Journal of Economic Analysis 2024 3 (4) 49-65

Journal of Economic Analysis

Homepage: https://www.anserpress.org/journal/jea

Exports of Renewable Energy Goods among RCEP members: Potential and Constraints

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ABSTRACT

Objective: The paper, specifically examines whether the recently formed Regional Comprehensive Economic Partnership (RCEP) can potentially facilitate minimising the constraints to renewable energy goods exports at the regional level in Asia. Data, Methodology and Findings: Using the panel data from 11 RCEP members from 2006 to 2014, this study has applied the 'meta frontier stochastic gravity frontier' methodology and confirms that the establishment of RCEP has the potential to improve trade in renewable energy commodities within the RCEP region. Policy Implications: The policy implication is that when countries work together, it will lead to enormous benefits for national, regional, and worldwide prospects of a more sustainable energy future. Practical Policy Implications: In terms of practical policy implications, the developed RCEP member countries should actively engage in promoting R&D activities and protecting intellectual property rights concerning renewable energy production, which are essential for countries to integrate with the world market and to lift the export frontiers of both the developed and developing RCEP member countries to reach the unrestricted export of renewable energy technology.

KEYWORDS

Regional Comprehensive Economic Partnership; Meta frontier; Stochastic frontier gravity model; Nationally Determined Contributions; Renewable energy goods exports

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ISSN 2811-0943
doi: 10.58567/jea03040003

Received 9 August 2023; Accepted 4 October 2023; Available online 2 November 2023; Version of Record 15 December 2024

1. Introduction

Given that Asia is a world leader in the manufacturing sector and the new driving force in world economic growth, the Asian region is experiencing rapidly growing demand for energy. Meanwhile, countries in this area are faced with higher pressure to mitigate greenhouse gas emissions from fossil fuel use. Despite the Asian countries using proportionally less natural gas and oil resources compared with the countries in the rest of the world, currently, the coal energy supply alone accounted for almost 50 per cent of the total energy supply. In addition, renewable energy, including hydropower and biofuels, only made up 15 per cent of the total number, which is even lower than at the world level. Therefore, there are strong incentives and necessities for the Asian countries to improve and sustain the development of renewable technologies to upgrade their energy systems and control greenhouse gas emissions, nationally and regionally. As renewable energy supply in many countries in the region does not meet their demand, the renewable energy technology trade whether it is embedded in the commodities or not facilitates the greater deployment of efficient renewable energy technologies.

It is commonly acknowledged that trade in renewable energy goods has positive impacts on reducing greenhouse gas emissions and the development of the renewable energy sector (Du *et al.* 2012; Sebri & Ben-Salha 2014; Jebli & Youssef 2015; Tiba *et al.* 2016). For exporting countries, increased trade in renewable energy commodities can facilitate energy industries expanding the production capacity domestically. For importers, renewable energy trade provides access to more renewable energy resources with affordable costs, implying more renewable energy consumption. More importantly, the technology transfer embodied in trade will significantly and sustainably boost the future development of renewable energy in importing countries. However, the strength of the nexus between renewable energy trade and emissions reduction depends on how effectively the trade constraints are eliminated in both exporting and importing countries. In this context, the contribution of regional cooperation cannot be overemphasised. Hence, the motivation for this study arises from the important research question, whether regional cooperation can offer a unique trade policy solution to regional and global climate challenges in Asia.

The Association of South East Asian Nations' initiative of the establishment of the Regional Comprehensive Economic Partnership (RCEP) will be an opportunity to fill the increasing energy demand gap and practice trade in renewable energy products across Asia. Particularly, for those members who lack the necessary renewable energy technology supply, RCEP offers a sustainable approach to gradually achieve their NDCs by creating and maintaining unconstrained renewable energy trade flows. However, one question that remains to be answered is whether trade in renewable energy goods has been sufficiently utilised effectively, or to what extent the RCEP agreement can stimulate the trade in renewable energy goods among member countries. The current literature leaves this area blank, and this study fills this research gap.

The hypotheses that are tested empirically in this paper are: (1) All selected RCEP members do not share the same technology set (economic environment) in terms of exporting renewable energy commodities; and (2) There is potential to improve renewable energy exports among RCEP members through regional cooperation agreement.

This study applies the stochastic frontier gravity model in a 'metafrontier' framework to evaluate the export potential of renewable energy commodities among the RCEP member countries. This paper treats countries with heterogeneous export levels differently. It is assumed that countries with higher trade volumes/values adopt a more efficient export technology set than countries with lower volumes/values in terms of exporting renewable energy goods. The country-specific export efficiency score comprises of the export efficiency with respect to its group frontiers (TEG) and also the meta-technology ratio (MTR), which is measured sequentially. Based on the empirical results, this study then proposes several policy suggestions on how governments can improve their export performance in renewable energy goods.

The rest of this paper is arranged as follows. Section 2 briefly reviews the literature on the gravity model, stochastic frontier production function (SFPF), and the metafrontier model. Section 3 introduces the theoretical framework of the metafrontier gravity model. Section 4 shows the empirical model and the data used in this paper, and Section 5 presents the results and discussion. Summary conclusions and policy suggestions are provided in the 6th section. The last section points out the limitations of this study and directions for future research.

2. Literature review

Since Tinbergen (1963) first introduced the gravity model into international trade, it has been widely used to analyse trade patterns, examine the effects of trade influencers, and, more importantly, identify trade barriers and estimate trade potentials. One significant problem of the conventional gravity model is that it does not perform well in explaining the impact of trade costs or trade resistances on export flows (Trefler, 1995). Initially, it is assumed that there is no trade cost, or all trade costs can be represented by the geographical distance variable in the gravity model (Deardorff, 1995). In the empirical analysis using conventional gravity model, the implicit trade cost is assumed to be covered by the normally distributed random error with a zero mean. For example, Baldwin (1994) and Nilsson (2000) among others used the conventional gravity model to estimate the 'trade potentials' of countries or regions. The term 'trade potential' is defined as the expected trade volume estimated by the gravity model. All implicit trade costs are embedded into the statistical random error with a mean of zero, and the 'trade potential' becomes a benchmark to judge whether the actual trade volume (as well as trade barriers) performs better or worse than the predicted volume. Such analyses are very restrictive without meaningful policy implications. Nevertheless, the word 'potential' should have referred to the maximum value that the trade could theoretically achieve if all implicit trade costs were eliminated.

