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Evaluating the International Competitiveness of RCEP Countries' Biomass Products in the Context of the New Development Paradigm

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Abstract: As research related to the clean use of primary energy and new energy technologies continues to intensify in countries around the world, biomass energy has been incorporated into the long-term development plans of many countries for energy use due to its unique zero-carbon emission advantages. However, there are fewer studies on the competitiveness of biomass products in the literature. In this study, we adopted the constant market share (CMS) model and IRCA index method to measure the long-term trend of international competitiveness of biomass energy products in Regional Comprehensive Economic Partnership (RCEP) countries, which enriches the research on the competitiveness of biomass energy products. The two methods integrate multiple indicators to analyze the competitiveness of biomass energy in each country, making up for the deficiency that the RCA index can only be analyzed from trade volume. The results show that (1) the international competitiveness of biomass energy products in RCEP countries is on an upward trend; (2) the main biomass energy products of RCEP countries lack comparative advantages in the world market; and (3) the export market structure of biomass energy products in RCEP countries is not adapted to the world market demand. Finally, based on the above research findings, this paper puts forward some policy suggestions for exporting biomass energy products.

Keywords: RCEP countries; biomass products; international competitiveness; improved CMS model; IRCA index

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1. Introduction

As environmental problems become increasingly prominent, reducing environmental pollution has become a common goal of all countries to reduce dependence on fossil fuels and strive to transition to renewable energy sources [1]. As an alternative to fossil fuels, renewable energy is playing an increasingly important role in the adjustment of energy structure [2]. Being an important renewable energy source [3], biomass energy is also the only renewable carbon source that can be developed and utilized in various forms [4]. It plays an important role in addressing global climate change, alleviating energy supply shortage, and protecting the ecological environment. Its characteristics of easy storage and flexible utilization open up a wide range of applications for biomass [5]. The past few decades have seen unprecedented growth in global bioenergy production [6]. Under the European Renewable Energy Regulations [7], biofuel production is expected to form an intrinsic convergence with the renewable energy sector in the coming years. The Regional Comprehensive Economic Partnership (RCEP) is a regional trade agreement initiated by ASEAN in 2012 and developed by a total of 15 member countries, namely China, Japan, Korea, Australia, New Zealand, and the 10 ASEAN countries. With the entry into force of RCEP, the development of regional trade within the scope of the agreement will usher in new opportunities, and green trade and the blue economy will become a common focus of countries.

ASEAN countries are endowed with resources [8], not only in terms of oil, coal, natural gas, and other traditional fossil energy with abundant reserves and price advantages, but also in terms of biomass, hydroelectric energy, solar energy, and other clean renewable energy. However, due to technological constraints, clean energy has yet to be developed. Japan and Korea are countries with extremely scarce energy resources but leading technology and a mature petrochemical industry, China is both a major energy producer and consumer, and Australia is a major energy producer. Because of differences in economic development and resource endowment, the RCEP countries have formed certain resource and technology complementarities. Globally, biomass polygeneration, power generation, and biological natural gas have matured in terms of technology, equipment, and commercial operation mode, and the industrial scale is rapidly expanding. However, in most RECP member countries, biomass energy has received far less attention and recognition than wind and solar energy. Biomass energy has the greatest development potential of any renewable energy. RCEP countries must be aware of their export strengths and weaknesses in order to effectively produce and export biomass energy products.

Scholars are currently using TOPSIS to study the competitiveness of biomass energy products, but there is little literature on the competitiveness of biomass energy products from RCEP member countries. The CMS model and improved IRCA index method were used in this study, making the research results more useful for reference. The CMS model is rated as a relatively common and effective method for analyzing product competitiveness, while the IRCA index rule overcomes the limitation that traditional RCA indexes only considers trade volume. As a result, by examining the evolution trend of international competitiveness of biomass energy products in RCEP countries, the aim of this study was to identify the advantages and disadvantages of each country in terms of export competitiveness, that is, in order to propose relevant policy implications for each country to improve the export competitiveness of biomass energy products in the global market, thus allowing each country to capitalize on its endowment to participate in international trade. This study has significant theoretical and practical implications, and enriches the research field of biomass energy competitiveness.

2. Review of the Literature

Biomass energy has always been an important source of energy for human survival. It is the fourth-largest energy source in the world after coal, oil, and natural gas in terms of total energy consumption, and occupies an important position in the overall energy system. A search of the relevant literature reveals that academic research on biomass energy products can be divided into four main areas.

(1) Research on the development status of biomass energy in different countries: Most scholars have analyzed from the perspective of biomass energy resources. For example, Liang et al. [9] pointed out that China has abundant biomass energy and technology resources, and the main biomass utilization technologies mastered are combustion technology, biomass biogas fermentation technology, biomass gasification technology, and biodiesel technology. According to Uddin and Taplin [10], Bangladesh has enormous biomass energy potential, but its contribution to electricity generation is still negligible. According to Lee et al. [11], limited biomass resources and high biofuel costs are major barriers to Korea meeting its 2030 biofuel implementation target. According to Welfle [12], Brazil has extensive biomass resources that are likely to be sufficient to balance the country's total primary energy demand by 2030, making Brazil a major exporter of energy end-use resources. Furthermore, some scholars have examined the use of biomass, concluding that it is primarily used for cooking and heating in developing countries, while it is primarily used for industrial applications in the heat, power, and road transport sectors in developed countries [13]. According to Lamers et al. [14], trade volumes are determined by both market factors and policies, but policy changes do not have the same impact on trade development as they do in the liquid biofuels sector.

(2) Analysis of problems in the development of biomass in different countries: International trade in various bioenergy commodities has grown rapidly in recent years, but this growth has also been hampered by a number of barriers [15]. Sun [16] and Elauria et al. [17] both pointed out that there are extensive information barriers to the development of biomass in developing countries in Asia. In terms of policies, according to Benti et al. [18], Ethiopia's efforts to use biomass face a lack of comprehensive national biomass policy regulations, inadequate technology transfer and localization, unmanageable air pollution, and land usability and rights, among other challenges. According to Yu et al. [19], the main causes of overcapacity in the wind and biomass sectors are excessive government subsidies and unbalanced domestic and international market structures. As for the technical aspect, according to Rashidi et al. [20], Malaysia has abundant biomass resources, but large-scale implementation still faces technical and economic barriers, as well as a lack of local scientific and technological expertise. According to Liu et al. [21], China's biomass power industry faces the following challenges: a lack of technology, low-capacity utilization, a weak industrial base, and low mechanization.

(3) Policy recommendations for biomass energy development in different countries: To improve the competitiveness of the biomass energy industry, Shang and Wang [22] proposed that China increase investment in scientific research, insist on independent technological innovation, establish product quality standards, and improve the industry standard system. To address the cost issue, Wang et al. [23] and Bhattacharya [24] argued that the government should implement investment subsidies or other financial incentives. Alsaleh et al. [25] discovered that capital input, labor input, GDP, inflation rate, and interest rates all have a significant impact on the technical efficiency of the bioenergy industry in both developing and developed EU28 countries. Some scholars also analyzed the countermeasures for its development from the production chain. For example, Yokoyama and Matsumura [26] proposed that Japan collaborate with housing manufacturers to revitalize forestry and create new industries and jobs through the use of green biomass such as forest residues. According to Idris et al. [27], converting coal-fired power plants to co-firing facilities can help to meet decarbonization targets. According to Stolarski et al. [28], municipalities in rural areas obtain solid biomass in a variety of ways. According to Uddin et al. [29], biogas production and energy conversion from olive waste can form an important recovery chain. Chiang et al. [30] demonstrated that in using suitable pretreatment technologies or combined pretreatment methods before thermal conversion, herbaceous and agricultural wastes can effectively improve the energy density and energy use efficiency of biomass. Cydzik [31] proposed using circular economy rules to improve wastewater treatment process performance and waste stream management solutions to reduce human activity's environmental impact.

(4) Quantitative study of the economic impact of developing biomass: Shang and Wang [32] evaluated the competitiveness indicators of biomass products in China based on the entropy and TOPSIS methods, and the results showed that the biomass industry was most competitive in developed regions and least competitive in less developed regions in China. Junginger et al. [33] quantified the volume and sources of imported and exported biomass and identified the drivers and barriers behind trade flows in the Netherlands. Yasmeen et al. [34] studied 52 "Belt and Road" panel countries from 1992–2017 using cross-sectional incremental data. The results show that the ecological footprint is negatively related to biomass consumption and that technological progress can reduce the ecological footprint of the economy. Rammer et al. [35] studied the impact of energy policy on firms' export performance based on data from firms in Germany, Switzerland, and Austria, and concluded that energy policy has little impact on firms' export performance. Ezealigo et al. [36] investigated the bioenergy potential of agricultural residues and municipal solid and liquid wastes using data from 2008 to 2018. The results indicate that biogas has a wide range of applications and great potential to address the current electricity crisis in Nigeria. Wang et al. [37] found that biomass contributes significantly to the reduction in greenhouse gas emissions in Canada.

A review of the literature shows that there is a relatively rich body of relevant domestic and international research on biomass energy products. However, few academics have investigated the competitiveness of biomass energy. Knapek et al. [38] assessed biomass energy from a price standpoint and concluded that it can only replace coal's competitiveness in heating when its price is close to zero. According to Millinger et al. [39], the most cost-competitive biofuels are still traditional biodiesel and bioethanol. The above graduate-material energy competitiveness literature compares biomass energy products with other energy products or different biomass energy products, rather than the export competitiveness of a country. Furthermore, empirical research on the international competitiveness of RCEP biomass energy products is still lacking in all trade items. As a result, using an improved CMS model and the IRCA index method, this study investigated the international competitiveness of RCEP national biomass energy products.

