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Welfare gains from international trade and renewable energy demand: Evidence from the OECD countries

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ABSTRACT

This paper uses a new measure of international trade, i.e. the international trade potential index, to measure the welfare gains from trade across countries. The measure is based on the import shares of countries in their gross domestic products. It is observed that gains from international trade are low in prosperous economies, but they are larger in poorer economies. Then, the paper investigates the impact of the index of international trade potential on renewable energy consumption in the unbalanced panel dataset of 36 Organisation for Economic Co-operation and Development member countries from 1966 to 2016. The novel evidence is that international trade potential is positively related to renewable energy consumption. It is also found that per capita income, per capita carbon dioxide emissions, and energy prices increase the demand for renewable energy.

1. Introduction

What determines the renewable energy demand? Answering this question is essential for possible problems due to climate change and energy sustainability. According to various papers (e.g., Gozgor et al., 2020; Omri and Nguyen, 2014), renewable energy demand will be the key aspect of energy sustainability. There will be a significant increase in renewable energy demand soon because renewable energy is a clean energy source (Gozgor, 2016). Therefore, the rising renewable energy consumption can help decrease greenhouse gas emissions and slow down global warming. This issue will be a practical policy implication for combating the climate change crisis.

At this stage, international trade is one of the leading determinants of energy consumption (Gozgor et al., 2020) and environmental degradation (Copeland and Taylor, 2004). According to the "Pollution Haven Hypothesis (PHH)," industrial production, which causes a high level of environmental degradation, is subject to strong regulations in advanced countries. Therefore, many firms in the developed countries move their production bases to the developing economies with softened environmental regulations in the production process (Cherniwchan et al., 2017; Copeland and Taylor, 2004; Eskeland and Harrison, 2003; Gozgor, 2014). In line with the PHH, developing economies can increase their production; however, environmental issues will be a secondary objective due to fewer government regulations. In developing economies, they are in a race to the bottom, i.e., government deregulation of the business environment will be the main policy implication to promote international trade and foreign direct investments.

International trade is also an important way of importing new products and thus helping to reach the required high technology level for renewable energy investments. International trade creates a significant potential for domestic firms to change their production bases to a more environmentally friendly nature. Therefore, the developed countries generally target reducing fossil-based energy sources to decrease CO_2 emissions. Thus, increasing renewable energy consumption and

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investments will be an important policy tool.

Furthermore, the welfare gains from international trade are calculated following Ricardo's model of comparative advantage and several new models (Arkolakis et al., 2012). However, gains from trade are difficult to measure since most products in the service sector are not tradeable. To solve the measurement problem, Costinot and Rodríguez-Clare (2018) estimate the welfare gains from trade in the United States and find that gains from trade are relatively low, which is around 2.5% of the gross domestic product (GDP). The evidence is related to the fact that the United States is a relatively close economy. For instance, the import share of the United States was only around 8% of the GDP at the beginning of the globalisation era (in 1991) (Ramanarayanan, 2020).[1] In addition, the services sector is essential in the United States economy. Most of these services are not subject to trade (e.g., banking and financial services and medical services) in the United States economy.

However, in developing economies, international trade is crucial for economic development. In small or poor economies, capital and skilled workers are scarce (Jha and Gozgor, 2019. Therefore, small or poor economies cannot take advantage of scale economies in their production. For instance, it is not feasible to produce a car in small or poor economies, as the domestic demand will be low due to inadequate income and market size (population). Therefore, these countries need to export products to provide higher economic performance. Therefore, gains from international trade are higher in small or poor economies than in large and rich countries (Banerjee and Duflo, 2019). It is also important to note that large competitors exist in export destinations, such as China, India, Indonesia, and Nigeria.[2] Therefore, international trade policies are the key to economic performance and environmental indicators (Shapiro, 2021).

Given these backdrops, this paper uses a new measure of international trade, so-called the international trade potential index, to calculate welfare gains from international trade. The measure is based on the import shares of countries in GDPs. This paper demonstrates that gains from international trade are low in rich economies. Still, it is larger in poorer economies. The evidence is in line with the arguments of Banerjee and Duflo (2019). Then the paper examines the effects of the international trade potential index, a measure of the potential rise in technology level and production structure, on the renewable energy demand in an unbalanced panel dataset of 36 Organisation for Economic Co-operation and Development (OECD) countries from 1966 to 2016. According to our hypothesis, which is based on the theoretical background of the PHH, we expect the positive effects of the gains from international trade on renewable energy demand in the case of the OECD economies. Thus, promoting international trade potential can be crucial for decreasing environmental degradation and providing sustainable and environment-friendly production and economic growth.