Further, McCallum (1995) found that the trade volume between the U.S. and Canada is much less than the trade 'behind the border', which implies consequential resistances that reduce the trade 'beyond the border'. The literature has made considerable progress on the gravity model's specifications to precisely treat trade costs. More and more proxies, such as tariffs, exchange rates, shared borders, and common languages, are included in the gravity equation to measure trade costs emanating from 'beyond the border'. Nevertheless, there still existed some trade resistances that cannot be easily quantified, such as institutional barriers or infrastructure constraints that exist within the importing countries; this paper describes these uncaptured resistances as the implicit trade costs. Anderson and van Wincoop (2004) have argued that international trade costs are very large and underestimated in the conventional gravity model. They emphasised that the measurement of trade costs needs to be improved and suggested a modified specification to the conventional gravity model. Soderlund and Tingvall, (2014) have argued, "Most research on institutions focuses on one or a few institutional variables such as rule of law, freedom to trade and corruption" (p.279). They showed that the impact of different institutional variables can vary and that conclusions on the impact of institutions depend on what measure of institutional quality is used. The interesting question here arises as to whether it is possible to have information on all the variables influencing institutional quality.

In the absence of full knowledge about the variables influencing institutional infrastructure, Kalirajan (2007) suggested another alternative solution to the conventional gravity model to quantitatively estimate the effects of the implicit trade cost on trade flows to overcome the limitations. His suggestion of the stochastic frontier gravity model (SFGM) framework heavily draws on the stochastic frontier production function (SFPF) modeling framework proposed by Aigner *et al.* (1977), Meeusen, and van den Broeck (1977) in the context of production economics. The main idea of their modeling is that it decomposes the error term into two parts, a non-negative term that represents the inefficiency, which constraints the output reaching from its potential maximum level and a random error that has the same meaning and distribution as in the conventional production function. The predicted values are known as the frontier maximum possible output. The differences between the actual and the predicted frontier output are caused by random disturbance and inefficiency. Therefore, the calculated production frontier refers to the theoretical-maximum output level if inefficiency does not exist in production while there are still uncontrollable random shocks.

This concept of SFPF can be adopted in the gravity model framework to improve the assessment of export performance. In the SFGM the implicit trade costs are treated as factors that reduce trade flows, not random errors as in the conventional gravity model. Therefore, it is assumed that the implicit trade costs are embodied in the inefficiency term and strictly follow a non-negative distribution. Now, the volume/value of the export potential becomes the estimated export frontier and is defined as the maximum export volume/value that can be achieved theoretically if all implicit trade costs are eliminated. Meanwhile, the export performance is represented by the ratio of actual export volume/value to the export potential, which is defined as the export efficiency score (EFS) indicating how well the export potential has been realised. The judgement of the relative performance becomes simple and straightforward by comparing the observation-specific export efficiency scores. Many studies (among others, Armstrong *et al*., 2008; and Ravishankar & Stack, 2014) have applied SFGM to assess the export performance and quantify the implicit trade cost. Findings of those papers have confirmed the assumption that the implicit trade cost is one of the main resistances that impede international trade.

Although EFS levels can be compared within a homogenous group, comparison between different heterogeneous groups may not be meaningful if firms in different groups choose different technologies and have different export frontiers. For example, the ASEAN members' export efficiency scores cannot be directly compared with the EU members' scores, as they are very likely to have different export frontiers.

To make comparisons across the heterogeneous groups practical and meaningful in the context of production economics, drawing heavily on Hayami and Ruttan (1971), Battese and Rao (2002) proposed the concept of the 'metafrontier' function. Later, Battese *et al.* (2004) and O'Donnell *et al.* (2008) further improved the metafrontier approach. It is assumed that a complete technology set exists for the production process, while each firm or group only has access to a part of the complete technology set. Because of the inefficiency in technology selection, theoretically, a metafrontier envelops all groups' production frontiers. If one group enjoyed the complete technology set without any constraints, its production frontier will coincide with the metafrontier. Therefore, the total inefficiency in production is decomposed into two components: the difference between actual production and each group's production frontier (the same as in SFPF) and the difference between each group's production frontier and the metafrontier. Correspondingly, each group's total production efficiency with respect to the metafrontier (TEM) is the product of the efficiency score with respect to its group frontier (TEG) and the meta-technology ratio (MTR), and the TEM is comparable between different groups. More details of the theoretical framework can be found in O'Donnel et al. (2008).

Battese *et al.* (2004) and O'Donnell *et al.* (2008) used two mathematical programming methods, linear programming (LP) and quadratic programming (QP), to estimate the parameters of the metafrontier. However, Huang *et al.* (2014) have pointed out that the parameters generated by the mathematical programming methods do not have statistical properties. In addition, the LP and QP methods also ignore the effects of random shocks in the second step of estimating the metafrontier, which may cause biased estimations. Therefore, Huang *et al.* (2014) developed a new stochastic metafrontier regression (SMFR) method to accommodate random shocks in the metafrontier function. By conducting two empirical regressions for the global agricultural industry and the hotel industry in Taiwan, they found that the MTR and TEM obtained from LP and QP were smaller than those from SMFR and recommended the use of the SMFR estimation to avoid any bias in the parameter estimates.

This paper applies the metafrontier production modeling framework to the gravity model and adopts the SMFR method of estimation to measure the export performance of renewable energy commodities among the RCEP members. It divides the RCEP countries into two groups based on their export values, and thus there are two individual group export frontiers.

