.

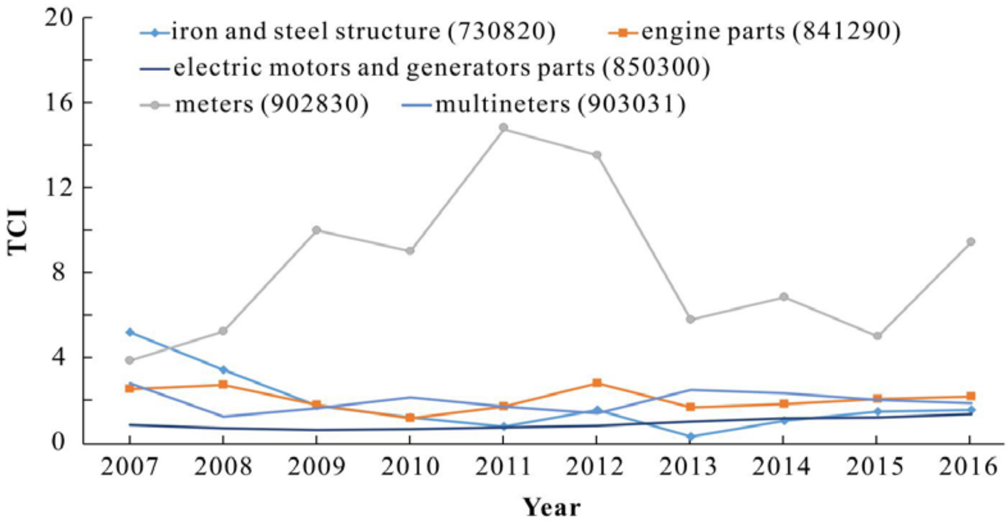

Fig. 6. TCI of major wind energy products (China as an exporter).

Table 7. TCI of wind energy products (US as an exporter).

HS code	Year									
	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
730820	0.001	0.001	0.0004	0.0002	0.004	0.004	0.004	0.009	0.002	0.0001
841290	1.08	0.63	0.74	0.96	0.84	0.86	0.83	0.55	0.56	0.52
848210	0.53	0.53	0.59	0.48	0.48	0.55	0.53	0.55	0.63	0.72
848220	0.44	0.59	0.99	0.96	0.88	0.83	0.82	0.92	1.02	1.13
848230	0.21	2.96	3.25	3.36	2.83	3.01	3.15	3.04	5.15	5.62
848240	3.28	0.32	0.54	0.50	0.60	0.60	0.63	0.58	0.67	0.66
848250	1.08	1.32	1.83	1.66	1.71	1.65	1.87	1.65	2.17	2.33
848280	1.02	1.07	1.07	1.12	1.04	1.23	1.17	1.11	1.38	1.16
848340	0.72	0.81	0.82	0.98	0.96	0.91	0.91	1.07	1.03	0.81
850231	0.03	0.02	0.01	0.02	0.01	0.00	0.01	0.01	0.00	0.00
850300	0.95	0.82	0.58	0.47	0.47	0.50	0.49	0.56	0.55	0.42
853710	1.10	1.27	1.13	1.02	0.98	1.01	1.06	1.10	1.11	1.17
853720	0.87	0.63	0.52	0.29	0.28	0.39	0.28	0.22	0.20	0.11
890790	0.46	0.06	0.52	0.09	0.13	0.46	0.14	0.21	0.18	0.21
902830	0.51	0.65	0.65	0.34	0.60	0.60	0.22	0.24	0.18	0.38
903020	6.53	4.90	3.53	3.67	5.27	5.09	3.82	5.25	4.07	5.77
903031	0.29	0.43	0.46	0.45	0.41	0.55	0.26	0.16	0.12	0.13
903039	3.73	4.66	4.42	4.94	7.84	10.01	6.15	4.85	4.68	4.76
903289	1.77	2.55	3.08	2.88	3.12	2.84	2.82	2.47	2.67	2.76