3. Research Methodology and Data Sources

3.1. Research Methodology

3.1.1. IRCA Index

In this study, a number of variables reflecting the competitiveness of biomass energy products were downscaled to obtain weights using the projection tracing method and multiplied with the traditional RCA index to construct a new IRCA index, as shown in the model of (1).

$$\boldsymbol{IRCA_{ij} = a_i RCA_{ij}} \tag{1}$$

Here, *a* denotes the weight, and *i* and *j* denote the *i*-th period in the *j*-th commodity group, respectively. In a mathematical sense, the weight *a* is a correction made to the export volume. The acquisition of the traditional RCA index and weights is described next.

(1) Traditional RCA Index

To measure a nation's industry's comparative advantage in international trade, Balassa proposed the revealed comparative advantage (RCA) index. This study used the RCA method to analyze the comparative advantage of 18 biomass products exported by RCEP countries based on pertinent data retrieved from the UN Comtrade database for the period 2008–2020 in order to quantitatively compare the comparative advantages of various biomass products exported by RCEP countries.

The formula for calculating the RCA of industry *j* in country *i* in international trade is given in Equation (2):

$$\boldsymbol{RCA = \frac{X_{ij}/X_i}{X_{wj}/X_w}} \tag{2}$$

where X_{ij} denotes the export value of industry *j in* country *i*, X_i denotes the export value of goods in country *i*, X_{wj} denotes the export value of industry j worldwide, and X_w denotes the export value of goods worldwide. If $RCA_{ij} < 1$, then industry j in country i is at a comparative disadvantage in international trade; if $RCA_{ij} > 1$, it is at a comparative advantage, and the larger the value, the greater the comparative advantage.

As the international trade environment changes and science and technology continue to innovate, some scholars have found that the traditional RCA index method has obvious limitations in scientometrics research [40]. The limitations of the RCA index method are that it focuses more on static analysis, so it cannot be used to predict the trend of a country's trade development; additionally, it does not take into account the fact that a country's resource endowment or even comparative advantage is actually evolving. To some extent, the important role of import trade in a country's foreign trade and industrial development is also ignored. The aim of this study was to improve on the RCA index method by introducing corresponding evaluation indexes and forming a new IRCA index, which is known as the IRCA index method. The IRCA index method calculates potential factors that affect a product's comparative advantage, such as economy, trade status, production factors, education level, and so on, reflecting the comparative advantage of biomass energy products in a more objective and multi-dimensional manner than the RCA index method.

We can clearly grasp the comparative advantage of a specific biomass energy product in a country by calculating the IRCA index, and this comparative advantage is closely related to the development of all aspects of the country, rather than trade volume alone. As a result, in this study, weight was added to the traditional RCA index using relevant indicators to overcome the traditional RCA index's weakness.

(2) Weights

The projection tracing method was used in this study to obtain weights. A group of statistical techniques known as projection tracing was used to process and analyze high-dimensional data. In order to analyze high-dimensional data, the basic idea is to project high-dimensional data onto a low-dimensional subspace and find a projection that accurately captures the structure or properties of the original high-dimensional data. This study used this method to transform multiple variables related to export competitiveness, i.e., p-dimensional data {x(i,j) | j = 1, 2, . . . , p} into one-dimensional data, i.e., innovation weights a = {a(1), a(2), a(3), . . . , a(p)}, where the larger the coefficient of a variable prediction vector, the greater the influence of that variable.

① Selection of indicators

Based on the availability of data, this paper identifies five specific factors that affect the trade flows of biomass products in each RCEP country: GDP, total population, biomass electricity generation (GWh), biomass electricity capacity (MW), and total renewable energy generation (GWh) for each country from 2008 to 2020.

② Projection tracing process

A. Normalization of the sample evaluation indicator set

This study used the min–max normalization method to normalize the data, with a transformation function for the series x as in Equation (3).

$$\boldsymbol{y_i} = \frac{(\boldsymbol{x_i} - \boldsymbol{min}(\boldsymbol{x}))}{(\boldsymbol{max}(\boldsymbol{x}) - \boldsymbol{min}(\boldsymbol{x}))} \tag{3}$$

B. Construction of the projection objective function

The p-dimensional data x(i,j) were multiplied synthetically by a = {a(1), a(2), a(3), . . . , a(p)}, which yields the projection value of Equation (4):

$$\boldsymbol{Z_i} = \sum_{j=1}^{p} \boldsymbol{a_j x_{ij}} \tag{4}$$

where a is the unit length vector. The projection needs to be analyzed as a scatter diagram, which requires that the local cohesion is shown as far as possible, but also that the cohesion points are spread out, so that the projection indicator function is expressed as in Equation (5).

$$\boldsymbol{Q}(\boldsymbol{a}) = \boldsymbol{S}(\boldsymbol{a})\boldsymbol{D}(\boldsymbol{a}) \tag{5}$$

$$\boldsymbol{S}(\boldsymbol{a}) = \sqrt{\frac{\mathbf{1}}{\boldsymbol{n}} \sum_{j=1}^{n} (\boldsymbol{z_i} - \bar{\boldsymbol{z}})^2} \tag{6}$$

$$\boldsymbol{D}(\boldsymbol{a}) = \sum_{i=1}^{n} \sum_{j=1}^{p} (\boldsymbol{R} - \boldsymbol{r_{ij}})\boldsymbol{f}(\boldsymbol{R} - \boldsymbol{r_{ij}}) \tag{7}$$

Here, $S(a)$ in Equation (6) is the standard deviation. $D(a)$ in Equation (7) denotes the local density. For the sequence, R is the window radius of the local density degree. For this study, $R(a) = 0.1S(a)$, r_{ij} is the inter-sample distance, shown by Equation (8), and $f(x)$ is the step signal, shown by Equation (9).

$$\boldsymbol{r_{ij}} = |\boldsymbol{z_i} - \boldsymbol{z_j}| \tag{8}$$

$$f(x) = \begin{cases} \mathbf{0}, & x < \mathbf{0} \\ \mathbf{1}, & x \geq \mathbf{0} \end{cases} \tag{9}$$

C. Optimization of the projection indicator function

Constrained non-linear function optimization was performed, and the optimal projection direction was estimated.

The maximizing scalar function is given in Equation (10).

$$\mathbf{max}(Q(a)) \tag{10}$$

The constraint is as in Equation (11).

$$s.t.\ \ \sum_{j=1}^{p} a_j^2 = 1 \tag{11}$$

The derived a = {a(1), a(2), a(3), . . . , a(p)} are the weights for this study.

3.1.2. Constant Market Share (CMS)

(1) Introduction to the model

The CMS model was proposed by Tyszynski in 1951 and later improved by several scholars such as Jepma (1989) to become a practical and more accurate tool for analyzing the factors influencing trade volatility. The model is widely used in international trade analysis.

From a theoretical standpoint, the model assumes that if a country's exports of biomass energy products remain competitive, its market share should also remain stable. As a result, the difference between actual changes in a country's exports and changes in the exports of its competitors must be due to changes in competitiveness or export structure. Based on this assumption and statistical principles, the CMS model compares the value, commodity structure, and market structure (sample) of RCEP countries' exports to the rest of the world over the same period and decomposes export growth into two levels. The first level includes structural, competitive, and second-order effects, while the second level includes growth effects, product effects, general competitiveness effects, specific competitive effects, pure second-order effects, and dynamic second-order effects. We can easily find the share of the contribution of the competitiveness of exports of biomass products in RCEP countries by analyzing the share of the different effects in the growth of goods exports and revealing the sources of export growth and the factors that constrain growth. The two-level decomposition of CMS model to export growth is shown in Figure 1.

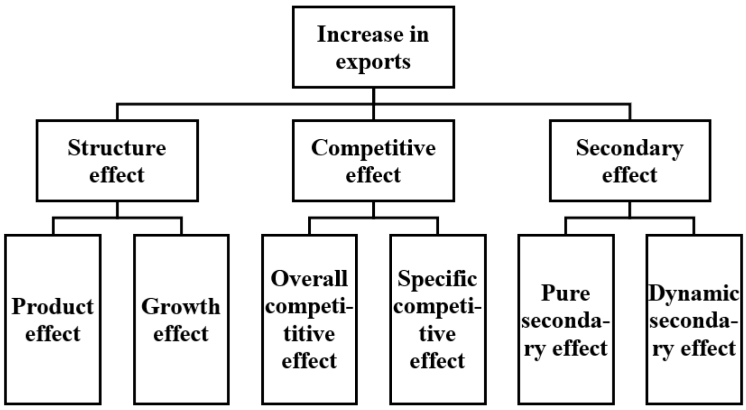

Figure 1. Schematic of the CMS model's two-level decomposition of export growth.

(2) Decomposition formula

① The formula for the one-layer decomposition is given in Equation (12).

$$\Delta q = \sum_i s_i^0 \Delta Q_i + \sum_i \Delta s_i Q_i^0 + \sum_i \Delta s_i \Delta Q_i \tag{12}$$

The first level of this modified CMS model splits the total effect of export growth into structural, competitiveness, and second-order effects. $\sum_i s_i^0 \Delta Q_i$ is the structural effect, representing the change in the value of exports of biomass energy products from a particular RCEP country due to a change in total imports of biomass energy products in the world market. $\sum_i \Delta s_i Q_i^0$ is the competitiveness effect, representing the change in the value of exports of biomass energy products from a given RCEP country due to a change in the competitiveness of that country's exports of biomass energy products. $\sum_i \Delta s_i \Delta Q_i$ is a second-order effect, representing the change in the value of the country's exports of biomass energy products due to the combined effect of changes in total imports of biomass energy products in the world market and the competitiveness of exports of biomass energy products from a particular RCEP country.

