Renewable and Nonrenewable Energy Consumption, Economic Growth, and Emissions: International Evidence

Thai-Ha Le,[a] Youngho Chang,[b] and Donghyun Park[c]

ABSTRACT

This study aims to reexamine how energy consumption interacts with economic growth and emissions using a panel data of a global sample consisting of 102 countries, from 1996 to 2012. The effects of renewable energy and nonrenewable energy sources are separately examined. The consumption of both renewable and nonrenewable energy appears to have contributed significantly to the level of income across countries, implying that promoting renewable energy benefits economic development. The empirical evidence suggests that the use of non-renewable energy consumption significantly raised the level of emissions across different income groups of countries. On the other hand, our findings suggest that the use of renewable energy sources helped tackle emissions in developed countries but not in developing countries. The success of developed countries in controlling emissions through renewable energy has significant policy implications for developing countries.

Keywords: Greenhouse gas emissions, Renewable energy sources, Nonrenewable energy sources, Growth, Global sample, Panel data

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1. INTRODUCTION

Most of the observed increase in global mean temperature (“global warming.” since the mid-20th century is believed to be attributable to human activities (US National Research Council, 2008). It is expected that human-induced warming of the climate will continue throughout the 21st century and beyond (US National Research Council, 2008). In this context, the significance of clean and sustainable environment was first recognized officially in the Kyoto Protocol (1997) that was endorsed by both developing and developed countries. The protocol identifies greenhouse gases (GHG) emissions, particularly carbon dioxide (CO_2) emissions, as the primary sources of global warming. More specifically, CO_2 emissions from burning fossil fuels and industrial processes account for 65% of global GHG emissions (IPCC, 2014).

Apart from CO_2, methane (CH_4) and nitrous oxide (N_2O) that are emitted from agricultural activities such as fertilization, irrigation, livestock and rice production, energy use and biomass burning are the other key sources of GHG emitted by human activities at the global scale. N_2O emissions and CO_2 emissions from forestry and other land use as well as from fossil fuel and industrial processes contribute much of GHG emissions at the global level (IPCC, 2014).

The Kyoto Protocol was a cornerstone in the promotion of renewable energy sources (RES) that would be a key solution to mitigating climate change and managing energy demand

a Fulbright University, Vietnam. IPAG Business School, Paris, France.

b Corresponding author. School of Business, Singapore University of Social Sciences, 461 Clementi Road, Singapore 599491 Tel: +65-6248-0159. E-mail: yhchang@suss.edu.sg.

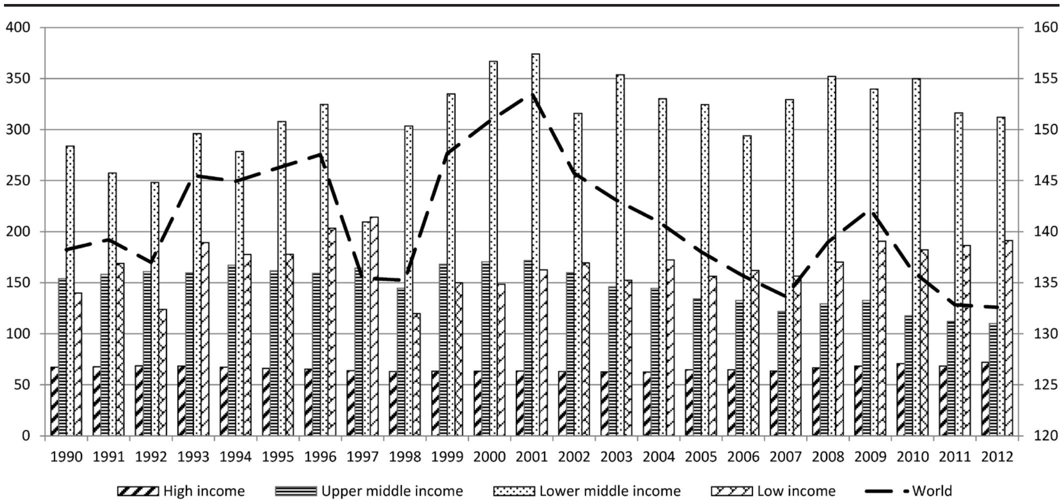
c Asian Development Bank, Philippines

growth. Countries of all income levels have been promoting and adopting policies to switch energy consumption towards RES. Since 1990, RES have grown at an average annual rate of 2.2%, which is slightly higher than the growth rate of world's Total Primary Energy Supply (TPES) of 1.9% (IEA, 2016). The growth rate has been especially high for solar photovoltaic and wind power, which grew at average annual rates of 46.2% and 24.3% respectively, from very low bases in 1990 (IEA, 2016). Nevertheless, the path through which consumption of RES leads to higher growth is uncertain (see, for instance, Domac et al., 2005; Masui et al., 2006; Chien and Hu, 2007; Krewitt et al., 2007; and Apergis and Payne, 2010). Overall, the growing threat of global warming, concentration of GHG emissions in the atmosphere, and climate change is a topic of growing global importance. In particular, it is important to find ways to mitigate their effects while finding alternative ways to meet rapidly growing energy demand worldwide (Stern, 2007).

Against the above background, this study sets three objectives. First, it examines how RES and Nonrenewable Energy Source (NES) influenced the level of economic development in a global sample of countries of varying income levels. Second, this study investigates how RES and NES impact the level of GHG emissions in the global sample, controlling for income and other factors. Third, this study analyzes whether the level of economic development influences the effect of RES and NRES on the level of GHG emissions. To do so, the global sample is separated into subsamples of countries at different levels of development using a panel approach. Figure 1 seems to suggest that different income groups of countries contribute differently to global GHG emissions in per capita terms.

The three main findings are as follows. First, the consumption of both renewable and non-renewable energy appears to promote economic growth for both developed and developing economies. While this evidence is found in several studies in the literature, almost no study uses a global sample (of 102 countries) like the one used here. Second, this study finds that renewable energy helped developed countries contain carbon emissions. In other words, renewable energy has been effective for controlling carbon emissions in developed countries. Most of the studies in the literature that examine the relationship between renewable energy and carbon emissions in a large sample of countries do not separately examine developing and developed countries [for instance,

Figure 1: Total greenhouse gas emissions per capita across countries by income level (1990-2012)



Note: Total greenhouse gas emissions are in terms of kt of CO_2 equivalent per capita.
Data source: Global sample obtained from World Development Indicators 2017

Apergis et al. (2010)] and many of the studies are national studies [e.g. Menyah and Wolde-Rufael (2010) for the US].

Third, this study finds renewable energy does not help containing carbon emissions in developing countries. Perhaps lack of data has hindered quantitative analysis of whether renewable energy can help control carbon emissions in developing economies. Tiwari (2011) was the only study that examines this issue. Using a simple SVAR approach including GDP, renewable energy consumption and CO_2 emissions, Tiwari (2011) finds that renewable energy did not contribute to tackling CO_2 emissions in India.

The rest of this study is organized as follows. Section 2 reviews relevant studies, focusing on two strands of literature, which are (1) the nexus between RES and economic growth and (2) the relationship between RES and NES and emissions. Section 3 presents the empirical model, data and methodology employed in this study. Section 4 reports the empirical results. Section 5 discusses the policy implications. Section 6 concludes the study.

2. LITERATURE REVIEW

There is a large literature that examines the dynamics of the relationships between electricity or energy consumption and economic growth, either in bivariate or multivariate frameworks [see, for instance, Le (2016), Le and Quah (2018), Fang and Le (2019); Le and Nguyen (2019)].[1] These studies delve into both a single country and many countries, and center on four hypotheses - growth; conservative; feedback; or neutrality - associated with this relationship [see, for example, Lee and Lee (2010), Belke et al. (2011), Stern and Kander (2012), Liddle (2013), Ouedraogo (2013), Karanfil and Li (2015), Yildirim et al. (2014), Tang et al. (2016)]. Specifically, (1) **the feedback hypothesis** states that energy consumption promotes economic growth and economic growth promotes higher energy consumption; (2) **the growth hypothesis** suggests that energy consumption drives economic growth; (3) **the conservative hypothesis** proposes a unidirectional link flowing from economic growth to energy consumption; and (4) **the neutrality hypothesis** states that there is no relationship between energy use and economic growth.

For instance, Liddle (2013) studied a global sample of 79 countries during the 1971-2007 period and the results indicate that energy consumption and electricity consumption contribute significantly to economic growth for all panels of countries at different income levels. Similarly, Tang et al. (2016) found evidence of growth hypothesis for Vietnam using the neoclassical Solow growth framework for the 1971–2011 period. The Granger causality test revealed unidirectional causality running from energy consumption to economic growth. On the other hand, Lee and Lee (2010) showed a positive bi-causal relationship between the level of economic activity and energy/electricity consumption for a group of 25 OECD countries from 1978 to 2004, which supports the feedback hypothesis. However, there are only a handful of studies in the field of renewable energy consumption in a disaggregated framework. The next section presents a selective review of the recent literature in the field of renewable energy consumption and economic growth.

