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IMPACT OF ENERGY EFFICIENCY AND RENEWABLE ENERGY ON ENVIRONMENTAL SUSTAINABILITY: EVIDENCE FROM EMERGING MARKET ECONOMIES

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Abstract

Since the era of the Industrial Revolution, energy consumption has considerably increased. As a consequence, a significant rise in greenhouse gas emissions has become a serious threat to environmental sustainability through climatic changes, global warming, natural disasters and pollution. In this context, increasing energy efficiency as well as the use of renewable energy can serve as important instruments for reduction of greenhouse gas emissions. The related literature has thus far generally focused on the impact of energy efficiency on greenhouse gas emissions at the sectoral level in developed countries, whereas this study explores the impact of energy efficiency and the use of renewable energy on greenhouse gas emissions in 22 emerging economies by applying Westerlund and Edgerton's (2007) LM bootstrap cointegration test. It reveals that energy efficiency reduces greenhouse gas emissions, but economic growth enhances greenhouse gas emissions in the long term.

Key words: carbon dioxide emissions, energy efficiency, environmental sustainability, greenhouse gas emissions, panel cointegration analysis

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1. Introduction

Despite some disruptions resulting mainly from world wars, regional conflicts, civil wars, economic crises and political instability, the globalized world has achieved significant improvements in the area of economic growth and development since the era of the Industrial Revolution. However, the considerable increase in global production and consumption has been accompanied by serious environmental issues, such as pollution, climatic change, natural resource depletion, deforestation, biodiversity loss, and waste disposal. Hence, environmental sustainability has become one of the critical, common issues faced by humankind. In this context, climatic change, global warming, and natural disasters are the leading environmental challenges being driven mainly by greenhouse gases consisting of carbon dioxide, nitrous oxide, methane, water vapour, ozone, and other chemicals, with CO_2 forming about 80% of these greenhouse gases (EPA, 2018). CO_2 is the primary long-lasting greenhouse gas in the atmosphere, and the CO_2 concentration reached 405.5 parts per million (146% of the pre-industrial level) in 2017 (WMO, 2018). The above-mentioned increases in the global CO_2 level in the atmosphere reduce the Earth's ability to radiate heat into space, which, in its turn, leads to global warming (Guerrero-Lemus and Martínez-Duart, 2013). Electricity and heat generation, transportation, and industry have been documented as the main sources of global CO_2 emissions (IEA, 2018).

Many national and international efforts, such as the 1992 United Nations Framework Convention on

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Climate Change, the Kyoto Protocol, and the 2015 Paris agreement, have been made to combat the climatic change, and scholars are paying increasing attention to the effects and determinants of greenhouse gas emissions. Previous studies revealed that many demographic, institutional, economic, and socio-cultural factors, such as age structure, urbanization, industrialization, type of government, institutional quality, economic growth, financial development, foreign direct investment inflows, use of fossil fuels, technological progress, and globalization, are the major determinants of greenhouse gas emissions (de Souza et al., 2018; Dogan and Inglesi-Lotz, 2017; Gianmoena and Rios, 2018; Máté-Balogh and Jambor, 2017; Mironiuc and Huian, 2017; Onofrei et al., 2017; Morales-Lage et al., 2016; Zhou et al., 2018). In addition, some scholars focus on the validity of the environmental Kuznets curve (EKC) (Ozturk and Al-Mulali, 2015; Sarkodie and Strezov, 2019).

Considering the research gap in the relevant literature, in this study we investigate the impact of energy efficiency and globalization on greenhouse gas emissions; based on a few empirical studies for emerging economies, our econometric models include the use of renewable energy and economic growth as control variables. In this context, improvements in energy efficiency mean employing less energy for the same output level, thus making a contribution towards reduction of greenhouse gas emissions. Renewable energy, including solar energy, wind energy, biomass energy, geothermal energy, etc., is also regarded as a clean source that can provide energy with near-zero harmful gases (Panwar et al., 2011). Therefore, the use of renewable energy is theoretically expected to decrease greenhouse gas emissions. Also, the projections reveal that CO_2 emissions can be decreased by 70% from now until 2050 if 80% of power generation and 65% of the total primary energy supply could be obtained through renewable energy sources (OECD/IEA & IRENA Report, 2017).

Furthermore, on the one hand, globalization may increase overall income and encourage countries to make environmental improvements; on the other hand, globalization may negatively affect the environment through the effects of scale. Thus, the net effect of globalization on greenhouse gas emissions depends on which impact outweighs the other (OECD, 2010). Lastly, the interaction between CO_2 emissions and economic growth is generally expressed by employing the EKC hypothesis, but the findings about the validity of EKC are mixed (Aye and Edoja, 2017; e.g., Ozturk and Al-Mulali, 2015; Sarkodie and Strezov, 2019).

