Article

Dynamic Change in the Export Technology Structure of China's Environmental Goods and Its International Comparison

Xuping Cao ^{1,2,3,*} and Nancy Hanson-Rasmussen ²¹ School of Economics and Management, Changshu Institute of Technology, Changshu 215500, China² School of Business, University of Wisconsin-Eau Claire, Eau Claire, WI 54702, USA; hansonrn@uwec.edu³ Suzhou Agricultural Modernization Research Center, Changshu 215500, China

* Correspondence: 201000065@cslg.edu.cn; Tel.: +86-152-6250-2916

Received: 17 August 2018; Accepted: 26 September 2018; Published: 30 September 2018

Abstract: Growing natural disaster intensity, ocean warming, air quality alerts, and a desire to emphasize sustainable practice has prompted countries to pay increased attention to the development of environmental industries. This has led to trade in environmental goods (EGs) and a need for export technology research. The purpose of this paper is to measure the evolution of the technological structure of China's export EGs and its position in the international industrial value chain. Based on the 2012 Asia-Pacific Economic Cooperation (APEC) EGs list and United Nations Comtrade (COMTRADE) data, this study uses the technical complexity index to empirically calculate the technology structure and level changes of China's EGs exports from 2007 to 2016. The results are then compared with those of the Asia-Pacific region and the world's major exporters of EGs. Additionally, this study proposes a method called "Equalization Technology Classification" that divides all EGs into five technical levels: high, medium-high, medium, medium-low, and low. The research finds that (1) China's EGs exports are predominately of medium-low technical complexity, and while the proportion of exported goods with high technical complexity is very low, the export technology structure is constantly being optimized. (2) Compared with Singapore, the United States, and the European Union, the overall technical level of China's exported EGs is lagging behind. (3) The overall technical level of exported EGs in major exporting countries is rapidly increasing but is especially impressive in South Korea and China, where growth ranks first and second in the world, respectively.

Keywords: environmental goods; technical complexity index; equilibrium technology method; China

1. Introduction

Environmental goods (EGs) are products that provide measurement, control, and restriction functions for ecosystem problems such as soil destruction, waste, noise, and water and air pollution [1], as well as goods that embrace power from the environment (e.g., oil spillage clean-up equipment, air cleaning machines, compacters, solar panels, and wind turbines). Global warming and environmental pollution are becoming more and more serious, and countries are paying increased attention to the development of environmental industries. Correspondingly, the world EGs trade is growing at a faster rate than all other goods and is making great contributions to protecting the natural environment and promoting global economic development [2]. China is an important driving force for the development of EGs trade in the world. In 2016, its export of EGs accounted for 10.92% of world exports, ranking first in the world [3].

However, China's economy has entered a new stage of "made in China", demonstrating a quality revolution. The quality of export commodities is more important than quantity [4]. In recent years,

China has actively integrated itself into economic globalization by taking advantage of its low labor costs. Many industries in China are already leading the world in export volume [5]. Economic theory and international development experience demonstrate that sustainable economic growth is inseparable from the continuous optimization of export technology structure [6]. Fan et al. [7] found a downward trend in the proportion of low value-added products in China's export structure, and those with medium value-added have gradually become the main export. This brings forth the question of whether the evolutionary trend of China's EGs export technology is the same as that of China's export technology? To this end, this paper will empirically measure the changes in China's EGs export technology.

Previous studies have focused on trade liberalization, EGs lists, and export technology measures. Rui et al. [8] found that EGs trade liberalization can have a positive spill-over effect on the global environment. In 2001, the Doha Declaration of the World Trade Organization (WTO) initiated negotiations on the liberalization of trade in EGs. However, members expressed differences of opinion on issues such as negotiation methods, product lists, and differential treatment. Therefore, the negotiations progressed slowly. Despite this, regional EGs negotiations have continued. The number of WTO regional trade agreements (RTAs) increases every year, many of which involve tariff reductions for EGs [9]. In 2012, the Asia-Pacific Economic Cooperation (APEC) Leaders Declaration proposed a list of 54 6-digit Harmonized Code EGs, and members reached a consensus on reducing tariffs on EGs [10]. The APEC list has been significantly streamlined compared to the Organization for Economic Co-operation and Development (OECD) list and has added clean technologies and renewable energy products [11]. In 2014, 14 WTO members, including the United States, China, the European Union, and Japan, launched a new round of EGs agreement negotiations using the APEC list to discuss the issue of global EGs trade liberalization. Today, the WTO EGs negotiations have not yet resulted in an agreed upon final list. Considering that these negotiations are based on the 2012 APEC EGs list, this study will measure the technical level of exports based on EGs found on the 2012 list.