There is no unique way through which RES can boost economic growth. However, several studies attempted to propose plausible mechanisms for such a relationship [see, for example, Domac et al. (2005), Masui et al. (2006), Chien and Hu (2007), Krewitt et al. (2007), Bhattacharya et al. (2016 and 2017), Armeanu et al. (2017).] Domac et al. (2005) and Chien and Hu (2007) proposed two channels through which renewable energy promotes economic growth. First, the expansion of renewable energy industries generates new business and employment opportunities, which contrib-

1. Bruns et al (2014) provide a meta-analysis of the extensive literature on testing for Granger causality between energy use and economic growth.

ute to economic growth. Second, the import substitution of energy might have direct and indirect effects on GDP and/or trade balance.

Renewable energy has some distinctive positive economic ripple effects compared to non-renewable energy. Armeanu et al (2017) pointed out that RES are eco-friendly sources of energy or green energy. As such, RES drive sustainable growth through energy and financial savings achieved by replacing NES and costly energy with low-priced RES, leading to slower depletion of natural resources. Besides a smaller negative effect on the environment than non-renewable energy, renewable energy has the potential of creating jobs associated with developing, setting up, and operating renewable *Energy Systems*. Compared to fossil fuel technologies, which tend to be mechanized and capital intensive, the renewable energy industry is more labor-intensive (IRENA, 2013). This implies that, on average, more jobs are created for each unit of RES consumed. The implicit scarcity of nonrenewable resources such as fossil fuels should drive market dynamics toward alternative resources. RES thus has the benefits of environmental and long-term economic sustainability, although renewable sources are not efficient enough to fully meet energy needs.

On the other hand, Kahia et al (2016) proposed that most renewable energy technologies might be less competitive than non-renewable energy due to a high level of initial capital cost and thus higher levelized cost of electricity. This explains the competitive disadvantage of renewable energy due to lengthy payback time needed to recover high initial capital costs (Baulch et al, 2018). This speedy decline of the costs of renewable energy technologies is mainly attributed to substantial advances and manufacturing capacities. They also explain why the share of RES in the energy mix is widely expected to rise.

The empirical evidence is mixed at best. Apergis and Payne (2010) examined the link between RES and GDP for a sample of 20 OECD countries during 1985-2005. The study detects a long-run equilibrium relationship between GDP, RES, gross fixed capital formation, and the labor force. Furthermore, Granger-causality test results indicate bidirectional causalities between RES and economic growth in both the short- and long-run. Similarly, Long et al. (2015) examined Chinese data during 1959-2012 and found that hydro and nuclear power have positive impact on economic growth. On the other hand, Menegaki (2011) investigated the causal relationship between renewable energy and economic growth for 27 European countries from 1997 to 2007 and found no evidence of causality between the two variables.

A number of studies have shown that energy consumption is closely linked to economic growth. At the same time, energy consumption is widely viewed as a key determinant of GHG emissions. It is therefore worthwhile to examine the nexus between economic growth, energy use, and GHG emissions by simultaneously considering them. Ang (2007) and Soytas et al. (2007) initiated this strand of research which explores the nexus between economic growth, energy, and CO_2 emissions. Recent works include Alkhathlan and Javid (2013), Saboori and Sulaiman (2013), Alshehry and Belloumi (2015) for a single country study and Arouri et al. (2012), Ozcan (2013) and Sebri and Ben-Salha (2014).

Alkhathlan and Javid (2013) examine Saudi Arabian data during 1980–2011, and showed that economic growth and energy consumption cause CO_2 emissions in Saudi Arabia in both the short and long-run. Energy consumption is also found to cause economic growth in the long-run, but there is no causal relationship between the two variables in the short run. Alshehry and Belloumi (2015) also examine Saudi Arabia and found that a relationship exists between CO_2 emissions, economic growth, energy consumption, and energy price at least in the long run. However, the causality results suggest that policies aimed at reducing energy usage and controlling for CO_2 emissions have negligible effects on Saudi Arabia's economic growth. An example of regional studies is Arouri et al. (2012), which tested the relationship between CO_2 emissions, energy consumption, and real

GDP for 12 Middle Eastern and North African Countries (MENA) in 1981–2005. They showed that future reductions in CO_2 emissions per capita can be achieved even as GDP per capita in the MENA region continues to grow.

The literature on the energy-growth nexus and the relationships between emissions, energy and growth is large but has several shortcomings. First, many of the studies are based on the Environmental Kuznets Curve (EKC) model, which suffers from some key weaknesses. Above all, the EKC model ignores key structural factors underlying the relationship between income, energy and emissions. For instance, the ability of a government to tackle environmental degradation could be hindered by institutional factors such as bureaucratic inefficiency, the influence of special-interest groups, and the resistance of state-owned enterprises. These factors are captured in the Index of Economic Freedom, which is used as the main indicator for governance quality in this study and explicitly incorporated into the empirical model that analyzes GHG emissions for a global sample of countries.

Second, most studies center on single country or regional groups of countries rather than a global sample of countries. The largest sample is Apergis and Payne (2010) with 80 countries, including both developed and developing countries. However, they do not separate their sample in developing and developed countries. According to Apergis and Payne (2011), it is worthwhile to compare developed versus developing countries since their projected energy needs and hence consumption are different. This is because developing countries have more energy-intensive industries to developed countries with large less-energy-intensive service sectors. Apergis and Payne (2011) do separately examine sub-samples of developed and developing countries, but only 80 countries are included. Furthermore, developing countries include both developing and emerging market economies. In contrast, this study separates developing countries into upper-middle-income and lower-middle-and-low-income countries.

Third, most studies employ primary or final energy consumption in the aggregate instead of considering renewable and nonrenewable energy separately (e.g., Chang, 2010 for China). Shafiei and Salim (2012) examine this relationship for OECD countries and find that nonrenewable energy consumption increases CO_2 emissions whereas renewable energy consumption decreases CO_2 emissions. The lack of global sample studies and failure to separate renewable and non-renewable energy is partly due to lack of data on renewable energy resources for a large number of countries. Fourth, the literature uses CO_2 emissions as a proxy for pollutant emissions, GHG emissions, environmental quality, and environmental degradation without considering other emissions for robustness checks or further analysis.

To this end, this study hopes to contribute to the literature on nexus between energy consumption, economic growth, and emissions by (1) applying advanced panel data techniques to a model that better controls for factors that influence the relationships between the variables of interest, (2) analyzing a global sample of countries and comparing the empirical results for different income groups of countries, (3) considering renewable and nonrenewable energy separately and explicitly in the empirical model, and (4) using a number of emissions indicators for completeness and robustness check.

3. DATA AND METHODOLOGY

3.1 Model and data description

The above literature suggests there is a relationship between environmental quality and various variables such as energy consumption, income, and governance quality. For the empirical analysis of this study, we extend the conventional neo-classical one-sector aggregate production function by including additional variables, namely renewable and non-renewable sources of energy used in the production process as well as governance quality and emissions. The baseline models are constructed as follows:

$$Y_{it} = \alpha_{0it} + \alpha_{1i} NES_{it} + \alpha_{2i} RES_{it} + \alpha_{3i} EMI_{it} + \alpha_{4i} GOV_{it} + \alpha_{5i} K_{it} + \alpha_{6i} L_{it} + \varepsilon_{it} \quad (1)$$

$$EMI_{it} = \beta_{0it} + \beta_{1i} NES_{it} + \beta_{2i} RES_{it} + \beta_{3i} Y_{it} + \beta_{4i} GOV_{it} + \beta_{5i} K_{it} + \beta_{6i} L_{it} + \epsilon_{it} \quad (2)$$

where i = 1, 2, 3, … N for each country in the panel and t = 1, 2, 3, … T refers to the time period. EMI_{it} is indicator of emissions, NES_{it} is nonrenewable energy consumption, RES_{it} is renewable energy consumption, Y_{it} is real GDP in constant 2010 US$ and used as a measure of economic output, GOV_{it} is indicator of governance, K_{it} is real gross fixed capital formation in constant 2010 US$ and used as a proxy for the growth of capital stock, L_{it} is total labor force and used as a measure of available labor in the market, and ϵ_{it} and ε_{it} are error terms. The novelty of this structure is to explicitly consider the possible impact of governance on the relationships between renewable and nonrenewable energy consumption, income level and emissions. Governance quality is added since it can influence the level of potential pollutant emissions (see, for instance, Barrett and Graddy, 2000; Leitao, 2010; Wood and Herzog, 2014; Le et al, 2016).[2] All variables are converted into natural logarithms.

For emissions, total GHG emissions is used as the main proxy. For completeness and robustness check, this study also employs two other proxies - nitrous oxide (N_2O) emissions and carbon dioxide (CO_2) emissions - since these two gas types are major sources of GHG emissions at the global level (IPCC, 2014). CO_2 emissions are in metric tons per capita while GHG emissions and N_2O emissions are transformed into metric tons of CO_2 equivalent and also expressed in per capita terms. Real GDP and real gross fixed capital formation are in constant 2010 US$, labor is measured in numbers, and = renewable and nonrenewable energy use are expressed in megajoules (MJ). All the data are extracted and computed from World Development Indicators 2017.