The global carbon dioxide emissions amounted to about 33242.52 million tonnes of carbon dioxide in 2017, China taking the leading position with 9229.7 million tonnes of carbon dioxide, and the United States of America, India, the Russian Federation, Japan, Germany, South Korea, Iran, Saudi Arabia, Canada, and Indonesia respectively following China in terms of carbon dioxide emissions. In this regard, although the emerging economies, such as China, South Korea, India, the Russian Federation, Indonesia, Mexico, Brazil and South Africa are the major drivers of the global economy that have experienced significant positive economic performances during the past three decades, they have also made most significant contribution to the global greenhouse gas emissions, as seen in Table 1. Further, all of the emerging economies, except the Czech Republic, Hungary, and the Russian Federation, experienced considerable increases in their CO_2 emissions between 1965 and 2017.

Table 1. Carbon dioxide emissions in emerging markets (million tonnes of carbon dioxide)

Countries	***1965***	***2017***
Brazil	51.5	466.8
Chile	16.7	92.3
China	488.5	9232.6
Colombia	21.3	84.7
Czech Republic	**156.2**	**103.9**
Egypt	22.9	217.3
Greece	22.5	74.9
Hungary	**59.5**	**47.7**
India	167.7	2344.2
Indonesia	20.1	511.5
Korea Rep.	24.9	679.7
Malaysia	7.0	255.8
Mexico	62.1	473.4
Pakistan	19.5	189.2
Peru	12.1	50.9
Philippines	13.2	119.9
Poland	253.0	308.6
Russian Federation	**2173.0***	**1525.3**
South Africa	115.2	415.6
Thailand	7.4	298.8
Turkey	25.1	410.9
United Arab Emirates	0.2	267.3

*the 1985 value, Source: BP (2018)

This study aims to investigate the long-run influence of energy efficiency and renewable energy along with globalization and economic growth on both CO_2 and greenhouse gas emissions in a sample of emerging economies by applying Westerlund and Edgerton’s (2007) LM bootstrap cointegration test that regards cross-sectional dependence and heterogeneity, and also produces robust results for small samples. We reveal that energy efficiency reduces, while economic growth raises greenhouse gas emissions in the long run, but neither the use of renewable energy nor globalization have any significant effects on greenhouse gas emissions for the overall panel. The contributions of the study to the relevant literature can be summarized as follows: first, the relevant literature concerning the energy efficiency-environment nexus has thus far been limited, and previous studies were generally conducted at the sectoral level, such as manufacturing, iron and steel industry, cement industry, transportation, and lighting, while this study investigates the impact of energy efficiency on CO_2 emissions at the macro level, and will therefore be useful for examining the effects of energy efficiency improvement on the overall economic environment; secondly, a limited number of scholars have thus far researched the impact of energy efficiency and the use of renewable energy on the environment in emerging economies, although namely emerging economies have lately been the main drivers of the global economy, and such economies as Brazil, China, India, Indonesia, Mexico and South Africa alone consume one-third of the world's energy (IEA, 2018; 2019). The next section of this study summarizes the literature concerning the determinants of CO_2 emissions, the energy efficiency-CO_2 emission nexus, and the renewables-CO_2 emission nexus. Then Section 3 explains the dataset and the empirical research method, while the analysis itself is described in Section 4. Lastly, the major conclusions and policy recommendations are presented in Section 5.

2. Relevant literature review

The global climatic change, ozone layer depletion, polar ice cap melting and natural disasters, all resulting mainly from greenhouse gas emissions and CO_2 emissions, have greatly increased scientific interest in both the determinants of greenhouse gasses and CO_2 emissions, and the possible measures to reduce the amounts of these harmful gases. In this regard, some part of the relevant literature focuses on the demographic, institutional framework (such as political democracy, economic freedom, and corruption), economic factors (such as economic growth, urbanization, industrialization, energy consumption, energy intensity, financial sector development, trade liberalization, foreign direct investment), and socio-cultural factors (such as consumers' lifestyle, attitudes and environmental awareness) that are or might be involved in CO_2 emissions (e.g. see Bae et al., 2016; Balogh and Jámbor, 2017; Luqman et al., 2019; Tajudeen et al., 2018; Wang et al., 2018; Wang et al., 2019a; Wang et al., 2019b), while other scholars investigate the validity of the EKC (e.g. see Dogan and Seker, 2016; Sarkodie and Strezov, 2019; Sharma, 2011;). However, relatively few studies have thus far investigated the impact of energy efficiency on the environment, although improvements in energy efficiency can make a significant contribution to environmental sustainability and can also be treated as a key factor for decoupling economic growth from fuel consumption (Wang et al., 2019b).

