Determinants of renewable energy consumption: importance of democratic institutions

Chaoyi Chen[1] Mehmet Pinar[2] Thanasis Stengos[3]

Abstract

There has been an increase in the use of renewable energy sources over recent years, which has led to a strand of literature examining the determinants of renewable energy consumption. However, most of the research used linear estimation models while reviewing the determinants of renewable energy consumption and ignored the indirect effect of democratic institutions on renewable energy consumption. With the use of a panel threshold model, this paper demonstrates that democratic institutions play a significant role in renewable energy consumption. In countries in which the democratic rights of people are preserved better, higher economic growth leads to increased use of renewable energy consumption; however, there is a negative association between economic growth and renewable energy consumption in less democratic countries. Increased trade openness leads to lower growth rates of renewable energy consumption in less democratic countries, while increases in real oil prices lead to increased renewable energy consumption in less democratic countries but play no significant role in more democratic countries. The findings of this paper suggest that democratic institutions are vital in channelling economic resources (economic growth) to renewable energy, and increased trade openness is associated with lower rates of renewable energy deployment in less democratic countries.

JEL Classification: C24; O13; Q2; Q43

Keywords: Renewable energy consumption; CO2 emissions; Threshold; Non-linear effects; Democracy

This is the authors' accepted version of the paper. The final paper will be published in a forthcoming issue of *Renewable Energy*. The final published manuscript could be accessed via: Chen, C., Pinar, M., Stengos, T. (2021). Determinants of renewable energy consumption: Importance of democratic institutions. Renewable Energy, https://doi.org/10.1016/j.renene.2021.07.030

[1] Institute of MNB, Corvinus University of Budapest, Budapest, Hungary & Magyar Nemzeti Bank (Central Bank of Hungary), Hungary. Email: chenc@mnb.hu

[2] Corresponding author: Business School, Edge Hill University, Ormskirk, Lancashire, L39 4QP, UK, Email: mehmet.pinar@edgehill.ac.uk

[3] Department of Economics and Finance, University of Guelph, Guelph, Ontario, N1G 2W1, Canada; Email: tstengos@uoguelph.ca

1. Introduction

The increased concerns over climate change, global warming, and energy security have led to increased use of renewable energy resources over the last years. The International Energy Agency (2019) forecasts that the world's total renewable-based power capacity will grow by 50% between 2019 and 2024. Given the global importance of renewable energy consumption, there is an increasing need to examine the determinants of renewable energy consumption. There has been an extensive literature that examined the effect of renewable energy consumption on economic growth (see e.g., Apergis and Payne, 2010, 2012; Omri, 2013; Ozturk and Bilgili, 2015; Bhattacharya et al., 2016; Inglesi-Lotz, 2016; Koçak and Şarkgüneşi, 2017; Chen et al., 2020 among many others). However, there is also an increased stream of literature that examined the determinants of renewable energy consumption (e.g., Baye et al., 2021; Brini et al., 2017; Gozgor et al., 2020; Luqman et al., 2019; Nguyen and Kakinaka, 2019; Omri and Nguyen, 2014; Ponce et al., 2020; Sadorsky 2009a; Sadorsky 2009b; Salim and Rafiq, 2012; Pereira da Silva et al., 2018 among many others).

Most of the existing streams of literature examined the effect of trade openness, GDP per capita, real oil prices, and CO2 emissions on renewable energy consumption. However, beyond the standard determinants of renewable energy consumption (e.g., trade openness, GDP per capita, real oil prices, and CO2 emissions), the importance of institutional quality for renewable energy consumption has been identified (Brunnschweiler, 2010; Bellakhal et al., 2019; Bourcet, 2020). Bourcet (2020) carries out a systematic literature review on empirical determinants of renewable energy consumption and suggests that there is an extensive literature that incorporated institutional quality measures in their estimations to measure the direct effect of institutional quality on renewable energy deployment (see e.g., Bayulgen and Ladewig, 2017; Cadoret and Padovano, 2016; Carley et al., 2017; Pfeiffer and Mulder, 2013; Uzar, 2020a, 2020b). In this paper, we argue that institutional quality not only affects renewable energy consumption directly but also has an indirect effect on renewable energy consumption through its effect on other factors. For instance, Ren et al. (2021) demonstrated that corruption (a measure of institutional quality) increases the per capita carbon emissions in Chinese provinces. In other words, institutional quality may have an indirect effect on renewable energy consumption through its impact on other determinants. On the other hand, Pfeiffer and Mulder (2013) demonstrated that renewable energy technology diffusion in developing countries increases in more democratic regimes. Furthermore, in countries in which there is no democratic pressure, governments may be less concerned with environmental pollution and do not impose strict environmental regulations (Mukherjee and Chakraborty, 2013). In this context, Abban and Hasan (2021) examine the role of other political factors such as the government's ideology and demonstrated that the left and central-leaning governments promote more renewable energy compared to right-wing governments. Similarly, Fankhauser et al. (2015) examined the determinants of the number of climate change legislation. They found that democratic countries tend to pass more climate change legislation compared to the non-democratic ones. It also has been demonstrated that the NGOs and civil society organizations are also key in achieving sustainable development goals (Fransen, 2013), and the engagement of such organizations could be more effective in societies in which democratic rights are preserved (Fredriksson et al., 2005). Henceforth, we expect that the effect of the economic factors on the use of renewable energy consumption to be varying based on the quality of democratic institutions.

To the best of our knowledge, only a handful of papers examined the potential non-linear or heterogenous effects of renewable energy consumption determinants on renewable energy consumption by analysing different samples. For instance, Wang and Zhang (2021) examine the effect of free trade on renewable energy consumption by carrying out analysis for three samples of countries (i.e., high, upper-middle and lower-middle-income country samples). Similarly, Ali et al. (2020) demonstrate that the effect of financial development and renewable energy consumption on economic growth is different in countries that are politically free, partly free and not free. In a related paper, Bamati and Raoofi (2020) also argue that different factors (e.g., CO2 emissions, oil prices and GDP per capita) have a differing effect on renewable energy consumption depending on the development level by obtaining results in two samples (i.e., developed and developing countries). Finally, Shahzad et al. (2021) also examine determinants of renewable energy consumption for the group of 7 (G-7) and emerging seven (E-7) separately. All the above-mentioned papers examine the varying effects of independent variables on the dependent variable; however, their classification of samples was exogenously determined by the authors. In this paper, on the other hand, we will examine the heterogeneous effects of the renewable energy consumption determinants with the use of the dynamic threshold panel model identifying these heterogeneous effects endogenously.