Guan et al. [12] proposed the technology-added value method for measuring export technology. Lall et al. [13] then proposed a complexity index method, and Du et al. [14] revised the method. Hausmann et al. [15] proposed the use of "product-relevant income levels" (*PRODY*) to determine the level of product labor productivity, also known as the technical complexity index. What these methods have in common is that they first determine the technical level of a single product, then calculate the overall technical level of the economy and assign the technical content of the product to the weighted sum of the income levels of countries (or regions). The difference between these methods is the measure and assignment of weight. Valuation weights of Guan et al. [12] and Lall et al. [13] are the world share of various products exported by various countries. Du et al. [14] revised the weight method to the world share of various types of products produced by various countries. The valuation weights of Hausmann et al. [15] are the export comparative advantage index after standardization of various products in various countries. In comparison, the application of the technical complexity method of Hausmann et al. [15] is more common, and the research data is more acquirable. These application areas involve cultural and creative industries, manufacturing, agriculture, etc., but there is a lack of research on the technical level of product export in the environmental industry [16–18]. To this end, this paper chooses the technical complexity method of Hausmann et al. [15] to empirically measure the dynamic changes of China's EGs export technology. The Hausmann et al. [15] method does not classify *PRODY* values. This study proposes a method called "Equalization Technology Classification" that divides all EGs into five technical levels—high, medium-high, medium, medium-low, and low—according to the *PRODY* value. This method facilitates clearer analysis and international comparison of renewable energy product technology.

Different classification criteria for *PRODY* values will have varying effects on the conclusions of the study, with each classification having limitations. The main classification methods of the previous literature are the "Experience Sorting Method" of Tang [19], the "Technical Fixed Classification" of

Zhu et al. [20], and the “Optimal Segmentation Method” of Wei [6]. Tang [19] classifies the *PRODY* values according to the author’s experience, ensuring that the technology classifications are as normal as possible, and the classification results of different scholars may be different. Zhu et al. [20] ignore the fact that technology changes over time. Wei [6] sorts *PRODY* data and then determines the number of categories according to needs, which is also likely to cause people to subjectively change the technology differences between samples. The “Equilibrium Technology Method” proposed in this paper emphasizes objectivity and will avoid the classification results being limited and influenced by time change and human experience.

In summary, although the negotiation process under the WTO framework is slow, the consensus of countries or regions is that the liberalization of trade in EGs can improve the global environment. In the context of the growing demand for global EGs, measurement of and empirical research on the technical complexity of EGs is rare. Ma J. and Xu H. believe that the technical level and price of China’s export EGs are generally low, but there is no detailed quantitative verification study [21,22]. To this end, based on previous research, this paper uses the technical complexity index to empirically measure the dynamic changes of China’s EGs export technology and compare it with major countries (or regions) such as the United States, Germany, the United Kingdom, Japan, and more. The objective of this paper is to discover the changes in the technological level of EGs exported by countries (or regions) around the world and the status of China’s export EGs in the international industrial value chain. The EGs technical complexity classification in this study adopts the “Equalization Technology Classification” method, and EGs are defined using the 2012 APEC EGs list.

2. Methods and Data

2.1. Methods

The export complexity method proposed by Hausmann et al. (2005) uses international trade data to replace hard-to-find global R&D data for various types of products. The basic assumption of this method is that the more technical the class of products that are being exported from high-income countries, the higher the technical complexity of the products. This method does not consider other factors such as trade friction and intervention. In the global manufacturing value chain, developed countries are generally in the process of high value-added value such as R&D design, brand, and key parts production, while developing countries are more involved in low value-added links such as raw material supply and assembly. The status of countries in the global value chain will be reflected in the technological structure of the products that they export. This method combines the per capita income of countries (or regions) with exports. The technological content of the export products of these countries (or regions) in the global value chain can be measured. The method used in this paper consists of three steps: calculating the technical complexity of various EGs, classifying the technical complexity of different EGs, and calculating the overall technical level of each country (or region).

(1) The equation for the technical complexity of EGs exports.

The $PRODY_k$ is the export technical complexity of the category k export EGs at the world level. The equation for $PRODY_k$ is

$$PRODY_k = \sum_j \frac{x_{jk}/X_j}{\sum_j x_{jk}/X_j} \times Y_j \quad (1)$$

The notations in Equation (1) and their meanings are as follows.

j	the j th EGs exporting country (or region)
k	the category of exported EGs
X_j	the total exports of all EGs in the country (or region) j
x_{jk}	the export value of category k EGs of the country (or region) j
Y_j	the per capita gross domestic product (GDP) of the country (or region) j
$PRODY_k$	the technical complexity of the category k exported EGs at the world level

(2) The principle of the “Equalization Technology Classification” method.

The basic principle of this method is to ensure that the *PRODY* value difference of adjacent technology grade products is equal, and there is no limit on the number of products owned by each grade.

First, the calculated *PRODY* values of *n*-type EGs are arranged from small to large into an ordered sample $(t_1, t_2, t_3, \dots, t_n)$, in which t_1 is the smallest and t_n is the largest.