This paper contributes to the current empirical literature in several aspects. Firstly, this paper creates a new index of international trade potential and uses it as a potential determinant of renewable energy consumption in an unbalanced panel dataset of 36 OECD member countries from 1966 to 2016. To the best of our knowledge, this is the first paper to examine the effects of international trade potential on renewable energy demand in the OECD countries. For this purpose, we implement various estimation techniques to provide robust empirical results. The paper shows that per capita income, carbon dioxide emissions, and energy prices increase renewable energy consumption. Most importantly, the trade potential index leads to a higher demand for renewable energy in the OECD countries.

The rest of the paper is organised as follows. Section 2 reviews the previous empirical papers in the literature. Section 3 introduces the trade potential index and explains the data and the estimation techniques. Section 4 discusses the empirical findings and policy implications. Section 5 concludes.

2. Literature review

2.1. Economic growth, international trade, and renewable energy consumption

A fast-developing strand of the literature examines the relationship between renewable energy consumption and economic growth (see, e.g., Apergis and Payne, 2010a and 2010b; Bhattacharya et al., 2016 and 2017; Fang et al., 2021; Gozgor, 2018; Gozgor et al., 2018; Lin and Moubarak, 2014). Compared to reflections on the traditional renewable energy-growth nexus, the new determinants of renewable energy consumption have motivated new research in this field. However, those studies do not agree on the relationship's direction and magnitude as they have used different data sets, periods, and methodologies. In one of the earliest studies, Sadorsky (2009a) analyses the determinants of renewable energy in the G7 countries using panel cointegration techniques. The author finds that real GDP per capita and the per capita carbon dioxide emissions are the main drivers of renewable energy consumption in the long run.

At the same time, the energy (especially crude oil) price has a negative but relatively minor impact on this consumption. In a subsequent study, Sadorsky (2009b) shows that real per capita income positively affects per capita renewable energy consumption in 18 emerging economies. The evidence is in line with Sadorsky (2009a). It implies that higher economic growth is crucial in increasing the share of renewable energy in total energy consumption. Salim and Rafiq (2012) analyse the determinants of renewable energy consumption in Brazil, China, India, Indonesia, the Philippines, and Turkey. The authors show that renewable energy consumption is influenced by income and pollutant emissions in Brazil, China, India, and Indonesia. However, per capita income is the only determinant of the renewable energy demand in the Philippines and Turkey in the long run. Furthermore, a positive relationship between economic growth and renewable energy consumption was also found by Belaïd and Zrelli (2019) for nine Mediterranean countries, by Rahman and Velayutham (2020) for South Asian economies, by Razmi et al. (2020) for 130 developing countries, by Fan and Hao (2020) for the Chinese provinces, by Chen et al. (2020) for Iran, and Belaïd et al. (2021) for the Middle Eastern and North Africa economies. Alam and Murad (2020) also found that economic growth promotes renewable energy consumption in the long run.

2.2. CO_2 emissions and renewable energy consumption

In a comprehensive study, Aguirre and Ibikunle (2014) illustrate that carbon dioxide emissions, energy consumption, GDP per capita, ratification of the Kyoto protocol, and high electricity usage rates in the industry sector are the fundamental drivers of renewable energy growth in 38 countries. Furthermore, Omri and Nguyen (2014) examine the determinants of renewable energy consumption in 64 countries and find that per capita carbon dioxide emissions positively affect renewable energy consumption. Paramati et al. (2016) find that carbon dioxide emissions hurt renewable energy demand in 20 emerging market economies. Chen and Lei (2018) show a positive economic development impact renewable energy consumption. In addition, the level of carbon dioxide emissions, per capita exports, per capita imports, and changes in urbanisation also explain the renewable energy consumption in the different Chinese regions.

On the other hand, Cheng et al. (2020) indicate that reducing the cost of carbon emissions increases renewable energy consumption in China. Moreover, Dong et al. (2018a and 2018b) and Yu et al. (2020) show that

[1] According to the Penn World Table (PWT) dataset, the average import share was 10.65% of the GDP in the 1990s in the United States, and it became 16.61% of the GDP from 2000 to 2019 on average.