Most of the existing literature that examined the determinants of the renewable energy consumption used linear estimation methods such as fully modified ordinary least square and dynamic ordinary least square (e.g., Sadorsky, 2009a, 2009b; Salim and Rafiq, 2012), panel autoregressive distributed lag (e.g., Pereira da Silva et al., 2018), panel cointegration tests (e.g., Bhattacharya et al., 2016; Koçak and Şarkgüneşi, 2017 and dynamic system GMM (e.g., Omri and Nguyen, 2014). A handful of papers in the literature employed specific methods to capture the potential non-linear and heterogeneous effects. Two methods that examine the non-linear effect of variables are the non-linear autoregressive distributed lag approach (ARDL) developed by Shin et al. (2014) (see e.g., Tugcu and Topcu (2018) and Qamruzzaman and Jianguo (2020) for the use of non-linear ARDL method) and quantile regression analysis (see e.g., Asongu and Odhiambo, 2021). Even though these methods examine the non-linear effects of independent variables on the dependent variable, the chosen non-linear effects are also pre-determined exogenously. For instance, non-linear ARDL examines the impact of independent variables through positive and negative shocks, and the effect of independent variables is examined in pre-determined (specific) quartiles in quantile regression analysis. On the other hand, Chang et al. (2009) used the panel threshold regression method proposed by Hansen (1999) and found that countries characterized by high economic growth can respond to high energy prices with increases in renewable energy consumption. Similarly, Raza et al. (2020) employ the generalized panel threshold regression model of Hansen (2000) to examine the non-linear effect of financial development on renewable energy consumption. However, Hansen's (1999) method used by Chang et al. (2009) was developed for a static panel threshold model where regression coefficients can take on a small number of different values. Furthermore, Hansen's (2000) method used by Raza et al. (2020) assumes exogeneous slope regressors and threshold variable. In this paper, we utilize the dynamic threshold panel model of Seo and Shin (2016), which allows the endogeneity in both regressors and threshold variables. The other threshold models (Caner and Hansen, 2004; Kremer et al., 2013; Kourtellos et al., 2016) either rely on an exogenous threshold variable or are not applicable in the context of a dynamic panel model. This paper examines the potential non-linear relationship between determinants of renewable energy and renewable energy consumption when democratic institutions are used as a threshold variable.

Our study contributes to the literature in a couple of ways. Firstly, most of the existing literature uses linear estimation methods to examine the determinants of renewable energy and ignores the potential non-linear effects. Furthermore, the existing literature examined the direct effect of institutions on renewable energy deployment and ignored the indirect effect of institutions on renewable energy consumption through its effect on other factors. To our knowledge, this paper contributes to the literature by examining the varying effects of determinants based on the quality of democratic institutions. Secondly, most of the existing literature carried out unit root tests that assume cross-sectional independence. However, it is almost certain that the macro-level data violates the cross-sectional independence assumption (Pesaran, 2015). Therefore, we use recently developed panel data methods to take into account the cross-sectional dependence, which is deemed to improve the power and size of the tests. Finally, to avoid the potential effect of sample selection bias, the empirical analysis considers a different set of samples.

The rest of the paper is organized as follows. Section 2 provides a detailed literature review based on the previous literature examining the determinants of renewable energy. Section 3 develops the empirical model and offers the estimation procedure adopted. Section 4 offers the data set. Section 5 provides the empirical results, and finally, section 6 concludes and offers some policy implications.

2. Literature review

There is a large stream of literature that highlights the importance of economic growth in the use of renewable energy. One strand of literature found a positive association between renewable energy consumption and economic growth (see e.g., Sadorsky, 2009a for G7 countries; Sadorsky, 2009b for emerging countries; Salim and Rafiq (2012) for Brazil, China, India, Indonesia, Philippines, and Turkey; Chang et al. (2015) for France and the UK; Omri et al. (2015) for Argentina, Belgium, Bulgaria, Canada, France, Pakistan, Spain, Switzerland, and the USA; Kahia et al. (2017) for 11 MENA countries; Rafindadi and Ozturk (2017) for Germany; Koçak and Şarkgüneşi (2017) for Albania, Georgia, and Romania; Pereira da Silva et al. (2018) for the sub-Saharan African countries, among many others). On the other hand, another stream of literature found a negative association between renewable energy consumption and economic growth (e.g., Bhattacharya et al., 2016; Marques and Fuinhas, 2012; Ocal and Aslan, 2013). The latter stream of literature (i.e., literature that found a negative association between renewable energy consumption and economic growth) suggests that the high costs of renewable energy deployment are probably being placed excessively upon the economy, which then leads to a deceleration in economic activity due to increased costs. For instance, Bhattacharya et al. (2016) found that the increased renewable energy consumption led to a decrease in output growth in India, Ukraine, the US, and Israel suggesting that these countries may continue to use non-renewable energy sources for the future growth process. In other words, the findings of the latter stream of the literature suggest that the increased economic growth could lead to lower use of renewable energy consumption.

Historical increases in greenhouse gas (GHG) emissions have resulted from the provision of energy services (see e.g., Agliardi et al., 2017) and the Intergovernmental Panel on Climate Change (IPCC) report on renewable energy stressed the importance of renewable energy consumption in mitigating the effects of climate change (Edenhofer et al., 2011). The increased importance of reducing CO2 emissions to combat global climate change encourages countries to use more renewable energies and promote environmental protection. Henceforth, previous studies in examining the determinants of renewable energy also included CO2 emissions as part of the explanatory variables. For instance, Sadorsky (2009a) and (2009b) found that increases in CO2 emissions per capita are found to be a major driver behind per capita renewable energy consumption in G7 countries and emerging economies. Salim and Rafiq (2012) showed that the pollutant emissions were major drivers of renewable energy consumption in Brazil, China, India, and Indonesia. Omri and Nguyen (2014) also found that the increases in CO2 emissions were the main driver of renewable energy consumption irrespective of their sample classification. On the other hand, Apergis and Payne (2014) also found a positive association between CO2 emissions and renewable energy consumption when examined the relationship for the Central American countries. Mac Domhnaill and Ryan (2020) also demonstrated that higher levels of greenhouse gas emissions promoted renewable energy in electricity production in the European Union during the period 2000-2015. Finally, Nguyen and Kakinaka (2019) found a varying relationship between renewable consumption and CO_2 emissions. Their findings suggest that renewable energy was positively associated with emissions in low-income countries, while the relationship between renewable energy consumption and emissions are negative in high-income countries.

Oil is considered to be the most likely substitute for renewable energy for most of the countries, and oil prices should be included in the model as a substitute for renewable energy consumption. It is expected that oil prices and demand for renewable energy to have a positive relationship. The increase in oil prices should lower the demand for oil, and countries are more likely to switch to more efficient (or less costly) options such as renewable energy. Even though the theoretical expectation is that oil prices and the renewable energy consumption is positively associated, both Sadorsky (2009a) and Omri and Nguyen (2014) found a small but negative relationship between oil prices and renewable energy consumption for G-7 and 64 countries, respectively. On the other hand, Brini et al. (2017) and Luqman et al. (2019) found that no significant relationship between oil prices and renewable energy consumption for Tunisia and Pakistan, respectively. On the other hand, Apergis and Payne (2014) showed that oil prices increase renewable energy consumption in Central American countries. Khan et al. (2017) examined the effect of the oil price drop in 2014 on renewable energy consumption and found no significant effect.

The previous literature argues that trade openness is a good proxy to measure the level of countries' engagement with other countries through the movement of goods and services, which would also enable countries to access renewable energy technologies and consequently use more renewable energy. The earlier stream of literature examined the relationship between trade openness and energy consumption (see e.g., Narayan and Smyth, 2009; Lean and Smyth, 2010a, 2010b; Sadorsky, 2011, 2012), while a new set of papers also highlighted the importance of trade openness for the use of renewable energy (Omri and Nguyen, 2014; Brini et al., 2017). Using a large panel data set, both Omri and Nguyen (2014) and Ben Jebli and Ben Youssef (2015) found that changes in trade openness have a statistically significant effect on renewable energy consumption except for high-income countries. Brini et al. (2017) also found that increased trade promoted renewable energy use in Tunisia. Similarly, Zeren and Akkuş (2020) also found that trade openness is a positive and significant determinant for renewable energy consumption for "Top Emerging Countries of Bloomberg" in the 1980–2015 period (see also Vural (2021) that found a positive effect of trade openness on renewable energy production in selected Latin American countries). However, trade openness could also lead to higher environmental degradation (see e.g., Le et al., 2016). Since democratic countries have a more substantial environmental commitment (Neumayer, 2002), and are more likely to pass climate change legislation (Fankhauser et al., 2015) compared to less democratic countries, the effect of trade openness on renewable energy may be different based on their institutional quality. For instance, a less democratic nation with less strict environmental policies (Fankhauser et al., 2015) may become a "pollution haven" for intensive economic production. In other words, trade openness of countries (i.e., total imports and exports as a percentage of GDP) may be increased through foreign direct investment, and the foreign direct investment flows to these countries may have increased due to their less strict environmental policies. Therefore, trade openness may have either a positive or negative effect on renewable energy consumption.

