Assessing the impact of factors driving global carbon dioxide emissions

ABSTRACT

The aim of this study is to empirically investigate the causal relationship between global CO_2 emissions and six of their potentially contributing factors (i.e., economic growth, energy consumption, population, trade openness, financial development and corruption), by using a panel data collected from 65 countries during 1995 to 2013. We developed a dynamic model and used a four-step testing procedures (i.e., panel unit root tests, panel cointegration tests, long-run estimates, i.e. FMOLS estimates and a Granger causality test). The results showed that the most important factors driving global CO_2 emissions were economic growth, energy consumption, corruption and financial development. It is recommended that countries develop their own CO_2 reducing policies by designing an appropriate combination/mix of policy tools, such as regulation, economic, voluntary and educational/ informational instruments to address their environmental pollution. Countries could consider all dimensions of well-being when they measure their economic development. Imposing pollution taxes on fossil fuel based energy supplies, developing emissions standards, strengthening anti-corruption strategies and educating people about the adverse effects of CO_2 emissions on the natural environment and human health are potential policy measures.

Keywords: CO_2 emissions, trade openness, financial development, emissions standards, and anti-corruption strategies.

1. INTRODUCTION

The industrial revolution of the late 18th century initiated an era of rapid economic growth which also affected the quality of the environment. More importantly, it started transforming the global economy from an organic economy based on labor power to an inorganic economy based on inexpensive fossil fuels [1,2]. Burning fossil fuels releases CO_2 emissions which are the major cause for global warming and climate changes [3,4,5]. The NASA confirms that atmospheric carbon dioxide has significantly increased since the industrial revolution [6]. Climate change, in recent decades, has caused widespread effects on natural and human systems including altering hydrological systems, affecting water resources in terms of quantity and quality, affecting biological activities of many species, and affecting crop yields [7]. It has been forecasted that there will be an increase in global temperatures - from 1.1° C to 6.4°C due to increases in CO_2 emissions and other greenhouse gases (GHG) emissions [5]. As a result, sea levels are projected to rise from 16.5 cm to 53.8 cm by 2100, which will cause diverse socio-economic complications in many coastal areas [8]. Though CO_2 emissions originate from both anthropogenic and natural sources, it is believed that human activities are responsible for altering the carbon cycle – both by increasing the concentration of CO_2 in the atmosphere and by lowering the earth's capacity to absorb CO_2 from the atmosphere [4,9].

Reducing CO_2 emissions is one of the preconditions to mitigate the aforementioned adverse effects of climate change on natural and human systems [7,8], and the reduction could be possible through formulating and implementing sound environmental policies. In formulating environmental policies, policy makers need to know what drives global CO_2 emissions. Previous researches' findings from econometric models on factors contributing to CO_2 emissions have been substantially documented in the literature [1,2,10]. Most of these studies suffer from either the omitted variable bias or by using a specified robust econometric model by applying data form a single country or a region [11,12,13]. This study has a couple of advantages over other articles published on the same issue. First, its econometric model was specified to reduce the omitted variable bias. Second, the study uses a panel data collected from 65 countries covering the period 1995 to 2013 to mitigate any bias in results drawn from using data collected from a single country/region. The paper is organized as follows. Section 2 provides a comprehensive survey of existing literature. Section 3 presents the empirical analysis. The findings of the empirical analysis are presented and discussed in Section 4. Finally, Section 5 presents the conclusion of the study.

2. LITERATURE REVIEW

Investigating the factors potentially contributing to CO_2 emissions is not a new topic. There is a plethora of empirical studies on the issue which can be divided into five categories: the economic growth and CO_2 emissions nexus, the economic growth-energy-CO_2 emissions nexus, the economic growth-energy-trade-CO_2 emissions nexus, the economic growth-energy-trade-population-CO_2 emissions nexus, and the economic growth-energy-trade-population-financial development-CO_2 emissions nexus.