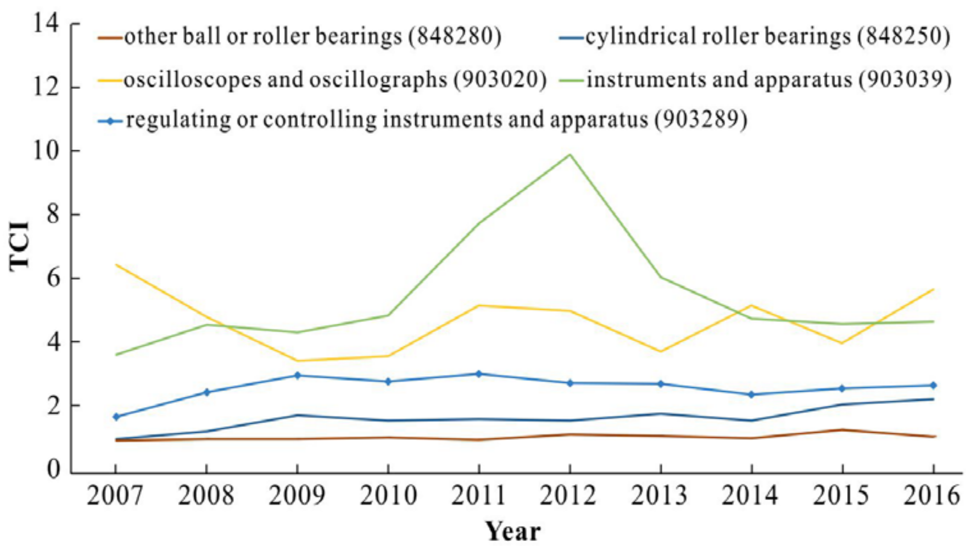

Fig. 7. TCI of major wind energy products (US as exporter).

5. CONCLUSION AND POLICY IMPLICATION

5.1 Conclusions

Based on the quantitative analysis and research conducted by various methods in this paper, we could draw the following conclusions:

i. The total wind energy trade volume between China and the United States is growing rapidly, and China's trade surplus has been increasing year by year. It has been from 2011 million US dollars in 2007 to 5,614 million US dollars in 2016, with an average annual growth rate of 12.27%. However, the average annual growth rate of US ‘wind energy products exports to China is slower than the average annual growth rate of China. China has been in a super-prominent position in Sino-US wind energy trade, and China's trade surplus has been increasing year by year. In 2007, China's trade surplus was 503.65 million US dollars. By 2016, China's trade surplus hit 3,303.87 million US dollars, which is an increase of 6.56 times, and with an average annual growth rate of 28.79%. It can be seen that the continuous growth of bilateral trade shows that there is a close trade complementarity between the two countries. This complementarity is not only the source for continued development, but also the main aspect of Sino-US bilateral trade.

ii. The TCD of Sino-US wind energy trade remains stable in general terms, the dependence of China's wind energy trade on the US is much higher than that of the U.S on China. It can be seen from Figure 4 that China's TCD to the US were greater than 2 during 2007-2016. However, the US' TCD to China were smaller than 1. This result indicates that China's wind energy products rely more on the US market, while the US wind energy products do not rely on China market.

iii. The Sino-US wind energy products are highly competitive in the international market. From 2007 to 2016, the SI of wind energy products between China and the United States in the international market has been at a high level. The lowest SI was 72.8 and the highest was nearly 78. which means that Sino-US wind energy products are fierce competitive in the international market. The increase in similarities between the trade structure and development policies of China and the United States, it will inevitably increase the competitiveness of the wind energy trade between the two countries.