② The two-level decomposition formula is as in Equation (13).

$$\begin{aligned}\boldsymbol{\Delta q} = \boldsymbol{s^0 \Delta Q} + \left(\textstyle\sum_i \boldsymbol{s_i^0 \Delta Q_i} - \boldsymbol{s^0 \Delta Q}\right) + \boldsymbol{\Delta s Q^0} + \left(\textstyle\sum_i \boldsymbol{s_i Q_i^0} - \boldsymbol{\Delta s Q^0}\right) + \left[\left(\boldsymbol{Q^1/Q^0} - \mathbf{1}\right) \textstyle\sum_i \boldsymbol{s_i Q_i^0}\right] \\ + \left[\textstyle\sum_i \boldsymbol{\Delta s_i \Delta Q_i} - \left(\boldsymbol{Q^1/Q^0} - \mathbf{1}\right) \textstyle\sum_i \boldsymbol{s_i Q_i^0}\right]\end{aligned} \tag{13}$$

In the above equation, q denotes the total exports of biomass energy products to the world from a particular RCEP country; Q denotes the total world imports of biomass energy products. Q_i denotes the total world imports of biomass energy products of type i; s denotes the share of exports of biomass energy products of a particular RCEP country to the world in the total world imports of biomass energy products. The term s_i denotes the share of the export value of biomass energy products of category i of the RCEP for a particular country in the total world import value of that category of biomass energy products. The term $s^0 \Delta Q$ denotes the growth effect. $\left(\sum_i s_i^0 \Delta Q_i - s^0 \Delta Q\right)$ denotes the product effect. The term $\Delta s Q^0$ denotes the overall competitive effect. $\left(\sum_i s_i Q_i^0 - \Delta s Q^0\right)$ denotes a specific competitive effect. $\left[\left(Q^1/Q^0 - 1\right) \sum_i s_i Q_i^0\right]$ denotes a pure second-order effect. $\left[\sum_i \Delta s_i \Delta Q_i - \left(Q^1/Q^0 - 1\right) \sum_i s_i Q_i^0\right]$ denotes dynamic second-order effects; 0 and 1 represent the base period and end period, respectively; Δ denotes the amount of change in both periods.

3.2. Data Sources

The biomass energy products mainly contain 18 products with HS codes 220710, 220720, 380210, 382490, 730900, 741999, 761100, 8406821, 840682, 841182, 841620, 841931, 841940, 841989, 842129, 824139, 847920, 847989, 824139, 847920, and 847989. The above-mentioned trade data of biomass products from RCEP countries as well as the rest of the world were retrieved for quantitative analysis based on the International Convention on Harmonized Commodity Description and Coding System (HS Code for short). The data for this study came from the United Nations Statistical Office's trade database (UN Comtrade).

4. Current Status of International Trade in Biomass Products in RCEP Countries

4.1. Product Codes

Table 1 shows the classification of biomass products for each traded commodity based on the HS codes.

4.2. Biomass Products in RCEP Countries: Trends in International Trade

Statistics from the United Nations Statistical Office Trade Data (UN Comtrade) show a general trend of increasing trade in biomass products in RCEP countries since 2008 (see table and graph). Figure 2 charts the general trend of trade in biomass products in RCEP countries from 2008 to 2020: from USD 48,496.64 million in 2009 to USD 58,936.66 million in 2020, an increase of USD 10,440.02 million or 21.53%. Until 2018, trade in biomass products in RCEP countries was in a trade deficit phase, with a deficit of USD 141,858 million in 2018; after 2019, it turned into a surplus, and the surplus has been widening year by year, with a trade surplus of 3543.19 in 2020, an increase of 30.42% compared to 2019. The specific data are shown in Table 2.

Table 1. Trends in the export value of biomass products from RCEP countries from 2008 to 2020.

HS	Product Description
220710	Unmodified ethanol
220720	Modified ethanol
380210	Activated carbon
382490	Additives for mortar and concrete
730900	Containers made of steel with a volume > 300 L
741999	Brassware
761100	Aluminum hoards, cans and other containers with a volume of >300 L
840681	Other turbines with more than 4000 kw
840682	Other turbines with a power of up to 4000 kw
841182	Other turbines with more than 5000 kw
841620	Furnaces; solid fuel powder or gasoline furnace burners
841931	Agricultural dryers
841940	Distillation units
841989	Industrial machines for processing materials using temperature changes
842129	Liquid filtration and purification machines and devices
842139	Gas filtration and purification machines and devices
847920	Machines for extracting and processing animal or vegetable fats and oils
847989	Machines and devices with unique functions

Source: Compiled by the author from the UN Comtrade database HS classification product descriptions.

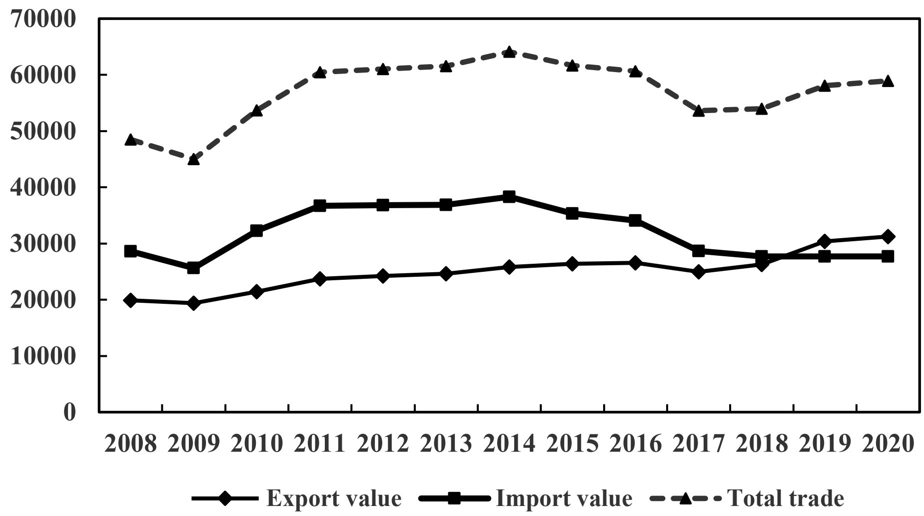

Figure 2. The general trend of trade in biomass products in RCEP countries from 2008 to 2020.

Table 2. Overall trends in biomass trade in RCEP countries from 2008 to 2020 (Unit: USD million).

Year	Export Value	Imports	Total Trade	Trade Surplus	Total Growth Rate (%)
2008	19,899.33	28,597.31	48,496.64	−8697.98	-
2009	19,387.5	25,630.83	45,018.33	−6243.33	−7.17%
2010	21,425.55	32,257.51	53,683.05	−10,831.96	19.25%
2011	23,721.2	36,722.48	60,443.68	−13,001.28	12.59%
2012	24,226.95	36,835.94	61,062.88	−12,608.99	1.02%
2013	24,645.82	36,891.64	61,537.46	−12,245.82	0.78%
2014	25,793.7	38,297.01	64,090.71	−12,503.31	4.15%
2015	26,377.69	35,316.37	61,694.06	−8938.68	−3.74%
2016	26,551.67	34,076.42	60,628.09	−7524.75	−1.73%
2017	24,946.72	28,674.09	53,620.81	−3727.37	−11.56%
2018	26,283.42	27,697	53,980.42	−1413.58	0.67%
2019	30,390.46	27,673.74	58,064.2	2716.72	7.57%
2020	31,239.93	27,696.74	58,936.66	3543.19	1.50%

Source: Authors' calculations based on UN Comtrade database data, 2021.

5. Results of IRCA Index Method Analysis

CMS model decomposition results can reveal the evolution trend of biomass energy product competitiveness and market factors. However, in order to better understand the relative advantages of specific products, we must use a new RCA method known as the IRCA method. The method was designed and built specifically for this purpose. The IRCA method was used in this study to assess the export trade competitiveness of biomass energy products in RCEP countries. This study optimizes the projection tracing method using a real-number-coded accelerated genetic algorithm (RAGA), setting the initial population size to 100, the maximum number of genetic generations to 1000, the crossover probability to 0.8, and the variation probability to 0.05, and the optimization process was carried out using MATLAB. The final one-dimensional projection index was 31.2 according to the genetic algorithm, and the weights of each variable were a = {0.5083, 0.6792, 0.0860, 0.0695, 0.5178}. The convergence process is shown in Figure 3. Due to the small quantity of data on relevant indicators for the 10 ASEAN countries, only six countries—China, Korea, Australia, Japan, Thailand, and Malaysia—were analyzed in this IRCA index method.

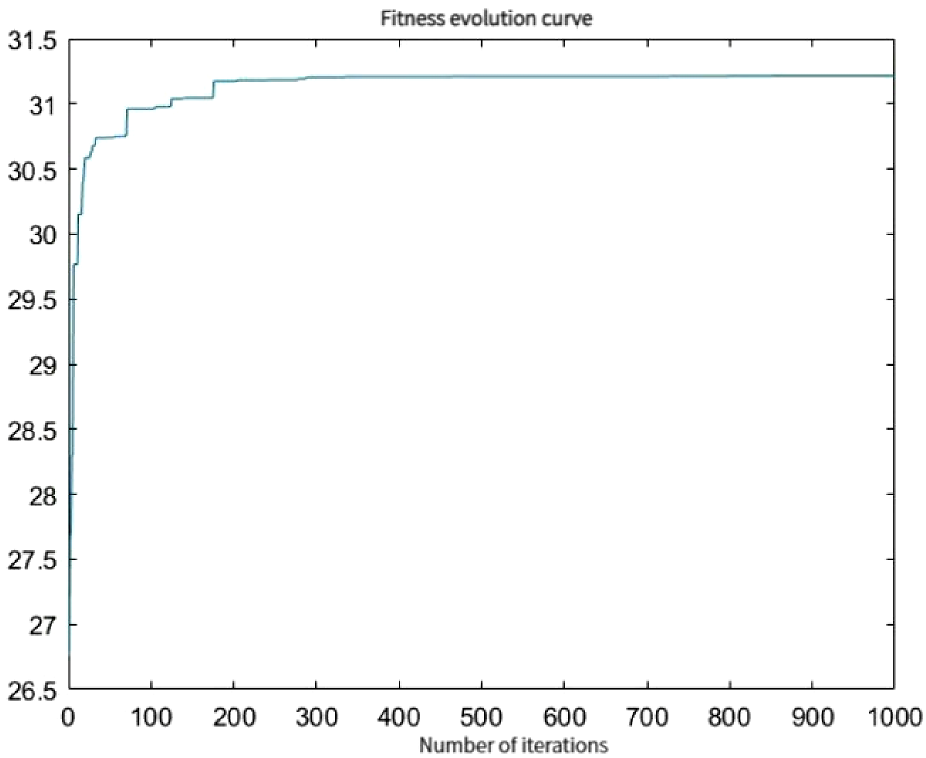

Figure 3. Genetic algorithm convergence process.

