BUSINESS AND ECONOMICS RESEARCH JOURNAL
ISSN: 2619-9491
www.berjournal.com

Business and Economics Research Journal Vol. 12, No.4, 2021 pp. 751-765 doi: 10.20409/berj.2021.350

The Effects of Renewable and Non-renewable Energy Consumption and Economic Growth on CO_2 Emissions: Empirical Evidence from Developing Countries

Salih Turedi[a], **Necati Turedi**[b]

Abstract: *This study examines the effects of renewable and non-renewable energy consumption and economic growth on CO_2 emissions for 53 developing countries during the period 1990-2014. For this purpose, the study employs a two-step difference Generalized Method of Moments (GMM) approach. Empirical results show that there is an inverted U-shaped relationship between economic growth and CO_2 emissions, which shows the validity of the environmental Kuznets curve (EKC) hypothesis. The effect of renewable energy consumption (REC) on CO_2 emissions was found to be negative and significant, while the effect of non-renewable energy consumption (NREC) was positive and significant. Moreover, both renewable and non-renewable energy consumption positively affect economic growth. Thus, for developing countries aiming to reduce CO_2 emissions and the consequent environmental pollution, it is necessary to reduce the share of NREC in total energy consumption and to increase the share of REC. Furthermore, because NREC positively affects economic growth, the efficiency of non-renewable energy resources should be increased in order not to damage the economic growth process while decreasing the use.*

Keywords: Renewable Energy Consumption, Non-renewable Energy Consumption, Economic Growth, CO_2 Emissions, Developing Countries

JEL: O44, Q40, Q53

Received : 21 May 2021
Revised : 13 August 2021
Accepted : 29 September 2021

Type : Research

1. Introduction

The increase in mechanization during the Industrial Revolution greatly increased production and hence energy demand as a fundamental production factor. Humans have met this increased energy demand by using fossil resources (non-renewable energy resources) such as coal, oil, and gas; however, the resulting greenhouse gas emissions are at levels much higher than the ecosystem can tolerate, yielding environmental pollution. Figure 1 illustrates the emissions and sources of CO_2 released into the atmosphere since the beginning of the Industrial Revolution.

In the period between 1751 and 2014, a total of 1474.4 billion metric tons of CO_2 emissions were emitted into the atmosphere. In this total amount, 202.5 billion metric tons (13.74%) have come from gas consumption, 519.5 billion metric tons (35.23%) from liquid fuel (oil) consumption, 698.5 billion metric tons (47.37%) from solid fuel (coal) consumption, 40.4 billion metric tons (2.74%) from cement production, and 13.50 billion metric tons (0.92%) from gas flaring. Thus, given the fact that 97.26% of the total CO_2 emissions

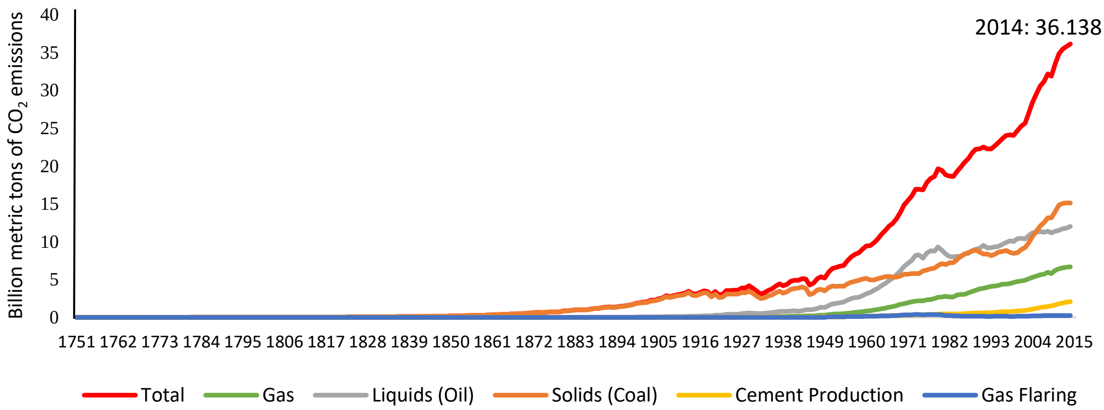
Cite this article as: Turedi, S., & Turedi, N. (2021). The effects of renewable and non-renewable energy consumption and economic growth on CO_2 emissions: Empirical evidence from developing countries. *Business and Economics Research Journal,* 12(4), 751-765. http://dx.doi.org/10.20409/berj.2021.350

The current issue and archive of this Journal is available at: ***www.berjournal.com***

[a] Assoc. Prof., PhD., Recep Tayyip Erdogan University, Faculty of Economics and Administrative Sciences, Department of Economics, Rize, Turkiye, salih.turedi@erdogan.edu.tr (ORCID ID: 0000-0001-6294-1007)
[b] Prof. PhD., Karadeniz Technical University, Faculty of Economics and Administrative Sciences, Department of Econometrics, Trabzon, Turkiye, nturedi@ktu.edu.tr (ORCID ID: 0000-0003-3816-8098)

in this period have arisen from the consumption of coal, oil, and gas, it can be seen that the consumption of fossil fuels has been the main determinant of CO_2 emissions. The increase in total CO_2 emissions gained speed after World War II due to the efforts of Western countries aiming to recover their economies; this increase was further accelerated since the 1980s with the involvement of developing countries in the economic development race. It is known that 39.4% of the total 1474.4 billion metric tons of CO_2 emissions were released between 1751 and 1979, while 60.6% were released between 1980 and 2014.

Figure 1. Global CO_2 Emissions and Sources (1751-2014)



Source: Prepared by the authors using the data obtained from Boden, T. A., Marland, G., Andres, R. J., 2017. Global, Regional, and National Fossil-Fuel CO_2 Emissions.