3. Threshold estimation model

Following the literature on the determinants of renewable energy consumption, we have the following form:

$$REC = f(CO_2, ROP, Y, TO) \tag{1}$$

where REC is renewable energy consumption, CO_2 is CO_2 emissions per capita, ROP is the real oil price, Y is the GDP per capita, and TO is the trade openness measured as total exports and imports as a percentage of GDP.

Let $\Delta\ln(.)$ denote the first difference of the logarithm representing the growth of the variables. Hence, the dynamic panel regression model (DPRM) of equation (1) in growth form can be written as

$$\Delta ln\left(REC_{i,t}\right) = \alpha\ \Delta\ln\left(REC_{i,t-1}\right) + \beta^T X_{i,t} + \mu_i + e_{i,t} \tag{2}$$

where subscripts $i = 1, \dots, N$ represents the country, $t = 1, \dots, T$ indexed the time, $X_{i,t} = \left[\Delta\ln\left(CO_{2_{i,t}}\right), \Delta\ln\left(ROP_{i,t}\right), \Delta\ln\left(Y_{i,t}\right), \Delta\ln\left(TO_{i,t}\right)\right]^T$, μ_i is the country fixed effects, and $e_{i,t}$ is the idiosyncratic error term.

Next, to examine the potential nonlinear impact of the set of explanatory variables on the renewable energy growth rate, we can extend equation (2) to a sample split form, where the group is determined by the value of a threshold variable. The dynamic panel threshold regression model (DPTRM) can be expressed as follows:

$$\Delta ln\left(REC_{i,t}\right) = \alpha_1\ \Delta\ln\left(REC_{i,t-1}\right) + \beta_1^T X_{i,t} + \mu_i + e_{i,t}, \quad q_{i,t} \le \gamma_0 \tag{3}$$

$$\Delta ln\left(REC_{i,t}\right) = \alpha_2\ \Delta\ln\left(REC_{i,t-1}\right) + \beta_2^T X_{i,t} + \mu_i + e_{i,t}, \quad q_{i,t} > \gamma_0 \tag{4}$$

where $q_{i,t}$ is the threshold variable, which is the quality of democratic institutions in this study, and γ_0 is the threshold level.

The compact form of the DPTRM is given as:

$$\Delta ln\left(RE_{i,t}\right) = \beta^T \Omega_{\mathrm{i,t}} + \delta^T \Omega_{i,t}\, I(q_{i,t} \le \gamma_0) + \mu_i + e_{i,t} \tag{5}$$

where $\Omega_{i,t} = \left[\Delta\ln\left(RE_{i,t-1}\right),\ X_{i,t}^T\right]^T$, $I(.)$ is the indicator function and $\delta = \beta_1 - \beta_2$ measures the level of the threshold effect. Note that, if $\delta = 0$, DPTRM reduces to DPRM.

To incorporate the endogeneity of the regressors originating from the bidirectional causalities, we use the first-difference GMM (FD-GMM) approach to estimate both equation

(2) and equation (5). This method was first proposed by Arellano and Bond (1991) for the DPRM and recently extended to the DPTRM by Seo and Shin (2016). Our set of instruments includes all the available lags in the difference of the endogenous variables up to five periods before the period t.

Finally, we employ a sup-Wald test proposed by Seo and Shin (2016) to test the presence of a threshold effect. As suggested by Seo and Shin (2016), following Hansen (1996), we use a bootstrapping approach to generate critical values.

4. Data

To investigate the potential differing effects of GDP per capita, real oil price, trade openness, and CO2 emissions on renewable energy consumption, we collected data for 97 countries covering the period between 1995 and 2015. We use a democracy score from the Polity IV (Marshall et al., 2016) as a proxy for democratic institutions for our threshold variable. The democracy variable ranges between -10 and +10, and lower (higher) values represent more autocratic (democratic) institutions. GDP per capita (constant 2010 US$), trade openness (measured as exports plus imports as a percentage of GDP) are taken from the World Development Indicators of the World Bank (World Bank, 2020). The renewable energy consumption (measured in millions of kilowatt-hours) and CO2 emissions per capita (measured in metric tons) are obtained from the U.S. Energy Information Administration (International Energy Outlook, 2019). Finally, we obtained oil prices (measured using the spot price on West Texas Intermediate crude oil) from the British Petroleum Statistical Review of World Energy (British Petroleum, 2019), which is deflated with the consumer price index (CPI) from the World Development Indicators and measured in 2010 constant prices.

Table 1 provides descriptive statistics for the whole sample, developing- and developed-country samples[1]. On average, developed countries consume more renewable energy, have higher GDP per capita, and have better democratic institutions compared to developing countries. On the other hand, on average, CO2 emissions per capita are relatively higher in developed countries compared to the developing countries. Even though real oil prices show variation across countries, on average, they are higher for developing countries compared to the developed countries.

<Insert Table 1 approximately here>

5. Results

We will examine the long-run relationship between renewable energy and respective determinants (i.e., CO2 emissions, real oil prices, trade openness, and GDP per capita) when we use the democracy variable as a threshold variable with the use of threshold variable estimation methods proposed in the methodology section. However, before the regression analysis (both linear and threshold estimation methods), we first check whether there is any cross-sectional dependence of the variables used. If such dependence exists, we will utilize unit root tests to account for such dependence. Furthermore, we will use second-generation panel unit root tests to examine the long-run equilibrium relationship among variables. Panel unit root tests would enable us to determine whether to use the levels or the first differences (growth) of the variables. Finally, after carrying out the panel unit root tests, we will provide the results obtained with linear and threshold GMM estimations.

5.1. Cross-sectional dependence tests

[1] Developed countries are chosen based on the high-income country classification of the World Bank (see Table A1 for the list of developed and developing countries).

The first generation of panel unit root tests that are based on the cross-sectional independence assumption (see e.g., Maddala and Wu, 1999; Choi, 2001; Levin et al., 2002; Im et al., 2003) and therefore these tests suffer from size distortions and the ignorance of cross-section dependence (Pesaran, 2015). The previous literature examining the determinants of renewable energy consumption mostly used the first generation of panel unit root tests (see e.g., Apergis and Payne, 2014; Omri and Nguyen, 2015), henceforth suffer from size distortions. More recent papers started to take into account the cross-section dependence (see e.g., Osman et al., 2016; Belaïd and Zrelli, 2019). Therefore, before proceeding, we first examine the presence of cross-sectional dependence by using the cross-section dependence test of Pesaran (2004). Table 2 presents the results for the cross-section dependence test of Pesaran (2004). For all the variables considered (i.e., ln(REC), ln(GDP per capita), ln (CO2 per capita), ln(Oil) and ln(Trade)), the results suggest that the null hypothesis of cross-sectional independence is strongly rejected at the 1% significance level for three sets of samples (i.e., all, developing and developed countries). As such, we find that all of the variables are cross-sectionally correlated irrespective of the sample of countries used.