[2] Note that environmental pollution (measured by CO2 emissions generally) has increased in developing economies due to the increasing levels of production in these developing economies.

renewable energy consumption reduces carbon emissions in China. The negative relationship between renewable energy consumption and CO_2 emissions is also found by Akram et al. (2020) in developing economies and Liu et al. (2020) for the United Kingdom.

2.3. Energy prices and renewable energy consumption

According to Gourevitch (1978) and Geller et al. (2006), oil prices negatively relate to energy consumption. As the price of crude oil increases, the demand for energy rises through technological innovation and carbon dioxide emissions cost reductions. In terms of the relationship between real oil prices and renewable energy consumption, the most noticeable literature provided by Broadstock et al. (2012), Dawar et al. (2021), Henriques and Sadorsky (2008), Inchauspe et al. (2015), Kyritsis and Serletis (2019), Reboredo (2015), Reboredo et al. (2017), Sadorsky (2012), and Shah et al. (2018).

Meanwhile, according to Padhan et al. (2020) and Zhang et al. (2022), oil prices positively and significantly affect renewable energy consumption by creating new technologies. For instance, Apergis and Payne (2015) show a long-run relationship between real oil prices and renewable energy in South American countries. Cheon and Urpelainen (2012) also indicate that oil prices increase renewable energy consumption through technological innovation. Gozgor et al. (2020) show that the rise in real oil prices causes higher renewable energy consumption. Fan and Hao (2020) show that energy prices and economic complexity are negatively related to the demand for energy in the panel dataset of 25 OECD countries.

3. Data and methods

3.1. Data and introducing the international trade potential index

This paper investigates the determinants of renewable energy consumption in an unbalanced panel dataset of 36 OECD countries from 1966 to 2016.[3] The sample is limited as the energy price indices ended in 2016. In addition, the dependent variable is renewable energy consumption (input-equivalent exajoules per capita). The related data are obtained from British Petroleum (2021). As control variables, we include the per capita GDP (constant US$ prices in 2010) and CO_2 emissions (metric tons per capita), and these data are obtained from the World Bank (2022). Energy prices are captured by the economy-wide energy price index (based on the constant prices, 2010 = 100). The related data are accessed from Liddle and Huntington (2020). Energy prices, per capita GDP, and CO_2 emissions per capita are used in the natural logarithmic form in the estimations.

At this stage, this paper also uses a new measure of international trade, the trade potential index, to calculate the welfare gains from international trade. The related data are obtained from the Penn World Table (PWT) (10.0) of Feenstra et al. (2015). Here, we follow the methodology of Gozgor (2017) and Waugh and Ravikumar (2016) and define the Trade Potential Index (TPI) as follows:

$$TPI_{it} = \left(\frac{1-M_{it}}{Y_{it}}\right)^{\frac{1}{1+\theta}} \tag{1}$$

Where M_{it} is the imports of country[4] i in time t relative to its GDP, calculated with the current $ prices.[5] Y_{it} is the GDP of country i in time t, calculated by the output-based real prices. θ denotes the trade elasticity, and it is accepted as *4*, following Simonovska and Waugh (2014), Waugh (2010), and Waugh and Ravikumar (2016).

In line with the arguments of Banerjee and Duflo (2019), the TPI data demonstrate that in large countries (measured by GDP), such as the United States, the welfare gains from international trade are low. Still, the gains from trade are significant in poorer countries, such as Colombia.

3.2. Data description

Table 1 shows the descriptive statistics of the Renewable Energy Consumption (*RE*), Trade Potential (*trade_pot*), Energy Prices (*lnenpr*), Economic Growth (*lngdpc*), and CO_2 emissions (*lnCO2*) in an unbalanced panel dataset of 36 OECD economies. The mean value is highest for economic growth, energy prices, CO_2 emissions, trade potential, and renewable energy consumption. Indeed, fluctuations or variations of the variables captured by the standard deviation are higher for economic growth, CO_2 emissions, renewable energy consumption, energy prices, and trade potential. (See also Fig. 1.)

Moreover, Table 2 illustrates the correlation between the variables. All variables, i.e., trade potential, energy prices, economic growth, and CO_2 emissions, have significantly correlated with renewable energy consumption.