3. Theoretical framework

3.1. Gravity Model: The metafrontier approach

Battese and Rao (2002), introduced the metafrontier approach to production economics to generate meaningful comparisons of technical efficiencies between groups that produce the same products but employ different technologies. It is assumed that a complete technology set exists for the production process, which is called the unrestricted technology set. However, because of a "lack of economic infrastructure and/or other characteristics of the production environment" (O'Donnell *et al.,* 2008, p. 232), each group of firms only has access to a part of the unrestricted technology set, which is named the restricted technology set. As all restricted technology sets are subsets of the unrestricted technology set, the unrestricted set is more efficient than the restricted sets when adopted in production. Theoretically, if one ideal firm can perfectly use the unrestricted technology set in production, its production frontier would envelop all other firms' frontiers, and this special frontier is called the metafrontier. Therefore, the metafrontier approach facilitates decomposing each group's total inefficiency into two components: the normal production inefficiency with respect to its group frontier, as in the SFPF analysis, and the technology gap, represented by the difference between the group frontier and the metafrontier.

Figure 1 indicates how the metafrontier approach has been applied to comparing the export performance of countries within and across heterogeneous groupings in this study. It is acknowledged in the literature that the major factors influencing the export performance are 'behind the border' constraints and 'beyond the border' constraints. Of these, the former is under the control of the exporting countries and the latter is not under the control of the exporting countries. 'Beyond the border' constraints are generally represented in empirical gravity analysis by 'import tariffs' and the 'exchange rate', which may vary across the exporting countries. However, those 'behind the border' constraints that exit within the importing countries, which are common to all the exporting countries, are generally included in the usual statistical random error term in the gravity equation.

It is rational to argue that trade costs mainly emerge from the 'behind the border' constraints that exist within the exporting countries, as the 'behind the border' constraints of the importing countries are not under the control of the exporting countries. Trade costs, which are one of the major components of competitiveness, establish themselves as constraints to export performance through the combined influence of weaknesses in the physical, and institutional infrastructures related to exports (Chang, 2010). For example, lack of proper road and port facilities within the exporting country would contribute to increasing trade costs. Similar is the case with lack of institutional infrastructures such as weak incentive instruments to promote R&D and the absence of transparency in regulations leading to information asymmetry among exporters. Thus, both physical and institutional infrastructures directly become the ingredients to influence the competitiveness of the exporting firms. Nevertheless, a researcher may not have full knowledge about all the sources of weak physical and institutional infrastructures that contribute to trade costs. However, it is possible to include the combined impact of the weak physical and institutional infrastructures into the gravity model even when the researcher does not have full information about all the weaknesses. This is explained in the following paragraphs.

For illustrative purposes, only two heterogeneous groups of counties with the APAC region are considered. Figure 1 shows that the metafrontier model consists of individual group frontiers and the metafrontier. Following Kalirajan (2007), the group frontiers of exports of renewable energy goods are drawn from each group's stochastic frontier gravity equations (f_1(.) and f_2(.)), and metafrontier is drawn from the metafrontier function f_m(.). Following Battese *et al.* (2004), the metafrontier function is defined as a deterministic parametric frontier with the condition that the metafrontier values are no smaller than the values of any deterministic group frontiers. In addition, it is also assumed that the metafrontier function is "a smooth function and not a segmented envelope of the stochastic frontier gravity equations for the different groups" (Battese *et al*, (2004), p. 93).

Assume that an individual country *i* from the second group adopts a restricted export technology set, which includes trade costs, and $Y(Xi)$ is actual exports with the input set X_i. If the country *i* can overcome all export inefficiencies under its restricted export technology set, it would produce at the group frontier with the predicted value $f_2(Xi)$. Therefore, the distance between $Y(Xi)$ and $f_2(Xi)$ represents the export inefficiency with respect to group frontier 2. Further, if the country *i* can advance its export technology set from the restricted export technology set to the unrestricted export technology set, its predicted exports value would increase from $f_2(Xi)$ to $f_m(Xi)$. The distance between $f_2(Xi)$ and $f_m(Xi)$ represents the inefficiency from the export technology gap. Overall, the distance between $Y(Xi)$ and $f_m(Xi)$ is the total export inefficiency with respect to the metafrontier, which can be compared between countries from the same or different groups.