Secondly, it is assumed that the technical complexity of the EGs is divided into *m* grades, and the *PRODY* value difference of the adjacent technology grade products is *D*. The equation for *D* is

$$D = \frac{t_n - t_1}{m} \quad (2)$$

Finally, the technical classification criteria for EGs are calculated. The standards for the 1, 2, 3, ..., *m* levels of EGs are $PRODY \leq t_1 + D$, $t_1 + D < PRODY \leq t_1 + 2D$, $t_1 + 2D < PRODY \leq t_1 + 3D$, ..., $t_n - D < PRODY$. This method can determine the technology classification standards of all EGs in the world in a given period of time. According to this standard, it is possible to clearly know how many high technically complex EGs are exported by a country (or region).

(3) The calculation method of the overall technical level of exported EGs (which we call *EXPY*).

Assume that the overall technical level of exported EGs in a country (or region) *j* is *EXPY_j*, and its equation is

$$EXPY_j = \sum_k \frac{x_{jk}}{X_j} \times PRODY_k \quad (3)$$

The calculated *EXPY* values are mainly used to compare the overall technical level of exported EGs in countries (or regions).

2.2. Data

2.2.1. Classification Data of the APEC EGs List

There is no uniform standard for the classification of EGs. Based on the product function and service industry perspective, this study divides 54 APEC EGs into five categories: environmentally friendly, pollution control and treatment, water purification, renewable energy, and environmental monitoring and analysis. The detailed classification and Harmonized Commodity Description and Coding System (HS) code description of APEC EGs are shown in Table 1. As can be seen from Table 1, the five categories of EGs contain a total of 54 HS 6-digit code subdivision products. The category of environmentally friendly products includes only the loaded bamboo multi-layer floor. There are 14 kinds of pollution control and treatment EGs, five kinds of water purification EGs, 16 kinds of renewable energy EGs, and 18 kinds of EGs for environmental monitoring and analysis.

Table 1. The classification and HS code description of APEC EGs.

Product Category	HS Code and Descriptions
Environmentally friendly	441872 (packing bamboo multi-layer floor)
Pollution control and treatment	847982 (grinding machine), 847989 (radioactive waste pressure real machine), 847990 (humidifier and dehumidifier parts), 840410 (boiler auxiliary equipment), 840490 (steam boiler parts), 840510 (hydrolyzed gas generator), 851410 (controlled atmosphere heat treatment furnace), 851420 (induction furnace and oven), 851430 (industrial electric furnace), 851490 (industrial furnace parts), 841182 (power > 5000 kw gas turbine), 841199 (gas turbine parts), 841780 (waste incinerator), and 841790 (waste incinerator parts)

Table 1. Cont.

Product Category	HSCode and Descriptions
Water and air purification	854390 (detector parts), 842121 (water treatment equipment), 842129 (filter press), 842139 (air cleaning machine), and 842199 (purifier parts)
Renewable energy	840290 (biomass boiler), 840420 (condenser), 847420 (milling machine), 854140 (solar battery), 841919 (solar water heater), 841939 (dryer), 841960 (liquefaction machine), 841989 (low temperature refrigeration equipment), 841990 (water heater parts), 841290 (wind turbine parts), 850164 (renewable fuel alternator), 850231 (wind power generation equipment), 850239 (renewable energy generator set), 850300 (wind power equipment parts), 850490 (transformer), and 901380 (heliostat)
Environmental monitoring and analysis	901580 (shipborne gravimeter), 902610 (liquid flow measuring instrument), 902620 (pressure gauge), 902680 (gas flow meter), 902690 (gas–liquid measuring instrument parts), 902710 (smoke analyzer), 902720 (chromatograph and electrophoresis), 902730 (spectrophotometer and photometer), 902750 (optical ray instrument), 902780 (mass spectrometer), 902790 (physical and chemical analysis instrument parts), 903149 (contour projector), 903180 (coordinate measuring instrument), 903190 (inertial platform balancing fixture), 903289 (generator controller), 903290 (controller parts), 903300 (heliostat parts), and 901390 (inertial measurement fixture)

Note: The data come from the COMTRADE database, and the product description is streamlined.

2.2.2. Sample Selection and Data Source

This study selected the world's top 27 exporters (or regions) of EGs from 2007 to 2016, including Austria, Belgium, Brazil, Canada, China, China Hong Kong, Czech Republic, Denmark, Finland, France, Germany, Hungary, Italy, Japan, Malaysia, Mexico, Netherlands, South Korea, Singapore, South Africa, Spain, Sweden, Switzerland, Thailand, the United Kingdom, the United States, and Vietnam (Table A1) [3]. From 2007 to 2016, the cumulative export volume of EGs of the 27 countries (or regions) accounted for over 90% of the world's total, demonstrating strong representation.