3.3. Methodology: panel data estimation techniques

3.3.1. Random-effects estimations

The random-effects estimations with the different estimation techniques; i.e., the Newey-West, the Driscoll-Kraay, the Panel Corrected Standard Errors (PCSE), and the Feasible Generalized Least Squares (FGLS), are employed when working with time-series and cross-sectional data, producing accurate standard error estimates (Bailey and Katz, 2011; Ikpesu et al., 2019).

The correct formula for the sampling variability of the ordinary least squares (OLS) estimates is given by the following square roots of the diagonal terms:

$$Cov.(\widehat{\beta}) = \left(X^TX\right)^{-1}\left\{X^T\Omega X\right\}\left(X^TX\right)^{-1} \quad \Omega = \sigma^2 I, \quad I = NT\times NT \tag{2}$$

For panel models with contemporaneously correlated and panel heteroskedastic errors, Ω is an $NT \times NT$ block diagonal matrix with an $N \times N$ matrix of contemporaneous covariance Σ along the diagonal. The functional form can be written as follows:

$$Y = \left(X^TX\right)^{-1}X^T\widehat{\Omega}X\left(X^TX\right)^{-1} \tag{3}$$

3.3.2. Dynamic system generalized method of moments (DSGMM)

The DSGMM provided by Arellano and Bover (1995) and Blundell and Bond (1998) gives unbiased results in endogeneity problems, measurement issues, and unobserved heterogeneity among countries. The DSGMM is suitable when $N < T$; otherwise, biased results will occur.[6] The DSGMM can be explained in the following way:

$$Dependent\ Var_{it} = \gamma_1 Explanatory\ Var_{it} + \gamma_2 Endogenous\ Var_{it} + v_i + \eta_{i,t} \tag{4}$$

where $i = 1, 2, 3 \ldots n$, and $t = 1, 2, 3 \ldots m$. v_i are the unobserved factors and η_{it} residuals that capture the omitted variables effect. Moreover, v_i and η_{it} are independent for each i overall t. Eq. (4) can be rewritten as follows:

[3] Australia, Austria, Belgium, Canada, Chile, Colombia, the Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Japan, Korea Republic, Latvia, Luxembourg, Mexico, the Netherlands, New Zealand, Norway, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, the United Kingdom, and the United States.

[4] We use the PWT 10.0 dataset to calculate import share data.

[5] According to this formula, the share of imports in the GDP must be <1.

[6] Roodman (2009a and 2009b) notes that a rule of thumb for avoiding over-identification of instruments is that the number of instruments is less than or equal to the number of groups in the regressions.

Table 1
Descriptive statistics.

Label	Variable	Definition	Source	Obs.	Mean	Std. Dev.	Min.	Max.
RE	Renewables Consumption	Input-equivalent Per Capita	British Petroleum (2021)	1174	0.1083	0.3521	0.00005	4.8076
TRADE-POT	International Trade Potential	Index	Authors' Calculation, Based on the PWT (10.0)	1174	0.1284	0.0405	−0.0970	0.2409
LNENPR	Economy-wide Energy Price	Real Index, 2010 = 100	Liddle and Huntington (2020)	1174	4.4210	0.2473	2.0621	4.9275
LNGDPC	GDP per Capita	Constant 2010 US$	World Bank (2022)	1174	10.219	0.6569	8.4765	11.625
$LNCO_2$	CO_2 Emissions	Metric Tons Per Capita	World Bank (2022)	1174	2.0651	0.5467	0.2691	3.5088

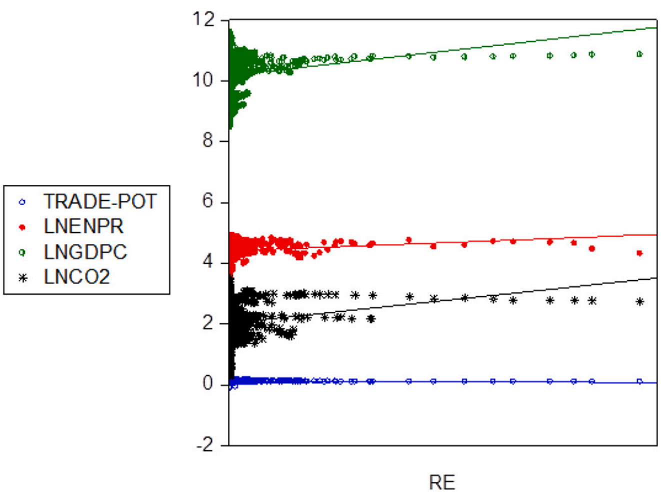

Fig. 1. Graphical transitory of the explanatory variables.