The main aim of this study is to investigate the impact of the improvements in energy efficiency on the environment at the macro level by considering the related literature. In the relevant literature, Tajudeen et al. (2018) explored the effect of energy efficiency on CO_2 emissions in 30 OECD members at the macro level and discovered that rising energy efficiency makes the largest contribution to the reduction of CO_2 emissions. The remaining studies, addressing the energy efficiency-environment nexus, were conducted at different sectoral levels (such as manufacturing, iron and steel industry, cement industry, transportation and lighting), as seen in Table 2. In this context, sectoral investigation of the nexus between energy efficiency and environment revealed that the improvements in energy efficiency make a significant contribution to mitigation of greenhouse gas emissions. However, while exploring the impact of energy efficiency on greenhouse gas emissions in the overall economy, it would be useful to research the general outcomes of energy efficiency policies and develop the new policies for environmental sustainability.

The impact of the globalization process on the environment was also investigated in very few studies, while some recent studies provided mixed findings, as expected theoretically. In this context, Shahbaz et al. (2018) researched the impact of globalization and its major components on CO_2 emissions in China over the period 1970-2012 by employing a time series analysis, and revealed that globalization reduced CO_2 emissions. Shahbaz et al. (2017) also investigated the impact of globalization on CO_2 emissions in Japan over the period 1970-2014, and found that globalization reduced CO_2 emissions in the short run, but raised CO_2 emissions in the long run. Haseeb et al. (2018) explored the same relationship for BRICS (Brazil, Russia, India, China, and South Africa) countries, but revealed no significant interaction between globalization and CO_2 emissions.

Table 2. Literature summary on the nexus between energy efficiency and environment

Study	***Sample***	***Sector***	***Findings***
Stefano (2000)	Melbourne University	Lighting systems	An energy-efficient lighting system reduced carbon dioxide emissions by about 10%
Worrell et al. (2001)	United States of America	Iron and steel industry	Increases in energy productivity were able to reduce CO_2 emissions by 19%
Pardo et al. (2011)	EU	Cement industry	An 11% decrease in the use of thermal energy per tonne of clinker led to a 3.7% decrease in CO_2 emissions
Pardo-Martínez and Silveira (2013)	Sweden	Manufacturing industry	Improvements in energy efficiency contributed to the reduction in CO_2 emissions
González et al. (2019)	Western EU countries	Transportation sector	Technological progress and improvements in fuel efficiency decreased CO_2 emissions
Martínez-Moya et al. (2019)	Port of Valencia	Port industry	Improvements in energy efficiency made a contribution to the reduction in CO_2 emissions

In our model, we included the use of renewable energy and economic growth as control variables. Relatively many scholars researched the interaction between the use of renewable energy and CO_2 emissions, and their studies would typically reveal that the improvements in the use of renewable energy made a significant contribution to the mitigation of CO_2 emissions. In one of such papers, Silva et al. (2012) explored the impact of the use of renewable energy for electricity production on CO_2 emissions in the US, Denmark, Portugal and Spain over the period 1960-2004 by employing a structural VAR, and revealed that increases in the use of renewable energy had a negative impact on CO_2 emissions. Qi et al. (2014) examined the impact of the use of renewable energy on CO_2 emissions under different scenarios by employing a general equilibrium model, and found that the use of renewable energy would decrease CO_2 emissions.

By applying panel cointegration and causality analyses, Dogan and Seker (2016) explored what effects the use of renewable energy had on CO_2 emissions in EU-15 countries between 1980 and 2012, and discovered that the use of renewable energy negatively affected CO_2 emissions and there existed a two-way causal interaction between CO_2 emissions and the use of renewable energy. Abolhosseini et al. (2014) reached similar conclusions with the same sample. Further, Kahia et al. (2016) analysed the impact of the use of renewable energy on CO_2 emissions in the MENA (Middle East and North Africa) region over the period 1980-2012 via a panel VAR and discovered that renewable energy utilization decreased CO_2 emissions.

Twumasi (2017) researched the interaction between CO_2 emissions and the use of renewable energy in the US, but found no significant relationship between the variables. Bulut (2017) explored the impact of the use of renewable energy on CO_2 emissions in Turkey by using the time-varying parameter estimation method for the 1970-2013 period and revealed an increasing effect of the use of renewable energy on CO_2 emissions. Li and Su (2017) explored the impact of the use of renewable energy on carbon dioxide emissions in the US over the period 1990-2015 via a VAR model and found that the use of renewable energy would initially increase CO_2 emissions, but later would decrease them considerably. Lastly, Khoshnevis-Yazdi and Falahatparvar (2017) analysed the effects of the use of renewable energy on CO_2 emissions in 13 EU states for the 1992–2014 period via panel causality and cointegration tests and discovered that the use of renewable energy had a negative effect on CO_2 emissions in the long run.