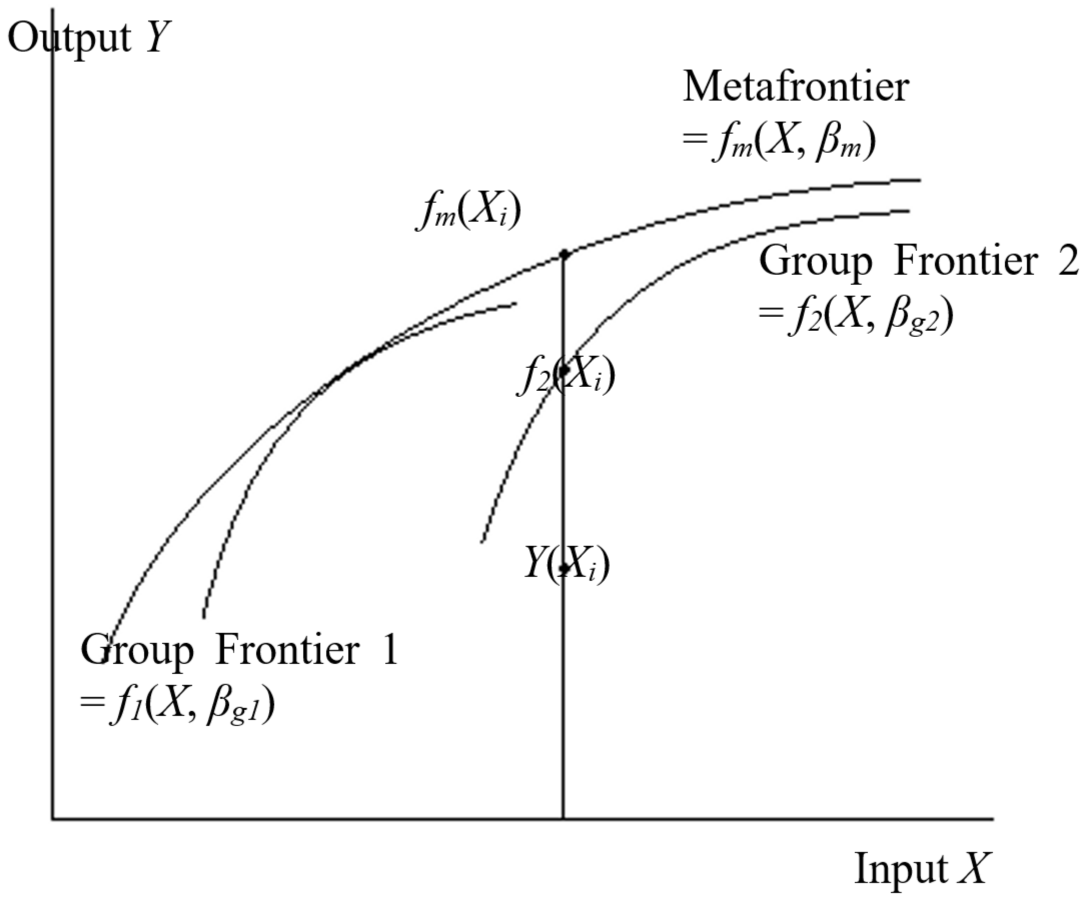

Figure 1. Metafrontier model illustration.

The calculation process is also divided into two steps. First, data on each country's inputs and actual exports vlaue is used to estimate the coefficients of each group's stochastic frontier gravity function (β_{g1} and β_{g2}) via SFPF, separately. Second, using the calculated group frontiers from the first step to estimate the coefficients of the metafrontier function (β_m).

3.2. Group frontiers by SFPF

Assume that there are N countries and all countries are divided into *K* groups based on their export technology sets. Each country's exports are determined by its stochastic frontier gravity equation respectively:

$$Y_{it} = f_k(X_{it}, \beta_k) \exp\left(-u_{it}^k + v_{it}^k\right) \quad (1)$$

Where: $i = 1,2, \ldots, N$; $k = 1,2, \ldots, K$.

According to equation (1), if the *i*th country belongs to the *k*th group, it can export Y with a vector of inputs X at time t. β_k is a vector of coefficients of the *k*th group exports equation. u_{it}^k represents the export inefficiency arising from the combined influence of trade costs emerging from various sources within the exporting country on which full information is not available, and v_{it}^k is the random shock. A natural logarithmic transformation is performed to transform equation (1) into a linear expression:

$$ln\, Y_{it} = ln\, f_k\,(X_{it}, \beta_k) - u_{it}^k + v_{it}^k \quad (2)$$

Conventionally, the production function $f_k(.)$ is presumed to be log-linear, such as the Cobb-Douglas function. According to the definition of the inefficiency term, u_{it}^k is strictly non-negative and assumed to follow a truncated normal distribution, $u_{it}^k \sim N^+(u^k, \sigma_{u^k}^2)$. The random error follows a normal distribution independently and identically, $v_{it}^k \sim N(0, \sigma_{v^k}^2)$. SFPF uses a maximum likelihood method to estimate each group stochastic frontier gravity model's parameters of equation (2).

The value of the group frontier is the theoretical maximum exports value if the country could fully utilise its restricted export technology set, which means there is no export inefficiency, though still the export technology set is not the unrestricted export technology. The ratio of the actual exports value to the predicted group frontier represents the efficiency of each country with respect to its group frontier (TEG). Based on the estimation results of each group exports frontier, the *i*th country's TEG can be expressed as

$$TEG_{it} = \frac{Y_{it}}{E\left(Y_{it} \middle| u_{it}^k = 0, X_{it}\right)} = \frac{Y_{it}}{f_k(X_{it}, \beta_k)\, exp\left(v_{it}^k\right)} = exp\left(-u_{it}^k\right) \quad (3)$$

3.3. Metafrontier with SMFR

Huang *et al.* (2014) illustrate two major drawbacks in the LP and QP estimation methods used to estimate the metafrontier by Battese et al, (2004) and O'Donnell et al., (2008). Firstly, their calculated parameters have no statistical meanings as the derivation logic is purely algebraic. More importantly, they indicate that the mathematical programming methods are confounded by random shocks. When calculating parameters of the metafrontier function, LP and QP use the predicted value of group frontiers from the first step, while Huang *et al.* (2014) argue that the adoption of estimated group frontiers neglects the effect of the errors between $f_k(X_{it}, \beta_k)$ and $f_k\left(X_{it}, \widehat{\beta_k}\right)$. Therefore, a random error term should be considered when estimating $f_m(X_{it}, \beta_m)$ to include this disturbance.

This paper analyses this issue from a different angle. As the distance between the group-specific frontiers and the metafrontier is caused by inefficiency in choosing an export technology set, their relationship can be considered analogous to the relationship between the actual exports value and the group frontier potential exports. Values of each group frontier can be treated as outputs of a stochastic export process, which is determined by the metafrontier function and contains an inefficiency term. Thus, the group frontiers' 'export process' can be expressed as:

$$f_k(X_{it}, \beta_k)\, exp\left(v_{it}^k\right) = f_m(X_{it}, \beta_m)\, exp(-u_{it}^m + v_{it}^m) \quad (4)$$

where the left-hand side represents the group frontier drawing from the results of equation (3), u_{it}^m is the inefficiency term in the exports technology selection, namely the export technology gap, and v_{it}^m is the random error in the 'export process'. Therefore, u_{it}^{m} is also assumed to be strictly non-negative and follows a truncated normal distribution, $u_{it}^{m} \sim N^{+}(u^{m}, \sigma_{u^m}^{2})$, and v_{it}^{m} follows a normal distribution, $v_{it}^{m} \sim N(0, \sigma_{v^m}^{2})$. Then, as the MTR shows the extent to which each restricted export technology set exploits the unrestricted export technology set, its expression is modified as:

$$MTR_{it}^{k} = \frac{f_k(X_{it}, \beta_k)\, exp\left(v_{it}^{k}\right)}{f_m(X_{it}, \beta_m)\, exp\left(v_{it}^{m}\right)} = exp(-u_{it}^{m}) \tag{5}$$