The environmental problems arising after World War II have also resulted in significant changes in the understanding of economic development. Environmental issues were ignored in the traditional development approach (prevalent in the 1950s and 1960s), the main objectives of which were improving industry, decreasing unemployment, increasing savings and capital accumulation, and increasing income per capita (economic growth). However, in the 1970s, global warming, climate change, and pollution have been recognized as global threats, and the conventional development approach has been replaced by sustainable development[1] discussions. Within this context, the causes of and suggested solutions for environmental pollution have become one of the main subjects of international discussion among economists and policymakers. The 1972 United Nations Conference on the Human Environment held in Stockholm is considered the first world conference on environmental issues. This conference was followed by the 1987 Brundtland Report, 1992 Rio Convention, 1994 UM Framework Convention on Climate Change and Environment, 1997 Kyoto Protocol, 2002 World Sustainable Development Convention, and 2019 UN 25th Climate Change Conference, all of which were initiatives for addressing the environmental policies and liabilities of countries and the measures that countries should take to reduce carbon release (environmental pollution). Because of the increasing importance of sustainable development and the continuing increase of CO_2 emissions, the determinants of CO_2 emissions are among the most popular subjects of energy literature. Within this scope, the effects of economic growth and energy consumption on CO_2 emissions have been discussed in many studies. In the literature in which the causality dimension of the relationships between variables has been examined, it can be seen that the variable "energy" is generally considered as total energy consumption (or use); the distinction between renewable and non–renewable energy has only recently been addressed in studies. Hence, from this aspect, it can be stated that there is a gap in the literature. In this study carried out on developing countries, the effects of economic growth and renewable and non–renewable energy consumption on CO_2 emissions are investigated. The findings obtained here could contribute to the creation of policies aimed at reducing environmental pollution in these countries. Following this introduction, the second section provides a review of empirical studies carried out on this subject. After the presentation of data and methodology in the third section, the fourth section addresses the empirical results of this study. The fifth and final section consists of conclusion and recommendations.

2. Literature Review

2.1. How Does Economic Growth Affect CO_2 Emissions?

Stating that earlier studies (for instance, Shafik [1994] and Holtz et al. [1995]) focused on the positive relationship between national income and CO_2 emissions, Liu (2005) found with the simultaneous equations model that there was a negative correlation between national income and CO_2 emissions for 24 OECD member countries. Using cointegration and the vector error correction model (VECM) for France, Ang (2007) examined causal relationships between pollution emissions, energy consumption, and output. The results indicated that (i) there was a very strong long-term relationship between the relevant variables for the period between 1960 and 2000, and (ii) growth created a causal effect on energy use and pollution increase in the long-term. Stating that environmental issues have drawn significant attention in recent years due to climate concerns and increasing pollution levels, Lotfalipour (2010) conducted the Toda-Yamamoto causality test using data from Iran for the period 1967-2007 and produced empirical evidence indicating that economic growth is a cause of CO_2 emissions. Saatci and Dumrul (2011), in a study carried out using Kejriwal's test for cointegration with structural breaks, determined that there was a long-term relationship between CO_2 emissions and economic growth in Turkey. Emphasizing that the CO_2 emissions originate largely from the use of non-renewable energy sources such as oil and coal, authors stated that the use of renewable energy sources should be increased in order to reduce the CO_2 emissions. According to the results of panel cointegration and causality tests conducted on newly industrialized countries (Brazil, China, India, Malaysia, Mexico, Philippines, South Africa, Thailand, and Turkey), Hossain (2011) stated that economic growth and CO_2 emissions were cointegrated. There was no long-term significant causality between these variables but there was a unidirectional causality in the short-term from economic growth to CO_2 emissions. Moreover, the EKC hypothesis was valid only in South Africa and Turkey. Using the autoregressive distributed lag (ARDL) bound test on data from Malaysia, Saboori et al. (2012) demonstrated that there was an inverted U-shaped relationship between economic growth and CO_2 emissions, as asserted by the EKC hypothesis. Accordingly, they concluded that economic growth increased CO_2 emissions in the short-term but decreased in the long-term. The results also indicated that there was no significant short-term causality between the variables; however, there was unidirectional causality from economic growth to CO_2 emissions in the long-term. Testing the relationship between economic growth and CO_2 emissions in the Gulf Cooperation Council (GCC) countries, Salahuddin and Gow (2014) determined that there was no significant relationship between these variables. In a study carried out on data from Turkey using Johansen and Gregory-Hansen cointegration methods, Yavuz (2014) found that there was a long-term relationship between CO_2 emissions, energy consumption, and growth. Stating that the increase in energy demand together with the economic growth process increased the consumption of fossil fuels, the author emphasized that Turkey should make use of its rich renewable energy resources to reduce CO_2 emissions.

As a result of their cross-sectional data analysis on 69 industrialized countries and 45 low-income countries, Cederborg and Snöbohm (2016) determined that an increase in economic growth caused an increase in CO_2 emissions. Noting that they could not obtain results supporting the EKC hypothesis, the researchers emphasized that market economy mechanisms are not sufficient for reducing emissions and, for this reason, legal regulations should be made. Aye and Edoja (2017) estimated the effect of economic growth on CO_2 emissions in 31 developing countries. According to the dynamic panel threshold regression model implemented for this purpose, the effect of economic growth on CO_2 emissions was negative in low-growth regimes and positive in high-growth regimes. Moreover, there was unidirectional and significant causality from economic growth to CO_2 emissions. Based on these findings, these researchers noted that it is important to increase energy efficiency and ensure the transition from non-renewable energy to renewable energy sources to achieve sustainability in growth and to reduce emissions. In an analysis performed on data from Azerbaijan, Mikayilov et al. (2018) studied the effects of economic growth on CO_2 emissions. The results of their analyses showed that economic growth had a positive and significant effect on CO_2 emissions in the long-term; thus, the EKC hypothesis was not valid for Azerbaijan. Emphasizing that understanding the causality relationship between energy consumption, carbon emissions, and economic growth would be useful for policymakers involved in formulating energy, environmental, and economic policies, Liu et al. (2019) analyzed China, India, and G-7 countries. The researchers found that the causality between economic growth and carbon emissions varied among the studied countries; there was bidirectional causality in China, India, Canada, Italy, Japan, and the USA, whereas there was unidirectional causality in France and no causality in Germany and the UK. According to the results obtained from the estimations of fixed effects model by using the annual data of 11 low-income countries for the period between 1991 and 2014, Rofiuddin et al. (2019) determined that economic growth increased the environmental pollution and they achieved empirical results suggesting the validity of EKC hypothesis in these countries. Hanif et al. (2019) carried out a study on 15 developing Asian countries by using a panel ARDL bound test and determined that economic growth increased CO_2 emissions. Based on this finding, the authors asserted that an environment-friendly growth strategy would contribute to the wealth levels of these countries. Using a bootstrap ARDL bound test, Tong et al. (2020) examined the cointegration and causality relationships between energy consumption, economic growth, and CO_2 emissions in E-7 countries. According to the results, there was no cointegration relationship between the variables in China, Indonesia, Mexico, and Turkey, but there was such a relationship in Brazil, India, and Russia. Moreover, it was found that there was a bidirectional causality relationship between economic growth and CO_2 emissions in Brazil, India, Mexico, and China.