Summarising, the interaction between CO_2 emissions and economic growth was previously investigated in a large number of studies via the EKC hypothesis, but the findings were mixed (e.g., Altıntaş and Kassouri, 2020; Aye and Edoja, 2017; Dogan and Seker, 2016; Ozturk and Al-Mulali, 2015; Sarkodie and Strezov, 2019; Shaheen et al., 2020;).

3. Data and econometric methodology

This study examines the impact of energy efficiency and the use of renewable energy, along with globalization and economic growth, on CO_2 and greenhouse gas emissions in emerging economies through a panel cointegration analysis.

3.1. Data

The focal point of this study was to assess the impact of energy efficiency and the use of renewable energy on the environment. Considering the relevant literature, the environment was represented by CO_2 emissions (e.g. see Dogan and Seker, 2016; Khoshnevis-Yazdi and Falahatparvar, 2017; Li and Su, 2017). Furthermore, the reliability of the empirical analysis was verified via another model which included total greenhouse gas emissions instead of CO_2 emissions because CO_2 emissions from fossil fuels, industrial processes, forestry and other land uses constitute more than two-thirds of the global greenhouse gas emissions. On the other side, GDP per unit of energy use (constant 2011 PPP $ per kg of oil equivalent) indicated energy efficiency, while the use of renewable energy was represented by renewable energy consumption because both energy efficiency and renewable energy are clean energy sources. Lastly, the econometric analysis also included the globalization process and economic growth. With consideration of the related empirical literature (Gurgul and Lach, 2014; Shahbaz et al., 2017), the globalization index of the KOF (2018) and real GDP per capita growth were used to represent economic growth. All of the variables were annual, and the globalization index was obtained from the database of the KOF Swiss Economic Institute (KOF, 2018), while the other variables were provided by the World Bank, as seen in Table 3.

Table 3. Dataset description

Variables	***Description***	***Source***
CO	Growth rate of CO_2 emissions (kt) (%)	World Bank (2018a)
GHG	Growth rate of greenhouse gas emissions (kt of CO_2 equivalent) (%)	World Bank (2018a)
ENGEF	Growth rate of GDP per unit of energy use (PPP $ per kg of oil equivalent) (%)	World Bank (2018b)
RENENG	Renewable energy consumption (% of total final energy consumption)	World Bank (2018c)
GLOB	Globalization index	KOF (2018)
GRW	Real GDP per capita growth (annual %)	World Bank (2018d)

The study sample was formed from emerging economies that are the key drivers of the current global growth and the main energy consumers in the world. In this context, we used the classification of the MSCI (2018) that evaluates global equity markets and classifies each country as a developed, emerging, frontier or standalone market. Hence, the sample for the first model (Model 1-dependent variable: CO_2 emissions) was composed of 22 emerging economies (Brazil, Chile, China, Colombia, the Czech Republic, Egypt, Greece, Hungary, India, Indonesia, Korea Republic, Malaysia, Mexico, Pakistan, Peru, the Philippines, Poland, Russia, South Africa, Thailand, Turkey, and the United Arab Emirates) and covered the period from 1992 to 2014.

The sample for Model 2 (dependent variable: total greenhouse gas emissions) excluded South Africa, retained the remaining 21 emerging economies from Model 1, and covered the period from 1992 to 2012. The samples and periods for the models were determined by data availability. The empirical analysis was conducted by employing Stata 14.0 and Eviews 10 software.

3. 2. Econometric model

The following two models in Eqs.(1-2) were developed to examine the impact of the improvements in energy efficiency and the use of renewable energy, along with globalization and economic growth, on both CO_2 and greenhouse gas emissions. After considering the relevant theoretical implications and empirical literature, we expected the use of renewable energy and energy efficiency to negatively affect CO_2 and greenhouse gas emissions. However, we were unable to form an expectation as to the effect of both globalization and economic growth on CO_2 and greenhouse gas emissions, as stated in the Introduction.

$$CO_{it} = \beta_0 + \beta_1 ENGEF_{it} + \beta_2 RENENG_{it} + \beta_3 GLOB_{it} + \beta_4 GRW_{it} + e_{it} \tag{1}$$

$$GHG_{it} = \beta_0 + \beta_1 ENGEF_{it} + \beta_2 RENENG_{it} + \beta_3 GLOB_{it} + \beta_4 GRW_{it} + e_{it} \tag{2}$$

3.3. Econometric methodology

Although time series analysis is generally used for country-level research, in this case, considering the insufficient number of observations at country level, we employed panel data analysis. The panel regression, causality and cointegration analyses can be used for the panel data. In this study, we preferred to employ panel cointegration analysis to see the long run impact of energy efficiency and the use of renewable energy on the environment.