Table 2
Correlation matrix.

Variable	RE	TRADE-POT	LNENPR	LNGDPC	$LNCO_2$
RE	1				
TRADE-POT	0.0891***	1			
LNENPR	0.1549***	−0.3268***	1		
LNGDPC	0.1698***	−0.7141***	0.1913***	1	
$LNCO_2$	0.1912***	−0.4942***	0.0202	0.6214***	1

Note: ***$p < 0.01$.

$$Dep.Var_{it} - Dep.Var_{i,t-1} = \gamma_1 \left(Exp.Var_{it} - Exp.Var_{i,t-1}\right) + \gamma_2 \left(End.Var_{it} - End.Var_{i,t-1}\right) + \left(\eta_{it} - \eta_{i,t-1}\right) \quad (5)$$

4. Empirical results

4.1. Initial tests: cross-sectional dependence

Since we rely on the panel data, there can be a cross-sectional dependence among different countries' series. In this cross-sectional dependency in the series, usual panel regression techniques are likely to produce biased estimated parameters. According to Pesaran (2004), the null hypothesis shows no cross-sectional dependence while the alternative hypothesis is cross-sectional dependence. The cross-sectional dependence statistics mean that the value is zero for a fixed value of T and N under a wider range of panel data frameworks, including homogeneous/heterogeneous dynamic models and non-stationary models. The fixed-effects/random-effects residuals will have exactly mean zero even for fixed T, provided that the disturbances are symmetrically distributed. According to Nickell (1981) and Pesaran and Smith (1995), the fixed-effects/random-effects estimations are biased in homogeneous and heterogeneous dynamic models. However, the cross-sectional dependence is still valid despite the small sample bias of the parameter estimates.

As per the result, the evidence rejects the null hypothesis of no cross-sectional dependence, providing evidence for cross-sectional dependence in the data because of the statistical significance of the cross-sectional dependence (CD) test statistics. Table 3 provides the evidence for the validity of the cross-sectional dependence in the data series as judged based on the significance level of the CD test statistics. We also provide the stationarity of the variables in the models. The Hausman test statistics show that the random-effects models can provide more efficient results than the fixed-effects models.

4.2. Random-effects estimations

We ensure no bias in our estimated parameters with the usual panel regression model estimation. At this stage, we employ four alternative estimation techniques for the random-effects model estimations: Newey and West's (1987), Driscoll and Kraay's (1998), the PCSE, and the FGLS estimations. The estimated results from the application of these procedures are subsequently produced.

Table 4 provides the results of the Newey-West, the Driscoll-Kraay, the PCSE, and the FGLS estimations, where the renewable energy consumption is a function of trade potential, energy prices, and economic growth, and CO_2 emissions.

The results of the Newey-West regression show that trade potential, energy prices, economic development, and CO_2 emissions positively affect renewable energy consumption in the OECD economies. Specifically, a 1% rise in trade potential, energy prices, economic growth, and carbon dioxide emissions lead to a 1.322%, 0.249%, 0.071%, and 0.116% increase in renewable energy consumption. We also employ the Driscoll-Kraay, the PCSE, and the FGLS estimations. The results show consistent results along with Newey-West significantly and respectively.

Given the above findings, it is observed that trade potential promotes renewable energy in the OECD countries. This evidence shows that gains from trade benefit the OECD countries when promoting renewable energy consumption. One can argue that the OECD countries get more export revenue while exporting commodities to other countries. More export revenue may be utilised by the governments of the OECD economies while giving incentives to renewable energy producers and providing renewable energy to the people at a subsidised rate (Shahbaz et al., 2019). From a consumer perspective, people in these economies demand renewable energy because it is available at an affordable price. Therefore, trade potential augments the renewable energy demand of the people in the OECD countries.

We also find that increase in income level drives renewable energy consumption in the OECD countries. This evidence is consistent with the recent study of Sadorsky (2009a) for the G7 countries, Sadorsky (2009b)

Table 3
Cross-sectional dependence tests.