2.2. How Do Renewable and Non-renewable Energy Consumptions Affect CO_2 Emissions?

The relationship between renewable and non-renewable energy consumption and CO_2 emissions has been a popular research subject in recent years. That non-renewable energy consumption (NREC) increased CO_2 emissions was a common finding in the literature, whereas the effect of renewable energy consumption (REC) on CO_2 emissions is still controversial and ambiguous. Some studies have reported that REC abates CO_2 emissions, whereas others have reported a non-significant or positive effect. For instance, in examining data from 19 developed and developing countries for 1984-2007 using the panel error correction model, Apergis et al. (2010) determined that REC had no significant contribution to decreasing CO_2 emissions, as its share of total energy consumption was quite limited. As a result of their study on the US using the Toda-Yamamoto causality test, Menyah and Wolde-Rufael (2010) reported that there was no significant causality from REC to CO_2 emissions. The researchers explained that REC had not yet reached a level that could contribute to a decrease in CO_2 emissions. A similar result was also reported by Al-Mulali et al. (2015) in an empirical analysis on Vietnam using the ARDL approach. Accordingly, REC was not shown to have an effective role in decreasing pollution. In a study of 16 EU member countries in the period 1990-2008, Boluk and Mert (2014) found that REC increased CO_2 emissions, although it was only half the increase caused by NREC. Farhani and Shahbaz (2014) used fully modified least squares (FMOLS) and dynamic ordinary least squares (DOLS) estimations for 10 Middle Eastern and North African (MENA) countries, they reported that renewable and non-renewable electricity consumption contributed to CO_2 emissions.

Investigating the determinants of CO_2 emissions in OECD countries from 1980 to 2011, Shafiei and Salim (2014) found that NREC increased CO_2 emissions and REC decreased it. Dogan and Seker (2016) investigated the effects of REC and NREC on CO_2 emissions in 23 countries ranking at the top in the Renewable Energy Country Attractiveness Index (RECAI) in the years 1985-2011. The LM bootstrap panel cointegration test used for this purpose showed that there was a long–term relationship between the variables; FMOLS and DOLS estimators showed that an increase in REC decreased carbon emissions, while an increase in NREC resulted in an increase in CO_2 emissions. Using a dynamic panel GMM approach, Fotis and Pekka (2017) empirically investigated the effect of REC on pollution in 19 EU countries in the period 2005-2013. The results showed that REC negatively affected pollution. In his panel data analysis for CO_2 emissions in 42 developing countries, Ito (2017) determined that the effect of REC on CO_2 emissions was negative, whereas NREC had a positive effect. Ali et al. (2017) reported similar results when studying the effect of renewable and non-renewable energy on environmental quality in selected South Asian countries (Bangladesh, India, Sri Lanka, and Pakistan). According to their results, REC in these countries in the period 1980-2013 improved environmental quality by decreasing CO_2 emissions, whereas NREC degraded environmental quality by increasing CO_2 emissions. Bhat (2018) used Pedroni cointegration and GMM methods in estimating the effect of renewable and non–renewable energy consumption on economic growth and CO_2 emissions in BRICS countries. According to the results reported by Bhat, NREC increased economic growth, whereas REC had no significant effect on economic growth. NREC had a significant positive effect on the emissions and REC had a significant negative effect on the emissions. Based on these results, the author concluded that to bring CO_2 emissions under control, these countries should implement policies that would ensure both growth and environmental sustainability. In their study on Pakistan using the ARDL bound test, Zaidi et al. (2018) determined that REC had no significant effect on CO_2 emissions while NREC was an important determinant of environmental pollution. For five Southern Common Market member countries (Argentina, Brazil, Paraguay, Uruguay, and Venezuela) for the period 1980–2014, Koengkan et al. (2020) determined that there was a bidirectional causal relationship between both non–renewable and renewable energy consumption and CO_2 emissions. Noting that these countries were dependent on fossil fuel consumption, the researchers suggested that policymakers should make comprehensive reforms aimed at transitioning to renewable energy to reduce environmental degradation. According to the results of Mahjabeen et al. (2020)'s analyses on D-8 countries (Turkey, Bangladesh, Indonesia, Iran, Malaysia, Egypt, Nigeria, and Pakistan) and covering the period 1990-2016, both renewable and non-renewable energy consumption had a positive effect on CO_2 emissions, even though the effect of REC was much weaker than that of NREC. Finally, Alonso (2021) analyzed the relationships between CO_2 emissions, REC, and NREC for the period between 1990 and 2015 in Mexico. Empirical findings showing that NREC is one of the main determinants of the increase in CO_2 emissions also showed that the REC reduced CO_2 emissions.

Table 1. Literature Summary

How Does Economic Growth Affect CO_2 Emissions?

Author(s)	Country	Period	Methodology	Findings
Liu (2005)	24 OECD countries	1975-1990	Three stages least squares	A negative correlation existed between the variables.
Ang (2007)	France	1960-2000	Cointegration and VECM	The variables were cointegrated and there was unidirectional causality from economic growth to pollution in the long-term.
Lotfalipour (2010)	Iran	1967-2007	Toda-Yamamoto causality	There was unidirectional causality from growth to CO_2 emissions.
Saatci and Dumrul (2011)	Turkey	1950-2007	Kejriwal (2008) cointegration	The variables were cointegrated and the EKC hypothesis was valid.
Hossain (2011)	Newly industrialized countries	1971-2007	Johansen Fisher panel cointegration and panel Granger causality	The variables were cointegrated. There was no evidence of causality in the long-term, but unidirectional causality from economic growth to CO_2 emissions in the short-term. The EKC hypothesis was valid only in South Africa and Turkey.
Saboori et al. (2012)	Malaysia	1980-2009	ARDL cointegration and VECM	The EKC hypothesis was valid in the short and long term. There was no significant causality in short-term but significant causality from economic growth to CO_2 emissions in the long-term.
Salahuddin and Gow (2014)	Gulf Cooperation Council countries	1980-2012	Pedroni cointegration and Panel mean group	There was no significant relationship between the variables.
Yavuz (2014)	Turkey	1960-2007	Johansen and Gregory-Hansen cointegration	The variables were cointegrated and the EKC hypothesis was valid.
Cederborg and Snöbohm (2016)	69 industrialized and 45 low-income countries	2012	OLS regression (Cross-sectional analysis)	Economic growth had a positive effect on CO_2 emissions. The EKC hypothesis was not valid.
Aye and Edoja (2017)	31 developing countries	1971-2013	Dynamic panel threshold regression model	The effect of economic growth on CO_2 emissions was negative in low-growth regimes and positive in high–growth regimes. There was unidirectional causality from growth to CO_2 emissions.
Mikayilov et al. (2018)	Azerbaijan	1992-2013	Johansen cointegration, DOLS, FMOLS, and CCR	Economic growth had a positive and significant effect on CO_2 emissions in the long term. The EKC hypothesis was not valid.
Liu et al. (2019)	China, India, and G7 countries	1965-2017	Multispatial convergent cross mapping (CCM)	There was bidirectional causality between economic growth and CO_2 emissions in China, India, Canada, Italy, japan, and USA. There was unidirectional causality from CO_2 emissions to economic growth in France and no causality in Germany and UK.
Rofiuddin et al. (2019)	11 Low-income countries	1991-2014	Fixed effect model	Economic growth led to environmental pollution by increasing CO_2 emissions. The EKC hypothesis was valid.
Hanif et al. (2019)	15 developing Asian countries	1990-2013	Panel ARDL and Panel ECM	Economic growth contributed to the generation of CO_2 emissions. The EKC hypothesis was valid.
Tong et al. (2020)	E7 countries	1971-2014	Bootstrap ARDL and Granger causality	The variables were cointegrated in Brazil, India, and Russia. There was bidirectional causality between economic growth and CO_2 emissions in Brazil, India, Mexico, and China. There was unidirectional causality from CO_2 emissions to economic growth in Indonesia, Russia, and Turkey.