The Index of Economic Freedom, provided by the Heritage Foundation, is chosen as the proxy for governance. The index is available for 1995 to 2018 but data availability differs for each country. The index measures the economic freedom of 186 countries based on several factors such as trade freedom, business freedom, investment freedom, and property rights. The index ranges from 0 to 100 and a higher score means greater freedom. The index comprises several dimensions: size of the government, i.e. government spending, taxes and government enterprises; property rights and legal structure; effective monetary and fiscal policies; and trade policies and regulation of business, including labor and credit markets.[3]

The relationship between economic freedom and renewable energy development and consumption has been documented in several studies (for instance, Bhattacharya et al, 2017; Bhattacharya, 2010). Bhattacharya et al (2017) argued that more freedom allows individuals to think innovatively and participate more efficiently in productive activities, including renewable energy deployment. Brunnschweiler (2010) employed Index of Economic Freedom as a measure of institu-

2. Please refer to Le et al (2016) for a detailed discussion on the impact of governance quality on environmental performance, with empirical evidence from Asian countries. The details are not mentioned here to conserve space.

3. A probably better proxy for the governance factor would be variables related to pollution regulations, i.e., the World Bank's Country Policy and Institutional Assessment (CPIA) indicators on the environment. However, this data series is only available for 2005-2014. Given that the data on emissions is only available until 2012, a sample period from 2005 to 2012 is insufficient to perform any meaningful empirical analysis.

tional quality in a study on finance for renewable energy and found that a stable institutional framework positively affects investments in the RE power sector. Loris (2015) argued that economically freer countries tend to consume energy more efficiently. Granted, there are unfree countries that have both extremely low electrification and high rates of energy efficiency, but on average, free and mostly-free countries use energy more efficiently than do mostly unfree and repressed economies.

This study employs pooled annual time series, with 102 countries and spanning 1996 to 2012. Data availability was the main criterion for both country sample and time period. The countries in this study sample are at various stages of economic development. Hence, in addition to the full sample, the countries are divided into three sub-samples according to the World Bank's income classification - high-income, upper-middle-income, and lower-middle-income and low-income.[4] Table 1 summarizes the list of countries in the sample.

Table 1: List of countries in the study sample

Income Groups	Country list (102 countries in total)
High-income countries (44 countries)	Argentina, Australia, Austria, Belgium, Canada, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Japan, South Korea, Latvia, Lithuania, Luxembourg, Malta, Netherlands, New Zealand, Norway, Poland, Portugal, Russia, Saudi Arabia, Singapore, Slovakia, Slovenia, Spain, Sweden, Switzerland, Trinidad and Tobago, United Arab Emirates, United Kingdom, United States, Uruguay, Venezuela
Upper-middle-income countries (27 countries)	Albania, Algeria, Azerbaijan, Belarus, Botswana, Brazil, Bulgaria, China, Colombia, Cuba, Dominican Republic, Ecuador, Gabon, Iran, Kazakhstan, Lebanon, Malaysia, Mexico, Namibia, Panama, Paraguay, Peru, Romania, South Africa, Thailand, Tunisia, Turkey
Lower-middle and low-income countries (31 countries)	Armenia, Bangladesh, Benin, Bolivia, Cambodia, Cameroon, Egypt, El Salvador, Guatemala, Haiti, Honduras, India, Indonesia, Kenya, Kyrgyz Republic, Moldova, Morocco, Mozambique, Nepal, Nicaragua, Nigeria, Pakistan, Philippines, Senegal, Sri Lanka, Tajikistan, Tanzania, Togo, Ukraine, Uzbekistan, Vietnam

Source: 2016 World Bank's income classification (GNI per capita): The groups are: low income, $1,025 or less; lower middle income, $1,026–4,035; upper middle income, $4,036–12,475; and high income, $12,476 or more.

Table 2 reports the means of the raw data of the variables during 1996-2012. On average, high-income countries perform better than upper-middle-income countries, and both groups perform better than lower-middle and low-income countries in terms of economic freedom and GDP per capita. High-income countries score the highest for nonrenewable and renewable energy consumption, followed by upper-middle-income countries, and then lower-middle and low-income countries. The same pattern holds for different types of GHG emissions.

4. METHODOLOGY

This study uses panel data techniques to investigate the relationships between GHG emissions (EMI), real GDP per capita (GDP), different types of energy use per capita (NES and RES), and governance (GOV) for 102 countries during 1996 to 2012. First, by pooling the time series data across countries, panel data allows for more observations and results in higher power for the Granger causality test (Pao and Tsai, 2010). This advantage is particularly relevant for short time

4. According to 2018 World Bank's income classification (GNI per capita), the groups are: low income, $1,005 or less; lower middle income, $1,006–3,955; upper middle income, $3,956–12,235; and high income, $12,236 or more. Many studies have adopted thresholds of income level proposed by the World Bank to classify countries in their study sample by income for econometric analysis, e.g., Agénor (2017), Barro and Lee (2013), De Vita & Kyaw (2016), Liddle (2013), Ozturk (2016), Samargandi et al (2015).

Table 2: Mean of the variables in the study (time period: 1996-2012)

Variables	Unit	All countries	High-income countries	Upper-middle-income countries	Lower-middle and low-income countries
ECONOMIC FREEDOM (GOV)	---	60.91	68.17	56.67	54.29
GDP (Y)	Constant 2010 US$	5.34e+11	9.54e+11	3.48e+11	9.95e+10
RENEWABLE ENERGY USE (RES)	Megajoules	442,852.7	265,237.1	594,292.5	563,053.3
NONRENEWABLE ENERGY USE (NES)	Megajoules	2,196,418	3,223,015	2,249,901	692,730.6
GHG EMISSIONS (GHG)	Kilograms (SI base unit)	397,274.1	459,993.9	506,311.9	218,680
CO_2 EMISSIONS (CO_2)	Kilograms (SI base unit)	256,461	330,417.1	325,960.6	90,959.18
N_2O EMISSIONS (N_2O)	Kilograms (SI base unit)	24,980.06	22,164.32	34,903.78	20,333.35
GROSS CAPITAL FORMATION (K)	Constant 2010 US$	1.28e+11	2.15e+11	1.02e+11	2.82e+10
TOTAL LABOR FORCE (L)	Number of people	2.61e+07	1.41e+07	4.05e+07	3.04e+07

Source: Authors' calculation.

series. Second, compared to time series and cross-sectional data, panel data allows for "more informative data, more variability, less collinearity among the variables, more degrees of freedom, and more efficiency."by controlling for individual heterogeneity (Baltagi, 2005).

Depending on whether there exists cointergration, which imply there is a long-run relationship, the parameters in the cointegrating vector are estimated. Estimations are performed on the four following samples. The first sample includes all the 121 countries. The second sample includes only high-income countries, the third sample includes only upper-middle-income countries, and the fourth sample includes only lower-middle and low-income countries.

Empirical techniques used in the empirical analysis are described and justified as follows. Three preliminary tests were performed prior to estimating the panel models. This study first employ variance inflation factor (VIF) in the proposed model to identify potential multicollinearity. The obtained VIF values are all below than 10, suggesting no multicollinearity in this dataset.[5] Next, the Wooldridge test (see Drukker, 2003 and Wooldridge, 2010) was performed to test for serial correlation in panel-data models; and the Modified Wald statistic (Greene, 2008) was derived as part of the test for the presence of group-wise heteroskedasticity in the fixed effect model.[6] These tests showed the presence of serial correlation and group-wise heteroskedasticity, which led to the choice of the feasible GLS (FGLS) as the econometric technique.[7] The FGLS method is also consistent and asymptotically efficient. Furthermore, in cross-sectional analysis the error variance is likely to vary across the groups, influencing the consistency of the estimators. Using GLS addresses this issue.

Consider the above baseline model captured in the following format:

$$Y_{it} = \alpha + X'_{it}\beta + \delta_i + \gamma_t + \varepsilon_{it} \tag{3}$$

where $i = \overline{1, N}$, $t = \overline{1, T}$, Y is a dependent variable, α is a constant, X is a vector of explanatory variables (see equation 1), β represents a vector of coefficients to be estimated, ε_{it} represents the residual

5. The VIF test results are not reported here to conserve space, but they are available upon request.

6. The Hausman test (with pooled OLS is preferred under the null hypothesis, while under the alternative, fixed effects is at least consistent and thus preferred) are conducted for all models in this study. The results suggested fixed effects are preferred for all the models, regardless of the different measures of governance and vulnerability. The Hausman test results are not reported here to conserve space but they are available upon request.

7. These test results are not reported here to conserve space, but they are available upon request.

terms, δ_i and γ_t are the cross-section (which account for cross country differences) and period fixed and random effects, respectively, the GLS estimator is based on the following moments:

$$g(\beta) = \sum_{i=1}^{M} g_i(\beta) = \sum_{i=1}^{M} Z_i' \hat{\Omega}^{-1} \varepsilon_i(\beta) \tag{4}$$

where Z_i' is the instrument matrix for the i-th cross-section, $\varepsilon_i(\beta) = (Y_{it} - \alpha - X_{it}'\beta)$ and $\hat{\Omega}$ is a consistent estimation of the variance-covariance matrix Ω.