We tested the presence of any cointegration interactions among CO_2 emissions, energy efficiency and renewable energy by applying the Westerlund and Edgerton (2007) LM bootstrap cointegration test. Westerlund and Edgerton's (2007) LM bootstrap cointegration test is based on the McCoskey and Kao (1998) LM test and considers cross-sectional dependence and heterogeneity while producing robust results for small samples. The cointegration test statistic is represented in Eq. (3):

$$LM_N^+ = \frac{1}{NT^2} \sum_{i=1}^{N} \sum_{t=1}^{T} \varpi_i^{-2} s_{it}^{\,2} \tag{3}$$

The s_{it} term in the above-mentioned equation represents the partial sum of error terms, while $\widehat{w}_i^{-2}$ is the long-run variance. Both terms are derived from the cointegration model estimated by a full, modified ordinary least squares method. For the test involving LM_N^+, critical values, bootstrapping should be employed in the event of a cross-sectional dependence among the series.

The cointegration coefficients are estimated by the panel AMG (Augmented Mean Group) estimator introduced by Eberhardt and Teal (2010). The AMG estimator considers the existence of cross-sectional dependence and heterogeneity; it is utilized when all of the variables are I(1), and calculates the panel cointegration coefficients as well as each country's coefficients. The panel cointegration coefficient is estimated by weighting the arithmetic averages of the cross-sectional cointegration coefficient, and therefore yields more reliable results when compared with Pesaran (2006) estimator of common correlated effects. Further, the panel AMG estimator takes into consideration the common factors and dynamic effects of the series, produces efficient results for an unbalanced panel, and can be used in the case of an endogeneity problem resulting from the error terms (Eberhardt and Bond, 2010). The AMG estimator decomposes the variables in the following way (Eqs. 4-7):

$$y_{it} = \beta_i^1 x_{it} + u_{it} \tag{4}$$

$$u_{it} = a_1 + \lambda_i^1 f_t + \varepsilon_{it}\,(i = 1 \ldots N, t = 1 \ldots, \; m = 1 \ldots k) \tag{5}$$

$$x_{mit} = \pi_{mi} + \delta_{mi}^1 g_{mt} + \rho_{1mi} f_{1mt} + \ldots + \rho_{nmi} f_{nmt} \tag{6}$$

$$f_t = \tau^1 f_{t-1} + \varepsilon_{it}, g_t = \Psi^1 g_{t-1} + \Omega_{it} \tag{7}$$

where: x_{it} represents the vector of observable covariates in the above equations, f_t and g_t are the unobserved common factors, and λ_i stands for the country-specific factor loadings.

4. Results and discussion

Testing of the cross-sectional dependence and heterogeneity among the cross-sections is very important for employment of the correct econometric tests for the unit root and cointegration. For this reason, the existence of any cross-sectional dependence was examined through Pesaran (2004) scaled LM test, the bias-corrected scaled LM test of Baltagi et al. (2012), and the $LM_{adj.}$ test of Pesaran et al. (2008) considering the cross-section and time dimensions of the dataset. The test results for both models are presented in Table 4. All of the test results revealed the presence of a cross-sectional dependence among the series. As a result, second-generation unit root and cointegration tests were utilized to check for the existence of the unit root and cointegration relations.

Homogeneity of the cointegration coefficients in the two models was analysed by applying the homogeneity tests introduced by Pesaran and Yamagata (2008). The results of the tests are depicted in Table 5. The null hypothesis in favour of homogeneity was accepted in the case of the first model, but it was rejected in the case of the second model. Thus, the cointegration coefficients were found to be homogeneous for the first model, but heterogeneous for the second model.

The test for the presence of a unit root in the series was conducted by using the CIPS (Cross-Sectional IPS (Im et al., 2003)) unit root test of Pesaran (2007) while taking into consideration the presence of cross-sectional dependence. The results of the test are displayed in Table 6. The results revealed that all of the variables were I(1). The cointegration relationship among the series was examined by applying Westerlund and Edgerton's (2007) LM bootstrap cointegration test while taking into consideration the cross-sectional dependence and heterogeneity among the series. The results of the test are displayed in Table 7. The null hypothesis in favour of a cointegration relationship was rejected for both models under cross-sectional independence. Nevertheless, the null hypothesis was accepted for both models under cross-sectional dependence. The bootstrap probability values were used due to the presence of cross-sectional dependence between the series. It was revealed that the series had a cointegration relationship.