Correspondingly, TEM is rectified as:

$$TEM_{it} = \frac{Y_{it}}{f_m(X_{it}, \beta_m) exp\ (v_{it}^{m})} \tag{6}$$

However, *TEM* is still the product of TEG and MTR, because using equations (3) and (5) *TEM* can be written as follows:

$$TEM = exp\left(-u_{it}^{k}\right) x\ exp(-u_{it}^{m}) = TEG\ x\ MTR \tag{7}$$

Recalling that both $f_k(.)$ and $f_m(.)$ are log-linear, equation (4) is transformed as:

$$l\,n\left(\, f_k(X_{it}, \beta_k)\, exp\left(v_{it}^{k}\right)\right) = l\,n\, f_m(X_{it}, \beta_m) - u_{it}^{m} + v_{it}^{m} \tag{8}$$

SFPF is used to estimate the parameters of the metafrontier function (equation 8) in the second step, and Huang *et al.* (2014) call this method SMFR. In practice, the value of the dependent variable in equation (8) comes from the estimation results in the first step, $f_k\left(X_{it}, \widehat{\beta_k}\right)$.

Thus, SMFR embodies a random error in the second step and clarifies the effects of each error term in both steps. To sum up, this study uses SFPF in the first step to estimate the gravity frontier equation and TEG for each group, respectively. Secondly, gathering the estimation results for all groups from the previous step, this study applies SMFR to estimate the metafrontier and MTRs. Finally, the estimated comparable trade efficiency scores with respect to the metafrontier are calculated as

$$\widehat{TEM_{it}} = \widehat{TEG_{it}} \times \widehat{MTR_{it}^{k}} \tag{9}$$

4. Empirical Model specification and data description

4.1. Empirical Model Specification

This paper applies the gravity model applying the metafrontier approach to evaluate the export performance of renewable energy goods among RCEP countries, assuming that different countries may have different export technology sets and export frontiers. The specific stochastic gravity equation used in the empirical analysis is expressed as:

$$\begin{aligned} ln\, TV_{ijt} = {} & \beta_0^k + \beta_1^k\, ln\, Exgdp_{it} + \beta_2^k\, ln\, Imgdp_{jt} + \beta_3^k\, ln\, Expop_{it} + \beta_4^k\, ln\, Impop_{jt} \\ & + \beta_5^k\, ln\, Dist_{ijt} + \beta_6^k\, ln\, Taf_{jt} + \beta_7^k\, ln\, ER_{ijt} + \beta_8^k CSL_{ijt} + \beta_9^k Time_t - u_{ijt}^{k} + v_{ijt}^{k} \end{aligned} \tag{10}$$

In the above equation, TV_{ijt} represents the export value of renewable energy commodities from exporting country *i* to the importing country *j* at time *t*, and *k* indicates which group the exporting country belongs to. *Exgdp* and *Imgdp* are real GDPs in exporter and importer countries, respectively, which are predicted to have a positive sign. According to Martinez-Zarzoso (2003), the population in exporting countries, *Expop*, is expected to have a mixed effect on exports, the same is with its counterpart's population, *Impop*. *Dist* is the geographic distance between capital cities of two trading partners and should have a negative sign. *Taf* is the tariff that the importer country imposes on imports, and it should reduce the export value as a trade cost. *ER* is the relative exchange rate, of which a higher value means that the exporter's currency appreciates relative to the importer's currency. Therefore, a higher *ER* would relatively increase the export price and reduce the trade volume, but the total effect depends on the elasticity of renewable energy goods. A proxy for a common spoken language between two countries *CSL* is included in equation (10) and expected to have a positive sign. *Time* is a time trend variable that captures the time effect. u_{ijt}^{k} and v_{ijt}^{k} are the export inefficiency term and the random error in each group's stochastic frontier gravity equation, for which the characteristics are discussed in the previous section. The metafrontier function used in SMFR has the same expression as equation (10), while it substitutes the dependent variable $\ln TV_{ijt}$ with the estimated values of the group's exports frontiers.

4.2. Data

Because of data limitations, the panel data set in this paper consists of data from 11 RCEP members from 2006 to 2014, and exporters are divided into two groups based on their export values. Group 1 includes countries with relatively higher export values, which are China, Japan, South Korea, Malaysia, and Singapore, while Australia, Indonesia, New Zealand, Philippines, Thailand, and Vietnam are included in the second group. Group 1 has 450 observations, and Group 2 has 522 observations as the Philippines' and Vietnam's export data to New Zealand are omitted. The export data is obtained from the United Nations Comtrade Database (UN Comtrade), and the HS code of renewable energy commodities is listed in Appendix I. Real GDP, population, and exchange rates are collected from the World Bank database. Data on distances and the index of common spoken language are taken from The Centre d'Études Prospectives et d'Informations Internationales CPEII, which is the main French institute for research into international economics. Tariff rates of each renewable energy commodity are obtained from the tariff download facility, and a weighted average ratio is used in the analysis. The following Table 1 shows the statistical summary of the data set, while only exporters' GDP and population data is presented as importers' data is almost the same. To avoid the $\ln(0)$ problem, the variable $\ln Taf_{it}$ is calculated as $\ln Taf_{it} = \ln(Taf_{it} + 1)$.

Table 1. Data set statistical summary.