<Insert Table 2 approximately here>

To account for the presence of cross-sectional dependence in the variables, the cross-sectionally augmented Im-Pesaran-Shin (CIPS) unit root test proposed by Pesaran (2007) is used, and Table 3 presents the CIPS unit root test results. When we use the levels of the variables, we fail to reject the null hypothesis of the unit root at the 10% significance level for all samples used. However, when the first-order differences of variables are used, the null hypothesis of non-stationarity is rejected at the 1% significance level for all of the variables irrespective of the sample used. Hence, based on the results, we find that the variables are stationary in first differences and will use the first differences of variables in the GMM estimation methods in the next subsection.

<Insert Table 3 approximately here>

5.2. Results with linear GMM and threshold estimation methods

We use (2) and (5) to estimate the long-run linear and non-linear relationship between renewable energy and its determinants, respectively. Table 4 provides the results from the linear specifications where estimates are obtained by using the dynamic panel regression model (DPRM). Before presenting our results, we should highlight that we carried out the panel autocorrelation test for AR1 disturbances from Wooldridge (2002) where the p-values for the of the AR(1) test suggest that the dynamic model does not suffer from serial correlation as we fail to reject the null hypothesis of no serial correlation. Our findings suggest that the previous growth rate of renewable energy is negatively associated with the current growth rate suggesting that the overall growth of renewable energy consumption declined overtime for all the samples. Higher economic growth rates are negatively related to the growth of renewable energy consumption in the whole sample, but this relationship is positive for the developed country sample suggesting that countries with high economic growth tend to increase renewable energy consumption relatively more. The findings for the developed country sample are in line with the conclusions from Sadorsky (2009a), Chang et al. (2015), Omri et al. (2015), Rafindadi and Ozturk (2017) where a similar relationship is obtained for most of the developed countries. On the other hand, countries with relatively higher economic growth in less democratic countries experience relatively lower growth rates in renewable energy consumption, suggesting that the increase in energy consumption in these countries was mainly from non-renewable energy sources. For instance, Kahia et al. (2016) found a negative bidirectional relationship between renewable and non-renewable energy consumption, suggesting that these two energy sources are working as substitutes.

This finding is in line with the literature that found a positive association between non-renewable energy consumption and economic growth (see e.g., Destek and Aslan, 2017; Dogan, 2016). Similarly, finding a negative association between renewable energy consumption and economic growth for some countries, Bhattacharya et al. (2016) suggested that these countries may continue to use non-renewable energy sources for future growth process rather than deployment of renewable energy. Furthermore, we find that the increases in CO2 emissions per capita lead to increased use of renewable energy consumption irrespective of the sample used, which agrees with the findings of Sadorsky (2009a, 2009b), Salim and Rafiq (2012), and Omri and Nguyen (2014). Similarly, the growth of oil prices and the growth of renewable energy consumption were positively associated, a finding that is in agreement with the theoretical expectations and results of Apergis and Payne (2014). Finally, the linear estimations highlight a differing effect of increased trade openness for developing and developed country samples where increased trade openness lowered the growth of renewable energy consumption in developing countries but increased the growth of renewable energy consumption in developed countries.

<Insert Table 4 approximately here>

However, the effect of renewable energy growth determinants may be different based on the quality of democratic institutions. Therefore, we test for potential non-linearity between renewable energy growth and its determinants by using the non-linear estimation specification in (5) where the democracy variable is used as a threshold variable. The modified Wald statistic proposed by Seo and Shin (2016) is used to test for the standard inference on the threshold variable and Table 5 presents the findings. The Wald statistic for the non-linear model specification is found to be 16.3838 and 32.2770 for the whole country and developing country samples, respectively, suggesting that we reject the null hypothesis of a linear model at the 10% and 1% significance levels when the whole and developing-country samples are used, respectively. For the developed countries, we fail to reject the null hypothesis of the linear model, suggesting that the findings in Table 4 for developed countries hold and the results for the developed countries are not reported.

<Insert Table 5 approximately here>

The findings with the threshold model suggest that economic growth positively and significantly increases renewable energy consumption in more democratic countries at the 1% level. Yet, economic growth decreases the growth of renewable energy consumption in non-democratic countries. In other words, the negative relationship between economic growth and renewable energy growth with the linear model could be misleading and democratic institutions in developing countries play an important role in renewable energy deployment. This finding could be due to the fact that democratic countries allocate more resources towards cleaner production. Furthermore, less democratic countries may have less of a concern or less restrictive environmental policies (Mukherjee and Chakraborty, 2013), and economic growth leads to relatively lower rates of renewable energy consumption growth. Furthermore, a higher number of climate change legislation in democratic countries compared to the non-democratic countries (Fankhauser et al., 2015) may lead to production schemes that rely more on renewable energy resources and that higher economic growth leads to more renewable energy consumption in democratic countries compared to less democratic ones. We also find that the coefficient on CO2 emissions per capita growth is larger in absolute terms for democratic countries compared to less democratic ones (high vs. low regime results). In other words, the growth of CO2 emissions leads to more renewable energy consumption in democratic countries compared to less democratic countries, since climate change concerns are taken into account more seriously by the former compared to the latter. On the other hand, we find that change in real oil prices is positively associated with the renewable energy consumption in both samples for less democratic countries suggesting that oil prices play a significant role in the shift towards renewable energy consumption, but this effect is not significant for the democratic group of countries.

Even though the previous literature that examined the relationship between trade openness and renewable energy consumption found a positive association between two variables (see e.g., Omri and Nguyen, 2014; Ben Jebli and Ben Youssef, 2015; Brini et al., 2017), we find that the trade openness is negatively associated with renewable energy consumption in both the overall and developing country samples for less democratic countries. One plausible explanation for this could be the pollution haven hypothesis. There has been significant evidence that foreign direct investment (FDI) and trade openness are positively related (see e.g., Aizenman and Noy, 2006; Biglaiser and de Rouen, 2006; Liargovas and Skandalis, 2012). Furthermore, countries with lack of strict environmental regulations and lower abatement costs (e.g., lower investment or use of renewable energy sources due to its higher cost) were found to be attracting more FDI flows (see e.g., Cole and Elliott, 2005; Kellenberg, 2009; Wagner and Timmins, 2009; Tang, 2015). Given that less democratic countries have less strict environmental regulations (Fankhauser et al., 2015), trade openness could have attracted more FDI and decreased deployment of renewable energy investment in less democratic countries. For instance, in a recent paper, Khan et al. (2021) found that FDI is negatively associated with renewable energy consumption for 69 countries of the Belt and Road Initiative. On the other hand, for developed countries, the findings are in the lines with the previous literature (see Table 4) where increased trade openness promotes higher growth of renewable energy consumption (e.g., Omri and Nguyen, 2014; Ben Jebli and Ben Youssef, 2015).

6. Conclusion and policy implications

There has been increasing attention to understand the determinants of renewable energy consumption over the last decade. This paper provides a theoretical discussion on how the effect of the determinants of renewable energy could vary based on the quality of democratic institutions. We then use a dynamic panel threshold model to estimate the impact of CO_2 emissions, economic growth, trade openness and real oil price on renewable energy consumption based on the democracy threshold. Our empirical analysis highlights the importance of democratic institutions in promoting renewable energy consumption.