4. EMPIRICAL RESULTS

The study first performs panel unit root tests that take into account cross-sectional dependence. These include the Pesaran (2007) and Pesaran, Smith and Yamagata (2013) panel unit root tests. The results reveal that the variables are non-stationary in level but stationary in first difference.[8] Since all variables are integrated of order one, this study examines the cointegration relationship among the variables of interest *EMI, RES, NES, K, L, Y* and *GOV* using the Durbin Hausman group mean test (DHg) and panel test (DHp) developed by Westerlund (2008). This test allows for cross-sectional dependence modelled by a factor model in which the errors of Eq. (1) and (2) are obtained by idiosyncratic innovations and unobservable factors that are common across units of the panel (Auteri and Constantini, 2005). In this case, heterogeneous autoregressive parameters are assumed across panel units.

The results indicate that the variables *EMI, RES, NES, K, L, Y* and *GOV* are bound by a cointegrating relationship. This result holds across different income groups of countries and is robust to different measures of emissions.[9] Given the presence of cointergration, the study next estimates the parameters in the cointegrating vectors that show the long-run relationships using FGLS for linear panel models.[10] The results are reported in Tables 3 and 4 where output (Y) and emissions are the dependent variables, respectively.

When output (*Y*) is the dependent variable, as shown in Table 3, for the global panel as well as different income groups of countries, the coefficients of renewable and nonrenewable energy consumption are found to be significantly positive at conventional levels. This implies that energy consumption, including both renewable and nonrenewable energy, benefits economic development. The results hold when different types of GHG emissions are included. This is consistent with a large volume of existing literature on the growth-energy nexus. The result supports the need for some caution in implementing energy conservative policies since they can harm economic performance.

A majority of the estimated coefficients of different types of GHG emissions suggests a significantly positive linkage between economic development and GHG emissions level for the whole sample and the majority of subsamples. This implies that economic growth has been generally associated with increase in GHG emissions. As such, efforts for curtailing GHG emissions alone (for instance, simply by reducing nonrenewable energy consumption, ceteris paribus) may adversely affect economic performance. This is consistent with the common understanding that economic growth across the world during the past decades has been significantly related to the increased use of primary energy consumption, which is likely to have adverse effects on the environment.

8. The unit root statistics are not presented here to conserve space, but they are available upon request.

9. The cointegration results are not reported here to conserve space, but they are available upon request.

10. Before the estimation, the stability of the relationship between the variables of interest is examined using Di Iorio and Fachin (2007)'s test for breaks in cointegrated panels. The results show acceptance of the null hypothesis of no break. That is, the relationship among the investigated variables is stable and not subject to structural breaks during the investigation period. To conserve space, the results are not presented here, but they are available upon request.

Table 3: FGLS Estimations: Dependent variable: Y

	All countries	High-Income Countries	Upper-Middle-Income Countries	Lower-Middle and Low-Income Countries
LOG_NES	0.135***	0.054**	0.137***	0.207***
	(9.92)	(2.08)	(4.23)	(9.77)
LOG_RES	0.049***	0.070**	0.082***	0.164***
	(8.29)	(2.36)	(6.10)	(8.85)
LOG_GHG	0.090***	0.078***	0.067***	0.027
	(7.60)	(3.58)	(2.75)	(1.64)
LOG_GOV	0.044***	0.088***	0.111***	0.082***
	(3.27)	(2.40)	(4.77)	(4.18)
LOG_K	0.805***	0.849***	0.571***	0.600***
	(74.66)	(59.95)	(25.88)	(28.73)
LOG_L	0.090***	0.009	0.130***	-0.009
	(8.27)	(0.48)	(4.08)	(-0.26)
_CONS	1.842***	1.311***	2.854***	2.450***
	(28.49)	(14.36)	(24.27)	(20.37)
N	1,676	712	445	519
	All countries	High-Income Countries	Upper-Middle-Income Countries	Lower-Middle and Low-Income Countries
LOG_NES	0.106***	0.133***	0.015	-0.189***
	(3.99)	(3.01)	(0.27)	(-2.99)
LOG_RES	0.051***	0.008	0.092***	0.150***
	(8.96)	(1.59)	(7.64)	(8.34)
LOG_CO2	0.063**	-0.011	0.152***	0.415***
	(2.58)	(-0.41)	(3.35)	(6.70)
LOG_GOV	0.032**	0.084**	0.112***	0.101***
	(2.22)	(2.28)	(4.86)	(5.29)
LOG_K	0.809***	0.828***	0.564***	0.560***
	(75.43)	(61.19)	(25.96)	(27.29)
LOG_L	0.051***	0.034*	0.148***	0.012
	(5.23)	(1.84)	(4.72)	(0.42)
_CONS	1.835***	1.348***	3.043***	3.187***
	(25.28)	(14.43)	(23.60)	(19.75)
N	1,711	733	459	519
	All countries	High-Income Countries	Upper-Middle-Income Countries	Lower-Middle and Low-Income Countries
LOG_NES	0.143***	0.112***	0.167***	0.206***
	(10.93)	(5.78)	(5.67)	(9.80)
LOG_RES	0.035***	0.020**	0.089***	0.159***
	(5.75)	(2.48)	(6.41)	(8.54)
LOG_N_2O	0.063***	0.032**	0.030**	0.043**
	(5.33)	(2.57)	(2.29)	(2.17)
LOG_GOV	0.010**	0.069*	0.107***	0.084***
	(2.05)	(1.86)	(4.57)	(4.28)
LOG_K	0.819***	0.837***	0.581***	0.597***
	(76.66)	(60.90)	(26.03)	(28.98)
LOG_L	0.076***	0.010	0.113***	-0.014
	(6.88)	(0.50)	(3.51)	(-0.41)
_CONS	1.827***	1.418***	2.866***	2.505***
	(28.06)	(15.38)	(24.42)	(20.14)
N	1,711	733	459	519

Note: *, ** and *** denote statistical significance at 10%, 5% and 1% respectively. Numbers in parentheses are t-statistics.

The coefficients of governance quality show significant and positive signs for all income groups of countries in most cases. This is in line with the notion that better governance promotes economic development.

When different types of GHG emissions are considered as dependent variables, as reported in Table 4, in most cases nonrenewable energy consumption significantly raises GHG emissions.

This is true for different income groups of countries. On the other hand, renewable energy consumption has a negative effect for the global sample and high-income countries. This means that policies that encouraged the use of renewable energy reduced the level of GHG emissions in high-income countries. However, for the groups of middle- and low-income countries, the coefficients of RES are negative in several cases but insignificant. As suggested by Apergis et al (2010), a number of factors may have contributed to the apparent inability of renewable energy consumption to reduce CO_2 emissions. First, the share of renewable energy consumption in total energy consumption has not increased significantly in these countries. Second, in some countries, natural gas prices dropped dramatically, making renewable energy less attractive compared to natural gas-fueled generation. Third, strong financial incentives, which are essential to support renewable energy development, have been inadequate in most of these countries.

The coefficients of Y confirm that there is a significantly positive relationship between economic growth and pollutant emissions in most of the cases. The coefficients of GOV are found to be significant and negative for high-income countries but insignificant for middle- and low-income countries. This result suggests that the government plays a vital role in reducing emissions in high-income countries but not in middle- and low-income countries. This finding is in line with Brunnschweiler (2010), Loris (2015) and Roberts and Olson (2013). Roberts and Olson (2013) documented that economically freer countries throughout the world continue to outperform their repressed counterparts in environmental protection. Economic freedom, and the wealth that flows from it, is wholly consistent with and supportive of a healthy environment. High-income countries have effective policy regimes and social acceptance from public, political and regulatory stakeholders which support viable investments in renewables. Effective institutional arrangements mitigate market failure and help to sustain growth momentum, mitigating pollutant emissions in the long-run (Brunnschweiler, 2010). Meanwhile, in developing countries, too many special interests are pursuing political and environmental agendas that interfere with the effort to curtail emissions (Loris, 2015). Green energy deployment faces policy changes and uncertainties, creating various barriers to adoption of renewable energy.

We conducted several types of robustness checks. First, instead of using aggregate renewable energy consumption per capita as a measure for RES, we restrict renewables to the electric power sector and re-estimate our baseline models with this new measure for RES.[11] We found that the results are qualitatively similar to what we obtained for the baseline models. Second, we examine the sensitivity of the results by employing "renewables to the electric power sector excluding hydroelectric."in lieu of "renewable energy consumption in aggregate form." Again, the empirical results remain qualitatively similar.[12] Third, to test for the robustness of the FGLS findings, the models are also estimated using the two-step GMM approach. The results are presented in Tables 5 and 6. Lack

11. Following one anonymous reviewer's comment, we computed the figures for "renewables to the electric power sector."by adding up percentages of renewable sources out of total sources for electricity production based on data from World Development Indicators. The country sample remains the same (i.e., 102 countries in total). We find that the sign and statistical significance of coefficient estimates of our variables are qualitatively the same to what we obtained from the original estimation with aggregate renewable energy consumption as the measure for RES. The results are not presented here to conserve space but they are available upon request.