The per capita GDP of each country (or region) is derived from the World Bank database and has been converted to purchasing power parity (PPP) or currency equilibrium between countries (Table A2) [23]. The PPP in this article uses the “Constant 2011 International \$” standard.

In order to ensure data consistency, the data in this paper is from the COMTRADE database, and the commodity codes use the HS2007 standard.

3. Results

3.1. EGs Technology Structure Determination

Using Equation (1), the annual average of *PRODY* (Table A3) for EGs from 2007 to 2016 was calculated. Then, the *PRODY* values were divided into five grades by using the “Equalization Technique Classification” method. The result is a classification of EGs into high technical complexity products ($\$42,919 < PRODY$), medium-high technical complexity products ($\$37,908 < PRODY \leq \$42,919$), medium technical complexity products ($\$32,898 < PRODY \leq \$37,908$), medium-low technical complexity products ($\$27,888 < PRODY \leq \$32,898$), and low technical complexity products ($PRODY \leq \$27,888$). The technology structure distribution of the world's EGs is shown in Table 2.

Table 2 makes evident the variances in the number of EGs in each of the five classifications. There are 24 kinds of medium technical complexity products, 14 kinds of medium-high complexity products, 10 kinds of medium-low technical complexity products, 5 kinds of high technical complexity products, and only 1 low technical complexity product.

Table 2. The technology structure distribution of the world's EGs.

Technical Complexity Classification	Classified Standard/\$	Product HS Code
High technical complexity products	$42,919 < PRODY$	902780, 902790, 902750, 902730, 902720
Medium-high technical complexity products	$37,908 < PRODY \leq 42,919$	902610, 847982, 441872, 903190, 902690, 841290, 841199, 903149, 851410, 847990, 901580, 840510, 841182, 854390
Medium technical complexity products	$32,898 < PRODY \leq 37,908$	850164, 850239, 840490, 840420, 841780, 903290, 842199, 850231, 847420, 902620, 841989, 841990, 841790, 851420, 842129, 903180, 842121, 903300, 841960, 851430, 847989, 841939, 902710, 851490
Medium-low technical complexity products	$27,888 < PRODY \leq 32,989$	840290, 901380, 901390, 903289, 850490, 840410, 854140, 850300, 902680, 841919
Low technical complexity products	$PRODY \leq 27,888$	842139

3.2. Dynamic Distribution of the Technical Complexity of China's Exported EGs

According to the classification criteria in Table 2, the dynamic distribution of the technical complexity of China's exported EGs from 2007 to 2016 is calculated and listed in Table 3.

As can be seen from Table 3, (1) China's EGs exports are concentrated in medium-low technical complexity products, and the proportion of high technical complexity products exported is low. From 2007 to 2016, the average annual export volume of medium-low technical complexity EGs was as high as 76.80%. The average annual export volume of high technical complexity EGs is only 1.57%, and that of medium-high technical complexity EGs reaches 6.01%. Statistics show that China's main exported EGs are concentrated in 847989 (radioactive waste compactor), 901380 (coordinate measuring instrument), 854140 (solar battery), 850300 (wind power equipment parts), 840410 (boiler auxiliary equipment), 840290 (biomass boiler), 850490 (transformer), and 901380 (heliostat). Except for the 847989 and 901380 EGs, which are of medium technical complexity, the other six categories are of low-medium technical complexity EGs (Table 2). (2) From the perspective of evolutionary trends, the export technology structure of China's EGs is constantly being optimized. The export proportion of China's medium-low technical complexity EGs fell from 79.63% in 2007 to 68.26% in 2016, a decrease of 14.28%. Correspondingly, the cumulative export share of medium-high and high technical complexity products increased from 7.41% in 2007 to 10.04% in 2016, an increase of 35.49%. The export proportion of medium technical complexity EGs also increased from 12.07% in 2007 to 19.32% in 2016, an increase of 60.07%.

Table 3. The dynamic distribution of the export technology structure of China's EGs.

Years	Technical Complexity Ration/%				
	High	Medium-High	Medium	Medium-Low	Low
2007	1.83	5.58	12.07	79.63	0.89
2008	1.57	5.59	13.13	78.66	1.05
2009	1.52	5.57	14.37	77.17	1.37
2010	1.17	4.81	11.35	81.72	0.96
2011	1.17	5.26	12.03	80.56	0.98
2012	1.40	5.60	13.48	78.41	1.11
2013	1.53	5.86	14.28	76.93	1.40
2014	1.71	7.02	15.96	73.60	1.71
2015	1.80	6.78	16.80	73.10	1.52
2016	2.01	8.03	19.32	68.26	2.38
Average	1.57	6.01	14.28	76.80	1.33

3.3. Comparison of Export Technology Structures of EGs in Major Economies

This paper compares the technology structure of EGs exports of the world's top six EGs exporters (Table A1) in 2007 and 2016 (Table 4).