The 18 commodities were divided into 4 categories according to the use attributes of the different biomass energy products: the first category is activated carbon (380210); the second category is all ethanol and other spirits (220710; 220720; 382490); the third category is reservoirs, tanks, and vats (730300; 741999; 761100); and the fourth category is steam, vapor, gas turbines, etc. (840681; 840682; 841182; 841620; 841931; 841940; 841989; 842129; 842139; 847920; 847989).

This study follows the traditional RCA index for classifying the level of competitiveness. The specific data are shown in Table 3.

Table 3. IRCA index for biomass products in RCEP countries.

Year	China				Australia				Korea				Japan				Thailand				Malaysia			
	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D
2008	2.73	0.34	0.62	0.34	0.02	0.02	0.010	0.010	0.003	0.053	0.08	0.08	0.18	0.30	0.17	0.39	0.006	0.05	0.003	0.002	0.003	0.020	0.003	0.001
2009	2.34	0.34	0.60	0.45	0.03	0.03	0.009	0.012	0.003	0.053	0.08	0.08	0.17	0.30	0.19	0.34	0.006	0.05	0.003	0.002	0.004	0.022	0.002	0.002
2010	2.28	0.41	0.60	0.49	0.03	0.03	0.009	0.013	0.002	0.062	0.09	0.09	0.19	0.32	0.21	0.42	0.005	0.06	0.004	0.003	0.004	0.022	0.002	0.002
2011	2.56	0.52	0.68	0.48	0.03	0.02	0.007	0.012	0.003	0.062	0.10	0.10	0.18	0.35	0.21	0.43	0.006	0.06	0.004	0.004	0.004	0.024	0.002	0.002
2012	2.47	0.64	0.67	0.54	0.02	0.03	0.008	0.008	0.002	0.057	0.10	0.10	0.15	0.35	0.22	0.37	0.005	0.06	0.005	0.004	0.004	0.033	0.002	0.002
2013	2.48	0.60	0.71	0.62	0.00	0.03	0.012	0.008	0.003	0.067	0.11	0.11	0.13	0.32	0.19	0.25	0.005	0.07	0.005	0.003	0.004	0.044	0.001	0.002
2014	2.32	0.70	0.75	0.69	0.00	0.02	0.010	0.007	0.005	0.080	0.11	0.11	0.12	0.31	0.17	0.20	0.005	0.07	0.005	0.003	0.004	0.038	0.001	0.003
2015	2.09	0.75	0.85	0.69	0.03	0.03	0.009	0.006	0.008	0.086	0.12	0.12	0.10	0.29	0.17	0.16	0.005	0.07	0.005	0.004	0.003	0.035	0.001	0.002
2016	2.21	0.80	0.86	0.91	0.03	0.05	0.009	0.006	0.003	0.092	0.12	0.12	0.11	0.31	0.17	0.19	0.006	0.08	0.008	0.002	0.003	0.042	0.001	0.002
2017	2.39	0.09	0.82	1.00	0.04	0.15	0.008	0.006	0.005	0.007	0.13	0.13	0.11	0.32	0.16	0.21	0.007	0.08	0.010	0.004	0.003	0.000	0.001	0.002
2018	3.12	0.07	0.97	1.06	0.00	0.07	0.006	0.007	0.005	0.014	0.14	0.14	0.12	0.33	0.19	0.21	0.007	0.08	0.011	0.002	0.004	0.006	0.002	0.003
2019	2.90	0.02	1.17	1.29	0.00	0.11	0.016	0.006	0.003	0.019	0.14	0.14	0.13	0.34	0.21	0.18	0.008	0.09	0.009	0.003	0.004	0.002	0.002	0.003
2020	2.71	0.32	1.29	1.63	0.00	0.14	0.013	0.007	0.003	0.020	0.13	0.13	0.11	0.34	0.20	0.16	0.008	0.09	0.011	0.003	0.003	0.000	0.002	0.002

Source: Authors' calculations based on UN Comtrade database data, A, B, C, and D for activated carbon; all ethanol and other spirits; reservoirs, tanks, and vats; and steam, vapor, and gas turbines, respectively.

(1) China: comparative advantage of activated carbon is more stable, and comparative advantage of remaining products is weaker but increasing

The IRCA index for activated carbon is consistently greater than 2, stable at around 2.7, and reached a peak of 3.12 in 2018, demonstrating that China's activated carbon has a competitive advantage on the global market and significant growth potential. On the other hand, up until 2019, the RCA index for all ethanol and other spirits; reservoirs, tanks, and vats; as well as steam, vapor, and gas turbines was consistently less than 1, indicating that these three major product categories essentially have no comparative advantage, though all exhibit an upward trend. This means that these three types of products have development potential, which could be attributed to the effectiveness of national support policies or the advancement of enterprise technology, both of which promote the expansion of comparative advantages. However, the factor endowment advantage of these products is relatively low, leaving a large development space.

The relative advantages of steam, vapor, and gas turbines and reservoirs, tanks, and vats rose from 0.62 and 0.34 in 2008 to 1.29 and 1.63 in 2020, respectively. China's exports of all ethanol do not have a comparative advantage in the global market, according to the IRCA index, which shows that the period from 2008 to 2020 is less than 1. In general, China has an abundance of biomass energy resources and has established a number of key backbone enterprises in the field of biomass energy power generation. The comparative advantages of most biomass energy products are favorable, but there is a significant gap between cellulosic ethanol technology and foreign core technologies, which affects ethanol's comparative advantages.

(2) Australia, Japan, Korea, Malaysia, Thailand: all biomass products do not have a comparative advantage

The trend in the IRCA index shows that the IRCAI results for biomass products in Australia, Japan, Korea, Malaysia, and Thailand are similar, all less than 1, i.e., no comparative advantage. This means that, despite their abundance of biomass energy resources, these countries lag behind other exporting countries in terms of technology or industrial scale, and thus the factor endowment advantage fails to promote export growth.

Except for a slight increase in the comparative advantage of all ethanol and other spirits, which increased from 0.02 in 2008 to 0.14 in 2020, Australia's comparative advantage in activated carbon, reservoirs, tanks, and vats, as well as steam, vapor, and gas turbines, shows a downward trend. This indicates that Australia has more room to advance in the export of biomass products. It is clear that, despite its vast territory and abundant biomass energy resources, Australia is deficient in biomass energy products, which could be attributed to a lack of promotion or difficult technological development.

In Korea, there is an upward trend in the comparative advantage of other spirits as well as steam and gas turbines. Korea has prioritized the development of the biomass energy industry in response to the growing importance of biomass energy resources and the acceleration of resource consumption, and exports of biomass energy products and biomass energy generation have increased.

In comparison to these nations, Japan's biomass products have a relatively high comparative advantage. While the comparative advantage of the other two products exhibited a downward trend, the comparative advantage of all ethanol and other spirits increased from 0.3 and 0.17 in 2008 to 0.34 and 0.2, respectively. Fossil fuels remain the primary source of energy in Japan, and they are widely used in a variety of fields such as electricity, heating, and transportation. However, because the Japanese government has recently invested heavily in biofuel research and development, the comparative advantages of some of its biomass energy products are improving.

The change in the IRCA index for Malaysia has been more stable, at around 0.002. This means that, despite Malaysia's abundant domestic biomass resources, the country's biofuel industry is primarily focused on thermal power generation. The country's lengthy visa procedures and a lack of open labor markets have hampered business.

The comparative advantages of all biomass products in Thailand show an upward trend, from 0.006, 0.05, 0.003, 0.002 in 2008 to 0.008, 0.09, 0.011, 0.003 in 2020 for activated carbon; all ethanol; other spirits; and steam, vapor, and gas turbines, respectively. There is also a greater potential for development that should be achieved by upgraded technology.

6. Analysis of CMS Model Results

6.1. Delineation of Study Intervals

The sample for this study consisted of 18 HS-coded biomass energy products, and all the data were taken from the United Nations Statistical Office Trade (UN Comtrade) database. In this study, we chose data on the export of biomass energy from the RCEP countries and the rest of the world from 2008 to 2020. We then analyzed the overall trend of the total export of biomass energy from the RCEP countries. The results show that over the past 13 years, the export trend of biomass energy products from RCEP countries has been decreasing, then increasing, then decreasing, and finally showing an increase (Figure 4). Therefore, we used four study periods in this work: in the first stage (2008–2009), due to the financial crisis, the export value of biomass from RCEP countries dropped significantly; in the second stage (2009–2016), with the gradual and slow recovery of the world economy, the export trade of biomass from RCEP countries showed a gradual increase again; in the third stage (2016–2017), RCEP countries' biomass export trade volume was on a downward trend; in the fourth stage (2017–2020), RCEP countries' biomass export trade volume turned from a downward to an upward trend. Due to the small quantity of data on biomass products exported by Brunei, Myanmar, Laos, Philippines, Cambodia, and Indonesia, these countries were not included in this CMS model.

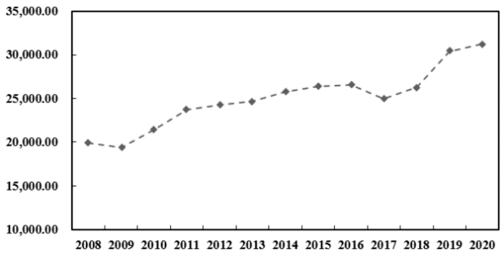

Figure 4. Export value of biomass products from RCEP countries from 2008 to 2020.