12. Following one anonymous reviewer's comment, we employed "renewables to the electric power sector excluding hydroelectric."for the RES variable. Due to the new data availability, the sample is now reduced to 70 countries only. We find that the results are not qualitatively significantly different as compared to what we obtained from the original estimation with aggregate renewable energy consumption as the measure for RES, in terms of the sign and statistical significance of the coefficient estimates. The results are not presented here to conserve space but they are available upon request.

Table 4: FGLS Estimations: Dependent variable: Emissions

	All countries	High-Income Countries	Upper-Middle-Income Countries	Lower-Middle and Low-Income Countries
Dependent variable: Greenhouse gas emissions				
LOG_NES	0.354***	0.750***	0.622***	0.203***
	(13.21)	(21.75)	(10.92)	(3.30)
LOG_RES	-0.026**	-0.193***	0.002	-0.041
	(-2.13)	(-7.58)	(0.18)	(-0.76)
LOG_Y	0.369***	0.227***	0.250***	0.193
	(7.60)	(3.58)	(2.75)	(1.64)
LOG_GOV	-0.021	-0.026	0.019	-0.064
	(-0.69)	(-0.41)	(0.41)	(-1.20)
LOG_K	0.272***	0.345***	0.168**	0.328***
	(6.06)	(5.95)	(2.01)	(3.66)
LOG_L	0.469***	0.339***	0.090*	0.932***
	(24.20)	(11.09)	(1.73)	(11.31)
_CONS	-1.522***	-0.437**	-0.877**	-1.206***
	(-9.84)	(-2.48)	(-2.54)	(-2.79)
N	1,676	712	445	519
	All countries	High-Income Countries	Upper-Middle-Income Countries	Lower-Middle and Low-Income Countries
Dependent variable: CO_2 emissions				
LOG_NES	0.938***	0.901***	1.057***	0.931***
	(72.78)	(33.32)	(36.93)	(62.39)
LOG_RES	-0.060***	-0.083***	0.020	0.003
	(-10.69)	(-13.43)	(1.54)	(0.21)
LOG_Y	0.061**	-0.021	0.156***	0.191***
	(2.58)	(-0.41)	(3.35)	(6.70)
LOG_GOV	-0.005	-0.100**	0.034	-0.064
	(-0.37)	(-1.97)	(1.40)	(-0.95)
LOG_K	0.050**	0.046*	0.022**	0.029**
	(2.26)	(1.99)	(2.64)	(1.96)
LOG_L	0.085***	0.224***	0.175***	0.006
	(9.18)	(9.16)	(5.56)	(0.28)
_CONS	-1.527***	-0.950***	-1.689***	-2.288***
	(-20.36)	(-6.71)	(-9.54)	(-21.88)
N	1,711	733	459	519
	All countries	High-Income Countries	Upper-Middle-Income Countries	Lower-Middle and Low-Income Countries
Dependent variable: N_2O emissions				
LOG_NES	0.315***	0.310***	0.451***	0.127**
	(11.82)	(5.31)	(7.83)	(2.52)
LOG_RES	-0.196***	-0.199***	-0.282*	0.077*
	(-16.99)	(-14.96)	(1.83)	(1.76)
LOG_Y	0.261***	0.282**	0.211**	0.210**
	(5.33)	(2.57)	(2.29)	(2.17)
LOG_GOV	-0.047	-0.427***	-0.078	-0.097
	(-1.48)	(-3.87)	(-1.64)	(-1.20)
LOG_K	0.318***	0.493***	0.289***	0.183**
	(7.01)	(4.95)	(4.17)	(2.49)
LOG_L	0.496***	0.692***	0.370***	0.691***
	(25.70)	(13.11)	(5.84)	(10.22)
_CONS	-1.761***	-2.277***	-0.764**	-2.268***
	(11.37)	(-7.45)	(-2.14)	(-6.41)
N	1,711	733	459	519

Note: *, ** and *** denote statistical significance at 10%, 5% and 1% respectively. Numbers in parentheses are t-statistics.

Table 5: Robustness checks: GMM Estimations: Dependent variable: Y

	All countries	High-Income Countries	Upper-Middle-Income Countries	Lower-Middle and Low-Income Countries
LOG_NES	0,051***	0.039*	0.092**	0.043**
	(2.63)	(1.85)	(2.03)	(1.97)
LOG_RES	0.043**	0.086**	0.014**	0.039**
	(2.30)	(2.57)	(1.97)	(1.96)
LOG_GHG	0.020**	0.026**	0.012**	0.022**
	(2.03)	(2.08)	(2.64)	(2.25)
LOG_GOV	0.003	0.080**	0.007	0.008
	(1.00)	(2.11)	(1.03)	(0.24)
LOG_K	0.107***	0.142***	0.130***	0.055*
	(5.48)	(3.63)	(3.95)	(1.81)
LOG_L	0.410**	0.163	0.250***	0.408***
	(2.54)	(0.57)	(2.58)	(3.02)
_CONS	0.125	2.006	0.208	0.026
	(0.22)	(1.40)	(0.33)	(0.05)
N	1,580	673	418	489
Sargan test: χ^2	0.24	1.23	2.04	1.97
AR1: t-statistic	-2.47**	-2.45**	-2.60**	-2.45**
AR2: t-statistic	-1.70*	-0.60	-1.64	-0.60

	All countries	High-Income Countries	Upper-Middle-Income Countries	Lower-Middle and Low-Income Countries
LOG_NES	0.051***	0.065**	0.056**	0.031**
	(3.75)	(2.64)	(2.60)	(2.54)
LOG_RES	0.021***	0.022**	0.026**	0.036
	(2.71)	(1.99)	(2.16)	(1.62)
LOG_CO2	0.002	0.037*	0.040**	-0.002
	(0.29)	(1.78)	(2.29)	(-0.30)
LOG_GOV	0.003	0.146***	0.060*	0.001
	(0.77)	(2.92)	(1.74)	(0.39)
LOG_K	0.112***	0.149***	0.103***	0.073***
	(9.01)	(8.00)	(4.47)	(3.78)
LOG_L	0.091**	0.174***	0.157*	0.050**
	(2.53)	(2.73)	(1.74)	(2.07)
_CONS	0.895***	1.302***	0.838***	0.343
	(6.02)	(3.76)	(3.27)	(1.55)
N	1,580	673	418	489
Sargan test: χ^2	0.24	0.26	0.36	0.64
AR1: t-statistic	-2.87***	-4.19***	-2.43**	-2.82***
AR2: t-statistic	-1.40	-1.48	-1.01	-1.77*

	All countries	High-Income Countries	Upper-Middle-Income Countries	Lower-Middle and Low-Income Countries
LOG_NES	0.050***	0.081**	0.053*	0.028**
	(3.82)	(2.22)	(1.71)	(2.32)
LOG_RES	0.021***	0.016**	0.035***	0.037*
	(3.23)	(2.28)	(3.21)	(1.65)
LOG_N_2O	0.007	0.018*	0.007*	0.010*
	(1,16)	(1.81)	(1.95)	(1.94)
LOG_GOV	0.003	0.152***	0.060*	0.002
	(0.85)	(2.83)	(1.72)	(0.52)
LOG_K	0.113***	0.145***	0.106***	0.074***
	(9.45)	(8.43)	(4.71)	(3.88)
LOG_L	0.098***	0.206***	0.134*	0.090**
	(2.59)	(2.97)	(1.95)	(2.13)
_CONS	0.909***	1.197***	0.939***	0.328
	(6.40)	(3.50)	(4.39)	(1.48)
N	1,613	692	432	489
Sargan test: χ^2	2.66	2.20	3.12*	1.02
AR1: t-statistic	-3.87***	-3.79***	-2.38**	-2.82***
AR2: t-statistic	-1.55	-1.44	-1.19	-1.76*

Note: Arellano-Bond dynamic panel-data estimation. *, ** and *** denote statistical significance at 10%, 5% and 1% respectively. Numbers in parentheses are t-statistics.