Test	RE	TRADE-POT	LNOLPR	LNGDPC	$LNCO_2$
Breusch-Pagan LM	14,472.77***	14,095.16***	10,887.62***	13,832.21***	6050.74***
Pesaran Scaled LM	389.97***	379.34***	288.97***	371.93***	152.71***
Bias-corrected Scaled LM	389.60***	378.96***	288.60***	371.55***	152.33***
Pesaran CD Test	118.52***	116.01***	101.08***	113.32***	24.92***

Note: ***$p < 0.01$.

Table 4
Random-effects estimations with different methods.

Method:	Newey-West	Driscoll-Kraay	PCSE	FGLS
TRADE-POT	1.3228***	1.3228***	1.3228***	1.3228***
	(0.3090)	(0.4850)	(0.5565)	(0.3661)
LNENPR	0.2499***	0.2499***	0.2499***	0.2499***
	(0.0637)	(0.0821)	(0.0549)	(0.0430)
LNGDPC	0.0713***	0.0713***	0.0713***	0.0713***
	(0.0152)	(0.0259)	(0.0133)	(0.0240)
$LNCO_2$	0.1161***	0.1161***	0.1161**	0.1161***
	(0.0367)	(0.0258)	(0.0498)	(0.0235)
Constant	−2.1350***	−2.1350***	−2.1350***	−2.1350***
	(0.4526)	(0.6641)	(0.3561)	(0.3335)

Notes: The dependent variable is the Renewable Energy Consumption (RE). () shows the standard errors. ***$p < 0.01$, and ** $p<0.05$.

for 18 emerging market economies, Gozgor et al. (2020) for the OECD countries, Marques et al. (2010) for 24 European countries, Omri and Nguyen (2014) for 64 countries, and Aguirre and Ibikunle (2014) for 38 countries where they find that income level promotes renewable energy demand. This finding shows that income level helps the OECD countries to increase the share of clean energy in the total energy mix. This issue indicates that people with their increased income level in the OECD economies chose to transition from fossil fuels to renewable energy to protect the natural environment. If this process continues, it becomes sure that the OECD economies to have sustainable green growth in the long run.

We also find the beneficial effect of energy price on the renewable energy demand in the OECD countries. This finding is also in line with the recent study by Gozgor et al. (2020) for the OECD countries. If the OECD countries rely on imported energy from other countries, increasing energy prices could be possible for domestic people due to higher imports bills. The rising energy prices will eat up the people's savings in the OECD countries if they do not shift their energy dependence behaviour. Therefore, the OECD economies continue to transition from coal oil to natural gas and fossil fuels to renewable energy.

Furthermore, we observe the beneficial effect of carbon dioxide emissions on renewable energy in the OECD countries. This finding is consistent with the recent study by Gozgor et al. (2020) for the OECD countries; Salim and Rafiq (2012) for Brazil, India, China and Indonesia. We can argue that since created pollution due to rising carbon emissions in the atmosphere brings the threat of climate change and global warming, it motivates people in the OECD economies to shift their energy consumption from fossil fuels to renewable energy. Using renewable energy could bring a win-win situation for the OECD countries. For example, using renewable energy can reduce pollution and solve the limited availability of fossil fuels in the future.

Therefore, our results are robust to consider different estimation techniques. Next, we provide additional results from the DSGMM estimations to address possible econometric concerns regarding the effects of international trade potential on renewable energy demand.

4.3. Panel DSGMM estimations

At this point, we address the potential problems of endogeneity, measurement bias, omitted variables bias, and unobserved heterogeneity. For this purpose, we utilise Arellano and Bover's (1995) and Blundell and Bond's (1998) estimations to provide unbiased estimators for the coefficients of interest. The method combines a regression in levels and a regression in differences. However, one must be careful to apply it to cases where periods are small relative to cross-sectional observations. Otherwise, asymptotic imprecision and biases may arise.

Table 5
DSGMM estimations.