As can be seen from Table 4, (1) The EGs export structures in China and South Korea are similar, and the proportion of medium-low technical complexity EGs is the highest. Although the proportions of medium-low technical complexity products in the two countries in 2016 were significantly lower than those in 2007, they still maintained a level of about 68%. Comparing the proportion of medium-high and high technical complexity EGs, Singapore, the United States, Germany, and Japan in 2016 reached 58.6%, 44.44%, 30.77%, and 28.98%, respectively, far higher than the 10% level of China and South Korea. (2) The growth rate of high technical complexity EGs in Singapore and Japan is high, from 7.95% and 7.35% in 2007 to 18.81% and 11.48% in 2016, respectively. In contrast, the proportions of high technical complexity EGs exports in China and South Korea has been slow, with only about 2% in 2016.

3.4. The Overall Technical Level of China's EGs and Its International Comparison

This paper selects the top 10 countries (or regions) that export EGs and five APEC members with large export volumes of EGs from 2007 to 2016 for a comparative analysis of *EXPY*. The top 10 exporters of EGs (or regions) are China, Germany, the United States, Japan, South Korea, Singapore, Italy, China Hong Kong, the United Kingdom, and France (Table A1). The other five APEC exporters of important EGs are Mexico, Malaysia, Canada, Thailand, and Vietnam. The EGs *EXPY* of 15 countries (or regions) from 2007 to 2016 are shown in Table 5.

As can be seen from Table 5, (1) Singapore ranks first in exported EGs's per average annual *EXPY* value. This is primarily because of the high proportion of medium-high and high complexity EGs in its export product structure. The products with high technical complexity are mostly 902780 (Mass spectrometer) and 902790 (Physical and chemical analysis instrument parts); those with medium-high technical complexity are mostly 841199 (gas turbine parts), 847990 (humidifier and dehumidifier parts), and 854390 (detector parts). In addition, the average annual *EXPY* values of exported EGs in the United States, European Union countries, and Japan are also in leading positions. (2) From 2007 to 2016, the overall technology of China's exported EGs is at a medium-low technical complexity level, ranking only higher than South Korea and Vietnam. For China, there is still a big gap with the world's major exporters of EGs such as Germany, the United States, and Japan.

(3) The *EXPY* value of China's exported EGs increased from \$28,438 in 2007 to \$32,330 in 2016, indicating that the overall technical level of China's EGs is constantly improving. It is worth noting that, except for Vietnam and Malaysia, the *EXPY* of the remaining EGs exporting countries (or regions) from 2007 to 2016 showed an overall growth trend. The *EXPY* growth rate of EGs in China and South Korea is as high as 13.69% and 14.92%, respectively, which is much higher than other countries (or regions). This shows that the gap between the overall technical level of EGs in these two countries and advanced countries (or regions) is shrinking. In addition, the *EXPY* growth rate of EGs in Singapore, China Hong Kong, Canada, Germany, and Japan also reached 8.63%, 7.96%, 6.13%, 5.76%, and 5.74%, respectively. This demonstrates that the world's EGs exporting countries (or regions) are increasingly competitive in terms of technology.

Table 4. The technology structure of EGs exports of the world's top six EGs exporters in 2007 and 2016.

	Ratio in 2007/%						Ratio in 2016/%					
	China	Germany	Japan	South Korea	Singapore	United States	China	Germany	Japan	South Korea	Singapore	United States
Low technical complexity products	0.89	4.02	1.20	0.47	0.69	3.48	2.38	7.21	1.13	1.17	0.53	4.62
Medium-low technical complexity products	79.63	22.23	36.86	79.72	24.55	17.77	68.26	15.58	35.80	67.66	23.16	18.15
Medium technical complexity products	12.07	46.11	38.94	13.56	24.77	31.16	19.32	46.44	34.09	20.37	17.71	32.79
Medium-high technical complexity products	5.58	18.43	15.65	5.83	42.03	35.58	8.03	21.23	17.50	9.12	39.79	30.86
High technical complexity products	1.83	9.21	7.35	0.42	7.95	12.01	2.01	9.54	11.48	1.69	18.81	13.58

Table 5. The overall technical level of exported EGs of 15 countries (or regions) from 2007 to 2016.