Our main findings suggest that i) economic growth leads to higher growth of renewable energy growth in democratic countries, but it is negatively associated with renewable energy growth in less democratic countries; ii) increases in CO_2 emissions have a larger significant impact on renewable energy consumption in more democratic countries compared to less democratic ones; iii) change in oil prices leads to higher renewable energy consumption in less democratic countries, but its effect on renewable energy is not significant in more democratic countries, iv) change in trade openness is negatively associated with the growth of renewable energy consumption in less democratic countries, but the relationship is insignificant in democratic countries, and the relationship is significant and positive for the developed country sample.

The recent literature highlighted the importance of institutional quality in renewable energy deployment (Brunnschweiler, 2010; Bellakhal et al., 2019; Bourcet, 2020). Our results provide channels through which democratic institutions are essential in promoting renewable energy consumption. Increased quality of democratic institutions would lead to more resource allocation to renewable energy use (i.e., economic growth) and promote more regulations in combating environmental pollution (Fredriksson et al., 2005). On the other hand, we find that oil prices have a significant and positive impact on renewable energy consumption in less democratic countries. Therefore, an increase in oil prices (e.g., through a higher tax on oil) would be a useful tool for promoting the growth of renewable energy consumption in less democratic countries. Finally, our findings suggest that the trade openness is positively associated with the growth of renewable energy consumption for developed countries. Therefore, policies that promote more trade in developed countries could help these countries to diffuse the adoption of production technologies using renewable energy.

<Insert Table A1 approximately here>

Acknowledgments. Mehmet Pinar gratefully acknowledges the financial support from the Research Investment Fund of Edge Hill University. Thanasis Stengos acknowledges the financial support by the Social Sciences and Humanities Research Council of Canada (grant number: 4301). The views expressed here are the authors' and not necessarily those of the Magyar Nemzeti Bank (Central Bank of Hungary).

References

Abban, A.R., Hasan, M.Z. (2021). Revisiting the determinants of renewable energy investment - New evidence from political and government ideology. *Energy Policy*, 151, 112184.

Agliardi, E., Pinar, M., Stengos, T. (2017). Air and water pollution over time and industries with stochastic dominance. *Stochastic Environmental Research and Risk Assessment*, 31, 1389-1408.

Aizenman, J., Noy, I. (2006). FDI and trade—Two-way linkages? *The Quarterly Review of Economic s and Finance*, 46(3), 317-337.

Ali, Q., Raza, A., Narjis, S., Saeed, S., Khan, M.T.I. (2020). Potential of renewable energy, agriculture, and financial sector for the economic growth: Evidence from politically free, partly free and not free countries. *Renewable Energy*, 162, 934-947.

Apergis, N., Payne, J.E. (2010). Renewable energy consumption and economic growth: Evidence from a panel of OECD countries, *Energy Policy*, 38, 656-660.

Apergis, N., Payne, J.E. (2012). Renewable and non-renewable energy consumption-growth nexus: Evidence from a panel error correction model, *Energy Economics*, 32, 733-738.

Apergis, N., Payne, J.E. (2014). Renewable energy, output, CO2 emissions, and fossil fuel prices in Central America: Evidence from a nonlinear panel smooth transition vector error correction model. *Energy Economics*, 42, 226-232.

Arellano, M., Bond, S. (1991). Some tests of specification for panel data: Monte Carlo evidence and an application to employment equations. *Review of Economic Studies*, 58(2), 277-297.

Asongu, S.A., Odhiambo, N.M. (2021). Inequality, finance and renewable energy consumption in Sub-Saharan Africa. *Renewable Energy*, 165, 678-688.

Bamati, N., Raoofi, A. (2020). Development level and the impact of technological factor on renewable energy production. *Renewable Energy*, 151, 946-955.

Baye, R.S., Olper, A., Ahenkan, A., Musah-Surugu, I.J., Anuga, S.W., Darkwah, S. (2021). Renewable energy consumption in Africa: Evidence from a bias corrected dynamic panel. *Science of the Total Environment*, 766, 142583.

Bayulgen, O., Ladewig, J.W. (2017). Vetoing the future: political constraints and renewable energy. *Environmental Politics*, 26(1), 49-70.

Belaïd, F., Zrelli, M.H., 2019. Renewable and non-renewable electricity consumption, environmental degradation and economic development: evidence from Mediterranean countries. *Energy Policy*, 133, 110929.

Bellakhal, R., Ben Kheder, S., Haffoudhi, H. (2019). Governance and renewable energy investment in MENA countries: How does trade matter? *Energy Economics*, 84, 104541.

Ben Jebli, M., Ben Youssef, S. (2015). Output, renewable and non-renewable energy consumption and international trade: Evidence from a panel of 69 countries. *Renewable Energy*, 83, 799-808.

Bhattacharya, M., Paramati, S.R., Ozturk, I., Bhattacharya, S., 2016, The effect of renewable energy consumption on economic growth: evidence from top 38 countries, *Applied Energy*, 162, 733-741.

Biglaiser, G., & De Rouen, K. (2006). Economic reforms and inflows of foreign direct investment in Latin America. *Latin American Research Review*, *41*(1), 51-75.

Bourcet, C. (2020). Empirical determinants of renewable energy deployment: A systematic literature review. *Energy Economics,* 85, 104563.

British Petroleum (2019). BP Statistical Review of World Energy (2019). Available via: https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html

Brini, R., Amara, M., Jemmali, H. (2017). Renewable energy consumption, International trade, oil price and economic growth inter-linkages: The case of Tunisia. *Renewable and Sustainable Energy Reviews*, 76, 620-627.

Brunnschweiler, C.N. (2010). Finance for renewable energy: an empirical analysis of developing and transition economies. *Environment and Development Economics*, 15(3), 241-274.

Cadoret, I., Padovano, F. (2016). The political drivers of renewable energies policies. *Energy Economics*, 56 261-269.

Caner, M., Hansen, B. (2004). Instrumental variable estimation of a threshold model. *Econometric Theory*, 20, 813-843.

Carley, S., Baldwin, E., MacLean, L.M. Brass, J.N. (2017). Global expansion of renewable energy generation: an analysis of policy instruments. *Environmental and Resource Economics*, 68(2), 397-440

Chang, T.H., Huang, C.M., Lee, M.C., 2009. Threshold effect of the economic growth rate on the renewable energy development from a change in energy price: evidence from OECD countries. *Energy Policy*, 37(12), 5796-5802.

Chang, T., Gupta, R., Inglesi-Lotz, R., Simo-Kengne, B., Smithers, D., Trembling, A. (2015). Renewable energy and growth: evidence from heterogeneous panel of G7 countries using Granger causality. *Renewable and Sustainable Energy Reviews*, 52, 1405–1412.

Chen, C., Pinar, M., Stengos, T. (2020). Renewable energy consumption and economic growth nexus: Evidence from a threshold model. *Energy Policy*, 139, 111295.

Choi, I., 2001. Unit root tests for panel data. *Journal of International Money and Finance*, 20(2), 249-272.

Cole M.A., Elliott, R.J.R. (2005) FDI and the capital intensity of "dirty" sectors: a missing piece of the pollution haven puzzle. *Review of Development Economics*, 9(4), 530-548.

Destek, M.A., Aslan, A. (2017). Renewable and non-renewable energy consumption and economic growth in emerging economies: Evidence from bootstrap panel causality. *Renewable Energy*, 111, 757-763.

Dogan, E. (2016). Analyzing the linkage between renewable and non-renewable energy consumption and economic growth by considering structural break in time-series data. *Renewable Energy*, 99, 1126-1136.