Variable	Unit	Mean	Std. Dev.	Min	Max
Group 1					
TV	$million	818.6661	2518.903	.2376	22443.64
GDP	$billion	2620.013	2849.899	147.797	10354.8
Pop	million	309.6003	516.3194	4.4014	1364.27
Dist	kilometre	4241.317	2729.887	315.5433	11041.03
ER	ratio	713.9561	2358.361	0.00086	16729.33
Taf	per cent	3.0118	2.2008	0	7.3344
CSL	ratio	0.1281	0.2057	0	0.6958
Group 2					
TV	$million	27.7905	101.408	0.00099	1501.027
GDP	$billion	550.7	404.4255	66.3717	1563.95
Pop	million	85.7017	78.3247	4.1846	254.4548
Dist	kilometre	4903.627	3006.154	886.1407	11041.03
ER	ratio	870.1148	3190.353	0.00005	21565.52
Taf	per cent	3.0594	2.3867	0	7.3344
CSL	ratio	0.1312	0.2393	0	0.9506

Source: Authors' calculation.

5. Results and discussion

5.1. Group frontiers results

In the first step, this paper used the software Stata version 16.1 to perform SFPF to estimate the stochastic frontier gravity equations parameters for two groups, separately. To test the assumption that the two groups adopt different technology sets for exporting renewable energy goods, estimation of stochastic frontier gravity equation was carried out by pooling all countries' data together. Table 2 presents the estimation results.

Table 2. SFPF estimation results for Group1, Group2, and the pooled data.

Dependent variable: ln TV			
Variables	Group 1	Group 2	Pooled Data
ln Exgdp	0.8514***	0.4370	1.1723***
	(0.1835)	(0.2793)	(0.1456)
ln Imgdp	0.3694***	1.0533***	0.6561***
	(0.1398)	(0.1755)	(0.1220)
ln Expop	0.0066	0.4517**	-0.0757
	(0.1516)	(0.2063)	(0.1148)
ln Impop	0.4450***	-0.4266**	-0.1357
	(0.1425)	(0.1756)	(0.1406)
ln Dist	-1.0364***	-1.5057***	-1.7890***
	(0.1627)	(0.3280)	(0.2698)
ln ER	0.0165	0.0429	-0.0331
	(0.0324)	(0.0458)	(0.0325)
ln Taf	-0.1749	-0.1159	-0.0307
	(0.1738)	(0.2380)	(0.1781)
CSL	0.1838	0.5506	-0.1379
	(0.6210)	(0.8864)	(0.6120)
Time	-0.0966***	-0.0507	-0.0121
	(0.0373)	(0.0563)	(0.0249)
Constant	-11.5998***	-9.7299	-11.3747**
	(4.0527)	(8.1251)	(4.6189)
mu	0.9132***	1.4326***	1.3398***
	(0.2171)	(0.4449)	(0.2666)
eta	0.0533***	0.0133	-0.0081
	(0.0124)	(0.0177)	(0.0069)
gamma	0.6480***	0.5323***	0.8575***
	(0.0667)	(0.0720)	(0.0332)
Log-likelihood	-475.3016	-832.9853	-1426.5018

*Notes: ***, **, and * represent significance at a 1 per cent, 5 per cent, and 10 per cent confidence level, respectively. Figures in brackets are standard errors of estimates. Source: Authors' estimation.*

As Table 1 indicates that there are wide variations in the dataset, it is necessary to do robustness checks to ensure the robustness of the empirical results. Hence, before generating each country's TEG, several hypotheses need to be examined. First of all, it is necessary to confirm the presence of the export inefficiency term in both the group's stochastic frontier gravity equations, which is determined by examining the significance of the coefficient *gamma*. *Gamma* is the ratio of the variance of the export inefficiency term to the total variance of both error terms, which is expressed as $\gamma = \frac{\sigma_u^2}{\sigma_u^2+\sigma_v^2}$ and takes a value between 0 and 1. A significant *gamma* proves that the inefficiency term causes part of the total deviation significantly. As shown in Table 2, a significant *gamma* at the 1 per cent confidence level means that it is appropriate to adopt SFPF framework to estimate the parameters of the gravity equations. In addition, estimations of u_{ijt}^k in both regressions provide the second piece of evidence that all countries' exports in renewable energy commodities have export inefficiency issues.

Secondly, it is essential to examine whether the two groups have different export technology sets and gravity frontiers. If all countries' exports share the same technology set, there would be no need to further measure the metafrontier and TEMs as TEGs would be directly comparable. Following Battese *et al.* (2004), this paper uses the likelihood-ratio (LR) test for the null hypothesis that two groups have the same stochastic gravity frontier. The *LR* statistic is calculated by:

$$LR = -2\{ln[L(H_0)/L(H_1]\} = -2\{ln[L(H_0)] - ln[L(H_1)]\} \quad (11)$$

where $\ln[L(H_0)]$ is the value of the log-likelihood function, which uses pooled data from all countries, and $\ln[L(H_1)]$ is the sum of the values of the log-likelihood function that estimates the group stochastic gravity frontiers. The *LR* statistic follows a Chi-square distribution, and the degrees of freedom are the difference between the number of parameters estimated under H_1 and H_0, which are 12 in this case. The bottom line in Table 2 displays the values of log-likelihood functions, and the LR statistic is 236.4298 and has a 0 p-value, significantly rejecting the null hypothesis. Thus, countries in different groups have different restricted technology sets, and it is appropriate to estimate each group's frontier separately.

Comparing the estimation results between Group 1 and Group 2, the absolute values of the corresponding coefficients are significantly different. However, the estimated parameters in Group 1 have the same sign as their counterparts in Group 2 and are in line with the theoretical expectations, except for the variable *Impop*. The population in importing countries has a significant and positive impact on exports in the first group, but a negative impact in the second group. This difference emerges because of the different properties of renewable energy commodities from different countries. It is reasonable to assume that export commodities from higher volume countries probably enjoy some kinds of comparative advantages, such as lower prices, better reputation, and more advanced technology. Therefore, when the market size in importing countries increases, individuals and companies would prefer products from the first group more than from the second group.

