The Effects of Renewable and Non-renewable Energy Consumption and Economic Growth on CO₂ Emissions: Empirical Evidence from Developing Countries

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Abstract: This study examines the effects of renewable and non-renewable energy consumption and economic growth on CO₂ 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 CO₂ emissions, which shows the validity of the environmental Kuznets curve (EKC) hypothesis. The effect of renewable energy consumption (REC) on CO₂ 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 CO₂ 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, CO₂ Emissions, Developing Countries

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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 CO₂ 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 CO₂ 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 CO₂ emissions...
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 CO₂ emissions. The increase in total CO₂ 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 CO₂ emissions were released between 1751 and 1979, while 60.6% were released between 1980 and 2014.

**Figure 1.** Global CO₂ Emissions and Sources (1751-2014)

![Graph showing global CO₂ emissions and sources](image)

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 CO₂ 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 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 CO₂ emissions, the determinants of CO₂ emissions are among the most popular subjects of energy literature. Within this scope, the effects of economic growth and energy consumption on CO₂ 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 CO₂ 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 CO₂ Emissions?

Stating that earlier studies (for instance, Shafik [1994] and Holtz et al. [1995]) focused on the positive relationship between national income and CO₂ emissions, Liu (2005) found with the simultaneous equations model that there was a negative correlation between national income and CO₂ 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 CO₂ 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 CO₂ emissions and economic growth in Turkey. Emphasizing that the CO₂ 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 CO₂ 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 CO₂ 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 CO₂ 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 CO₂ emissions, as asserted by the EKC hypothesis. Accordingly, they concluded that economic growth increased CO₂ 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 CO₂ emissions in the long-term. Testing the relationship between economic growth and CO₂ 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 CO₂ 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 CO₂ 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 CO₂ 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 CO₂ emissions in 31 developing countries. According to the dynamic panel threshold regression model implemented for this purpose, the effect of economic growth on CO₂ emissions was negative in low-growth regimes and positive in high-growth regimes. Moreover, there was unidirectional and significant causality from economic growth to CO₂ 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 CO₂ emissions. The results of their analyses showed that economic growth had a positive and significant effect on CO₂ 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, Rufuiddin 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\textsubscript{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\textsubscript{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\textsubscript{2} emissions in Brazil, India, Mexico, and China.

2.2. How Do Renewable and Non-renewable Energy Consumptions Affect CO\textsubscript{2} Emissions?

The relationship between renewable and non-renewable energy consumption and CO\textsubscript{2} emissions has been a popular research subject in recent years. That non-renewable energy consumption (NREC) increased CO\textsubscript{2} emissions was a common finding in the literature, whereas the effect of renewable energy consumption (REC) on CO\textsubscript{2} emissions is still controversial and ambiguous. Some studies have reported that REC abates CO\textsubscript{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\textsubscript{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\textsubscript{2} emissions. The researchers explained that REC had not yet reached a level that could contribute to a decrease in CO\textsubscript{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\textsubscript{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\textsubscript{2} emissions.

Investigating the determinants of CO\textsubscript{2} emissions in OECD countries from 1980 to 2011, Shafieie and Salim (2014) found that NREC increased CO\textsubscript{2} emissions and REC decreased it. Dogan and Seker (2016) investigated the effects of REC and NREC on CO\textsubscript{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\textsubscript{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\textsubscript{2} emissions in 42 developing countries, Ito (2017) determined that the effect of REC on CO\textsubscript{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\textsubscript{2} emissions, whereas NREC degraded environmental quality by
increasing CO₂ emissions. Bhat (2018) used Pedroni cointegration and GMM methods in estimating the effect of renewable and non–renewable energy consumption on economic growth and CO₂ 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 CO₂ 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 CO₂ 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 CO₂ 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 CO₂ emissions, even though the effect of REC was much weaker than that of NREC. Finally, Alonso (2021) analyzed the relationships between CO₂ 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 CO₂ emissions also showed that the REC reduced CO₂ emissions.
Table 1. Literature Summary