Edenhofer, O., Pichs-Madruga, R., Sokona, Y., Seyboth, K., Matschoss, P., Kadner, S., Zwickel, T., Eickemeier, P., Hansen, G., Schlmer, S., von Stechow, C. (2011). IPCC

Special Report on Renewable Energy Sources and Climate Change Mitigation. Cambridge University Press, Cambridge, United Kingdom; New York, NY, USA.

Fankhauser, S., Gennaioli, C., Collins, M. (2015). The political economy of passingclimate change legislation: evidence from a survey. *Global Environmental Change*, 35, 52-61.

Fransen, L. (2013). The Embeddedness of Responsible Business Practice: Exploring the Interaction Between National-Institutional Environments and Corporate Social Responsibility. *Journal of Business Ethics*, 115, 213-227.

Fredriksson, P.G., Neumayer, E., Damania, R., Gates, S. (2005). Environmentalism, democracy, and pollution control. *Journal of Environmental Economics and Management*, 49(2), 343-365.

Gozgor, G., Mahalik, M.K., Demir, E., Padhan, H. (2020). The impact of economic globalization on renewable energy in the OECD countries. *Energy Policy*, 139, 111365.

Hansen, B.E. (1996). Inference when a nuisance parameter is not identified under the null hypothesis. *Econometrica* 64, 413-430.

Hansen, B.E. (1999). Threshold effects in non-dynamic panels: estimation, testing, and inference. *Journal of Econometrics*, 93, 345-368.

Hansen, B.E., 2000. Sample splitting and threshold estimation. *Econometrica*, 68, 575-603.

Im, K.S., Pesaran, M.H., Shin, Y., 2003. Testing for unit roots in heterogeneous panels. *Journal of Econometrics*, 115(1), 53-74.

Inglesi-Lotz, R., 2016, The impact of renewable energy consumption to economic growth: A panel data application, *Energy Economics*, 53, 58-63.

International Energy Agency, 2019. Renewables 2019. Available via: https://www.iea.org/reports/renewables-2019

International Energy Outlook, 2019. U.S. Energy information administration. Washington, DC: U.S. Department of Energy.

Kahia, M., Ben Aïssa, M.S., Charfeddine, L. (2016). Impact of renewable and non-renewable energy consumption on economic growth: New evidence from the MENA Net Oil Exporting Countries (NOECs). *Energy*, 116(1), 102-115.

Kahia, M., Aïssa, M.S.B., Lanouar, C., 2017. Renewable and non-renewable energy use economic growth nexus: the case of MENA Net Oil Importing Countries. *Renewable and Sustainable Energy Reviews*, 71, 127-140.

Kellenberg, D.K. (2009). An empirical investigation of the pollution haven effect with strategic environment and trade policy. *Journal of International Economics*, 78(2), 242-255.

Khan, A., Chenggang, Y., Hussain, J., Kui, Z. (2021). Impact of technological innovation, financial development and foreign direct investment on renewable energy, non-renewable energy and the environment in belt & Road Initiative countries. *Renewable Energy*, 171, 479-491.

Khan, M.I., Yasmeen, T., Shakoor, A., Kahn, N.B., Muhammed, R. (2017). 2014 oil plunge: Causes and impacts on renewable energy. *Renewable and Sustainable Energy Reviews*, 68(1), 609-622.

Koçak, E., Şarkgüneşi, A. (2017). The renewable energy and economic growth nexus in Black Sea and Balkan countries, *Energy Policy*, 100, 51-57.

Kourtellos, A., Stengos, T., Ming, T.C. (2016). Structural threshold regression. *Econometric Theory*, 32(4), 827-860.

Kremer, S., Bick, A., Nautz, D. (2013). Inflation and growth: new evidence from a dynamic panel threshold analysis. *Empirical Economics*, 44(2), 861-878.

Mac Domhnaill, C., & Ryan, L. (2020). Towards renewable electricity in Europe: Revisiting the determinants of renewable electricity in the European Union. *Renewable Energy, 154,* 955-965.

Marshall, M.G., Gurr, T.R., and Jaggers, K. (2016). Polity IV project: Political regime characteristics and transitions 1800-2015. Center for Systemic Peace.

Mukherjee, S., Chakraborty, D., 2013. Is environmental sustainability influenced by socioeconomic and sociopolitical factors? Cross-country empirical analysis. *Sustainable Development*, 21(6), 353-371.

Le, T.-H., Chang, Y., Park, D. (2016). Trade openness and environmental quality: International evidence. *Energy Policy*, 92, 45-55.

Lean H.H., Smyth R., 2010a. CO2 emissions, electricity consumption and output in ASEAN. *Applied Energy*, 87(6), 1858-1864.

Lean, H.H., Smyth, R. 2010b. Multivariate Granger causality between electricity generation, exports and GDP in Malaysia. *Energy*, 35(9), 3640-3648.

Levin, A., Lin, C.F., Chu, C.S.J., 2002. Unit root tests in panel data: asymptotic and finite sample properties. *Journal of Econometrics*, 108(1), 1-24.

Liargovas, P.G., Skandalis, K. (2012). Foreign Direct Investment and Trade Openness: The Case of Developing Economies. *Social Indicators Research*, 106, 323-331.

Luqman, M., Ahmad, N., Bakhsh, K. (2019). Nuclear energy, renewable energy and economic growth in Pakistan: Evidence from non-linear autoregressive distributed lag model. *Renewable energy*, 139, 1299-1309.

Maddala, G.S., Wu, S.A., 1999. Comparative study of unit root tests with panel data and a new simple test. *Oxford Bulletin of Economics and Statistics*, 108(S1), 1-24.

Marques, A.C., Fuinhas, J.A. (2012). Is renewable energy effective in promoting growth? *Energy Policy*, 46, 434-442.

Narayan, P.K., Smyth, R. (2009) Multivariate Granger causality between electricity consumption, exports and GDP: evidence from a panel of Middle Eastern countries. *Energy Policy*, 37, 229-236.

Neumayer, E. (2002). Do Democracies Exhibit Stronger International Environmental Commitment? A Cross-Country Analysis. *Journal of Peace Research*, 39 (2), 139-164.

Nguyen, K.H., Kakinaka, M. (2019). Renewable energy consumption, carbon emissions, and development stages: Some evidence from panel cointegration analysis. *Renewable Energy*, 132, 1049-1057.

Ocal, O., Aslan, A., 2013. Renewable energy consumption–economic growth nexus in Turkey. *Renewable and Sustainable Energy Reviews*, 28, 494-499.

Omri, A. (2013). CO2 emissions, energy consumption and economic growth nexus in MENA countries: Evidence from simultaneous equations models. *Energy Economics*, 40, 657-664.

Omri, A., Mabrouk, N.B., Timar, A.S., 2015. Modeling the causal linkages between nuclear energy, renewable energy and economic growth in developed and developing economies. *Renewable and Sustainable Energy Reviews*, 42, 1012-1022.

Omri, A., Nguyen, D.K. (2014). On the determinants of renewable energy consumption: international evidence. *Energy*, 72, 554-560.

Osman, M., Gachino, G., Hoque, A. (2016). Electricity consumption and economic growth in the GCC countries: panel data analysis. *Energy Policy*, 98, 318-327.

Ozturk, I., Bilgili, F., 2015, Economic growth and biomass consumption nexus: dynamic panel analysis for Sub-Sahara African countries, *Applied Energy*, 137, 110-116.

Pereira da Silva, P., Cerqueira, P.A., Ogbe, W. (2018). Determinants of renewable energy growth in Sub-Saharan Africa: Evidence from panel ARDL. *Energy*, 156, 45-54.

Pesaran, M.H., 2004. General Diagnostic Tests for Cross Section Dependence in Panels. Cambridge Working Papers in Economics No. 0435. Cambridge University, Cambridge.