The economic growth and CO_2 emissions nexus

Researchers all over the world have attempted to estimate the relationship between environmental pollution and economic growth, employing various techniques. The findings of most studies showed no consistent relationship between CO_2 emissions and economic growth. However, in numerous studies the nexus was found as an inverted *U* shaped curve; also known as the Environmental Kuznets Curve (EKC). The EKC exhibits that at the beginning of a country's economic development, environmental degradation rises and then it levels off and falls with continuous economic growth [14,15,16]. The findings of other studies, however, showed that the relationship is monotonically increasing or non-declining. This implies that higher levels of economic activity require the use of more non-renewable natural resources, such as coal, oil and gas which results in more CO_2 emissions [17,18].

The economic growth, energy and CO_2 emissions nexus

It is based on the reality that any transformation of raw materials into economic output requires energy, which is generated mostly from fossil fuels, and causes CO_2 emissions [1,2]. Thus, economic growth and energy consumption and their potential contribution to CO_2 emissions has been inevitable and documented in the literature [19,20,21,22,23,24,25,26]. For example, Rehman et al. [27] examined the impact of CO_2 emission and the consumption of electrical, fossil fuel, and renewable energy on the status of the economy in Pakistan from 1990 to 2017. The researchers used the autoregressive distributed lag bounds method to examine the cointegration concept. They also utilized the Dickey-Fuller and the Phillips-Perron unit tests for checking the stationary of the variables, and the Johansen cointegration test for investigating the robustness of the long run relationships between the aforementioned variables. The result of the econometric model showed that only the relationship between the gross domestic product (GDP) per capita and CO_2 emissions was a bidirectional one, but the remained relationships between the variables were unidirectional ones. The findings of the study showed a stronger impact of the variables on the GDP per capita in the long run than that of in the short run. Similar to the Chandio et al.'s findings, the researchers suggested that the government should promote the use of renewable energy resources and make proper decision on reducing the CO_2 emissions [28]. One of the controversial debates in environmental economics, which began in the 1980s, is the relationship between environmental pollution and economic growth.

Ahmed et al. [29] investigated the relationship between per capita CO_2 emissions and GDP per capita in 63 countries over 51 years during 1960 to 2010. Using a graphical analysis approach, the results of the study showed that such relationship followed a sigmoid curve indicating that the per capita carbon dioxide emissions of a country increased when its economy transitioned from a labor-intensive technology to a capital-intensive one caused by an increase in the rate of economic growth. The results also showed that the amount of relative emissions varied amongst the countries and could be occurred because of the heterogeneity in the structure of the economies, and the disparity in the mode of production used in the countries' manufacturing processes.

Chandio et al. [30] examined a dynamic linkage between the amounts of energy consumption in the industrial sector of Pakistan with the rate of economic growth in the country during 1983-2017. The econometric method that the researchers used was the autoregressive distributed lag cointegration model to find both short-and-long run relationship between the rates of economic growth with different sources of energy consumption including industrial and renewable energy consumption, and industrial gas consumption for energy. The country's substantial economic growth caused by using advanced production technologies on one side yields challenges to continue promoting the industry with respect to the energy consumption. This postulation was also found in Chandio et al.'s research [30]. In particular, the findings of their study showed that there was a positive relationship between Pakistan's economic growth and the amounts of energy consumption (i.e., both power and gas) in the industrial sector of the country, whereas a negative relationship between economic growth and industrial oil consumption in the long run was found despite the fact that such relationship in the short run was found to be positive. The researchers suggested that the government should encourage industries to use more renewable energy resources (e.g., solar, hydro, wind, biomass, etc.) rather than using fossil fuels, oil and gas.

The economic growth, energy, trade and CO_2 emissions nexus

Grossman and Krueger [31] and Ahmed et al. [1] argued that trade openness causes not only a movement of goods and services across borders but also dissemination of modern technologies and managerial philosophies to developing countries. These help developing countries reduce environmental pollution when outputs are being produced using these technologies and philosophies. However, trade can cause a shift in the production of pollution intensive output from a developed country, where environmental regulations are more stringent, to a developing country with less stringent environmental regulations, which is known as the *pollution haven hypothesis*. Having realized the significance of trade openness for environmental pollution, recent studies have measured it while studying the causal relationship of CO_2 emissions with their potentially contributing factors [32,33,34]. Most of these studies were conducted on single countries, such as China, Malaysia, and Turkey and found a significant positive correlation between trade openness and CO_2 emissions.