Table 1. (Continued)

How Do Renewable and Non–renewable Energy Consumptions Affect CO_2 Emissions?

Author(s)	**Country**	**Period**	**Methodology**	**Findings**
Apergis et al. (2010)	19 developed and developing countries	1984-2007	Panel cointegration and ECM	REC had no significant effect on CO_2 emissions.
Menyah and Wolde–Rufael (2010)	US	1960-2007	Toda–Yamamoto causality	There was no significant causality from REC to CO_2 emissions.
Al–Mulali et al. (2015)	Vietnam	1981-2011	ARDL cointegration	NREC increased CO_2 emissions while REC had no significant effect on decreasing CO_2 emissions.
Boluk and Mert (2014)	16 EU members countries	1990-2008	Fixed effect model	REC contributed approximately 1/2 less than NREC to CO_2 emissions in the EU countries.
Farhani and Shahbaz (2014)	10 MENA countries	1980-2009	Panel cointegration Panel FMOLS and DOLS	The variables were cointegrated. Both renewable and non–renewable electricity consumption contributed to CO_2 emissions.
Shafiei and Salim (2014)	29 OECD countries	1980-2011	Johansen Fisher panel cointegration, AMG estimator and panel Granger causality	The variables were cointegrated. REC had a negative effect on CO_2 emissions, whereas NREC had a positive effect on it in the long-term. There was unidirectional causality from CO_2 emissions to REC and bidirectional causality between NREC and CO_2 emissions.
Dogan and Seker (2016)	23 countries ranking at the top in the Renewable Energy Country Attractiveness Index (RECAI)	1985-2011	LM bootstrap panel cointegration, panel FMOLS and DOLS	The variables were cointegrated. An increase in REC decreased carbon emissions, while an increase in NREC resulted in an increase in CO_2 emissions.
Fotis and Pekka (2017)	19 EU countries	2005-2013	Dynamic panel GMM	REC negatively affected pollution.
Ito (2017)	42 Developing countries	2002-2011	Dynamic panel GMM and PMG	The effect of REC on emissions was negative, while the effect of NREC was positive. REC and NREC were substitutes.
Ali et al. (2017)	South Asian countries (Bangladesh, India, Sri Lanka, and Pakistan)	1980-2013	Johansen cointegration and Larsson et al., Panel cointegration. Panel FMOLS	The variables were cointegrated. REC improved environmental quality by decreasing CO_2 emissions, whereas NREC degraded environmental quality by increasing CO_2 emissions.
Bhat (2018)	BRICS countries	1992-2016	Pedroni cointegration and Dynamic panel GMM	NREC had a significant positive effect on the emissions and REC had a significant negative effect on the emissions.
Zaidi et al. (2018)	Pakistan	1970-2016	ARDL cointegration	REC had no significant effect on CO_2 emissions while NREC was an important determinant of environmental pollution.
Koengkan et al. (2020)	Argentina, Brazil, Paraguay, Uruguay, and Venezuela	1980-2014	Panel VAR regression and Panel Granger causality	There was a bidirectional causal relationship between both NREC and REC and CO_2 emissions.
Mahjabeen et al. (2020)	D-8 countries	1990-2016	Panel ARDL, Panel FMOLS and DOLS	REC and NREC had a positive effect on environmental degradation.
Alonso (2021)	Mexico	1990-2015	ARDL cointegration	NREC was one of the main sources of the increase in CO_2 emissions. An increase in REC reduced CO_2 emissions.

3. Data and Methodology

3.1. Data

This study examines the effects of renewable and non–renewable energy consumption and economic growth on CO_2 emissions by using a balanced panel dataset of 53 countries covering the period 1990-2014[2]. These countries are: Angola, Argentina, Bangladesh, Benin, Bolivia, Botswana, Brazil, Bulgaria, Cameroon, Chile, China, Columbia, Costa Rica, Democratic Republic of the Congo, Dominican Republic, Ivory Coast, Egypt, El Salvador, Equator, Gabon, Ghana, Honduras, India, Indonesia, Kenya, Malaysia, Mauritius, Mexico, Mongolia, Morocco, Mozambique, Nicaragua, Nigeria, Panama, Paraguay, Peru, Philippines, Poland, Republic of the Congo, Romania, Saudi Arabia, Senegal, South Africa, Sri Lanka, Tanzania, Thailand, Togo, Trinidad and Tobago, Tunisia, Turkey, Uruguay, Yemen, and Zimbabwe. In the estimation models, foreign direct investment (FDI) and trade openness (OPEN), which have been reported to have a strong relationship with CO_2 emissions in various studies (e.g., Ren et al. [2014], Shahbaz et al. [2018], Huang et al. [2019], Salehnia et al. [2020], and Essandoh et al. [2020]) were used as control variables. All variables were obtained from the World Development Indicators (WDI, 2018) database and used in logarithmic form. Detailed information about the variables is given in Table 2.