Table 6: Robustness checks: GMM Estimations: Dependent variable: Emissions

	All countries	High-Income Countries	Upper-Middle-Income Countries	Lower-Middle and Low-Income Countries
Dependent variable: Greenhouse gas emissions				
LOG_NES	0.421**	0.632***	0.521***	0.461***
	(1.96)	(3.92)	(3.50)	(5.85)
LOG_RES	-0.151*	-0.066**	-0.035**	-0.047
	(-1.75)	(-1.96)	(-2.06)	(-1.59)
LOG_Y	0.502	0.202*	0.021**	0.226**
	(1.54)	(1.88)	(2.20)	(1.98)
LOG_GOV	-0.001	-0.064**	0.071	-0.042***
	(-0.03)	(-2.46)	(0.59)	(-2.60)
LOG_K	-0.015	-0.098	1.236***	-0.021
	(-0.12)	(-1.61)	(3.33)	(-0.30)
LOG_L	1.860***	-0.208	1.208**	0.315**
	(2.94)	(-0.62)	(2.62)	(2.33)
_CONS	-2.951	2.702	2.823***	0.288
	(-0.78)	(1.63)	(6.34)	(0.19)
N	1,580	673	418	489
Sargan test: χ^2	0.80	0.71	1.12	1.02
AR1: t-statistic	-2.82***	-2.83***	-2.70**	-1.73*
AR2: t-statistic	-1.77*	-1.81*	-1.56	0.89

	All countries	High-Income Countries	Upper-Middle-Income Countries	Lower-Middle and Low-Income Countries
Dependent variable: CO_2 emissions				
LOG_NES	1.401***	0.708***	0.738***	1.711***
	(3.77)	(16.75)	(6.20)	(3.68)
LOG_RES	-0.361***	-0.043***	-0.165**	-0.378*
	(-2.75)	(-2.72)	(-2.14)	(-1.77)
LOG_Y	2.222*	0.093	1.191**	2.665**
	(2.58)	(1.08)	(2.33)	(2.39)
LOG_GOV	-0.122	-0.030**	-0.068**	-0.090
	(-1.36)	(-2.55)	(-2.50)	(-1.14)
LOG_K	-0.255	0.046**	-0.086	-0.035
	(-1.10)	(2.33)	(-0.71)	(-0.21)
LOG_L	3.595***	0.187**	0.818**	3.631***
	(2.98)	(2.13)	(2.39)	(2.60)
_CONS	-17.919***	-1.482***	-5.956	-31.869***
	(-2.82)	(-3.02)	(-1.59)	(-2.68)
N	1,580	673	418	489
Sargan test: χ^2	1.37	3.35*	2.81	1.94
AR1: t-statistic	-2.50**	-1.96**	2.74**	-2.22**
AR2: t-statistic	-1.08	-1.95*	-1.16	-0.50

	All countries	High-Income Countries	Upper-Middle-Income Countries	Lower-Middle and Low-Income Countries
Dependent variable: N_2O emissions				
LOG_NES	0.183	0.190**	0.281**	0.322**
	(1.60)	(2.12)	(2.31)	(2.15)
LOG_RES	-0.125***	-0.106**	-0.014*	-0.033
	(-2.58)	(-2.05)	(-1.91)	(-0.63)
LOG_Y	0.311***	0.245**	0.278*	0.880*
	(2.72)	(-2.07)	(1.72)	(1.84)
LOG_GOV	-0.281**	-0.139***	0.110	0.050
	(-1.97)	(-3.13)	(0.88)	(0.685)
LOG_K	3.441***	2.899***	1.820***	0.240**
	(4.45)	(2.66)	(5.03)	(2.22)
LOG_L	1.860***	-0.208	1.208**	0.287*
	(2.94)	(-0.62)	(2.62)	(1.81)
_CONS	-2.951	2.702	2.823***	8.195***
	(-0.78)	(1.63)	(6.34)	(4.17)
N	1,613	692	432	489
Sargan test: χ^2	0.89	0.70	3.35*	2.01
AR1: t-statistic	-2.21**	-1.72*	-2.11**	-2.46**
AR2: t-statistic	-0.10	-1.25	-1.95*	-1.73*

Note: *, ** and *** denote statistical significance at 10%, 5% and 1% respectively. Numbers in parentheses are t-statistics.

of substantial differences between the estimates from the two models support the robustness of the FGLS results.[13]

5. POLICY IMPLICATIONS

This study confirms that renewable energy can be a key solution to reducing emissions level across the globe and that renewable energy contributes significantly to economic development. As such, it is important to look at policies that encourage the use of renewable energy across the globe. However, for middle- and low-income countries, RES does not affect GHG emissions and there is still a lot of scope for policy improvement in developing countries if they are to use RES to tackle environmental problems.

Renewable energy development over the last decade has been mainly led by high income countries and emerging economies. Some positive progress is being made recently in developing world. New global investment reached US$270.2 billion in 2014, driven by solar power installations in China and Japan and offshore wind projects in Europe (UNECE *Renewable Energy* Status, 2015). With regard to new global investment in renewable power and fuels, the annual investment developed countries reached US$138.9 billion in 2014, representing an increase of 3% since 2013. Meanwhile, developing countries invested US$131.3 billion, which represents an increase of 36% over 2013 (UNECE *Renewable Energy* Status, 2015). Expansion of investments is expected to lower technology costs and foster market development. This has been a policy driven process, fueled by subsidies.

For years, renewable energy technology was erroneously seen as a costly luxury by some critics, affordable only for rich countries. However, 2015 was the first year when investment in non-hydro renewables was higher in developing countries than advanced countries, with investments reaching US$156 billion, mainly in China, India, and Brazil (FS-UNEP Collaborating Centre, 2016). The technical potential for renewable energy in the developing world is enormous (see Baulch et al (2018) for Vietnam). Many developing countries have abundant renewable energy resources, such as biomass, geothermal energy, solar energy, and wind power, as well as the ability to manufacture the relatively labor-intensive systems that harness these energy sources (Flavin and Aeck, 2010). By developing RES, developing countries can reduce their dependence on oil and natural gas, creating energy portfolios that are less vulnerable to oil and other energy price fluctuations. In many circumstances, these investments can be less expensive than fossil fuel *Energy Systems*. Developing countries are now learning from the pioneering experiences of r developed countries. Nevertheless, renewable energy markets in the developing world are still progressing slowly due to key economic, financial, and technical barriers. As such, policy can play a vital role in lowering barriers and risks.

Second, the empirical evidence of this study implies that even though nonrenewable energy had contributed to higher emissions levels across the globe, one must be careful when imple-

13. Following one anonymous reviewer's comment, we have tried to sort out and match our study sample to the 80 countries as in the study by Apergis and Payne (2011). The study by Apergis and Payne (2011) includes a set of different variables compared to ours. Specifically, their 5 variables are: RE, NRE, K and L as explanatory variables for Y. Meanwhile, our study includes RE, NRE, EMI, GOV, K, L and Y in the baseline model with Y and EMI are considered dependent variables in two separate models. As such, we could include only 70 countries out of the 80 countries as in the study sample of Apergis and Payne (2011) due to the availability of the required data set for our variables. We find that the results with fewer countries are only somewhat different (i.e., the statistical significance of GOV coefficients in several cases of middle-income country groups). Apart from that, we can mostly retain what we conclude from our original (and bigger) sample of 102 countries for other variables that are our main interests in this study.

menting energy conservation policies since they may reduce economic growth. This is also implied by the positive association found between economic growth and emissions level. On the other hand, since the results indicate that renewable energy increases income, policymakers may seek to replace nonrenewable energy with renewable energy. This substitution can help maintain the level of energy input required for sustaining economic growth, while reducing the emissions levels at a global scale. Green and Yatchew (2012) discuss leading approaches to the decarbonisation of electricity supply. Price supports through long term contracts, such as feed-in-tariffs, have been very effective at promoting rapid escalation of renewable supply, largely because risks have been transferred away from suppliers and tariffs have been generous. Masui et al. (2006) suggested some viable solutions to climate change, including adopting environmentally sustainable technologies, energy saving, improving energy efficiency, forest conservation, reforestation, and water conservation. The promotion of RES is another widely accepted solution to the mitigation of CO_2 emissions. Krewitt et al. (2007) argue that RES could provide as much as half of the world's energy needs by 2050 under a target-oriented scenario that prevents any dangerous anthropogenic interference with the climate system. In this context, RES is expected to play a key role in global energy sustainability.

The renewable energy industry also generates other significant economic benefits. For example, local governments can collect property and income taxes and other payments from renewable energy projects. These revenues can be used to support vital public services, particularly in rural communities where such projects are often located. Finally, the empirical findings imply that the reduction in GHG emissions can go hand in hand with economic development, which would further strengthen environmental protection at the global level.

6. CONCLUSION

This study empirically examines the relationship between renewable energy sources and green growth. While there is a large empirical literature on the energy-growth nexus and the relationships between emissions, energy and growth, there are no studies that use a global sample and very few studies that separately examine the effects of renewable energy and nonrenewable energy sources. The lack of global studies and failure to separately consider both renewable and non-renewable energy in the energy-emissions-economic growth literature is partly due to lack of data on renewable energy resources for a large number of countries. Furthermore, many studies ignore key structural factors underlying the relationship between emissions, energy and income which can hinder the ability of a government to tackle environmental degradation. Such institutional factors, including bureaucratic inefficiency, the influence of special-interest groups, and the resistance of state-owned enterprises, are captured in the Index of Economic Freedom, which is used in this study. This factor is explicitly incorporated into the empirical analysis of GHG emissions for a global sample of countries.