Based on the above stages, we used the CMS model to measure the export data of biomass products of RCEP countries in each stage, before comparing the change trends of each interval in order to reveal the change pattern of international competitiveness of biomass products of RCEP countries.

6.2. Results and Analysis

The CMS breakdown results for each country are shown in Tables 4–12.

Table 4. Results of CMS model decomposition of China's biomass export growth (Unit: USD million).

Year	2008–2009		2009–2016		2016–2017		2017–2020	
	Amount of Contribution	Contribution Rate	Amount of Contribution	Contribution Rate	Amount of Contribution	Contribution Rate	Amount of Contribution	Contribution Rate
Growth in export value	−203.20	100.00%	5480.18	100.00%	−1621.98	100.00%	5400.30	100.00%
Structural effects	−1232.27	−606.42%	1583.31	28.89%	1238.21	76.34%	−370.91	−6.87%
Product effects	−331.00	−162.89%	375.09	6.84%	2635.55	162.49%	−710.07	−13.15%
Growth effects	−901.27	−443.53%	1208.21	22.05%	−1397.34	−86.15%	339.16	6.28%
Competitive effects	1567.23	771.26%	4042.36	73.76%	−3349.88	−206.53%	6153.73	113.95%
Overall competitiveness effect	879.23	432.68%	3312.42	60.44%	−262.67	−16.19%	4856.02	89.92%
Specific competitive effects	688.00	338.58%	729.94	13.32%	−3087.21	−190.34%	1297.72	24.03%
Second-order effects	−538.16	−264.84%	−145.49	−2.65%	489.69	30.19%	−382.53	−7.08%
Pure second-order effects	−322.93	−158.92%	1171.00	21.37%	485.02	29.90%	259.94	4.81%
Dynamic second-order effects	−215.24	−105.92%	−1316.49	−24.02%	4.67	0.29%	−642.47	−11.90%

Data source: Authors' calculations based on UN Comtrade database data, using CMS model.

Table 5. Results of the CMS model decomposition of Vietnam's biomass export growth (Unit: USD million).

Year	2008–2009		2009–2016		2016–2017		2017–2020	
	Amount of Contribution	Contribution Rate	Amount of Contribution	Contribution Rate	Amount of Contribution	Contribution Rate	Amount of Contribution	Contribution Rate
Growth in export value	247.22	100.00%	4055.29	100.00%	1015.65	100.00%	4739.02	100.00%
Structural effects	−727.04	−294.09%	1054.82	26.01%	2558.86	251.94%	−516.48	−10.90%
Product effects	−298.12	−120.59%	380.20	9.38%	3483.20	342.95%	−829.06	−17.49%
Growth effects	−428.92	−173.50%	674.62	16.64%	−924.34	−91.01%	312.57	6.60%
Competitive effects	1495.82	605.06%	2780.51	68.57%	621.17	61.16%	5515.86	116.39%
Overall competitiveness effect	851.61	344.48%	2621.32	64.64%	2268.43	223.35%	4247.05	89.62%
Specific competitive effects	644.21	260.58%	159.20	3.93%	−1647.26	−162.19%	1268.81	26.77%
Second-order effects	−521.56	−210.97%	219.98	5.42%	−2164.41	−213.11%	−260.36	−5.49%
Pure second-order effects	−308.21	−124.67%	805.46	19.86%	−89.94	−8.86%	233.00	4.92%
Dynamic second-order effects	−213.35	−86.30%	−585.48	−14.44%	−2074.47	−204.25%	−493.35	−10.41%

Data source: Authors' calculations based on UN Comtrade database data, using CMS model.

Table 6. Results of the CMS model decomposition of New Zealand's biomass export growth (Unit: USD million).

Year	2008–2009		2009–2016		2016–2017		2017–2020	
	Amount of Contribution	Contribution Rate	Amount of Contribution	Contribution Rate	Amount of Contribution	Contribution Rate	Amount of Contribution	Contribution Rate
Growth in export value	−18.00	100.00%	−5.87	100.00%	−17.62	100.00%	−15.20	100.00%
Structural effects	−27.07	−150.33%	24.64	420.05%	7.84	44.51%	−1.89	−12.46%
Product effects	−10.30	−57.19%	6.28	107.08%	16.17	91.75%	−3.58	−23.54%
Growth effects	−16.77	−93.14%	18.36	312.96%	−8.33	−47.25%	1.68	11.08%
Competitive effects	14.14	78.54%	−16.13	−274.98%	−25.93	−147.11%	−12.84	−84.46%
Overall competitiveness effect	−1.56	−8.64%	−18.79	−320.21%	−10.87	−61.68%	−16.20	−106.58%
Specific competitive effects	15.70	87.18%	2.65	45.22%	−15.06	−85.43%	3.36	22.12%
Second-order effects	−5.08	−28.21%	−14.38	−245.06%	0.46	2.61%	−0.47	−3.09%
Pure second-order effects	−2.91	−16.18%	−4.67	−79.66%	3.75	21.30%	−0.54	−3.57%
Dynamic second-order effects	−2.17	−12.03%	−9.70	−165.40%	−3.29	−18.69%	0.07	0.48%

Data source: Authors' calculations based on UN Comtrade database data, using CMS model.

Table 7. CMS model decomposition results for Singapore's biomass export growth (Unit: USD million).

Year	2008–2009		2009–2016		2016–2017		2017–2020	
	Amount of Contribution	Contribution Rate	Amount of Contribution	Contribution Rate	Amount of Contribution	Contribution Rate	Amount of Contribution	Contribution Rate
Growth in export value	−300.81	100.00%	920.39	100.00%	115.09	100.00%	−272.19	100.00%
Structural effects	−429.52	−142.79%	424.65	46.14%	368.12	319.85%	−541.01	−198.76%
Product effects	−140.92	−46.85%	106.04	11.52%	660.63	574.00%	−631.21	−231.90%
Growth effects	−288.60	−95.94%	318.60	34.62%	−292.50	−254.15%	90.20	33.14%
Competitive effects	221.64	73.68%	874.84	95.05%	3783.15	3287.10%	−111.23	−40.87%
Overall competitiveness effect	−15.37	−5.11%	466.62	50.70%	476.60	414.11%	−347.70	−127.74%
Specific competitive effects	237.01	78.79%	408.22	44.35%	3306.55	2872.99%	236.47	86.88%
Second-order effects	−92.92	−30.89%	−379.10	−41.19%	−4036.19	−3506.95%	380.05	139.63%
Pure second-order effects	−45.67	−15.18%	253.43	27.53%	−547.75	−475.93%	−4.70	−1.73%
Dynamic second-order effects	−47.26	−15.71%	−632.52	−68.72%	−3488.43	−3031.02%	384.75	141.36%

Data source: Authors' calculations based on UN Comtrade database data, using CMS model.

Table 8. Results of CMS model decomposition of Thailand's biomass export growth (Unit: USD million).

Year	2008–2009		2009–2016		2016–2017		2017–2020	
	Amount of Contribution	Contribution Rate	Amount of Contribution	Contribution Rate	Amount of Contribution	Contribution Rate	Amount of Contribution	Contribution Rate
Growth in export value	14.04	100.00%	139.78	100.00%	20.28	100.00%	−20.72	100.00%
Structural effects	−157.47	−1121.35%	187.95	134.46%	999.14	4926.73%	−5.64	−27.22%
Product effects	−41.38	−294.65%	20.66	14.78%	1102.99	5438.80%	−36.80	−177.55%
Growth effects	−116.09	−826.70%	167.28	119.68%	−103.85	−512.07%	31.15	150.33%
Competitive effects	238.35	1697.32%	965.40	690.66%	−127.90	−630.66%	−7.42	−35.79%
Overall competitiveness effect	163.91	1167.20%	−21.33	−15.26%	145.14	715.69%	−49.78	−240.18%
Specific competitive effects	74.45	530.12%	986.72	705.92%	−273.04	−1346.36%	42.36	204.40%
Second-order effects	−66.84	−475.97%	−1013.56	−725.12%	−850.96	−4196.06%	−7.67	−36.99%
Pure second-order effects	−49.11	−349.73%	279.66	200.07%	18.52	91.31%	−0.31	−1.51%
Dynamic second-order effects	−17.73	−126.24%	−1293.22	−925.19%	−869.48	−4287.38%	−7.35	−35.48%

Data source: Authors' calculations based on UN Comtrade database data, using CMS model.

Table 9. Results of the CMS model decomposition of Japan's biomass export growth (Unit: USD million).

Year	2008–2009		2009–2016		2016–2017		2017–2020	
	Amount of Contribution	Contribution Rate	Amount of Contribution	Contribution Rate	Amount of Contribution	Contribution Rate	Amount of Contribution	Contribution Rate
Growth in export value	−2633.10	100.00%	312.40	100.00%	−2373.49	100.00%	−506.29	100.00%
Structural effects	−4246.54	161.28%	4197.89	1343.77%	2884.38	121.52%	−748.88	−147.91%
Product effects	−2156.61	81.90%	1259.69	403.24%	4352.93	183.40%	−1177.33	−232.54%
Growth effects	−2089.93	79.37%	2938.20	940.54%	−1468.56	−61.87%	428.45	84.62%
Competitive effects	2166.48	−82.28%	−2709.40	−867.30%	−4400.09	−185.38%	251.01	49.58%
Overall competitiveness effect	2632.31	−99.97%	−2278.24	−729.28%	1717.18	72.35%	−411.08	−81.19%
Specific competitive effects	−465.83	17.69%	−431.16	−138.02%	−6117.26	−257.73%	662.10	130.77%
Second-order effects	−553.04	21.00%	−1176.10	−376.48%	−857.78	−36.14%	−8.43	−1.66%
Pure second-order effects	−446.40	16.95%	−784.86	−251.24%	637.07	26.84%	10.60	2.09%
Dynamic second-order effects	−106.64	4.05%	−391.24	−125.24%	−1494.86	−62.98%	−19.03	−3.76%

Data source: Authors' calculations based on UN Comtrade database data, using CMS model.