Table 2. Description of the Variables

Variable	Description
CO_2	CO_2 emissions (metric tons per capita)
GDPpc	GDP per capita (constant 2010 US$)
REC	Renewable energy consumption (% of total final energy consumption)
NREC	Non-renewable (fossil fuel) energy consumption (% of total)
FDI	Foreign direct investment, net inflows (% of GDP)
OPEN	The total value of imports and exports of goods and services (% of GDP)

3.2. Methodology

This study investigates the empirical relationships between the variables using the two-step difference GMM method, which is one of the dynamic panel data methods and has been developed by Arellano and Bond (1991). The models with lagged dependent variables among the independent variables are called dynamic panel data models (Baltagi, 2005; Tatoglu, 2012).

$$y_{it} = \delta y_{i,t-1} + \beta \chi_{it} + u_{it} \qquad [u_{it} = \mu_i + v_{it}] \tag{1}$$

where, (y_{it}) refers to the dependent variable, (χ_{it}) to the independent variable, $(y_{i,t-1})$ to the lagged dependent variable, and (u_{it}) to the error term. In Eq. (1), $(y_{i,t-1})$ is correlated with (u_{it}). This causes the emergence of an endogeneity problem and, thus, deviant OLS. Moreover, the presence of individual-specific effects in the model and $(y_{i,t-1})$'s relationship with (u_{it}) cause the fixed effect estimator's $[E(u_{it}/\chi_{kit}) \neq 0]$ assumption to be violated. Finally, the correlation between $(y_{i,t-1})$ and (μ_i) that is a component of (u_{it}) does not meet the random effect estimator's $[E(\mu_{it}/\chi_{kit}) \neq 0]$ assumption. Due to the abovementioned problems, static panel data methods such as OLS, fixed effect, and random effect are biased and non-efficient in dynamic model estimations. For this reason, Arellano and Bond (1991) proposed a difference-GMM estimator, allowing consistent coefficient estimations in cases of a short period (T) and large cross-sectional dimension (N) (Baltagi, 2005; Bun and Sarafidis, 2013). According to Arellano and Bond (1991), the problems arising from the inclusion of $(y_{i,t-1})$ in the right-hand side of the equation as an independent variable are eliminated by using a two-step process. Primarily, the first difference of the equation to be estimated is taken in order to eliminate the individual effects. Then, to resolve the endogeneity problem, lagged levels of the right hand side variables are used as instruments (Soto, 2009).

The first difference of Equation (1) can be written as:

$$y_{it} - y_{i,t-1} = \delta(y_{i,t-1} - y_{i,t-2}) + \beta(\chi_{it} - \chi_{i,t-1}) + (u_{it} - u_{i,t-1}) \quad or \quad \Delta y_{it} = \Delta\delta y_{i,t-1} + \Delta\beta\chi_{it} + \Delta u_{it} \tag{2}$$

The consistency of the GMM estimator depends on the absence of no serial autocorrelation between the differenced error terms, as well as the validity of the instruments. In this parallel, Arellano and Bond (1991) recommended AR(1) and AR(2) tests to determine the presence of autocorrelation. In the AR(1) test, the null hypothesis is that the error term is not serially correlated at the first order. The AR(2) test examines the null hypothesis that the error term exhibits no second-order serial correlation. At the end of the estimation, it is expected that test statistic should be significant in AR(1) (p-value > z smaller than 0.05), i.e. the rejection of null hypothesis, and that the null hypothesis couldn't be rejected in AR(2) test (p-value > z greater than 0.05). In testing the validity of instrumental variables, the authors recommend using the Sargan test. Acceptance of the null hypothesis, which states that the over–identifying restrictions are valid, indicates that the instrumental variables are valid (Nayan et al., 2013; Bhattacharya et al., 2017).

4. Empirical Results

4.1. Preliminary Results

Before the empirical analysis, basic estimation methods such as Pearson's correlation analysis, simple panel regression analysis, and scatter plot were used in order to achieve preliminary information about the relationship between the variables. According to the results of the correlation analysis, CO_2 emissions have negative correlation with REC (–0.67) and positive correlation with NREC (0.83), GDPpc (0.86), FDI (0.14), and OPEN (0.15). The findings obtained from the regression analysis are consistent with the results of the correlation analysis. Such that, a 1% increase in REC decreases the CO_2 emissions by 0.56% but a 1% increases in NREC, GDPpc, FDI, and OPEN increase the CO_2 emissions by 1.39%, 1.09%, 0.13%, and 0.40%, respectively. Finally, considering the distribution of the observations and direction (slope) of regression lines, it can be seen that scatter plots also corroborate the results of correlation and panel regression analyses. In conclusion, the basic tests conducted yielded a preliminary result that, in developing countries being examined, the renewable energy consumption decreased the CO_2 emissions, whereas non–renewable energy consumption, economic growth, foreign direct investments, and trade openness increased the CO_2 emissions (hence, environmental pollution), (Figure 2).