The coefficients of *Taf* in both regressions are negative but not statistically significant even at the 10 per cent confidence level. This implies that the effect of reducing tariff rates for renewable energy commodities imports would be insignificant. The coefficient *eta* indicates whether the export inefficiency changes overtime or not. The positive values of *eta* in both group's gravity equations means that the u_{ijt}^k has been decreasing over the estimation period, or the export efficiency scores have been improving, for the two groups. However, the changes are significant in Group 1 but not significant in Group 2.

TEGs are calculated based on the group gravity estimation results, and each country's average TEG is shown in Table 3.

Table 3. Estimations of the export efficiency scores with respect to the group frontiers.

Group 1	TEG	Group 2	TEG
China	0.3643	Australia	0.3322
Japan	0.3506	Indonesia	0.1779
South Korea	0.3836	New Zealand	0.2830
Malaysia	0.2535	Philippines	0.1908
Singapore	0.4302	Thailand	0.4644
		Vietnam	0.2181
Group Mean	0.3564	Group mean	0.2611

Source: Authors' calculation.

In Group 1, Singapore's export performance with the highest TEG of 0.4302 was the best relative to other countries in the group, while Malaysia had the lowest TEG of 0.2535 during the sample period. The remaining three countries' TEG estimations worked out to be slightly above the group mean. In Group 2, Thailand's export efficiency was considerably higher than that of the other countries with a value of 0.4644, followed by a value of 0.3322 in Australia during the sample period. The other four countries' TEG estimations were much lower than the group mean. The group mean of TEG in Group 1 was greater than that of Group 2. Nevertheless, the estimates of TEGs are not comparable across the two groups. The next step is to generate comparable TEMs by calculating MTRs for all countries together.

5.2. Metafrontier results

The estimations of all countries' theoretically maximum export values with respect to their group frontiers from the first step are used to estimate the metafrontier function. This paper used the software Stata version 16.1 to run the SMFR estimation with respect to equation (10). Table 4 lists the estimated coefficients of the metafrontier gravity equation.

Table 4. Estimations of the metafrontier gravity equation.

Dependent variable: Estimations of the values of the group gravity frontiers	
Variables	SMFR
ln Exgdp	0.5581***
	(0.0127)
ln Imgdp	0.7363***
	(0.0144)
ln Expop	0.4401***
	(0.0174)
ln Impop	-0.0323
	(0.0201)
ln Dist	-1.3623***
	(0.0239)
ln ER	0.0337***
	(0.0037)
ln Taf	-0.1455***
	(0.0158)
Csl	0.5085***
	(0.0685)
Time	-0.1379***
	(0.0023)
Constant	-8.6987***
	(0.4065)
mu	1.9091***
	(0.1493)
eta	0.0295***
	(0.0005)
gamma	0.9687***
	(0.00025)
Log-likelihood	1225.4878

*Notes: ***, **, and * represent significance at a 1 per cent, 5 per cent, and 10 per cent confidence level, respectively. Figures in brackets are standard errors of estimates. Source: Authors' calculation.*

As analysed in the group estimation results, the estimation of *gamma* shows significant export inefficiency (a technology gap) between the metafrontier and the group frontiers. The ratio $1-\gamma=\frac{\sigma_v^2}{\sigma_u^2+\sigma_v^2}$, which has the exact opposite meaning to γ that measures the effect of random error on the total deviation, is used to examine the presence of the random error in the metafrontier function. The value of this ratio is 0.0313 in the SMFR estimation result, but statistically significant at the 1 per cent level, which implies that a significant random error exists. This result is consistent with the conclusion in the work of Huang *et al.* (2014) and supports the use of SMFR estimation for the current data set. Table 5 reports the estimated MTRs and TEMs based on the SMFR estimation results.

Table 5. Estimations of the meta-technology ratios and the export efficiency scores with respect to the metafrontier.

	SMFR estimates	
Group 1	MTR	TEM
China	0.4020	0.1401
Japan	0.4974	0.1698
South Korea	0.3737	0.1394
Malaysia	0.2922	0.0684
Singapore	0.5820	0.2356
Group Mean	0.4295	0.1507
Group 2		
Australia	0.0365	0.0116
Indonesia	0.0731	0.0127
New Zealand	0.0223	0.0045
Philippines	0.0972	0.0187
Thailand	0.0703	0.0314
Vietnam	0.0768	0.0198
Group Mean	0.0627	0.0164

Source: Authors' calculation.

The average MTRs of Group 1 are substantially higher than those of Group 2, which indicates that the restricted technology set in Group 1 is more efficient than the restricted technology set in Group 2. Dominated by this difference, the calculated TEMs based on equation (9) have the same characteristic. Overall, all countries in Group 1 enjoy a more advanced technology set and have better export performance than countries in Group 2, though both the groups are using the restricted export technology sets. This is direct evidence that exports from countries in Group 1 are structurally and substantially more efficient than from Group 2 countries. As shown in Table 4, the significantly positive *eta* in the SMFR gravity equation estimation demonstrates that each country's MTR is increasing over the sample period.

To sum up, the TEM estimations suggest that huge potential exists for all RCEP countries to improve the performances of their renewable energy commodities exports, and the implicit trade cost significantly hinders the export value within this region. Countries in the first group achieve higher average scores in both TEG and MTR, and thus higher average scores in TEM than the second group.