Method:	One-stage DSGMM	Two-stage DSGMM
RE_{t-1}	1.1003*** (0.0024)	1.1001*** (0.0002)
$TRADE\text{-}POT_{t-1}$	0.1177* (0.0722)	0.1026*** (0.0150)
$LNENPR_{t-1}$	0.0115*** (0.0037)	0.0111*** (0.0003)
$LNGDPC_{t-1}$	0.0129* (0.0075)	0.0132*** (0.0007)
$LNCO_{2t-1}$	0.0074* (0.0040)	0.0065*** (0.0009)
Constant	−0.2127** (0.0828)	−0.2107*** (0.0066)
Sargan Test	N/A	30.9442

Notes: The dependent variable is the Renewable Energy Consumption (RE). () denotes the robust standard errors. ***$p < 0.01$, **$p < 0.05$, and *$p < 0.1$. DSGMM: Dynamic Systematic Generalised Method of Moments.

Table 5 provides the results derived from the DSGMM. The results show that trade potential, energy prices, economic growth, and CO_2 emissions increase the usage of renewable energy consumption in the OECD economies.

We also get consistent results from the two-stage DSGMM estimations, similar to the one-stage DSGMM. In one stage, the DSGMM results from a 1% rise in trade potential, energy prices, economic growth, and CO_2 emissions, increasing renewable energy consumption by 0.114%, 0.010%, 0.012%, and 0.006%, respectively. Specifically, a 1% increase in trade potential, energy prices, economic growth, and CO_2 emissions increase renewable energy consumption by 0.103%, 0.011%, 0.013%, and 0.006%, respectively.

4.4. Discussion and policy implications

We observe that trade gains guide the increasing demand for renewable energy. This evidence shows that if the OECD countries are open to trade, the wealth gained from trade helps these economies invest money in generating renewable energy. These economies also supply renewable energy to the people at an affordable price. Hence, providing clean energy to the people for their consumption and production activities also increases government expenditure on clean energy subsidies (Gozgor et al., 2019). This evidence further implies that wealth gains from trade help these economies to mitigate the government spending on energy subsidies. As long as the government spending on clean energy subsidies increases, it becomes beneficial for these economies to have green growth and a sustainable natural environment (i.e., socio-economic and environmental welfare) in the long run (Kutan et al., 2018). Our paper demonstrates that promoting international trade potential can be essential for decreasing environmental degradation and providing sustainable and environment-friendly production and economic growth.

Moreover, income increases, energy prices and carbon emissions fuel the demand for renewable energy in the OECD countries. This evidence shows that these are the driving factors for increasing renewable energy. This issue is obvious because income increases enable people in these economies to access clean energy for consumption and production activities. Given the strong environmental regulatory framework, people in these economies prefer to demand renewable energy irrespective of the rising energy prices. Renewable energy investments can increase renewable energy consumption (Gu et al., 2021; Paramati et al., 2018). This evidence in our paper shows that energy prices increase renewable energy.

Finally, the threat of climate change due to rising carbon emissions encourages people to use renewable energy to protect the life-supporting natural environment. Therefore, governments in these economies need to pay attention to these driving factors to check rising pollution levels by promoting renewable energy usage (Paramati et al., 2017).

5. Conclusion

This paper used a new measure of trade openness, i.e., the international trade potential index, to measure the welfare gains from international trade across the OECD countries. This measure was based on the import shares of countries in the GDPs. The paper observed that gains from international trade are low in rich economies but larger in poorer economies. We then analysed the impact of international trade potential on renewable energy consumption in an unbalanced panel dataset of 36 OECD countries from 1966 to 2016. The novel evidence in this paper is that international trade potential promotes renewable energy consumption. It is also found that per capita income, per capita CO_2 emissions, and energy prices increase the demand for renewable energy.

It is important to note that our findings are limited to the OECD countries. At this stage, future papers should include other advanced and developing economies. Indeed, different energy and environmental indicators can be included in the empirical examinations to analyse whether international trade potential is a significant determinant. Another research agenda can be to analyse the effects of economic uncertainty on energy demand, following the procedures in Baum et al. (2021) and Erzurumlu and Gozgor (2022), including international trade potential measures.

CRediT authorship contribution statement

Zhou Lu: Writing – original draft, Project administration. **Giray Gozgor:** Writing – original draft, Conceptualization. **Mantu Kumar Mahalik:** Writing – original draft, Methodology. **Hemachandra Padhan:** Writing – original draft, Formal analysis. **Cheng Yan:** Writing – original draft, Visualization.

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Appendix A. Supplementary data

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