4.2. Results of Unit Root Tests

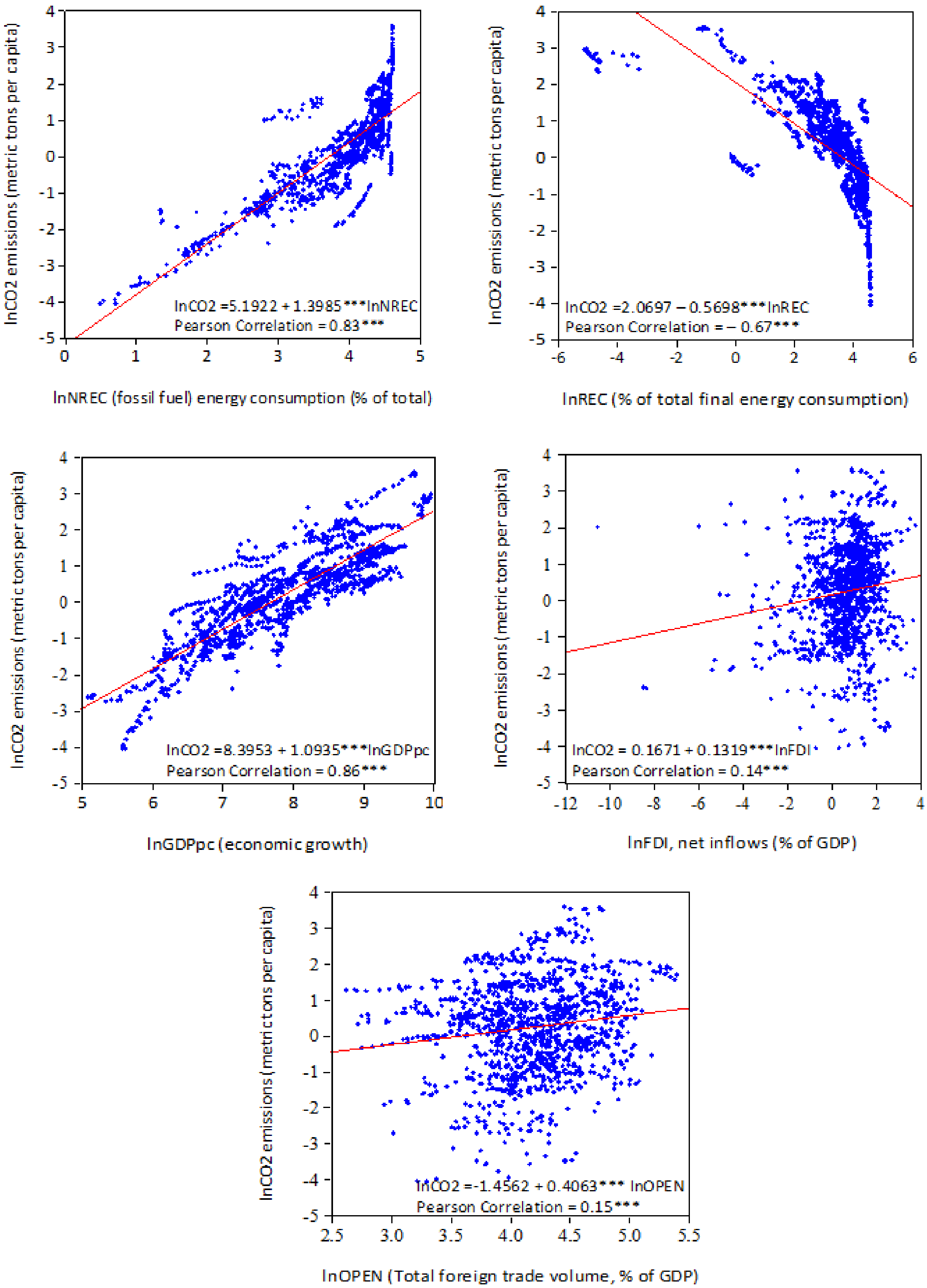
To have reliable estimations in empirical analyses, it should first be determined if the variables are stationary or not. For this reason, before the GMM estimation, the stationarity of variables was tested using the approaches of Breitung (2000) and Im et al. (2003, IPS); the results are presented in Table 3. The Breitung test showed that all the variables included unit root (they were not stationary), whereas the IPS test showed that the variables other than $lnCO_2$, lnFDI, and lnOPEN had unit root at the level. On the other hand, in the tests repeated by taking the first differences of variables, all the variables were found to be stationary. After the Breitung and IPS tests, Pesaran's (2007) CIPS test, which is one of the second-generation unit root tests and which allows cross-sectional dependence, was used as a robustness test. The CIPS results showed that all the variables were stationary at the first differences, which was especially in agreement with the Breitung (2000) test results.

Table 3. Results of Breitung, IPS, and CIPS Unit Root Tests

Level	Breitung	IPS	CIPS	First Differences	Breitung	IPS	CIPS
$lnCO_2$	2.068	–1.789**	–2.383	$\Delta lnCO_2$	–11.249***	–22.957***	–3.332***
ln(GDPpc)	4.421	0.058	–2.281	ΔlnGDPpc	–10.399***	–14.418***	–2.970***
$ln(GDPpc)^2$	3.569	0.546	–3.060***	$\Delta ln(GDPpc)^2$	–10.441***	–14.325***	–3.828***
lnREC	0.831	–0.192	–1.786	ΔlnREC	–9.688***	–21.785***	–3.236***
lnNREC	1.732	–0.277	–2.110	ΔlnNREC	–11.358***	–21.554***	–3.192***
lnFDI	–0.227	–9.494***	–2.528	ΔlnFDI	–6.608***	–20.863***	–3.905***
lnOPEN	–0.120	–4.302***	–2.129	ΔlnOPEN	–15.002***	–20.522***	–3.177***

***p < 0.01, **p < 0.05. The critical values for the CIPS test are –2.76 (1%), –2.62 (5%), and –2.54 (10%).

Figure 2. The Relationship between the Variables



4.3. Results of Two-step Difference GMM Estimation

The two-step difference GMM estimation results are presented in Table 4. To reveal the relationship between variables more clearly in the analyses, three more model estimations (Models 2, 3, and 4) were made in addition to the main model (Model 1). Before the results were interpreted, diagnostic tests were used to determine if the two-step difference GMM estimator was effective and consistent. For this purpose, the Wald test was applied first; it was determined that all the models had general significance at 1%. The validity of the instrumental variables was then tested using the Sargan test; it was determined that the significance values of all the (χ^2) statistics were higher than 0.05; thus, the instruments were valid. Finally, as expected, p-value of AR(1) < 0.05 and p-value of AR(2) > 0.05 were found for all the estimation models. Empirical results can be interpreted after determination that the two-step difference GMM estimator is consistent through the use of diagnostic tests.

According to the main model results, the coefficient of (GDPpc) is positive and that of $(GDPpc)^2$ is negative and significant. This result indicates that the EKC hypothesis[3] asserting that there is an inverted U-shaped relationship between environmental pollution and GDP per capita (economic growth) is valid for developing countries. This finding is consistent with the results reported by Saboori et al. (2012), Yavuz (2014), Hanif et al. (2019), and Rofiuddin et al. (2019). Additionally, the rise in CO_2 emissions accompanying economic growth can be explained by the intense use of non-renewable energy sources in the production process, as the average share of NREC in the total energy consumption in these countries for the period between 1990 and 2014 was 60%. The effects of NREC and REC on CO_2 emissions were found to be positive and negative, respectively. According to the results, which are in accord with the results indicated by Shafei and Salim (2014), Dogan and Seker (2016), Ito (2017), Ali et al. (2017), and Bhat (2018), a 1% increase in NREC increases CO_2 emissions by 0.28%, whereas a 1% increase in REC decreases CO_2 emissions by 0.15%. Moreover, it was also determined that FDI and OPEN have a positive and significant effect on CO_2 emissions.