Pesaran, M.H., 2007. A simple panel unit root test in the presence of cross-section dependence. *Journal of Applied Econometrics*, 22(2), 265-312.

Pesaran, M.H., 2015. Testing weak cross-sectional dependence in large panels. *Econometric Reviews*, 34, 1089–1117.

Pfeiffer, B., Mulder, P., 2013. Explaining the diffusion of renewable energy technology in developing countries. *Energy Economics*, 40, 285-296.

Ponce, P., López-Sánchez, M., Guerrero-Riofrío, P., Flores-Chamba, J. (2020). Determinants of renewable and non-renewable energy consumption in hydroelectric countries. *Environmental Science and Pollution Research*, 27, 29554-29566.

Qamruzzaman, M., Jianguo, W. (2020). The asymmetric relationship between financial development, trade openness, foreign capital flows, and renewable energy consumption: fresh evidence from panel NARDL investigation. *Renewable Energy*, 159, 827-842.

Rafindadi, A.A., and Ozturk, I. (2017). Impacts of renewable energy consumption on the German economic growth: Evidence from combined cointegration test. *Renewable and Sustainable Energy Reviews*, 75, 1130-1141.

Raza, S.A., Shah, N., Qureshi, M.A., Qaiser, S., Ali, R., Ahmed, F. (2020). Non-linear threshold effect of financial development on renewable energy consumption: evidence from panel smooth transition regression approach. *Environmental Science and Pollution Research*, 27, 32034-32047.

Ren, Y.-S., Ma, C.-Q., Apergis, N., Sharp, B. (2021). Responses of carbon emissions to corruption across Chinese provinces. *Energy Economics*, 98, 105241.

Sadorsky P. (2009a). Renewable energy consumption, CO2 emissions and oil prices in the G7 countries. *Energy Economics,* 31, 456-462.

Sadorsky P. (2009b). Renewable energy consumption and income in emerging economies. *Energy Policy,* 37, 4021-4028.

Sadorsky P. (2011). Trade and energy consumption in the Middle East. *Energy Economics,* 33, 739-749.

Sadorsky P. (2012) Energy consumption, output and trade in South America. *Energy Economics*, 34, 476-488.

Salim, R.A., Rafiq, S. (2012). Why do some emerging economies proactively accelerate the adoption of renewable energy? *Energy Economics,* 34(4), 1051-1057.

Seo, M.H., Shin, Y., (2016). Dynamic panels with threshold effect and endogeneity, *Journal of Econometrics*, 195 (2), 169-186.

Shahzad, U., Lv, Y., Doğan, B., Xia, W. (2021). Unveiling the heterogeneous impacts of export product diversification on renewable energy consumption: New evidence from G-7 and E-7 countries. *Renewable Energy*, 164, 1457-1470.

Shin, Y., Yu, B., Greenwood-Nimmo, M. (2014). Modelling Asymmetric Cointegration and Dynamic Multipliers in a Non-linear ARDL Framework. In: W.C. Horrace, R.C. Sickles (Eds.), Festschrift in Honor of Peter Schmidt, Springer, 2014, pp. 281-314.

Tang, J. (2015). Testing the Pollution Haven Effect: Does the Type of FDI Matter? *Environmental and Resource Economics*, 60, 549-578.

Tugcu, C.T., M. Topcu, M. (2018). Total, renewable and non-renewable energy consumption and economic growth: revisiting the issue with an asymmetric point of view. *Energy*, 152, 64-74.

Vural, G. (2021). Analyzing the impacts of economic growth, pollution, technological innovation and trade on renewable energy production in selected Latin American countries. *Renewable Energy*, 171, 210-216.

Uzar, U. (2020a). Is income inequality a driver for renewable energy consumption? *Journal of Cleaner Production*, 255, 120287.

Uzar, U. (2020b). Political economy of renewable energy: Does institutional quality make a difference in renewable energy consumption? *Renewable Energy*, 155, 591-603.

Wagner, U.J., Timmins, C.D. (2009) Agglomeration effects in foreign direct investment and the pollution haven hypothesis. *Environmental and Resource Economics*, 43(2), 231-256.

Wang, Q., Zhang, F. (2021). Free trade and renewable energy: A cross-income levels empirical investigation using two trade openness measures. *Renewable Energy*, 168, 1027-1039.

Wooldridge, J.M. (2002). Econometric Analysis of Cross Section and Panel Data. Cambridge, MA: MIT Press.

World Bank (2020). World Development Indicators. Washington, DC: The World Bank.

Zeren, F., Akkuş, H.T. (2020). The relationship between renewable energy consumption and trade openness: New evidence from emerging economies. *Renewable Energy*, 147, 322-329.

TABLES

Table 1. Descriptive Statistics					
		All			
Variables	Mean	Std. Dev.	Maximum	Minimum	Observations
ln(REC)	0.7268	1.3539	-5.1496	4.3469	2037
ln(GDP per capita)	8.7058	1.5146	5.6364	11.6260	2037
ln(CO2 per capita)	0.8419	1.5588	-3.9533	3.7318	2037
ln(Oil)	4.0459	0.5445	2.5064	7.1741	2037
ln(Trade)	4.2930	0.5263	2.6928	6.2761	2037
Democracy	5.2347	5.9082	-10.0000	10.0000	2037
		Developing			
ln(REC)	0.3673	1.2988	-5.1496	3.0931	1323
ln(GDP per capita)	7.8746	1.0607	5.6364	9.9762	1323
ln(CO2 per capita)	0.1390	1.4481	-3.9533	2.9989	1323
ln(Oil)	4.1213	0.5153	2.7064	7.1741	1323
ln(Trade)	4.2241	0.4886	2.6928	6.2761	1323
Democracy	3.4439	6.0042	-10.0000	10.0000	1323
		Developed			
ln(REC)	1.3929	1.2118	-1.6975	4.3469	714
ln(GDP per capita)	10.1759	1.0006	6.1915	11.6260	714
ln(CO2 per capita)	2.0876	0.7821	-1.7879	3.7318	714
ln(Oil)	3.9125	0.5694	2.5064	4.7202	714
ln(Trade)	4.4039	0.5717	2.8142	6.0904	714
Democracy	8.3599	4.1942	-7.0000	10.0000	714

Note: Democracy is the democracy index from polity IV. ln(REC), ln(GDP per capita), ln (CO2 per capita), ln(Oil), and ln(Trade) are the logarithms of renewable energy consumption, GDP per capita, CO2 emissions per capita, real oil price, trade openness, respectively.

Table 2. Cross-section dependence test						
	All		Developing		Developed	
	Statistic	P-value	Statistic	P-value	Statistic	P-value
Ln(REC)	4.433***	0.0003	4.662***	0.0000	4.128***	0.0000
Ln(GDP per capita)	41.63***	0.0000	40.51***	0.0000	61.44***	0.0000
Ln(CO2 per capita)	24.69***	0.0000	2.933***	0.0034	38.56***	0.0000
Ln(Oil)	106.4***	0.0000	178.1***	0.0000	106.4***	0.0000
Ln(Trade)	55.16***	0.0000	29.24***	0.0000	34.2***	0.0000

Note: This table provides the results of the cross sectional dependence test of Pesaran (2004). Under the null hypothesis of cross-sectional independence, the statistic is distributed as a two-tailed standard normal. ln(REC), ln(GDP per capita), ln (CO2 per capita), ln(Oil) and ln(Trade) are the logarithms of renewable energy consumption, GDP per capita, CO2 emissions per capita, real oil price, trade openness, respectively. *** denotes significance level at the 1% level.