Years	EXPY Value of EGs/\$														
	Singapore	United States	United Kingdom	France	Italy	Canada	Germany	Japan	China Hong Kong	Thailand	Malaysia	Mexico	China	South Korea	Vietnam
2007	36,835	36,711	36,405	36,026	35,997	35,611	35,563	34,554	33,662	32,488	33,423	32,429	28,438	28,056	33,663
2008	37,645	37,044	36,741	36,630	36,593	35,993	35,343	34,711	32,539	34,113	33,282	32,497	29,674	29,301	27,033
2009	35,966	36,316	36,654	34,626	34,055	34,315	33,780	32,866	31,720	32,258	31,767	31,488	29,307	28,257	27,602
2010	37,833	36,136	35,998	35,671	35,639	35,569	34,660	34,135	33,060	34,137	33,313	32,550	30,789	30,064	29,075
2011	38,066	36,716	36,716	36,129	36,016	36,101	35,486	34,864	34,225	34,559	34,139	32,912	31,668	31,452	30,132
2012	38,294	36,450	36,721	36,149	35,919	35,817	35,802	34,573	33,961	34,415	34,579	32,984	31,451	31,078	31,139
2013	38,260	36,917	37,016	36,430	36,390	36,256	35,969	34,859	33,938	34,588	33,813	32,899	31,755	31,811	32,340
2014	38,922	37,266	37,348	36,844	36,890	36,511	36,387	35,564	34,819	34,622	34,523	33,596	32,855	32,842	32,039
2015	39,521	37,617	37,789	37,007	37,435	37,120	36,727	36,069	35,921	33,572	33,323	33,838	32,636	33,328	32,849
2016	40,013	38,383	38,133	37,996	37,937	37,795	37,613	36,538	36,341	32,994	32,894	34,155	32,330	32,241	31,523
Average	38,136	36,956	36,952	36,351	36,287	36,109	35,733	34,873	34,019	33,774	33,506	32,935	31,090	30,843	30,739

4. Conclusions and Discussion

The innovation in this research is the “Equalization Technology Classification” method for technical complexity classification. It provides an opportunity to expand the application of the technical complexity index in the field of EGs. The technical complexity index has been used to empirically measure and compare the EGs export technology structure of major EGs exporting countries (or regions) from 2007 to 2016.

(1) The general empirical results summary. This study found that China’s exported EGs are of predominately medium-low technical complexity, and the proportion of those with high technical complexity is very low. However, the technology structure of China’s EGs exports is continually being optimized. Additionally, the overall technical level of Singapore’s exported EGs ranks first in the world. The overall technical level of EGs in the United States, the European Union, and Japan is also high, and although China’s ranking is relatively low, there are opportunities for collaboration with the top exporting countries. Finally, the overall technical level of major EGs exporting countries (or regions) is rapidly increasing. However, the technological upgrading level of South Korea and China’s EGs ranks first and second in the world, respectively. In short, global EGs technology competition is becoming increasingly fierce.

(2) Implications and recommendations for policy-makers. This paper demonstrates positive trends in the technological progress of China’s environmental industry. On the one hand, the low proportion of medium-high and high technical complexity exports restricts the overall technical level of China’s EGs. To this end, China’s EGs manufacturers need to abandon short-term market interests, strengthen investment in talent and technology research, and strive to enhance their position in the global environmental industry value chain. On the other hand, the export trade of EGs is too singular. China’s EGs manufacturers should actively extend comprehensive cooperation with Singapore, the United States, and the European Union, such as the standardization of EGs technology, cooperative research on production equipment for EGs, and further opening of investment in the environmental field.

(3) A comparison of the results of this study with other research findings. Ma J. found that China’s EGs export prices are relatively low, relying mainly on quantitative advantages to obtain the total export value advantage [21]. The conclusions of this study fully verify the above viewpoints. Statistics show that China’s main exported EGs are concentrated in 847989 (radioactive waste compactor), 901380 (coordinate measuring instrument), 854140 (solar battery), 850300 (wind power equipment parts), 840410 (boiler auxiliary equipment), 840290 (biomass boiler), 850490 (transformer), and 901380 (heliostat). Most of these categories are of low-medium technical complexity EGs. On the other hand, China’s advanced pollutant monitoring and analysis instruments and equipment are mainly imported [21]. This is also one of the important reasons for the low level of China’s export EGs. Xu H. found that China’s EGs have a large gap in technological innovation with developed countries such as the European Union and the United States [22]. The conclusions of this study also validate Xu H.’s point of view, but this gap is shrinking.

(4) Limitations and future research proposals. At present, the scope of EGs mainly includes three standards of APEC, OECD, and World Bank, but the standards vary greatly. This has a great impact on the research conclusions. Although the current list of APEC EGs forms the basis for negotiations concerning the WTO environmental trade agreement, the final EGs list will certainly change. Researchers must pay close attention to the progress of relevant negotiations concerning EGs trade. Additionally, the technical complexity index also has limitations. For example, the processing trade factor and the implementation of the technology export restriction policy are not considered. Therefore, future improvements and application studies of this method are worth exploring.

Author Contributions: X.C. and N.H.-R. wrote the paper, X.C. analyzed the data, and X.C. collected the data. The study was designed by X.C. and N.H.-R., and the final version was checked and revised by N.H.-R.

Funding: This work was supported by Jiangsu Agricultural Development Committee Agricultural Soft Science Research Foundation in China (Grant No. 18ASS036).

Acknowledgments: We are grateful for the comments and criticisms of an early version of this manuscript by the journal's editors and reviewers.

Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

The following abbreviations are used in this manuscript:

EGs	Environmental Goods
APEC	Asia-Pacific Economic Cooperation
OECD	The Organization for Economic Co-operation and Development
COMTRADE	United Nations Comtrade Database
WTO	World Trade Organization
RTAs	Regional Trade Agreements
HS	Harmonized Commodity Description and Coding System
PPP	Purchasing Power Parity
GDP	Gross domestic product
PRODY	Product-relevant income levels
EXPY	Overall export technical level

Appendix A

Table A1. The world's major exporters of EGs from 2007 to 2016.

Country (or Region)	The Annual Average of Export Value/\$100 Million
China	793.17
Germany	592.20
United States	530.50
Japan	348.29
South Korea	330.67
Singapore	154.12
Italy	153.23
China Hong Kong	149.34
United Kingdom	149.01
France	109.87
Mexico	104.48
Netherlands	90.48
Switzerland	84.58
Malaysia	77.56
Canada	70.24
Denmark	69.81
Thailand	55.95
Spain	54.27
Sweden	53.33
Belgium	48.84
Hungary	45.29
Australia	44.10

Table A1. Cont.

Country (or Region)	The Annual Average of Export Value/\$100 Million
Czech Republic	40.56
Vietnam	30.26
Finland	24.09
South Africa	20.52
Brazil	16.00

Table A2. The GDP ¹ per capita of major exporters based on PPP ² from 2007 to 2016.

Country (or Region)	GDP Per Capita/\$									
	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Austria	43,878	44,418	42,619	43,336	44,453	44,552	44,303	44,345	44,354	44,491
Belgium	41,623	41,619	40,356	41,086	41,249	41,046	40,928	41,384	41,723	42,095
Brazil	13,271	13,806	13,653	14,539	14,973	15,118	15,430	15,371	14,666	14,024
Canada	41,647	41,611	39,924	40,699	41,565	41,795	42,339	43,079	43,149	43,238
China	7285	7948	8652	9526	10,384	11,146	11,951	12,759	13,570	14,399
China Hong Kong	45,937	46,635	45,390	48,108	50,086	50,378	51,732	52,789	53,595	54,354
Czech Republic	28,844	29,373	27,804	28,353	28,797	28,527	28,380	29,120	30,605	31,339
Denmark	46,374	45,866	43,383	43,998	44,403	44,337	44,564	45,057	45,459	45,991
Finland	42,467	42,575	38,868	39,848	40,684	39,913	39,428	39,018	38,942	39,659
France	37,772	37,635	36,341	36,872	37,457	37,345	37,367	37,531	37,766	38,061
Germany	40,474	40,989	38,784	40,429	42,693	42,822	42,914	43,561	43,938	44,357
Hungary	23,492	23,734	22,202	22,404	22,841	22,582	23,119	24,161	25,034	25,664
Italy	38,612	37,954	35,710	36,201	36,347	35,228	34,220	33,946	34,302	34,655
Japan	36,697	36,278	34,317	35,750	35,775	36,368	37,149	37,337	37,883	38,283
South Korea	28,014	28,588	28,643	30,352	31,229	31,777	32,549	33,426	34,178	34,986
Malaysia	20,685	20,989	20,092	21,107	21,819	22,591	23,224	24,195	25,002	25,669
Mexico	16,044	16,008	15,012	15,535	15,923	16,324	16,316	16,460	16,672	16,832
Netherlands	46,528	47,134	45,126	45,525	46,067	45,411	45,191	45,668	46,494	47,270
Singapore	68,423	66,037	63,688	72,105	75,013	76,029	78,549	80,305	80,892	81,443
South Africa	11,741	11,990	11,676	11,888	12,119	12,215	12,340	12,372	12,363	12,237
Spain	34,330	34,164	32,653	32,507	32,068	31,109	30,679	31,195	32,291	33,320
Sweden	44,051	43,466	40,863	42,943	43,755	43,308	43,476	44,168	45,679	46,568
Switzerland	56,269	56,756	54,806	55,866	56,184	56,150	56,536	57,218	57,264	57,428
Thailand	12,607	12,757	12,605	13,487	13,535	14,448	14,778	14,853	15,237	15,683
United Kingdom	38,384	37,903	36,042	36,367	36,608	36,893	37,399	38,252	38,839	39,309
United States	51,011	50,384	48,558	49,373	49,791	50,520	51,008	51,932	53,029	53,445

Note: ¹ The data come from the World Bank; ² The PPP uses the “Constant 2011 International \$” standard.

Table A3. The annual average of technical complexity for EGs from 2007 to 2016.