This study examines the relationship between energy consumption, emissions, income and governance for a panel data of 102 countries for 1996 to 2012. For the full sample of countries, it is found that both renewable and non-renewable energy consumption contribute significantly to income. The finding also holds across different groups of countries.[14] This suggests that policies which

14. We conducted tests for differences in coefficients of different income groups of countries. Specifically, we generate dummies for RES, NES, and GOV to account for different groups of income classification. We then put them together into the same equations to perform estimation and then test for differences in coefficients using F-tests. Chi-square statistics are all significant at 5% which indicates the statistical differences across groups. As such, it justifies our separation of the whole sample into subsamples by income level.

promote the use of renewable energy can benefit economic development. The empirical results also show that better governance improved environmental performance in high-income countries. However, for middle- and low-income countries, the effect of governance on the environment was negligible. This is consistent with Le et al (2016) who find that governance does not have a significant effect on environmental performance in middle- and low-income countries. This implies that these countries have relatively weak environmental policies which need to be strengthened.

As expected, an increase in non-renewable energy consumption caused a significant increase in the level of emissions for different income groups of countries. However, the effect of renewable energy sources on the level of emissions for different income groups of countries is more ambiguous. For the high-income sub-sample, renewable energy appears to benefit the environment, while for upper-middle-income countries and low and lower-middle-income countries, the effect of renewable energy is insignificant. The evidence thus suggests that renewable energy sources contribute significantly to environmental protection in developed countries. In contrast, developing countries are still struggling to utilize renewable energy sources to tackle GHG emissions, implying substantial scope for policy improvements in this area. The results are robust to different measures of GHG emissions.

REFERENCES

Agénor, P.R. (2017). "Caught in the Middle? The Economics of Middle-Income Traps." *Journal of Economic Surveys* 31(3): 771-791. https://doi.org/10.1111/joes.12175.

Alkhathlan, K. and M. Javid (2013). "Energy consumption, carbon emissions and economic growth in Saudi Arabia: an aggregate and disaggregate analysis." *Energy Policy* 62: 1525-1532. https://doi.org/10.1016/j.enpol.2013.07.068.

Alshehry, A.S. and M. Belloumi (2015). "Energy consumption, carbon dioxide emissions and economic growth: The case of Saudi Arabia." *Renewable and Sustainable Energy Reviews* 41: 237-247. https://doi.org/10.1016/j.rser.2014.08.004.

Ang, J.B. (2007). "CO2 emissions, energy consumption, and output in France." *Energy Policy* 35(10): 4772-4778. https://doi.org/10.1016/j.enpol.2007.03.032.

Apergis, N. and J.E. Payne (2010). "*Renewable Energy* Consumption and Economic Growth: Evidence from a Panel of OECD Countries." *Energy Policy* 38: 656-660. https://doi.org/10.1016/j.enpol.2009.09.002.

Apergis, N. and J.E. Payne (2011). "On the causal dynamics between renewable and non-renewable energy consumption and economic growth in developed and developing countries." *Energy Systems* 2(3): 299-312. https://doi.org/10.1007/s12667-011-0037-6.

Apergis, N. and J.E. Payne (2012). "Renewable and non-renewable energy consumption-growth nexus: Evidence from a panel error correction model." *Energy Economics* 34(3): 733-738. https://doi.org/10.1016/j.eneco.2011.04.007.

APEC (2014). "APEC Targets Doubling of *Renewable Energy*." APEC News Releases, 21st November 2014. Retrieved on 7th September, 2016. Available at: http://www.apec.org/Press/News-Releases/2014/1121_renewables.aspx.

Armeanu, D.Ș., G. Vintilă and S.C. Gherghina (2017). "Does renewable energy drive sustainable economic growth? Multivariate panel data evidence for EU-28 countries." *Energies* 10(3): 381. https://doi.org/10.3390/en10030381.

Arouri, M.E.H., A.B. Youssef, H. M'henni, and C. Rault (2012). "Energy consumption, economic growth and CO2 emissions in Middle East and North African countries." *Energy Policy* 45: 342-349. https://doi.org/10.1016/j.enpol.2012.02.042.

Auteri, M. and M. Constantini (2005). "Intratemporal Substitution and Government Spending: Unit Root and Cointegration Tests in a Cross Section Correlated Panel." XVII Conference Paper, Societa Italiana di economia pubblica, Pavia, Universita. Retrieved on 17th September, 2016. Available at: http://www-3.unipv.it/websiep/wp/419.pdf.

Baltagi, B. (2008). *Econometric analysis of panel data*. John Wiley & Sons. New York.

Barrett, S. and K. Graddy (2000). "Freedom, growth, and the environment." *Environment and development economics* 5(4): 433-456. https://doi.org/10.1017/S1355770X00000267.

Barro, R.J. and J.W. Lee (2013). "A new data set of educational attainment in the world, 1950-2010." *Journal of development economics* 104: 184-198. https://doi.org/10.1016/j.jdeveco.2012.10.001.

Baulch, B., D. Do, and T.H. Le (2018). "Solar Home Systems in Ho Chi Minh City: A promising technology whose time has not yet come." *Renewable Energy* 118: 245-256. https://doi.org/10.1016/j.renene.2017.10.106.

Belke, A., F. Dobnik, and C. Dreger (2011). "Energy consumption and economic growth: New insights into the cointegration relationship." *Energy Economics* 33(5): 782-789. https://doi.org/10.1016/j.eneco.2011.02.005.

Brunnschweiler, C.N. (2010). "Finance for renewable energy: an empirical analysis of developing and transition economies." *Environment and development economics* 15(3): 241-274. https://doi.org/10.1017/S1355770X1000001X.

Bhattacharya, M., S.A. Churchill, and S.R. Paramati (2017). "The dynamic impact of renewable energy and institutions on economic output and CO2 emissions across regions." *Renewable Energy* 111: 157-167. https://doi.org/10.1016/j.renene.2017.03.102.

Bhattacharya, M., S.R. Paramati, I. Ozturk, and S. Bhattacharya (2016). "The effect of renewable energy consumption on economic growth: Evidence from top 38 countries." *Applied Energy* 162: 733-741. https://doi.org/10.1016/j.apenergy.2015.10.104.

Bruns, S.B., C. Gross and D.I. Stern (2014). "Is there really Granger causality between energy use and output?" *The Energy Journal* 101-133. https://doi.org/10.2139/ssrn.2331340.

Chang, C.C. (2010). "A multivariate causality test of carbon dioxide emissions, energy consumption and economic growth in China." *Applied Energy* 87(11): 3533-3537. https://doi.org/10.1016/j.apenergy.2010.05.004.

Chien, T. and J.L. Hu (2007). "Renewable Energy and Macroeconomic Efficiency of OECD and non-OECD Economies." *Energy Policy* 35: 3606-3615. https://doi.org/10.1016/j.enpol.2006.12.033.

De Vita, G. and K.S. Kyaw (2016). "Tourism development and growth." *Annals of Tourism Research* 60(9): 23-26. https://doi.org/10.1016/j.annals.2016.05.011.

Di Iorio, F. and S. Fachin (2007). "Testing for breaks in cointegrated panels-with an application to the Feldstein-Horioka puzzle." *Economics: The Open-Access, Open-Assessment E-Journal* 1. https://doi.org/10.2139/ssrn.1716662.

Domac, J., K. Richards and S. Risovic (2005). "Socio-economic Drivers in Implementing Bioenergy Projects." *Biomass and Bioenergy* 28: 97-106. https://doi.org/10.1016/j.biombioe.2004.08.002.

Drukker, D.M. (2003). "Testing for serial correlation in linear panel-data models." *Stata Journal* (3)2: 168-177. https://doi.org/10.1177/1536867X0300300206.

European Commission (2001). Directive 2001/77/ec of the European parliament and of the council of 27 September 2001 on the promotion of electricity produced from renewable energy sources in the internal electricity market. *Official Journal of the European Communities L*, 283/33-40.

European Commission (2009). Directive 2009/28/EC of the European parliament and of the council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC. *Official Journal of the European Union L*, 140/16-62 5.6.2009.

Fang, Z. and T.H. Le (2019). "Cointegrating Relationship and Granger Causal Analysis in *Energy Economics* - A Practical Guidance." In: *Handbook of Energy Finance: Theories, Practices and Simulations*, Eds: Stéphane Goutte and Nguyen Duc Khuong, World Scientific Publishing.

Flavin, C. and M.H. Aeck (2010). "Energy for development." The Potential Role of Renewable Energy in Meeting the Millennium Development Goals (Paper prepared for the REN21 Network). Retrieved on 4th November, 2016. Available at: http://www.worldwatch.org/system/files/ren21-1.pdf.

FS-UNEP Collaborating Centre (2016). "Global Trends in Renewable Energy Investment 2016." Frankfurt School-UNEP Centre/BNEF 2016. Retrieved on 4th November, 2016. Available at: http://fs-unep-centre.org/sites/default/files/publications/globaltrendsinrenewableenergyinvestment2016lowres_0.pdf.

Green, R. and A. Yatchew (2012). "Support schemes for renewable energy: an economic analysis." *Stata Economics of Energy & Environmental Policy* 1(2): 83-98. https://doi.org/10.5547/2160-5890.1.2.6.

Greene, W.H. (2008). *Econometric Analysis* (6th ed.). Upper Saddle River, NJ: Prentice Hall.

IEA (2016). "Key renewables trends. Extracted from: Renewables Information (2016 edition)." International Energy Agency. Retrieved on 13th November, 2016. Available at: https://www.iea.org/publications/freepublications/publication/KeyRenewablesTrends.pdf.