Table 4. Results of two–step Difference GMM Estimation

	Model [1]: Main model		Model [2]		Model [3]		Model [4]	
	Dependent Variable: $lnCO_2$		Dependent Variable: lnGDPpc		Dependent Variable: lnREC		Dependent Variable: lnNREC	
	$(lnCO_2)_{t-1}$	0.5627*** [27.51]	$(lnGDPpc)_{t-1}$	0.9665*** [260.56]	$(lnREC)_{t-1}$	0.8308*** [87.69]	$(lnNREC)_{t-1}$	0.7175*** [84.33]
	lnGDPpc	0.3869*** [3.23]	$lnCO_2$	0.0226*** [8.25]	$lnCO_2$	–0.0809*** [-8.61]	$lnCO_2$	0.1758*** [61.59]
	$(lnGDPpc)^2$	–0.0118* [-1.76]	lnREC	0.0253*** [8.01]	lnGDPpc	0.0502*** [6.53]	lnGDPpc	–0.1358*** [-20.19]
	lnREC	–0.1584*** [-14.17]	lnNREC	0.0285*** [9.23]	lnNREC	–0.1303*** [-7.93]	lnREC	–0.1271*** [-10.53]
	lnNREC	0.2840*** [18.47]	lnFDI	0.0009*** [11.03]	lnFDI	–0.0003*** [-2.82]	lnFDI	0.0021*** [26.61]
	lnFDI	0.0011*** [5.98]	lnOPEN	0.0562*** [29.24]	lnOPEN	–0.0009 [-0.24]	lnOPEN	0.0139*** [6.75]
	lnOPEN	0.0513*** [5.81]						
Wald test and ($p > \chi 2$)	17270.12***	0.0000	142796.45***	0.0000	54143.36***	0.0000	30146.82***	0.0000
AR(1) test and ($p > z$)	–3.3098***	0.0009	–4.4833***	0.0000	–4.0521***	0.0001	–2.7265***	0.0064
AR(2) test and ($p > z$)	–1.1033	0.2699	–1.7976	0.0722	–1.2181	0.2232	–0.0256	0.9795
Sargan test and ($p > \chi 2$)	46.8125	1.0000	48.4143	1.0000	49.4557	1.0000	51.7003	1.0000
Number of cross-sections	53		53		53		53	
Number of observations	1219		1219		1219		1219	

***$p < 0.01$, *$p < 0.10$. z-statistics are in [...] parentheses.

5. Conclusion and Recommendations

In this study, the effects of renewable and non-renewable energy consumption and economic growth on CO_2 emissions were examined for 53 developing countries over the period between 1990 and 2014 by using a two-step difference GMM method. The empirical results showed that, in developing countries, (i) there is an inverted U-shaped relationship between economic growth and CO_2 emissions as asserted by the EKC hypothesis, (ii) the non-renewable energy consumption increases CO_2 emissions, while renewable energy consumption decreases it, and (iii) there is a substitution relationship between renewable and non-renewable energy consumption as specified by Ito (2017). Based on these findings, it can be stated that, to reduce CO_2 emissions in developing countries, the energy consumption structure should be changed; in other words, NREC should be decreased while increasing REC. Within this context, the governments of these countries should support the transition from NREC to REC by making use of instruments such as incentives, investments, legal regulations, etc. However, this transformation should be achieved without damaging the economic growth process. Because, besides creating environmental pollution by increasing CO_2 emissions, NREC also positively affects economic growth in developing countries. In addition to promoting the use of renewable energy resources, energy policies should also aim to increase the efficiency of non-renewable energy resources. Thus, a higher level of output could be achieved with lower levels of NREC and further increases in CO_2 emissions could be prevented.

Declarations and Disclosures

Ethical Responsibilities of Authors: The authors of this article confirm that their work complies with the principles of research and publication ethics.

Conflicts of Interest: No potential conflict of interest was reported by the authors.

Funding: The authors received no financial support for the preparation and/or publication of this article.

Author Contributions: The authors confirm contribution to the article as follows: Conceptualization and design, S. Turedi and N. Turedi; data collection, S. Turedi; analysis of data and interpretation of results, S. Turedi and N. Turedi; writing the first draft of the manuscript, S. Turedi and N. Turedi; review and editing, N. Turedi and S. Turedi. The manuscript/article was read and approved by all the authors, and all authors accepted responsibility for their article.

Plagiarism Checking: This article was screened for potential plagiarism using a plagiarism screening program.

End Notes

1. *The concept of "sustainable development" has been described in Brundtland Report (1987) as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs".*
2. *The reason for limiting the analysis to this period is that data on fossil fuel energy consumption (% of total) after 2014 is not available for every country in the database of World Development Indicators (WDI).*
3. *According to EKC hypothesis, environmental pollution initially increases with an increase in income per capita and then, after a specific level of income per capita, it decreases.*

References

Ali, S., Anwar, S., & Nasreen, S. (2017). Renewable and non-renewable energy and its impact on environmental quality in South Asian countries. *Forman Journal of Economic Studies,* 13, 177-194.

Alonso, H. C. (2021). Impact of renewable energies on greenhouse gas emissions in Mexico. *Problemas del desarrollo*, 52(204), 59-83.

Al-Mulali, U., Saboori, B., & Ozturk, I. (2015). Investigating the environmental Kuznets curve hypothesis in Vietnam. *Energy Policy*, 76, 123-131.

Ang, J. B. (2007). CO_2 emissions, energy consumption, and output in France. *Energy Policy,* 35(10), 4772-4778.

Apergis, N., Payne, J. E., Menyah, K., & Wolde-Rufael, Y. (2010). On the causal dynamics between emissions, nuclear energy, renewable energy, and economic growth. *Ecological Economics,* 69(11), 2255-2260.

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

Aye, G. C., & Edoja, P. E. (2017). Effect of economic growth on CO_2 emission in developing countries: Evidence from a dynamic panel threshold model. *Cogent Economics & Finance,* 5(1), 1379239.

Baltagi, H. B. (2005). *Econometric analysis of panel data* (3rd edition). New York: John Wiley & Sons.

Bhattacharya, M., Churchill, S. A., & Paramati, S. R. (2017). The dynamic impact of renewable energy and institutions on economic output and CO_2 emissions across regions. *Renewable Energy,* 111, 157-167.

Boden, T. A., Marland, G., Andres, & R. J. (2017). Global CO_2 emissions from fossil-fuel burning, cement manufacture, and gas flaring: 1751-2014. Retrieved May 20, 2020, from http://cdiac.ess–dive.lbl.gov/ftp/ndp030/global.1751_2014.ems

Boluk G., & Mert, M. (2014). Fossil & renewable energy consumption, GHGs (greenhouse gases) and economic growth: Evidence from a panel of EU (European Union) countries. *Energy,* 74, 439-446.

Breitung, J. (2000). The local power of some unit root tests for panel data. In: B. Baltagi (Ed.), *Nonstationary panels, panel cointegration, and dynamic panels, advances in econometrics* (pp. 161-178). Amsterdam: JAI Press.

Brundtland, G. H. (1987). *Our common future-report of the world commission on sustainable development.* New York: Oxford University Press.

Bun, M. J. G., & Sarafidis, V. (2013). Dynamic panel data models. Discussion Paper No. 01, University of Amsterdam.

Cederborg, J., & Snöbohm, S. (2016). *Is there a relationship between economic growth and carbon dioxide emissions?* Södertörns University, Institution of Social Sciences, Economics.

Dogan, E., & Seker, F. (2016). The influence of real output, renewable and non-renewable energy, trade and financial development on carbon emissions in the top renewable energy countries. *Renewable and Sustainable Energy Reviews*, 60, 1074-1085.