Table 10. Results of CMS model decomposition of Malaysia's biomass export growth (Unit: USD million).

Year	2008–2009		2009–2016		2016–2017		2017–2020	
	Amount of Contribution	Contribution Rate	Amount of Contribution	Contribution Rate	Amount of Contribution	Contribution Rate	Amount of Contribution	Contribution Rate
Growth in export value	−16.61	100.00%	310.34	100.00%	−606.59	100.00%	362.35	100.00%
Structural effects	−341.38	2055.50%	434.04	139.86%	−249.47	−41.13%	−78.60	−21.69%
Product effects	−85.70	516.02%	79.39	25.58%	−27.28	−4.50%	−117.80	−32.51%
Growth effects	−255.68	1539.48%	354.65	114.28%	−222.19	−36.63%	39.20	10.82%
Competitive effects	489.24	−2945.75%	−81.23	−26.17%	−832.53	−137.25%	485.50	133.98%
Overall competitiveness effect	301.12	−1813.06%	−34.36	−11.07%	−449.48	−74.10%	310.06	85.57%
Specific competitive effects	188.12	−1132.68%	−46.87	−15.10%	−383.05	−63.15%	175.44	48.42%
Second-order effects	−164.46	990.24%	−42.47	−13.69%	475.41	78.37%	−44.54	−12.29%
Pure second-order effects	−100.81	606.97%	−23.53	−7.58%	120.54	19.87%	20.51	5.66%
Dynamic second-order effects	−63.66	383.27%	−18.94	−6.10%	354.87	58.50%	−65.05	−17.95%

Data source: Authors' calculations based on UN Comtrade database data, using CMS model.

Table 11. Results of the CMS model decomposition of Australia's biomass export growth (Unit: USD million).

Year	2008–2009		2009–2016		2016–2017		2017–2020	
	Amount of Contribution	Contribution Rate	Amount of Contribution	Contribution Rate	Amount of Contribution	Contribution Rate	Amount of Contribution	Contribution Rate
Growth in export value	13.97	100.00%	7.07	100.00%	−8.63	100.00%	100.86	100.00%
Structural effects	−108.22	−774.47%	130.58	1846.02%	1696.38	19,646.37%	−14.59	−14.46%
Product effects	−41.08	−293.94%	32.12	454.16%	1746.62	20,228.12%	−28.88	−28.63%
Growth effects	−67.15	−480.53%	98.45	1391.86%	−50.23	−581.75%	14.29	14.17%
Competitive effects	187.13	1339.12%	1417.09	20,033.98%	−114.22	−1322.77%	127.07	125.99%
Overall competitiveness effect	102.18	731.19%	−70.85	−1001.69%	48.64	563.31%	83.06	82.35%
Specific competitive effects	84.95	607.93%	1487.94	21,035.67%	−162.86	−1886.09%	44.01	43.64%
Second-order effects	−64.93	−464.65%	−1540.59	−21,780.00%	−1590.80	−18,423.59%	−11.63	−11.53%
Pure second-order effects	−38.56	−275.92%	410.50	5803.47%	16.54	191.52%	5.37	5.32%
Dynamic second-order effects	−26.37	−188.73%	−1951.09	−27,583.47%	−1607.34	−18,615.11%	−17.00	−16.85%

Data source: Authors' calculations based on UN Comtrade database data, using CMS model.

Table 12. Results of CMS model decomposition of Korea's biomass export growth (Unit: USD million).

Year	2008–2009		2009–2016		2016–2017		2017–2020	
	Amount of Contribution	Contribution Rate	Amount of Contribution	Contribution Rate	Amount of Contribution	Contribution Rate	Amount of Contribution	Contribution Rate
Growth in export value	−274.46	100.00%	1651.81	100.00%	−14.38	100.00%	859.51	100.00%
Structural effects	−1389.57	−506.28%	1617.25	97.91%	1706.63	11,866.07%	−536.85	−62.46%
Product effects	−492.48	−179.43%	435.55	26.37%	2536.42	17,635.52%	−778.33	−90.56%
Growth effects	−897.09	−326.85%	1181.70	71.54%	−829.79	−5769.46%	241.48	28.10%
Competitive effects	1666.04	607.01%	805.68	48.78%	−1481.20	−10,298.63%	1323.18	153.95%
Overall competitiveness effect	784.21	285.72%	364.52	22.07%	953.45	6629.29%	592.98	68.99%
Specific competitive effects	881.83	321.29%	441.16	26.71%	−2434.65	−16,927.92%	730.20	84.96%
Second-order effects	−550.93	−200.73%	−771.12	−46.68%	−239.82	−1667.43%	73.18	8.51%
Pure second-order effects	−343.29	−125.07%	233.39	14.13%	214.46	1491.11%	55.89	6.50%
Dynamic second-order effects	−207.65	−75.66%	−1004.51	−60.81%	−454.28	−3158.54%	17.28	2.01%

Data source: Authors' calculations based on UN Comtrade database data using CMS model.

6.2.1. China

(1) The international competitiveness of Chinese biomass energy products is rising

The overall competitiveness effect is favorable, demonstrating that an improvement in overall competitiveness benefits China's exports of biomass and vice versa. The competitiveness of China's biomass products during the financial crisis has continued to be a positive force on export growth, as indicated by the overall competitiveness effect in 2008–2009, which was 432.68%. In 2017–2020, the overall competitiveness effect fell to 89.92%, but its contribution rose significantly, demonstrating an improvement in the overall competitiveness of Chinese biomass energy products.

The positive specific competitiveness effect suggests that changes in the international market's demand and the structure of China's exports of biomass energy products are consistent with one another. It is important to note that the specific competitiveness effect, which was the largest impediment of all effects in 2016–2017, played a suppressive role in the growth of Chinese biomass by 190.34%. This shows that the commodity structure of Chinese biomass exports continued to deteriorate during this time and did not adapt to current trends in the demand on the international market, even though it had a further 24.03% boosting effect in 2017–2020. Overall, the competitiveness of China's biomass energy products has increased in recent years.

(2) World import demand is becoming less influential on exports, and China's biomass products have clustered in regional markets

It is not difficult to observe the decline in the structural effect's contribution from 606.42% in 2008–2009 to 6.97% in 2017–2020, which shows that the impact of global import demand on exports is waning. The market effect accounted for −162.89% of total growth from 2008 to 2009, while the growth effect of biomass products accounted for −443.53%; from 2017 to 2020, the growth effect accounted for 6.28%, and the market effect accounted for 13.15%. The main distinction between these two phases is between the growth effect and the market effect. As the relative contribution of the growth effect declined, it is clear that the volume of Chinese biomass exports has decreased as a result of the decline in global demand. The relative market effect contribution is growing, suggesting that China is placing more emphasis on exporting biomass products to markets with rising demand.

(3) The commodity structure of China's biomass export trade needs to be further optimized

CMS estimates show that the product effect decreases from 6.84% in 2009–2016 to −13.15% in 2017–2020. This indicates that the product mix of China's biomass energy trade is on a deteriorating trend. In addition, dynamic second-order effects are also a factor affecting the growth of China's exports of biomass products. A positive value means that China is exporting more biomass products than the global average in rapidly expanding product markets, and the opposite is also true. Table 4 illustrates how dynamic second-order effects constrain the growth of China's biomass exports. The dynamic second-order effect is negative in all three periods, with the exception of 2016–2017, indicating that China's biomass exports are no longer as competitive internationally in goods with rapidly increasing global import demand. China has made little progress in the utilization of non-power generation biomass, such as clean heating, biogas, and liquid fuel, and many other aspects are still in the fragmented and early stages of development, with no good pattern of multiple biomass energy utilization. As a result, its export structure is unable to meet market demand.

6.2.2. Vietnam

(1) The overall competitiveness effect positively contributes to export growth and is gradually becoming the primary pulling force

The contribution to the export growth of biomass energy products in 2008–2009 was 344.48%, indicating that the overall competitiveness of Vietnam's biomass energy products continued to rise despite the financial crisis. It was 89.62% in 2017–2020, indicating that international competitiveness is still the main driver of Vietnam's biomass energy products.

The specific competitiveness effect decreased during the first three phases, having a pulling effect on Vietnam's biomass export growth of 260.58% in 2008–2009 and an inhibitory effect of 162.19% in 2016–2017. This shows that Vietnam's biomass exports' commodity structure continued to deteriorate during this time and did not adjust to the current trend of changes in the demand on the global market. Although the additional 26.77% increase in 2017–2020 was not as significant as the overall competitiveness effect, it nonetheless demonstrates that Vietnam's biomass exports are starting to adjust to the shifting trends of the current global market demand.

(2) World import demand is becoming less influential on exports

The structural effect on Vietnam's biomass exports has declined in recent years, with a structural effect of −294.09% in 2008–2009, which greatly hindered the growth of Vietnam's exports. The years 2016–2017 saw a greater boost to export growth from the structural effect again, which shows that the increase in demand for Vietnam's biomass products in the world market during this period drove the growth of Vietnam's exports.

Vietnam's exports of biomass have increased in recent years due to an increase in global demand, as shown by the growth effect, which drove export growth from −173.50% in 2008–2009 to 6.60% in 2017–2020. The growth effect from 2016 to 2017 was, however, −91.01%, indicating that the decline in exports during this time was primarily brought on by weak global demand. Vietnam's biomass exports during this time period were concentrated in markets with lower demand, which to some extent hampered export growth. This is indicated by the fact that the product effect in 2017–2020 acted as a damper on export growth by 17.49%.