| Author(s)          | Author(s)          | Country                  | Period          | Methodology                          | Findings                                                                                                                                                                                                 |
|--------------------|--------------------|--------------------------|-----------------|--------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Liu (2005)         | Ang (2007)         | 24 OECD countries        | 1975-1990       | Three stages least squares           | A negative correlation existed between the variables. The variables were cointegrated and there was unidirectional causality from economic growth to pollution in the long-term.                                 |
|                    |                    | France                   | 1960-2000       | Cointegration and VECM              |                                                                                           |                                                                                           |                                                                                           |
| Lotfalipour (2010) | Saatci and Durnul (2011) | Iran                    | 1967-2007       | Toda-Yamamoto causality             | There was unidirectional causality from growth to CO\(_2\) emissions. The variables were cointegrated and the EKC hypothesis was valid.                                                                  |
|                    |                    | Turkey                   | 1950-2007       | Kejriwal (2008) cointegration       | 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. |
| Hossain (2011)     |                    | Newly industrialized countries | 1971-2007     | Johansen Fisher panel cointegration and panel Granger causality | There was unidirectional causality from growth to CO\(_2\) emissions. The variables were cointegrated. There was no evidence of causality in the long-term, but significant 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. | Economic growth had a positive effect on CO\(_2\) emissions. The EKC hypothesis was not valid.                          |
|                    | Mikayilov et al. (2018) | Azerbaijan              | 1992-2013       | Johansen cointegration, DOLS, FMOLS, and CCR | Economic growth contributed to the generation of CO\(_2\) emissions. The EKC hypothesis was valid.                                                                                                    |
|                    | Liu et al. (2019)  | China, India, and G7 countries | 1965-2017     | Multispatial convergent cross mapping (CCM) | Economic growth contributed to the generation of CO\(_2\) emissions. The EKC hypothesis was valid.                                                                                                    |
|                    | Rofiuddin et al. (2019) | 11 Low-income countries | 1991-2014       | Fixed effect model                  | Economic growth contributed to the generation of 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 | Economic growth contributed to the generation of CO\(_2\) emissions. The EKC hypothesis was valid.                                                                                                    |
Table 1. How Do Renewable and Non–renewable Energy Consumptions Affect CO₂ Emissions?

| Author(s)                  | Country                          | Period       | Methodology                                      | Findings                                                                 |
|---------------------------|----------------------------------|--------------|-------------------------------------------------|---------------------------------------------------------------------------|
| Apergis et al. (2010)     | 19 developed and developing      | 1984-2007    | Panel cointegration and ECM                      | REC had no significant effect on CO₂ emissions.                           |
|                           | countries                        |              |                                                 |                                                                            |
| Menyah and Wolde–Rufael   | US                               | 1990-2007    | Toda–Yamamoto causality                        | There was no significant causality from REC to CO₂ emissions.            |
| (2010)                    |                                  |              |                                                 |                                                                            |
| Al–Mulali et al. (2015)   | Vietnam                          | 1981-2011    | ARDL cointegration                              | NREC increased CO₂ emissions while REC had no significant effect on       |
|                           |                                  |              |                                                 | decreasing CO₂ emissions.                                                 |
| Boluk and Mert (2014)     | 16 EU members countries          | 1990-2008    | Fixed effect model                              | REC contributed approximately 1/2 less than NREC to CO₂ emissions in the  |
|                           |                                  |              |                                                 | EU countries.                                                             |
| Farhadi 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 CO₂ emissions.                    |
| Shafiei and Salim (2014)  | 29 OECD countries                | 1980-2011    | Johansen Fisher panel cointegration, AMG         | The variables were cointegrated. REC had a negative effect on CO₂        |
|                           |                                  |              | estimator and panel Granger causality           | emissions, whereas NREC had a positive effect on it in the long-term.    |
|                           |                                  |              |                                                 | There was unidirectional causality from CO₂ emissions to REC and bidirectional causality between NREC and CO₂ emissions. |
| Dogan and Seker (2016)    | 23 countries ranking at the top  | 1985-2011    | LM bootstrap panel cointegration, panel FMOLS   | The variables were cointegrated. An increase in REC decreased carbon     |
|                           | in the Renewable Energy Country  |              | and DOLS                                        | emissions, while an increase in NREC resulted in an increase in CO₂      |
| Attractiveness Index (RECAI)|                                 |              |                                                 | 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,| 1980-2013    | Johansen cointegration and Larsson et al., Panel| The variables were cointegrated. REC improved environmental quality by   |
|                           | India, Sri Lanka, and Pakistan   |              | cointegration. Panel FMOLS                      | decreasing CO₂ emissions, whereas NREC degraded environmental quality by  |
|                           |                                  |              |                                                 | increasing CO₂ 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 CO₂ emissions while NREC was an         |
|                           |                                  |              |                                                 | important determinant of environmental pollution.                        |
| Koengkan et al. (2020)    | Argentina, Brazil, Paraguay,     | 1980-2014    | Panel VAR regression and Panel Granger          | There was a bidirectional causal relationship between both NREC and RE and CO₂ emissions. |
|                           | Uruguay, and Venezuela           |              | causality                                       |                                                                           |
| 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 CO₂ emissions. An     |
|                           |                                  |              |                                                 | increase in REC reduced CO₂ emissions.                                   |
3. Data and Methodology