Essandoh, O. K., Islam, M., & Kakinaka, M. (2020). Linking international trade and foreign direct investment to CO_2 emissions: Any differences between developed and developing countries? *Science of the Total Environment,* 712, 1-10.

Farhani, S., & Shahbaz, M. (2014). What role of renewable and non-renewable electricity consumption and output is needed to initially mitigate CO_2 emissions in MENA region? *Renewable and Sustainable Energy Reviews,* 40, 80-90.

Fotis, P. N., & Pekka, V. (2017). The effect of renewable energy use and economic growth on pollution in the EUROZONE. *Economics and Business Letters,* 6(3), 88-99.

Hanif, I., Raza, S. M. F., Gago-de-Santos, P., & Abbas, Q. (2019). Fossil fuels, foreign direct investment, and economic growth have triggered CO_2 emissions in emerging Asian economies: Some empirical evidence. *Energy,* 171, 493-501.

Holtz-Eakin, D., & Selden, T. M. (1995). Stoking the fires? CO_2 emissions and economic growth. *Journal of Public Economics,* 57(1), 85-101.

Hossain, S. (2011). Panel estimation for CO_2 emissions, energy consumption, economic growth, trade openness and urbanization of newly industrialized countries. *Energy Policy,* 39, 6991-6999.

Huang, Y., Chen, X., Zhu, H., Huang, C., & Tian, Z. (2019). The heterogeneous effects of FDI and foreign trade on CO_2 emissions: Evidence from China. *Mathematical Problems in Engineering,* 2019, 1-14.

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

Ito, K. (2017). CO_2 emissions, renewable and non-renewable energy consumption, and economic growth: Evidence from panel data for developing countries. *International Economics,* 151, 1-6.

Koengkan, M., Fuinhas, J. A., & Santiago, R. (2020). The relationship between CO_2 emissions, renewable and non-renewable energy consumption, economic growth, and urbanisation in the Southern Common Market. *Journal of Environmental Economics and Policy,* 9(4) 383-401.

Liu, H., Lei, M., Zhang, N., & Du, G. (2019). The causal nexus between energy consumption, carbon emissions and economic growth: New evidence from China, India and G7 countries using convergent cross mapping. *PLoS ONE,* 14(5), 1-18.

Liu, X. (2005). Explaining the relationship between CO_2 emissions and national income: The role of energy consumption. *Economics Letters,* 87(3), 325-328.

Lotfalipour, M. R., Falahi, M. A., & Ashena, M. (2010). Economic growth, CO_2 emissions, and fossil fuels consumption in Iran. *Energy,* 35(12), 5115-5120.

Mahjabeen, N., Shah, S. Z., Chughtai, S., & Simonetti, B. (2020). Renewable energy, institutional stability, environment and economic growth nexus of D-8 countries. *Energy Strategy Reviews,* 29.

Menyah, K., & Wolde-Rufael, Y. (2010). CO_2 emissions, nuclear energy, renewable energy and economic growth in the US. *Energy Policy*, 38(6), 2911-2915.

Mikayilov, J. I., Galeotti, M., & Hasanov, F. J. (2018). The impact of economic growth on CO_2 emissions in Azerbaijan. *Journal of Cleaner Production,* 197(1), 1558-1572.

Nayan, S., Kadir, N., Ahmad, M., & Abdullah, M. S. (2013). Revisiting energy consumption and GDP: Evidence from dynamic panel data analysis. *Procedia Economics and Finance,* 7, 42-47.

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

Ren, S., Yuan, B., Ma, X., & Chen, X. (2014). International trade, FDI (foreign direct investment) and embodied CO_2 emissions: A case study of Chinas industrial sectors. *China Economic Review,* 28, 123-134.

Rofiuddin, M., Aisyah, S., Pratiwi, D. N., Annisa, A. A., Puspita, R. E., & Nabila, R. (2019). Does economic growth reduce pollution? Empirical evidence from low ıncome countries. *In E3S Web of Conferences,* 125, 06002. EDP Sciences.

Saatci, M., & Dumrul, Y. (2011). The relationship between economic growth and environmental pollution: The estimation of environmental Kuznetz curve with a cointegration analysis of structural breaks for Turkish economy (in Turkish). *Erciyes University Journal of Faculty of Economics and Administrative Sciences,* 37, 65-86.

Saboori, B., Sulaiman, J., & Mohd, S. (2012). Economic growth and CO_2 emissions in Malaysia: A cointegration analysis of the Environmental Kuznets Curve. *Energy Policy,* 51, 184-191.

Salahuddin, M., & Gow, J. (2014). Economic growth, energy consumption and CO_2 emissions in Gulf Cooperation Council countries. *Energy,* 73, 44-58.

Salehnia, N., Alavijeh, N. K., & Salehnia, N. (2020). Testing Porter and pollution haven hypothesis via economic variables and CO_2 emissions: A cross-country review with panel quantile regression method. *Environmental Science and Pollution Research,* 27, 31527-31542.

Shafiei, S., & Salim, R. A. (2014). Non-renewable and renewable energy consumption and CO_2 emissions in OECD countries: A comparative analysis. *Energy Policy,* 66, 547-556.

Shafik, N. (1994). Economic development and environmental quality: An econometric analysis. *Oxford Economic Papers,* 46, 757-773.

Shahbaz, M., Nasir, M. A., & Roubaud, D. (2018). Environmental pollution in France: The effects of FDI, financial development and energy innovations. *Energy Economics,* 74, 843-857.

Soto, M. (2009). System GMM estimation with a small number of individuals. Retrieved April 3, 2020, from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.465.9928&rep= rep1&type=pdf

Tatoglu, F. Y. (2012). *Panel data econometrics with Stata application* (in Turkish). İstanbul: Beta Publishing.

Tong, T., Ortiz, J., Xu, C., & Li, F. (2020). Economic growth, energy consumption, and carbon dioxide emissions in the E7 countries: A bootstrap ARDL bound test. *Energy, Sustainability and Society,* 10(20), 1-17.

World Bank. (2018). World Development Indicators. Retrieved July 9, 2018, from https://databank.worldbank.org/source/world–development–indicators

Yavuz, N. C. (2014). CO_2 Emission, energy consumption, and economic growth for Turkey: Evidence from a cointegration test with a structural break. *Energy Sources, Part B: Economics, Planning, and Policy,* 9(3), 229-235.

Zaidi, S. A. H., Danish, Hou. F., & Mirza. F. M. (2018). The role of renewable and non renewable energy consumption in CO_2 emissions: A disaggregate analysis of Pakistan. *Environmental Science and Pollution Research,* 25, 31616-31629.

This Page Intentionally Left Blank