iv. The Sino-US major wind energy products still have strong trade complementarity in bilateral trade. China and the United States each have complementary wind energy products through the quantitative analysis of the 19 wind energy products' complementarities. China's wind energy products that are more complementary to the United States are iron steel structure (730820), engine parts (848210), electric motors and generators parts (850300), electricity supply or production meters (902830), oscilloscopes and oscillographs (903020), multimeters (903031); US' wind energy products that are more complementary to China are tapered roller bearings (848220), needle roller bearings (848240), cylindrical roller bearings (848250), other ball or roller bearings (848280), other electric control devices (for a voltage not exceeding 1000 volts) (853710), oscilloscopes and oscillographs (903020), instruments and apparatus (903039), regulating or controlling instruments and apparatus (903289), and the number of wind energy products that TCI with an upward trend are more than that of a downward trend. It indicates that China and the United States are moving toward a more comparative advantage of their own resource in the structural adjustment and professional division of labor for exporting wind energy products.

5.2 Policy Implications

Based on the above findings, we propose the following policy implications for continued healthy development of Sino-US wind energy trade.

i. China and the United States should make full use of their own comparative advantages and enhance the complementarity of wind energy products. Specifically, China should continue to enhance its exports in iron and steel structure (730820), engine parts (848210), electric motors and generators parts (850300), electricity supply or production meters (902830) and multimeters (903031); the US should continue to intensify its research and development on tapered roller bearings (848220), needle roller bearings (848240), cylindrical roller bearings (848250), other ball or roller bearings (848280), other electric control devices (for a voltage not exceeding 1000 volts) (853710), oscilloscopes and oscillographs (903020), instruments and apparatus (903039), regulating or controlling instruments and apparatus (903289), consolidate its own superior industries in the world market. Only by taking the initiative to carry out structural adjustment in accordance with their own comparative advantages, can China and the United States enhance the complementarity of wind energy trade and achieve win-win.

ii. China should actively adopt a series of measures to reasonably control China's trade surplus with wind energy products. The data shows that since 2007, China's trade surplus with wind energy products has been increasing year by year, which means that the dependence of China's wind energy trade on the United States is gradually increasing, and in the long term, it may bring about the risk of wind energy trade. Therefore, while trying to maintain the export of wind energy products, China would better also adopt a series of measures to increase the import of wind energy products, such as implementing trade policies that encourage the import of wind energy products. At the same time, the United States should also try to guide trade and pay more attention to the China's wind energy market.

iii. Both China and the United States should actively develop new field to achieve a balanced development in different regions. Therefore, China and the United States both should fully understand the existing trade relations and enhance the comparative advantages of their own, in an attempt to strengthen the economic cooperation and trade ties between Sino-US and other countries and regions in the wind energy field.

ACKNOWLEDGEMENT

This paper is supported by the Major Program of National Social Science Foundation of China "Systematic Evaluation on the Operating Mechanism of Poverty Reduction Performances of Solar PV Projects and Policy Innovations" (No.17ZDA085), by Natural Science Foundation of China (NSFC) project (No. 71773119), and by the Fundamental Research Funds for the Central Universities, China University of Geosciences (Wuhan) (No. CUG170101).

REFERENCES

[1] Wu J. and C. Li. 2012. Thoughts on China's wind power equipment tender system. *Wind Energy* 3: 22-25.

[2] Pinson P., 2013. Forecasting challenges for its operational management. *Statistics* 28(4): 564-585.

[3] Jiang P., Ge Y., and Wang C., 2016. Research and application of a hybrid forecasting model based on simulated annealing algorithm: A case study of wind speed forecasting. *Journal of Renewable & Sustainable Energy* 8(1): 226-239.

[4] Labordena M. and J. Lilliestama. 2015. Cost and transmission requirements for reliable solar electricity from deserts in China and the United States. *Energy Procedia* 76: 77-86.

[5] Gosens J., 2017. Natural resource endowment is not a strong driver of wind or PV development. *Renewable Energy* 113: 1007-1018.

[6] Jing S. and Q.S. Li. 2013. From photovoltaics to wind energy dispute - a game interpretation of Sino-American new energy cooperation. *International Forum* 15(02): 61-66.