6. Summary Conclusions and Policy Suggestions

6.1. Summary Conclusions

It is acknowledged that when countries are able to work together, it will have increasingly important implications for national, regional, and worldwide prospects of a more sustainable energy future. Collaboration among countries with respect to developing new and innovative strategies could increase the phase of moving toward low-carbon-intensive energy systems. Such collaborative actions that countries take would have impacts beyond their borders and by nature facilitate a more win-win situation for all countries globally. Although the availability of cost-effective and potentially efficient renewable energy technologies is a necessary condition for the promotion of green growth nationally and internationally, determined commitment to make use of such technologies by nations is thus crucial. International trade in renewable energy commodities provides an effective way of achieving NDCs nationally, even when individual countries may not have sufficient infrastructure readily available to them to fulfil NDCs. The establishment of RCEP provides an excellent opportunity for Asia-Pacific countries to enhance the trade within this region. Under this circumstance, it is necessary to examine whether renewable energy goods exports have been flowing without constraints in the Asia-Pacific region.

This paper applied the stochastic frontier gravity model with a metafrontier approach to evaluate renewable energy commodities export performances of selected RCEP members. The metafrontier approach decomposed the total export efficiency score into two components: export efficiency score with respect to the group frontier and the meta-technology ratio of the restricted technology set to the unrestricted technology set. In the first step, the SFPF estimation results confirmed the assumption that the two groups have different technologies and estimated each country's TEG and the values of the group gravity equation frontiers. Based on the estimations in the first step, this paper applied the SMFR approach to measure the MTRs. The results show that Group 1 has a significant higher average MTR than Group 2, which means that countries in Group 1 are more export efficient in adopting its restricted technology set for exports. This is a direct evidence that exports from countries from Group 1 are structurally and substantially more efficient than those from Group 2. Differences in MTRs dominated the TEM calculations, which meant that countries' TEMs in Group 1 were overwhelmingly higher than those in Group 2. Overall, countries with relatively higher export values of renewable energy commodities performed better in realising their trade potentials than other countries. However, the small numbers of the TEM show that all RCEP members need to work harder to reduce the implicit trade costs. The establishment of RCEP does have the potential to considerably improve trade in renewable energy commodities within the Asia-Pacific region.

This paper also finds evidence that there exists a significant random error in the metafrontier function, which supports the suggestion of Huang *et al*. (2014) to use the SMFR method to estimate metafrontiers. Overall, countries with relatively higher export values of renewable energy commodities performed better in realising their trade potentials than other countries. However, the small numbers of the TEM show that all RCEP members need to work harder to reduce the implicit trade costs. The establishment of RCEP does have the potential to considerably improve trade in renewable energy commodities within the Asia-Pacific region.

6.2. Policy Suggestions

This study proposes the following policy suggestions based on the estimation results. RCEP members should keep their commitments in the RCEP agreement to gradually reduce tariff rates on renewable energy commodities to zero. Meanwhile, governments should provide export tax rebates for renewable energy goods exports to further reduce the export price. However, only focusing on price reduction is not enough. Governments should also pay attention to improving export efficiency and reducing implicit trade costs. RCEP countries should cooperate more closely to eliminate non-tariff measures, as they have become the main barriers to trade within this region. Moreover, implementing more stringent regulations and policies in the renewable energy sector is likely to increase the competitiveness of renewable energy commodities then to increase export efficiency. In addition, Governments should encourage residents and businesses to use renewable energy generated electricity when applicable, such as providing subsidies for small solar PV panels installed. However, countries may experience an efficiency loss in renewable energy exports during the transition from fossil energy to renewable energy in the short run.

RCEP members need to urgently establish more generally accepted technical standards and technology certification systems under the RCEP scheme to smoothen the technology transfer process within the region. Also, to increase the technology diffusion across RCEP member countries, it is important to improving the exporting environment, such as infrastructure and endowment availabilities, which mainly affect the technology gap among the member countries. The importance of R&D investment should not be neglected. It has the potential to increase trade in renewable energy commodities between RCEP members. Governments, as well as private investors, should keep a faster growth rate of R&D expenditure compared with investment in renewable energy supply. In this context, it is crucial to protecting intellectual property rights concerning renewable energy production, which are essential for countries to integrate with the world market and to lift the export frontiers of all member countries to reach the unrestricted renewable energy export technology.

7. Limitations and Directions for future research

This paper adopted the concepts of export efficiency with respect to group frontiers and meta-technology ratio. However, it did not clearly distinguish the differences between those two ratios, though it argues that the technology gap between group frontiers and metafrontier is caused by the inefficiency of the macroeconomic environment. Future studies can be conducted on identifying which factors contribute to TEG and MTR, respectively.

This study mainly analyses the feasibility issue of improvements brought by the establishment of RCEP on renewable energy trade. As the RCEP agreement formally came into force on the 1st of January 2022, with more data becoming available, it would be interesting to evaluate the actual impact of the RCEP agreement on trade in renewable energy commodities.

Funding Statement

This research received no external funding.

Acknowledgments

Acknowledgments to anonymous referees' comments and editor's effort.

Conflict of interest

All the authors claim that the manuscript is completely original. The authors also declare no conflict of interest.

Appendix

A1. HS code of renewable energy commodities from the APEC 54 list.

HS code	Commodities
840290	Steam or other vapor generating boilers; super-heated water boilers
840490	Parts for auxiliary plant for boilers, condensers for steam, vapor power unit
840690	Parts for steam and other vapor turbines
841182	Gas turbines, except turbojets and turbo-propellers, of a power exceeding 5,000 kW
841199	Parts of gas turbines (841182)
841290	Engine and motor parts, nesoi (wind turbine blades and hubs)
841919	Instantaneous or storage water heaters, nonelectric other than instant water heaters
841990	Parts of machinery, plant or laboratory equipment involving temperature change, nesoi

850164	AC generators (alternator), of an output exceeding 750 kVA
850231	Other electric generating sets: wind-powered
850239	Electric generating sets and rotary convertors: other
850300	Parts suitable for use solely or principally with the machines of heading 8,501 or 8,502
850490	Parts for electrical transformers, static converters, and inductors
854140	Photosensitive semiconductor devices, including photovoltaic cells
901380	Optical devices, appliances, and instruments, nesoi
901390	Parts and accessories for optical devices, appliances, and instruments, nesoi

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