3.1. Data

This study examines the effects of renewable and non-renewable energy consumption and economic growth on CO₂ emissions by using a balanced panel dataset of 53 countries covering the period 1990–2014. 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 CO₂ 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 |
|----------|-------------|
| CO₂      | CO₂ 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).

\[ y_{it} = \beta y_{i,t-1} + \beta x_{it} + u_{it} \]

where, \( y_{it} \) refers to the dependent variable, \( x_{it} \) 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 \[ E(u_{it}/x_{it}) \neq 0 \] assumption to be violated. Finally, the correlation between \( y_{i,t-1} \) and \( \mu_i \) that is a component of \( u_{it} \) does not meet the random effect estimator’s \[ E(\mu_i/x_{it}) \neq 0 \] 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:
\begin{equation}
\Delta y_t = \Delta y_{t-1} - \Delta y_{t-2} + \beta (y_{it} - y_{it-1}) + (u_t - u_{t-1}) \quad \text{or} \quad \Delta y_t = \Delta \delta y_{t-1} + \Delta \beta x_t + \Delta u_t
\end{equation}

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, CO₂ 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 CO₂ emissions by 0.56% but a 1% increases in NREC, GDPpc, FDI, and OPEN increase the CO₂ 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 CO₂ emissions, whereas non-renewable energy consumption, economic growth, foreign direct investments, and trade openness increased the CO₂ 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 lnCO₂, 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  |
|------------|----------|-------|-------|-------------------|----------|-------|-------|
| lnCO₂      | 2.068    | −1.789*** | −2.383 | ΔlnCO₂            | −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*** | Δln(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          | −11.365*** | −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%).
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Figure 2. The Relationship between the Variables

![Graphs showing the relationship between CO₂ emissions and various economic indicators.](image-url)
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 \((\chi^2)\) 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 \(\text{GDPpc}\) is positive and that of \(\text{GDPpc}^2\) 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 \(\text{CO}_2\) 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 \(\text{CO}_2\) 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 \(\text{CO}_2\) emissions by 0.28%, whereas a 1% increase in REC decreases \(\text{CO}_2\) emissions by 0.15%. Moreover, it was also determined that FDI and OPEN have a positive and significant effect on \(\text{CO}_2\) emissions.
Table 4. Results of two–step Difference GMM Estimation

|                      | Model [1]: Main model | Model [2] | Model [3] | Model [4] |
|----------------------|-----------------------|-----------|-----------|-----------|
| Dependent Variable: lnCO₂ |                      |           |           |           |
| (lnCO₂)ₜ₋₁           | 0.5627*** [27.51]     |           |           |           |
| lnGDPpc              | 0.3869*** [3.23]      |           |           |           |
| (lnGDPpc)²           | ~0.0118** [-1.76]     |           |           |           |
| lnREC                | ~0.1584*** [-14.17]   |           |           |           |
| lnNREC               | 0.2840*** [18.47]     |           |           |           |
| lnFDI                | 0.0011*** [5.98]      |           |           |           |
| lnOPEN               | 0.0513*** [5.81]      |           |           |           |

Wald test and (p > χ²) 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 > χ²) 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 CO2 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 CO2 emissions as asserted by the EKC hypothesis, (ii) the non-renewable energy consumption increases CO2 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 CO2 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 CO2 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 CO2 emissions could be prevented.

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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.

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