[7] Du K.P., 2012. Domestic norms of China's clean energy does not constitute a "subsidy allowable" - Taking the Sino-US wind energy dispute as an example. *Western Law Review* (03): 123-127.

[8] Huang Z.X. and Y. Luo. 2011. Legal issues on Sino-US renewable energy trade dispute - concurrently on the improvement of WTO's Green Subsidy Rules. *Business Research* 28(05): 35-43.

[9] Shen D.Y. and B.H. Gong, 2011. A solution to the Sino-US clean energy industry dispute - A case study of the dispute between China and the United States on the subsidy of wind energy equipment. *World Economy Research* 7: 49-53.

[10] Zheng W., 2013. Reflections on China–US energy cooperation: Overcoming differences to advance collaboration. *Utilities Policy* 27: 93-97.

[11] Hughes L., and J. Meckling. 2017. The politics of renewable energy trade: The US-China solar dispute. *Energy Policy* 105: 256-262.

[12] Zhang H., Zhou D., and Cao J., 2011. A quantitative assessment of energy strategy evolution in China and US. *Renewable & Sustainable Energy Reviews* 15(1): 886-890.

[13] Zhang B., 2013. Evolution and analysis of the complementarity of bilateral goods trade in China and the United States - based on the analysis of 1991-2011 data. *International Trade Issues* 12: 58-67.

[14] Liao M. and T.H. Wu. 2012. Armington elasticity estimation and import welfare analysis of US imports of Chinese wind power products. *Chinese Journal of Eco-Agriculture* 10: 116-120.

[15] Liu H., 2014. Changes in Sino-US trade commodity structure and analysis of causes. *Foreign Trade and Economic Cooperation* 9: 8-9.

[16] Wang L., 2016. Analysis of the elements of Sino-US bilateral trade under the division of global value chain - a re-examination of the HOV theorem. *South China Economy* 11: 59-80.

[17] Lewis J.I., 2014. Managing intellectual property rights in cross-border clean energy collaboration: the case of the US–China Clean Energy Research Center. *Energy Policy* 69(2): 546-554.

[18] Wu C.Y. and M.C. Hu. 2015. The development trajectory and technological innovation capabilities in the global renewable energy industry. *Portland International Conference on Management of Engineering and Technology*. Portland, OR, USA, 2-6 August. IEEE.

[19] Yuan J., Na C., Xu Y., and C.H. Zhao, 2015. Wind turbine manufacturing in China: A review. *Renewable & Sustainable Energy Reviews* 51: 1235-1244.

[20] Yu, Q., Roe, S.M., Xu, S., Williamson S., Cui N., Jin J., and Peterson T.D., 2015. China-US cooperation on China's subnational low carbon planning toolkit development and application. *Journal of Renewable & Sustainable Energy* 7(4): 71-77.

[21] Argentiero A., Atalla T., Bigerna S., Micheli S., and Polinori P., 2017, Comparing renewable energy policies in E.U.15, US and China: a Bayesian DSGE model. *Energy Journal* 38: 77-96.

[22] Li Y., 2011. Sino-US Clean Energy Cooperation: Fundamentals, Mechanisms and Problems. *Modern International Relations* 1:14-21.

[23] Zhang W., Yang J., Sheng P., Li X., andWang X., 2014. Potential cooperation in renewable energy between China and the United States of America. *Energy Policy* 75(C):403-409.

[24] Xue B., Ma Z., Geng Y., Heck P., Ren W., Tobias M., Maas A., Jiang P., Puppim de Oliveira J.A., and Fujita T., 2015. A life cycle co-benefits assessment of wind power in China. *Renewable & Sustainable Energy Reviews* 41:338-346.

[25] Wang J., Yang C., Liu F., Meng X., Wang J., and Liu J., 2016. The development and utilization of new clean energy. In *IEEE International Conference on Power Renewable Energy.* Shanghai, China, 21-23 October.