IPCC (2014). "Climate Change 2014: Mitigation of Climate Change." Working Group III Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

International *Renewable Energy* Agency (IRENA) (2013). "Renewable Energy Jobs: Status, Prospects & Policies." IRENA Working Paper. Retrieved on 29th May 2018. Available at: http://www.irena.org/documentdownloads/publications/renewableenergyjobs.pdf.

Kahia, M., M.S.B. Aïssa, and L. Charfeddine (2016). "Impact of renewable and non-renewable energy consumption on economic growth: New evidence from the MENA Net Oil Exporting Countries (NOECs)." *Energy* 116: 102-115. https://doi.org/10.1016/j.energy.2016.07.126.

Karanfil, F. and Y. Li (2015). "Electricity consumption and economic growth: exploring panel-specific differences." *Energy Policy* 82: 264-277. https://doi.org/10.1016/j.enpol.2014.12.001.

Krewitt, W., S. Simon, W. Graus, S. Teske, A. Zervos, and O. Shaefer (2007). "The 2 Degrees C Scenario-A Sustainable World Energy Perspective." *Energy Policy* 35: 4969-4980. https://doi.org/10.1016/j.enpol.2007.04.034.

Le, T.H, Y.H. Chang, and D.H. Park (2016). "Governance, Vulnerability to Climate Change, and Green Growth: International Evidence." Working paper No. 500, November 2016, ADB Economics Working Paper Series. https://doi.org/10.2139/ssrn.2894763.

Le, T.H. and P.C. Nguyen (2019). "Is energy security a driver for economic growth? Evidence from a global sample." *Energy Policy* 129: 436-451. https://doi.org/10.1016/j.enpol.2019.02.038.

Le, T.H. (2016). "Dynamics between energy, output, openness, and financial development: Evidence from Sub-Saharan African countries." *Applied Economics* 48(10): 914-933. https://doi.org/10.1080/00036846.2015.1090550.

Le, T.H. and E. Quah (2018). "Income level and the emissions, energy and growth nexus: Evidence from Asia and the Pacific." *International Economics* 156(C): 193-205. https://doi.org/10.1016/j.inteco.2018.03.002.

Lee, C.C. and J.D. Lee (2010). "A panel data analysis of the demand for total energy and electricity in OECD countries." *The Energy Journal*: 1-23. https://doi.org/10.5547/ISSN0195-6574-EJ-Vol31-No1-1.

Leitao, A. (2010). "Corruption and the Environmental Kuznets Curve: Empirical Evidence for Sulfur." *Ecological Economics* 69(11): 2191-2201. https://doi.org/10.1016/j.ecolecon.2010.06.004.

Liddle, B. (2013). "The energy, economic growth, urbanization nexus across development: Evidence from heterogeneous panel estimates robust to cross-sectional dependence." *The Energy Journal*: 223-244. https://doi.org/10.5547/01956574.34.2.8.

Long, X., E.Y. Naminse, J. Du, and J. Zhuang (2015). "Nonrenewable energy, renewable energy, carbon dioxide emissions and economic growth in China from 1952 to 2012." *Renewable and Sustainable Energy Reviews* 52: 680-688. https://doi.org/10.1016/j.rser.2015.07.176.

Loris, N.D. (2015). "Economic freedom, energy, and development." T. Miller and AB Kim (Eds.), 2015. *Index of economic freedom*: 57-68.

Masui, T., T. Hanaoka, S. Hikita and M. Kainuma (2006). "Assessment of CO2 Reductions and Economic Impacts Considering Energy-Saving Investments." *The Energy Journal* 1: 175-190. https://doi.org/10.5547/ISSN0195-6574-EJ-VolSI2006-NoSI1-8.

Menegaki, A.N. (2011). "Growth and renewable energy in Europe: A random effect model with evidence for neutrality hypothesis." *Energy Economics* 33: 257-263. https://doi.org/10.1016/j.eneco.2010.10.004.

Menyah, K. and Y. Wolde-Rufael (2010). "CO_2 emissions, nuclear energy, renewable energy and economic growth in the US." *Energy Policy* 38(6): 2911-2915. https://doi.org/10.1016/j.enpol.2010.01.024.

Ouedraogo, N.S. (2013). "Energy consumption and economic growth: Evidence from the economic community of West African States (ECOWAS)." *Energy Economics* 36: 637-647. https://doi.org/10.1016/j.eneco.2012.11.011.

Ozcan, B. (2013). "The nexus between carbon emissions, energy consumption and economic growth in Middle East countries: A panel data analysis." *Energy Policy* 62: 1138-1147. https://doi.org/10.1016/j.enpol.2013.07.016.

Ozturk, A. (2016). "Examining the economic growth and the middle-income trap from the perspective of the middle class." *International Business Review* 25(3): 726-738. https://doi.org/10.1016/j.ibusrev.2015.03.008.

Pao, H.T. and C.M. Tsai (2010). "CO_2 emissions, energy consumption and economic growth in BRIC countries." *Energy Policy* 38: 7850-7860. https://doi.org/10.1016/j.enpol.2010.08.045.

Pesaran, M.H. (2007). "A simple panel unit root test in the presence of cross-section dependence." *Journal of Applied Econometrics* 22: 265-312. https://doi.org/10.1002/jae.951.

Pesaran, M.H., L.V. Smith and T. Yamagata (2013). "Panel unit root tests in the presence of a multifactor error structure." *Journal of Econometrics* 175(2): 94-115. https://doi.org/10.1016/j.jeconom.2013.02.001.

Roberts, J.M. and R. Olson (2013). "How economic freedom promotes better health care, education, and environmental quality." Heritage Foundation Washington, DC.

Saboori, B. and J. Sulaiman (2013). "Environmental degradation, economic growth and energy consumption: Evidence of the environmental Kuznets curve in Malaysia." *Energy Policy* 60: 892-905. https://doi.org/10.1016/j.enpol.2013.05.099.

Samargandi, N., J. Fidrmuc, and S. Ghosh (2015). "Is the relationship between financial development and economic growth monotonic? Evidence from a sample of middle-income countries." *World Development* 68: 66-81. https://doi.org/10.1016/j.worlddev.2014.11.010.

Sebri, M. and O. Ben-Salha (2014). "On the causal dynamics between economic growth, renewable energy consumption, CO_2 emissions and trade openness: fresh evidence from BRICS countries." *Renewable and Sustainable Energy Reviews* 39: 14-23. https://doi.org/10.1016/j.rser.2014.07.033.

Shafiei, S. and R.A. Salim (2014). "Non-renewable and renewable energy consumption and CO_2 emissions in OECD countries: a comparative analysis." *Energy Policy* 66: 547-556. https://doi.org/10.1016/j.enpol.2013.10.064.

Soytas, U., R. Sari, and B.T. Ewing (2007). "Energy consumption, income, and carbon emissions in the United States." *Ecological Economics* 62(3): 482-489. https://doi.org/10.1016/j.ecolecon.2006.07.009.

Stern, N.H. (2007). *The economics of climate change: The Stern review*. Cambridge University Press. https://doi.org/10.1017/CBO9780511817434.

Stern, D.I. and A. Kander (2012). "The role of energy in the industrial revolution and modern economic growth." *The Energy Journal*: 125-152. https://doi.org/10.5547/01956574.33.3.5.

Tang, C.F., B.W. Tan, and I. Ozturk (2016). "Energy consumption and economic growth in Vietnam." *Renewable and Sustainable Energy Reviews* 54: 1506-1514. https://doi.org/10.1016/j.rser.2015.10.083.

Tiwari, A.K. (2011). "A structural VAR analysis of renewable energy consumption, real GDP and CO_2 emissions: Evidence from India." Economics Bulletin 31(2): 1793-1806.

UNECE *Renewable Energy* Status (2015). Retrieved on 20th September, 2016. Available at: https://www.unece.org/fileadmin/DAM/energy/se/pp/EnComm24_Nov.2015/gere_2_Hullin_REN21.pdf.

US National Research Council (2008). "Understanding and Responding to Climate Change." Board on Atmospheric Sciences and Climate, US National Academy of Sciences, p.2.

Westerlund, J. (2008). "Panel cointegration tests of the Fisher effect." *Journal of Applied Econometrics* 23(2): 193-233. https://doi.org/10.1002/jae.967.

Wood, J. and I. Herzog (2014). "Economic Freedom and Air Quality." Fraser Institute, Vancouver, Canada.

Wooldridge, J.M. (2010). *Econometric analysis of cross section and panel data* (2nd ed). The MIT Press. Cambridge, Massachusetts.

World Development Indicators (2017). The World Bank. Retrieved on 30th March 2018. Available at: https://datacatalog.worldbank.org/dataset/world-development-indicators.

Yıldırım, E., D. Sukruoglu and A. Aslan (2014). "Energy consumption and economic growth in the next 11 countries: The bootstrapped autoregressive metric causality approach." *Energy Economics* 44: 14-21. https://doi.org/10.1016/j.eneco.2014.03.010.