(3) International competitiveness slows in products with rapidly growing world import demand

The negative second-order effect indicates that the deterioration in the export structure of Vietnam's biomass products and the decline in their competitiveness have combined to dampen export growth. The second-order effect increased from −210.97% in 2008–2009 to −5.49% in 2017–2020, indicating that this dampening effect is decreasing but still constitutes an impeding force for export growth.

It should be noted that the pure second-order effect's contribution rose to a positive value of 4.92% in the period from 2017 to 2020, indicating that the adjustment of product mix to global market demand played a role in export growth during that time. The table indicates that dynamic second-order effects also constrain the expansion of China's biomass exports. With the exception of 2016–2017, the dynamic second-order effect is negative for all three time periods, which indicates that Vietnam's exports of biomass are no longer as competitive internationally among goods with rapidly increasing global import demand.

6.2.3. New Zealand

(1) Overall competitiveness is gradually increasing its role in impeding export growth, and the structure of biomass exports is improving

Unsurprisingly, the overall competitiveness effect was negative for the entire period of 2008–2020, indicating that the declining competitiveness of New Zealand's biomass products is restricting export growth. The effect decreased from −8.64% in 2008–2009 to −106.58% in 2017–2020, increasing and continuing to restrain export growth even after offsetting other effects.

The specific competitiveness effect increased from −87.18% in 2008–2009 to 22.12% in 2017–2020, showing that the decline in exports during the first phase was primarily attributable to a deterioration in the commodity mix of New Zealand's biomass exports during this period, which is not in line with current trends in the demand on the international market. Additionally, the commodity mix of exports improved in 2017–2020.

(2) Growth in world demand contributes to export growth, with exports concentrated in markets where demand is low

The growth effect from 2008–2009 was −93.14%, indicating that the downturn in world market demand after the financial crisis significantly hampered export growth; however, as the economy recovered, the rise in world demand for biomass products contributed 312.96% to New Zealand's export growth from 2009–2016. The growth effect remained positive in 2017–2020.

The product effect increased from 57.19% in 2008–2009 to −23.54% in 2017–2020, indicating that the effect is still a large disincentive to export growth, i.e., New Zealand's biomass exports are still concentrated in countries with low demand, weakening the effect of elevated world market demand on export growth.

(3) Second-order effects on New Zealand's biomass exports are diminished

The second-order effect decreased from −28.21% in 2008–2009 to −245.06% in 2009–2016, indicating that a combination of low world market demand, reduced export competitiveness, and deteriorating export structure led to a reduction in exports during this period, and thus a greater hindering effect. However, the second-order effect for 2017–2020 was −3.57%, with a significant decrease in the impact. It is worth noting that both the dynamic second-order effect and the pure second-order effect were negative in the first three periods, i.e., New Zealand biomass products have a small market share in a product market where world import demand is growing faster and the product mix is not well adapted to market demand.

6.2.4. Singapore

(1) Declining overall competitiveness inhibits export growth, but product export structure improves

The overall competitiveness of Singapore's biomass products increased over the years 2008–2017, with positive contributions of 5.11%, 50.70%, and 414.11%, which can be seen as a gradual increase, i.e., the overall competitiveness of Singapore's biomass products increased over these periods, significantly contributing to the growth of exports, although the effect dropped to −127.74% in 2017–2020, turning from positive to negative. However, this effect decreased to −127.74% from positive to negative in 2017–2020, indicating that the overall competitiveness started to decline and discouraged exports of biomass products in these years. The specific competitiveness effect is positive for all periods, suggesting that the structure of Singapore's biomass exports has been optimized in response to changes in international market demand.

(2) Growth in world demand contributes to export growth, with exports concentrated in markets where demand is low

The growth effect for 2008–2009 was −94.54%, indicating that low world demand in the aftermath of the financial crisis significantly hampered export growth; however, as the economy recovered, rising world demand for biomass products contributed 34.64% to Singapore's export growth from 2009–2016, and the growth effect remained positive in 2017–2020.

The product effect increased from −46.85% in 2008–2009 to −231.9% in 2017–2020, indicating that the effect remains a large disincentive to export growth, i.e., Singapore's biomass exports are also concentrated in countries with low demand, weakening the effect of elevated world market demand on export growth.

(3) The commodity mix of Singapore's biomass export trade has been optimized, contributing significantly to export growth

A positive dynamic second-order effect indicates that Singapore's export share of biomass products is growing faster than the world average in fast-growing product markets and vice versa. A negative dynamic second-order effect for all three periods except

2017–2020 implies that the international competitiveness of China's biomass exports is slowing down in products with fast-growing world import demand. The dynamic second-order effect, however, increased significantly over the period of 2017–2020, as evidenced by the dynamic second-order effect for the period of 2017–2020 being 141.36%. The product mix was not well adapted to the demand on the global market during the period, which in turn hampered export growth, according to the pure second-order effect for the time period, which was −1.73%. Singapore is lacking in fossil energy, so it carried out energy transformation earlier, and its stable economy, sound facilities, and the high technical level of its labor force have laid a good foundation for energy development.

6.2.5. Thailand

(1) Gradual decline in the international competitiveness of biomass products

The competitiveness effect was positive and contributed more in both 2008–2009 and 2009–2016, indicating that the increased competitiveness had a significant boost to Thailand's biomass exports in both periods, but the competitiveness effect inhibited export growth by −630.66% and −35.79% in 2016–2017 and 2017–2020, respectively. Even though the overall competitiveness effect for 2016–2017 was 715.69%, the specific competitiveness effect was so small that, as a result, it ultimately prevented export growth from being aided. This suggests that Thailand's biomass exports' commodity structure continued to deteriorate during this time, and did not adjust to the current trends in global market demand. Thailand's infrastructure is poor, and its biomass energy development lacks a strong power grid.

(2) Growth in world demand contributes to export growth, with exports concentrated in markets where demand is low

The growth effect in 2008–2009 was −826.7%, indicating that the low demand in the world market after the financial crisis greatly hindered export growth. With the recovery of the economy, 2009–2016 and 2017–2020 acted as a boost of 119.68% and 150.33%, respectively, indicating that the rising world demand for biomass products has contributed to Thailand's export growth in recent years.

The product effect increased from −294.65% in 2008–2009 to −177.55% in 2017–2020, indicating that the effect still has a significant dampening effect on export growth, i.e., Thai biomass exports are still concentrated in countries with low demand, weakening the effect of elevated world market demand on export growth.

(3) The export structure of biomass products is not adapted to changes in world market demand

As can be seen from the table, the dynamic second-order effect has limited the growth of Thailand's exports of biomass energy products. Although the dynamic second-order effect increased from −126.24% in 2008–2009 to −35.48% in 2017–20120, the dynamic second-order effect was negative in all phases. This suggests that Thai biomass products have a smaller market share in the product markets where global import demand is increasing more quickly. That is, in the product markets where global import demand is growing more quickly, Thai biomass products' level of international competitiveness has not increased as quickly. The pure second-order effect, which in 2009–2016 contributed 200.07% to export growth, then changed from being positive to negative in 2017–2020, suggests that the product export structure degraded over time and became less responsive to shifts in global market demand. Although Thailand is rich in biomass energy resources, its biomass energy industry cannot keep up with market demand due to its unbalanced development and insufficient capital and technology.

6.2.6. Japan

(1) Overall competitiveness declining, biomass export structure improving

The overall competitiveness effect declined from 99.97%% in 2008–2009 to −729.28% in 2009–2016, turning from a positive to a negative value, indicating a decline in the overall export competitiveness of Japanese biomass products. Although it rose again to 72.35% in 2016–2017, the effect fell again to −81.19% in 2017–2020. The specific competitiveness effect, on the other hand, contributed −17.69%, −138.02, and −257.73% in the first three periods, indicating that the commodity structure of Japanese biomass exports deteriorated in these three periods and did not adapt to the current trends in international market demand, while the commodity structure of exports showed an improvement in 2017–2020, with a specific competitiveness effect of 130.77%.

(2) Growth in world demand contributes to export growth, with exports concentrated in markets where demand is low

The growth effect in 2008–2009 was −79.73%, indicating that low world market demand in the aftermath of the financial crisis greatly hindered export growth. As the economy recovered, the rise in world demand for biomass products contributed 940.54% and 84.62% to Japan's export growth in 2009–2016 and 2017–2020, respectively. However, it can be seen that the product effect decreased from 81.90% in 2008–2009 to −232.54% in 2017–2020, turning from positive to negative, indicating that Japanese biomass exports are still concentrated in countries with low demand, significantly weakening the effect of rising world market demand on export growth.

(3) Deteriorating export structure and slower improvement in competitiveness in product markets where import demand is growing more rapidly

The dynamic second-order effect was negative for all time periods, despite growing from −4.05% in 2008–2009 to −3.76% in 2017–2020. This suggests that in the product markets where global import demand is increasing more quickly, Japanese biomass products have a smaller market share. In other words, the rise of Japanese biomass products' global competitiveness in the product markets where global import demand is growing more quickly has been slow. Dynamic second-order effects limit the growth of Japanese exports of biomass products. The pure second-order effect contributed 26.84% to export growth in 2009–2016 but only 2.09% in 2017–2020, implying a gradual deterioration of the product export structure, which is less adapted to changes in world market demand and thus contributes less to export growth. This also confirms the slow start of Japan's biomass energy industry, which is still dominated by fossil fuels in China.

6.2.7. Malaysia

(1) Declining and then improving international competitiveness and improving export structure

The contribution of 1,813.06 to the growth of exports of biomass energy products in 2008–2009 indicates that the overall competitiveness of Malaysian biomass energy products continued to rise amidst the financial crisis. Although the overall competitiveness turned negative in 2009–2016 and 2016–2017, the contribution reached 85.57% in 2017–2020, indicating that the overall competitiveness increase is still the main driver of biomass energy products in Malaysia.