The cointegration coefficients were forecast by the panel AMG estimator of Eberhardt and Teal (2010) while taking notice of the cross-sectional dependence and heterogeneity. The results of the test are presented in Table 8. The panel cointegration coefficients revealed that ENGEF negatively affects CO, while GRW positively affects CO in the first model, but both GLOB and RENENG have no significant effects on CO. Similar results were obtained when GHG was employed instead of CO. In the first model, the cross-sectional cointegration coefficients showed that ENGEF negatively affected CO in all countries except the Czech Republic, Egypt, Indonesia, Thailand, and the United Arab Emirates, while GRW positively affected CO in all countries except Indonesia, Malaysia, Peru, and the United Arab Emirates. RENENG, however, negatively affected CO only in Chile, while GLOB negatively affected CO in Egypt, Greece, and the United Arab Emirates. In the second model, the cross-sectional cointegration coefficients showed that ENGEF negatively affected GHG in all countries except Colombia, Egypt, Greece, Indonesia, Mexico, the Philippines, the Russian Federation, Thailand, and the United Arab Emirates, while GRW positively affected GHG in all countries except Chile, Egypt, Indonesia, Mexico, Peru, Poland, the Russian Federation, Thailand, United Arab Emirates.

Table 5. Homogeneity tests' results

Model-1		
Test	**Test statistic**	**Prob.**
$\tilde{\Delta}$	-0.994	0.840
$\tilde{\Delta}_{adj.}$	-1.148	0.875
Model-2		
Test	**Test statistic**	**Prob.**
$\tilde{\Delta}$	1.238	0.108
$\tilde{\Delta}_{adj.}$	1.452	0.073

Table 6. Unit root test results

Model-1				
Variables	***Constant***		***Constant+Trend***	
	Zt-bar	***p-value***	***Zt-bar***	***p-value***
CO	-1.319	0.194	-0.492	0.311
d(CO)	-6.934	0.000	-4.234	0.000
ENGEF	-2.793	0.103	-1.174	0.120
d(ENGEF)	-9.487	0.000	-7.110	0.000
RENENG	2.114	0.983	4.971	0.980
d(RENENG)	-1.053	0.006	0.533	0.003
GLOB	-0.005	0.498	3.051	0.999
d(GLOB)	-2.936	0.002	0.066	0.026
GRW	-1.147	0.126	0.555	0.710
d(GRW)	-4.330	0.000	-1.734	0.041
Model-2				
Variables	***Constant***		***Constant+Trend***	
	Zt-bar	***p-value***	***Zt-bar***	***p-value***
GHG	-0.675	0.250	0.925	0.823
d(GHG)	-8.814	0.000	-5.991	0.000
ENGEF	-1.269	0.102	0.867	0.807
d(ENGEF)	-7.373	0.000	-5.553	0.000
RENENG	3.403	0.976	5.949	0.890
d(RENENG)	-1.538	0.062	0.178	0.051
GLOB	0.816	0.793	2.732	0.997
d(GLOB)	-2.472	0.007	-0.369	0.035
GRW	-0.442	0.329	1.192	0.883
d(GRW)	-3.445	0.000	-2.688	0.04

RENENG, however, negatively affected GHG only in Mexico, Russian Federation, and Turkey, while GLOB negatively affected GHG in Chile, Russia, and Turkey. On the other side, RENENG positively affected GHG in Mexico, whereas GLOB positively affected GHG in Malaysia. The impact of ENGEF on CO and GHG was found to be negative in most of the countries, and this finding is consistent with the relevant theoretical presumptions. Also, the findings coincide with the results proposed by Tajudeen et al. (2018) for OECD countries and the results proposed by González et al. (2019); Martínez-Moya et al. (2019); Pardo-Martínez and Silveira (2013); Pardo et al. (2011); Stefano (2000); Worrell et al. (2001); who researched the impact of energy efficiency on the environment of different sectors in developed countries.

Table 7. LM Bootstrap cointegration test results (upon Westerlund and Edgerton (2007))

Model-1						
LM_N^+	***Constant***			***Constant+Trend***		
	Test statistic	**Asymptotic p-value**	**Bootstrap p-value**	**Test statistic**	**Asymptotic p-value**	**Bootstrap p-value**
	13.815	0.000	0.422	23.926	0.000	0.389
Moldel-2						
LM_N^+	***Constant***			***Constant+Trend***		
	Test statistic	**Asymptotic p-value**	**Bootstrap p-value**	**Test statistic**	**Asymptotic p-value**	**Bootstrap p-value**
	16.880	0.000	0.438	32.712	0.000	0.208

Table 8. Estimation of the cointegration coefficients (Model-1 and Model-2)