HS Coding	The Annual Average of <i>PRODY</i> /\$
842139	22,878
840290	28,044
901380	28,369
901390	29,266
903289	29,977
850490	30,310
840410	30,724
854140	31,144
850300	31,266
902680	31,329
841919	32,725
850164	32,926
850239	33,605
840490	33,674
840420	33,843
841780	34,245
903290	34,496
842199	34,792
850231	34,893
847420	34,911
902620	35,410
841989	35,520
841990	35,594
841790	35,661
851420	35,730
842129	36,306
903180	36,414
842121	36,420
903300	36,732
841960	36,737
851430	37,020
847989	37,271
841939	37,505
902710	37,544
851490	37,637
902610	38,161

Table A3. Cont.

HS Coding	The Annual Average of <i>PRODY</i> /\$
847982	38,404
441872	38,643
903190	38,969
902690	39,126
841290	39,139
841199	39,192
903149	39,569
851410	39,811
847990	40,144
901580	40,402
840510	40,762
841182	41,203
854390	41,792
902780	43,182
902790	44,488
902750	45,200
902730	45,688
902720	47,929

Note: The raw data of the calculation results are from the COMTRADE database.

References

1. Gong, Q. Evaluation of international competitive advantages of China's environmental products. *For. Econ. Trade Pract.* **2014**, *2*, 36–39.
2. Wen, W.; You, H. Can environmental product trade liberalization improve the environmental quality of developing countries? *Int. Econ. Trade Res.* **2017**, *33*, 22–36.
3. The United Nations COMTRADE Database. Available online: <https://comtrade.un.org> (accessed on 11 July 2018).
4. Li, K. Chinese Government Working Report. In Proceedings of the 13th National People's Congress, Beijing, China, 5 March 2018.
5. Dai, X.; Zhang, E. Does China's export technical complexity really catch up with developed countries? *Int. Trade Issues* **2011**, *7*, 3–16.
6. Wei, H. Re-measurement of structural changes in China's export commodities. *Int. Trade Issues* **2015**, *4*, 16–26.
7. Fan, G.; Guan, Z.; Yao, Z. Analysis of international trade structure: Technical distribution of trade products. *Econ. Res.* **2006**, *8*, 70–78.
8. Wan, R.; Nakada, M.; Takarada, Y. Trade liberalization in environmental goods. *Resour. Energy Econ.* **2018**, *51*, 44–66. [[CrossRef](#)]
9. Wen, W.; You, H. Liberalization of environmental products trade: Competitiveness and decision-making of Chinese enterprises. *Int. Econ. Coop.* **2015**, *2*, 36–40.
10. Li, L.; Zhang, B. The impact of APEC environmental inventory on China and its strategic choices. *J. Shanghai Univ. Int. Bus. Econ.* **2014**, *5*, 5–15.
11. Ronald, S. *Environmental Goods: A Comparison of the Apec and Oecd Lists*; OECD Papers; OECD Publishing: Paris, France, 2003; Volume 10.
12. Guan, Z. Looking at the strength of “Made in China” from the US market—Focusing on emerging technology products. *Int. Econ. Rev.* **2002**, *4*, 5–12.

13. Lall, S.; John, W.; Zhang, J. The sophistication of exports: A new measure of product characteristics. *World Dev.* **2006**, *34*, 222–237. [[CrossRef](#)]
14. Du, X.; Wang, W. The technology structure of China's export trade and its Changes: 1980–2003. *Econ. Res.* **2007**, *7*, 137–151.
15. Hausmann, R.; Jason, H.; Dani, R. What you export matters. *J. Econ. Growth* **2005**, *12*, 1–25. [[CrossRef](#)]
16. Wang, X.; Yang, L.; Qian, Z. Export structure transformation, technical complexity upgrade and China's manufacturing carbon emissions—from the perspective of embedding global value chains. *Sankei Rev.* **2017**, *3*, 5–18.
17. Yin, Z.; Tian, T. The change of China's agricultural products export competitiveness and international comparison-based on the analysis of the complexity of export technology. *Agric. Technol. Econ.* **2013**, *1*, 77–86.
18. Cong, H.; Wu, F.; Zou, D. Estimation and international comparison of technology structure of China's cultural and creative products trade export. *Explor. Econ. Issues* **2016**, *9*, 85–92.
19. Tang, B. Analysis of the measurement and influencing factors of China's high-tech industry value chain status. *Economics* **2012**, *10*, 65–70.
20. Zhu, S.; Chen, Y.; Xie, R. "The competition of the dragon and elephant" and "The dance of the dragon and elephant"—An analysis of Sino-Indian trade relations based on the export technology structure. *Stat. Res.* **2009**, *26*, 25–32.
21. Ma, J. Analysis of the trade competitiveness of China's environmental goods. *Int. Econ. Trade Explor.* **2011**, *27*, 34–47.
22. Xu, H. China's environmental product trade faces international checks and balances and development path choices. *For. Trade Econ. Pract.* **2017**, *9*, 44–47.
23. The World Bank Database. Available online: <http://databank.worldbank.org> (accessed on 20 July 2018).

© 2018 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<http://creativecommons.org/licenses/by/4.0/>).