Table 3. Panel unit root tests												
	All				Developing				Developed			
	Statistic	10%	5%	1%	Statistic	10%	5%	1%	Statistic	10%	5%	1%
Level												
ln(REC)	-2.33	-2.54	-2.61	-2.73	-2.52	-2.52	-2.58	-2.69	-2.23	-2.54	-2.61	-2. 73
ln(GDP per capita)	-1.81	-2.54	-2.61	-2.73	-1.66	-2.52	-2. 58	-2. 69	-1.81	-2.54	-2. 61	-2. 73
ln(CO2 per capita)	-2.45	-2.54	-2.61	-2.73	-2.42	-2.52	-2. 58	-2. 69	-2.45	-2.54	-2. 61	-2. 73
ln(Oil)	-2.35	-2.54	-2.61	-2.73	-2.24	-2.52	-2. 58	-2. 69	-2.45	-2.54	-2. 61	-2. 73
ln(Trade)	-1.71	-2.54	-2.61	-2.73	-2.27	-2.52	-2. 58	-2. 69	-1.71	-2.54	-2. 61	-2. 73
First difference (Δ)												
Δln(REC)	-4.34***	-2.51	-2.57	-2.7	-4.32***	-2.58	-2.67	-2.83	-4.15***	-2.54	-2.62	-2.76
Δln(GDP per capita)	-3.10***	-2.51	-2.57	-2. 7	-3.70***	-2.58	-2.67	-2.83	-2.86 ***	-2.54	-2. 62	-2.76
Δln(CO2 per capita)	-4.41 ***	-2.51	-2.57	-2. 7	-4.28***	-2.58	-2.67	-2.83	-4.57***	-2.54	-2. 62	-2.76
Δln(Oil)	-3.88***	-2.51	-2.57	-2. 7	-3.15***	-2.58	-2.67	-2.83	-2.94***	-2.54	-2. 62	-2.76
Δln(Trade)	-3.77***	-2.51	-2.57	-2. 7	-4.20***	-2.58	-2.67	-2.83	-3.34***	-2.54	-2. 62	-2.76

Note: This table provides the results of the CIPS test of Pesaran (2007). We include a constant and trend and two lags. As the limit distribution of the CIPS statistic is not normal, and the corresponding critical values are tabulated in Pesaran (2007). 10%, 5%, 1% are the critical values at 10%, 5%, and 1% level. ln(REC), ln(GDP per capita), ln (CO2 per capita), ln(Oil), and ln(Trade) are the logarithms of renewable energy consumption, GDP per capita, CO2 emissions per capita, real oil price, trade openness, respectively. *** denotes significance level at the 1% level.

Table 4. Linear Dynamic Panel Regression Results			
Variables	All	Developing	Developed
$\Delta\ln\,(\text{REC})_{t-1}$	-0.4276*	-0.3892***	-0.3976
	(0.0962)	(0.0051)	(0.1021)
$\Delta\ln\,(\text{GDP per capita})_t$	-0.0084**	-0.4789	0.3270***
	(0.0441)	(0.9480)	(0.0000)
$\Delta\ln\,(\text{Co2 per capita})_t$	0.2377***	0.2715***	0.0683***
	(0.0000)	(0.0000)	(0.0000)
$\Delta\ln\,(\text{Oil})_t$	0.0374***	0.0518***	0.0194***
	(0.0000)	(0.0000)	(0.0000)
$\Delta\ln(\text{Trade})_t$	-0.0356***	-0.0877***	0.0083***
	(0.0013)	(0.0001)	(0.0000)
Observations	1455	930	510
Panel AR(1)	0.2093	0.4510	0.1074

Note: This table provides estimations of the linear dynamic panel model using a dynamic panel regression model (DPRM) from (2). The lag length is one. P-values are provided in brackets. ***, **, and * denote significance at the 10%, 5% and 1% levels, respectively. ln(REC), ln(GDP per capita), ln (CO2 per capita), ln(Oil) and ln(Trade) are the logarithms of renewable energy consumption, GDP per capita, CO2 emissions per capita, real oil price, trade openness, respectively. Panel AR(1) shows p value of the panel autocorrelation test of Wooldridge (2002) under the null of no serial correlation.

Table 5. Dynamic Panel Threshold Regression Results when Democracy is used as a threshold variable

Countries	All		Developing	
Threshold	7.00*		4.00***	
	Low	High	Low	High
$\Delta\ln\,(\text{REC})_{t-1}$	-0.4471***	-0.5939***	-0.4040***	-0.6256***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)
$\Delta\ln\,(\text{GDP per capita})_t$	-1.3965**	0.6994*	-2.2009***	1.2970**
	(0.0252)	(0.0742)	(0.0000)	(0.0265)
$\Delta\ln\,(\text{CO2 per capita})_t$	0.2480**	0.3131*	0.2797***	0.1475
	(0.0181)	(0.0964)	(0.0089)	(0.4288)
$\Delta\ln\,(Oil_t)$	0.0955***	0.0219	0.1641***	-0.0183
	(0.0008)	(0.4410)	(0.0008)	(0.6211)
$\Delta\ln(Trade_t)$	-0.2396*	-0.1676	-0.3887**	-0.0154
	(0.0966)	(0.3517)	(0.0193)	(0.9259)
SupWald P value	0.0553		0.0050	
SupWald Statistic	16.3838		32.2770	
Observations	1455		930	

Note: This table provides estimations of the dynamic panel threshold regression model (DPTRM) from (5). ***, **, and * denote significance at the 10%, 5% and 1% levels, respectively. ln(REC), ln(GDP per capita), ln (CO2 per capita), ln(Oil), and ln(Trade) are the logarithms of renewable energy consumption, GDP per capita, CO2 emissions per capita, real oil price, trade openness, respectively. The lag length is one and p-values are provided in brackets.

Appendix Table A1. List of countries

Country	Developed	Country	Developed
Albania		Japan	X
Algeria		Jordan	
Australia	X	Kazakhstan	
Austria	X	Kenya	
Azerbaijan	X	Korea, Rep.	X
Bangladesh		Latvia	X
Belgium	X	Lithuania	X
Benin		Luxembourg	X
Bhutan		Madagascar	
Bolivia		Malawi	
Botswana		Malaysia	
Brazil		Mauritania	
Bulgaria		Mauritius	
Burkina Faso		Mexico	
Cameroon		Mongolia	
Canada	X	Morocco	
Chad		Nepal	
Chile		Netherlands	X
China		New Zealand	X
Colombia		Norway	X
Costa Rica		Pakistan	
Cyprus		Panama	
Czech Republic	X	Paraguay	
Denmark	X	Philippines	
Dominican Republic		Poland	X
Ecuador		Portugal	X
El Salvador		Romania	
Equatorial Guinea		Russian Federation	
Estonia		Rwanda	
Eswatini		Saudi Arabia	
Finland	X	Senegal	
France	X	Singapore	X
Gabon		Slovak Republic	X
Gambia, The	X	Slovenia	X
Georgia		South Africa	
Germany	X	Spain	X
Ghana		Sri Lanka	
Greece	X	Sudan	
Guatemala		Sweden	X
Guyana		Switzerland	X
Honduras		Tanzania	
Hungary	X	Thailand	
India		Togo	
Indonesia		Turkey	
Iran, Islamic Rep.		Uganda	
Ireland	X	United Kingdom	X
Israel	X	United States	X
Italy	X	Uruguay	
Jamaica			