Model-1				
Countries	***ENGEF***	***RENENG***	***GLOB***	***GRW***
Brazil	-1.399746***	-0.295544	-0.2299374	1.421601***
Chile	-0.8354956***	-0.8845702*	-0.1447064	1.36846***
China	-1.30554***	-0.0786326	-0.1799426	1.302656***
Colombia	-1.150164***	-0.3010181	-0.0783674	1.186095**
The Czech Rep.	-0.8830494	0.0629261	-0.319718	1.193783***
Egypt	-0.3846237	-0.0933598	-1.906397*	1.679877*
Greece	-0.9603578***	-0.0560287	-0.2494621***	1.030128***
Hungary	-1.073318***	0.0662625	-0.1139898	1.176369***
India	-1.422378***	0.0832803	-0.032885	0.9946007**
Indonesia	1.046779	0.8765038	0.2355644	0.7005981
Korea Rep.	-1.312767***	-0.8763225	0.122809	1.420882***
Malaysia	-0.6923014*	5.172354	1.057629	1.319699
Mexico	-0.7950294***	-0.338451	-0.3206339	1.150385***
Pakistan	-1.222782**	0.2815981	0.1892269	1.281802***
Peru	-0.9841212**	0.143688	-0.4378973	0.7612842
Philippines	-1.03331***	0.3339375	-0.2192932	1.800484***
Poland	-0.9532877***	-0.1594474	0.0728622	0.9753035***
Russia	-1.046895***	-3.472654	-0.116604	0.9353111***
South Africa	-1.094846***	-0.3107946	-0.1852902	1.096556**
Thailand	-0.17776	0.0316438	-0.2048516	0.9802797***
Turkey	-1.065069***	-0.1619469	-0.1072348	1.090892***
United Arab Emirates	-0.5128028	4.27493	-5.027039***	1.129421
Panel	**-0.875403***	**2.104471**	**-0.3725526**	**1.181658***
Model-2				
Countries	**ENGEF**	**RENENG**	**GLOB**	**GRW**
Brazil	-8.719096**	0.5696891	-0.209675	7.976513**
Chile	-0.5433919*	-0.5241772	-0.3010599*	0.4598287
China	-1.001721***	-0.223784	-0.2591091	0.8839385***
Colombia	0.8348123	0.9987091	0.1456942	0.848943*
The Czech Rep.	-0.8944901***	-0.0638975	0.2027481	0.6944439*
Egypt	-0.2058354	-2.255617	-0.7950556	0.7081265
Greece	-0.6005708	-0.1194432	-0.2100646	0.7912196*
Hungary	-0.6054674***	0.2194805	0.0015497	0.9388654***
India	-0.8443937**	-0.1306872	-0.1635303	1.409553***
Indonesia	0.2332859	3.643774	0.1077722	5.540826
Korea Rep.	-0.6618026***	1.856738	-0.0405134	1.035189***
Malaysia	-1.293935**	1.97089	1.368033**	0.9884719*
Mexico	-0.4567944	0.3112449**	-0.3323503	0.6728578
Pakistan	-1.125708***	0.0108398	0.1413728	0.8057733***
Peru	-1.334482***	0.7908849	-0.1353595	1.151639
Philippines	1.225016	0.5426007	0.0414927	-3.405277*
Poland	-0.4455395**	-0.3925871	0.2099695	0.6749365
Russia	-1.079571	-0.48275**	-2.542955**	0.6496801
Thailand	-0.4608316	0.1643331	-0.5455602	-0.0101672
Turkey	-0.8888634***	-0.4227969**	-0.5152653***	0.6755861***
United Arab Emirates	0.1238594	-1.48382	0.0626054	-0.1431167
Panel	**-0.8926439***	**-3.953351**	**0.1062257**	**1.111801***

Nevertheless, the impact of ENGEF on CO varied from country to country. In this context, the most significant effects of ENGEF on the decrease in CO were respectively discovered in India, Brazil, Korea Republic, China, Pakistan, Colombia, and Hungary. The largest effect of ENGEF on CO was observed in India (a 1% increase in ENGEF led to a 1.42% decrease in CO), while the smallest effect of ENGEF on CO was observed in Malaysia (a 1% increase in ENGEF led to a 0.69% decrease in CO). The same pattern could be observed while assessing the interaction between ENGEF and GHG, although the largest effect of ENGEF on GHG was estimated for Brazil, and the smallest – for Poland. Consequently, improvements in ENGEF made a considerable contribution to decarbonisation of the emerging economies. Despite that, the cross-country variations in the impact of ENGEF on the decrease in CO were found to be resulting from the improvements in technological progress towards energy efficiency because the aforementioned countries were able to achieve significant improvements in the area of energy efficiency during the period under consideration. Nevertheless, although some countries, such as Poland, Czech Republic and the Philippines, were able to achieve significant improvements in the area of energy efficiency, they still had relatively insignificant decreases in their CO_2 emissions. This contradictory finding can be explained considering the fact that the reductions in CO_2 emissions by improving energy efficiency could be partially offset by the increases in production.