The specific competitiveness effect contributed 1,132.68% to the growth of Malaysia's biomass exports in 2008–2009, but then played a dampening role of 63.15% in 2016–2017, indicating that the commodity mix of Malaysia's biomass exports continued to deteriorate during this period. A total of 48.42% of this effect contributed to export growth in 2017–2020, although not as much as the overall competitiveness effect boost, which is not as significant as the overall competitiveness effect contribution but shows that Malaysia's biomass exports are beginning to adapt to the current trends in international market demand.

(2) Rising demand has had a lesser effect on export growth

The growth effect in 2008–2009 was −1539.48%, indicating that the low world market demand after the financial crisis greatly hindered export growth. As the economy recovered, it played a boosting role of 114.28% and 10.82% in 2009–2016 and 2017–2020, respectively, indicating that rising world demand for biomass products has contributed to Malaysia's export growth in recent years, but the effect is waning.

The product effect increased from −516.02% in 2008–2009 to −32.51% in 2017–2020, showing that the effect still acts as a dampening effect on export growth, i.e., Malaysia's biomass exports are still largely concentrated in nations with lower demand, weakening the effect of high world market demand on export growth. The European Union is a major importer of Malaysian biodiesel, but EU policies aimed at reducing biodiesel demand have significantly harmed Malaysian exports.

(3) Improved export structure but slower improvement in international competitiveness in markets with a faster growth in import demand

Due to the financial crisis, the product export structure gradually deteriorated and was less adapted to the changing global market demand, which hampered export growth. However, it should be noted that the pure second-order effect was positive in both 2016–2017 and 2017–2020, indicating that Malaysia's biomass export structure is starting to adapt to the current trends in global demand.

The dynamic second-order effect increased from −383.27% in 2008–2009 to −17.95% in 2017–2020, indicating that Malaysian biomass products still have a relatively small market share in the world market for products with higher growth in import demand, but this share is expanding, i.e., the international competitiveness has increased, but at a slower pace. Although Malaysia is rich in biomass energy resources, its technology is not well developed, which weakens its export competitiveness.

6.2.8. Australia

(1) International competitiveness is becoming a major driver of Australian biomass exports

The overall competitiveness effect contributed 731.19% to the growth of biomass exports in 2008–2009, indicating that the overall competitiveness of Australian biomass products continued to rise despite the financial crisis. The figure of 82.35% of the contribution in 2017–2020 indicates that international competitiveness is becoming a key driver for Australian biomass products.

The growth of Australia's biomass exports was boosted by the specific competitiveness effect by 607.93% in 2008–2009, but this effect was dampened by −1886.09% in 2016–2017, indicating that the country's biomass exports' commodity mix deteriorated over this time. However, a further increase of 43.64% in 2017–2020 demonstrates that Australian biomass exports are starting to adjust to the current trends in global market demand, even though this is not as significant as the overall competitiveness effect contribution.

(2) Increasing world import demand boosts export growth, and the export structure of biomass products deteriorates

The growth effect increased from −480.53% in 2008–2009 to 1391.86% in 2009–2016, i.e., the economic recovery after the financial crisis led to a significant increase in world demand, which contributed significantly to the growth of Australian exports. Although the growth effect fell to a negative value in 2016–2017, it rebounded to 14.17% in 2017–2020, indicating that increased world import demand has boosted Australian export growth in recent years. The product effect rose to 454.16% in 2009–2016 before falling back to 28.63% in 2017–2020, meaning that despite world demand increasing over this period, export growth was ultimately dampened by a deterioration in the export mix of biomass products.

(3) The international competitiveness of Australian biomass products has been slow to improve in product markets where demand is growing more rapidly

The dynamic second-order effect has constrained the growth of Australia's exports of biomass energy products, as shown in the table. The dynamic second-order effect was negative for all time periods, though it grew from −188.73% in 2008–2009 to −16.85% in 2017–2020. This suggests that in a product market where global import demand is increasing more quickly, Australian biomass products have a comparatively small market share. However, it was positive in each of the three periods that followed, suggesting a gradual improvement in the mix of products exported to account for shifts in global market demand. The pure second-order effect had a dampening effect on export growth of 275.92% in 2008–2009.

6.2.9. Korea

(1) Concrete competitiveness is becoming the main driving force for Korea's biomass energy exports

The overall competitiveness effect contributed 285.72% to the growth of exports of biomass products in 2008–2009, indicating that the overall competitiveness of Korean biomass products is still on the rise despite the financial crisis (68.99% in 2017–2020).

The specific competitiveness effect contributed 321.69% to the growth of Korea's biomass exports in 2008–2009, though it then played a significant role in dampening the exports in 2016–2017, indicating that the commodity structure of Korea's biomass exports continued to deteriorate during this period. However, in 2017–2020, it again acted as a boost of 84.96%, though it can be seen that Korean biomass exports are starting to adapt to the current trends in international market demand, and that specific competitiveness is gradually becoming the main driving force for Korean biomass products.

(2) Increasing world import demand boosts export growth and the export structure of biomass products deteriorates

The growth effect rose from −326.85% in 2008–2009 to 71.54% in 2009–2016, i.e., the economic recovery after the financial crisis, led to a significant increase in world demand, which greatly contributed to the growth of Korea's exports. Although the growth effect fell to a negative value in 2016–2017, it rebounded to 28.10% in 2017–2020, indicating that increased world import demand has boosted customs export growth in recent years. The product effect rose to 26.37% in 2009–2016 before declining to −90.56% in 2017–2020, meaning that despite the increase in world demand over this period, export growth is ultimately dampened by the deterioration in the export structure of biomass products. A report by the Korean government points out that in order to promote the development of solar and wind industries, Korea will reduce subsidies for biomass power projects, a move that will further hinder the growth of exports of biomass products.

(3) Expanded share of biomass products in product markets where demand is growing more rapidly

According to the dynamic second-order effect, which rose from −75.66% in 2008–2009 to 2.01% in 2017–20120, Korean biomass products are gaining a market share in sectors of the economy where global import demand is expanding more quickly. In 2008–2009, the pure second-order effect had a dampening effect on export growth of –125.07%, but in the three following periods, it had a positive impact. This indicates that the interaction of global market demand, product competitiveness on a global scale, and export structure increased the export value of Korean biomass products.

7. Conclusions and Recommendations

7.1. Research Findings

The majority of RCEP member nations have abundant biomass energy resources, and all of them are focusing more and more on the growth of the biomass energy industry as their ability to compete globally rises. With the exception of Thailand and Singapore, the other RCEP members' competitiveness effects have a positive pulling effect on export growth. However, the comparative advantage of biomass products in RCEP countries is consistently low from a global standpoint. Activated carbon has a relatively strong comparative advantage over the other three products, whereas those advantages are relatively weak. While the rest of the countries lack comparative advantages in biomass products, Japan and China's comparative advantages are stronger than those of the other countries, though still at a low level. This is primarily due to each country's lack of subsidy policies and the relatively outdated biomass power generation technology. The precise causes of the low comparative advantage, however, remain unclear. Future research should focus on examining the key elements affecting the competitiveness of biomass exports, such as in-depth analyses based solely on factor endowment or technological innovation perspectives, in order to offer more specific recommendations for nations to increase the competitiveness of biomass products. The rest of the RCEP countries, with the exception of Singapore and South Korea, have a small market share in regions where the demand for biomass products is growing more quickly, which severely restricts the growth of biomass product exports in each nation.

7.2. Policy Recommendations

(1) Fostering comparative advantages of biomass products to improve competitiveness

First, while the majority of biomass energy products in RCEP countries have weak comparative advantages, their biomass energy resources are extremely rich and have the potential to be utilized. Planting agricultural plants in conjunction with ecological construction will aid in the growth of the biomass energy power generation industry. However, because biomass energy resources are dispersed, countries must commit to large-scale and mature resource use. The most essential feature of building a new development paradigm is to achieve a high level of self-reliance and self-improvement. The government should increase investment in relevant fields, encourage technological innovation capacity improvement, and strive to reduce costs in order to improve the export competitiveness of biomass energy products from various countries. In particular, China's relatively primitive ethanol fuel technology results in a low comparative advantage for ethanol exports. China should focus on improving ethanol technology. Despite the fact that Korea, Australia, New Zealand, and ASEAN countries have abundant biomass energy resources, their infrastructure is outdated, putting them at a competitive disadvantage in the production and processing of biomass energy products. As a result, it is critical to accelerate the development of new energy technologies with independent intellectual property rights and to reverse the backward status quo of some biomass energy conversion technologies. Efforts should be made to take command of the future global biomass energy technology competition.

(2) Efforts to optimize the export market structure of biomass products

Poor structure is an important factor affecting the international competitiveness of biomass products in the RCEP countries. According to the previous CMS model analysis, it can be seen that except for Singapore and Korea, the RCEP countries have a small share of the markets with faster import demand for biomass products. Therefore, countries should focus on adjusting and optimizing the product and market structure of biomass energy, and a greater emphasis should be placed on Eastern European countries with growth potential, etc. Malaysia should seek potential importers other than the EU in order to boost biomass product exports. Singapore, with its advanced equipment, should focus on exporting biomass products with high technical demands. China is exporting more biodiesel, and with the help of national policies and international demand, enterprises must improve capacity utilization and reduce costs in order to promote export growth.

(3) Accelerating the pace of energy transformation and upgrading

Energy services with the goal of improving the efficiency of energy systems are recommended, so that energy shifts from a product-based economy to a service-based economy. On the one hand, the total operating cost of biomass energy enterprises is high, and governments should fully utilize existing renewable energy tariff subsidy policies, such as prioritizing the full amounts of tariff subsidies based on the cogeneration ratio of power generation projects, as well as actively encouraging biomass power generation enterprises to transform into cogeneration enterprises to supplement electricity with heat in order to achieve normal profitability. Small- and medium-sized businesses are encouraged to seek third-party energy operation services, which can not only reduce enterprise costs and increase production motivation, but also better respond to energy conservation and emission reduction policies.

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