RENENG did not have any significant impact on greenhouse gas emissions for the overall panel, although it negatively affected CO in Chile and negatively affected GHG in Mexico, the Russian Federation and Turkey. Its effect on the environment was relatively insignificant compared with the effect of energy efficiency. Normally, renewable energy is accepted as a clean energy source, and the optimal use of renewable energy is considered to minimize the negative environmental effects and generate minimum by-products (Panwar et al., 2011). In this regard, our findings contradict the theoretical considerations. Furthermore, the findings are not consistent with the findings of Dogan and Seker (2016); Gielen et al. (2019); Jebli et al. (2016); Khoshnevis-Yazdi and Falahatparvar (2017) who discovered a decreasing impact of renewable energy on CO_2 emissions in the EU countries. This inconsistency may be present because the emerging economies under consideration have not been engaged in sufficient improvements in the use of renewable energy due to its requirement of high capital investments. For these countries, the share of renewable energy consumption out of total energy consumption amounted to 15%, on average. Nevertheless, the use of renewable energy is considered to positively affect the environment quality in the emerging economies in case they raise their use of renewable energy after making the sufficient investments in this area.

The globalization process had no significant effects on CO and GHG for the overall panel, but reduced CO in Egypt, Greece, and United Arab Emirates. It also reduced GHG in Chile, Russia, and Turkey, at the same time raising GHG in Malaysia. Hence, the positive environmental impact of the globalization process outweighs its negative environmental impact. Our findings are consistent with theoretical considerations; they also coincide with the findings proposed by Shahbaz et al. (2017) and Shahbaz et al. (2018).

Finally, it was found that GRW positively affected both CO and GHG in the largest part of the emerging market economies. However, the environmental deterioration can perhaps be mitigated at a higher level of economic development, as the EKC hypothesis suggests. These findings coincide with the ones proposed by Aye and Edoja (2017); Dogan and Seker (2016), Kasperowicz (2015).

5. Conclusions

Climatic change, natural disasters, pollution, deforestation, and the loss of biodiversity have resulted in policy makers and scholars investigating environmental sustainability. As a result, increased attention is paid to non-renewable energy sources as the causes of soaring greenhouse gas emissions at both a national and an international level. In this regard, energy efficiency and the use of renewable energy are coming into prominence as environmentally friendly sources.

In this study, the impact of both energy efficiency and the use of renewable energy on greenhouse gas emissions in emerging economies was investigated through the second-generation cointegration analysis. Data availability limited the sample of the study and the period under consideration. The empirical analysis revealed that improvements in energy efficiency made a significant contribution to the decreases in CO_2 and greenhouse gas emissions, while economic growth raised greenhouse gas emissions in the largest part of the countries. The use of renewable energy, however, did not have any significant effects on greenhouse gas emissions in most of the countries in the sample. Therefore, we can conclude that the emerging market economies achieved partial success in environmental protection, and lowered energy costs through their energy efficiency policies. The insignificant effect of the use of renewable energy on greenhouse gas emissions largely resulted from the relatively low share of the use of renewable energy in total energy consumption. This is explained by the fact that production of renewable energy requires high capital investments. Thus, our findings propose that the use of renewable energy can positively affect the quality of the environment in case the countries raise their use of renewable energy after making the sufficient investments in this area in the nearest future. Furthermore, the environmental deterioration caused by the economic growth can be alleviated at higher levels of economic development, as the EKC hypothesis suggests. Finally, the decreasing effect of globalization on greenhouse gas emissions was observed only in a few countries. This tendency proposes that the positive environmental impact of the globalization process outweighs its negative environmental impact.

On balance, the research revealed that the right efficiency policies could make a significant contribution to reduction of greenhouse gas emissions as well as energy costs. However, although the significant interactions between the use of renewable energy and CO_2 as well as between the use of renewable energy and greenhouse gas emissions were revealed only for a few countries, the requirements of high capital investments for renewable energy production determine that the use of renewable energy can serve as an instrument for improving environmental sustainability in the near future. In this regard, leading the developing and emerging economies to transit towards energy efficient technologies and the use of renewable energy through financial and technological supports would help to achieve the targets defined in such international agreements as the Kyoto protocol and Paris agreement. Future studies can focus on a comparative analysis to reveal how successful different economic sectors are in improving their energy efficiency.

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