The economic growth, energy, trade, population and CO_2 emissions nexus

It is a general consensus that an increase in human population adds more CO_2 in the atmosphere than the CO_2 amount one can reduce by changing lifestyles, such as by adopting energy efficient appliances and light bulbs, or using high-mileage vehicles, or adopting recycling [35]. In order to investigate whether there is a dynamic causal relationship between CO_2 emissions and some other factors, like income, energy use, urbanization (as a proxy for human population), and trade liberalization, for a panel including all newly industrialized countries, Hossain [36] found no long-run causal relationship but a short-run unidirectional causal relationship. This short-run causality was running from GDP growth and trade liberalization to CO_2 emissions. Using different econometric tests, such as the unit root, cointegration, and Granger causality tests Kasman and Duman [2] examined the relationship between CO_2 emissions and the aforementioned four control variables, for a panel including new EU member and candidate countries. They found both a short-run unidirectional causality running from urbanization, energy use, and trade openness to CO_2 emissions, and a long-run, bidirectional causal relationship among these variables. Ahmed et al. [1] examined the long-run association as well as the causal relationship between CO_2 emissions and the four control variables for a panel including five selected South Asian economies. They found that all the contributing factors, except income, have a statistically significant positive effect on CO_2 emissions.

The economic growth, energy, trade, population, financial development and CO_2 emissions nexus

Literature shows that countries with well-developed financial systems tend to grow faster in terms of per capita income which, according to the EKC hypothesis, will eventually improve environmental quality [31,37]. However, financial intermediaries under well-developed financial systems tend to offer affordable consumer loans to individuals; this makes it easier to buy items like cars, heaters, refrigerators, air conditioners, and washing machines whose use will accelerate CO_2 emissions [38]. Other studies found that financial development could be an instigating factor that intensifies CO_2 emissions [39,40,41]. On the contrary, other researchers argued that financial development either reduces emissions or has no effect on CO_2 emissions [42,43,44]. This survey of the relevant literature does not provide any conclusive evidence about the causal relationship between CO_2 emissions, income, energy use, population, trade openness and financial development. These inconclusive results urge researchers to conduct further studies including on relevant variables, or by developing sound models as well as employing an appropriate methodology.

In recent years, the study of corruption has gained importance among environmental economists as they believe it to be one of the dominant reasons of environmental degradation. Theoretically, corruption has a direct impact on the environment, in terms of lowering the stringency of environmental regulations, as well an indirect impact which operates through corruption's effect on income and the resultant income's effect on pollution [45,46]. Welsch [47] attempted to quantify both the direct and indirect effects of corruption on the environment and found that the direct effect is always positive but the indirect effect is ambiguous depending on the income level; thus, the resulting total effect is unknown. The researcher found an overall monotonically increasing relationship between corruption and pollution. The relationship becomes relatively stronger for low-income countries. With a critical view of the study, Cole [48] argued that the study incorporates neither potential endogeneity of corruption in estimating the relationship nor enough data (not more than one year) to explain unobserved heterogeneity across countries. Later, Cole [48] conducted a study using data for a sample of 94 countries covering the period 1987–2000, with the objective to quantify both the direct and indirect impacts of corruption on environmental pollution, specifically air pollution emissions. The study found a positive direct effect of corruption on both sulfur dioxide and carbon dioxide emissions, but a negative indirect effect, with a larger positive value, and therefore a negative total effect for all countries, except the high-income countries in the sample. Both studies found that the direct effect of corruption on the environment is positive. This result is consistent with Lopez and Mitra [49] who stated that corruption causes pollution for a given per capita income to increase to a level higher than the socially optimal level. The resulting higher level of pollution delays a nation to reach the turning point in its EKC curve [49,50].

Fredriksson et al. [46] developed a model analyzing the impact of corruption on environmental policy, and concluded that greater corruption weakens the stringency of environmental policy. Other studies examined how corruption can affect the relationship between political stability and the stringency of environmental policy (SEP), trade and SEP, and foreign direct investment (FDI) and SEP, respectively [45,51,52]. The findings of these studies showed similar results, namely that greater corruption, less political stability, more trade and FDI make environmental policy less stringent. Most of the previous studies on the effect of corruption on the environment are theoretical in nature and meaningful for ideal cases. The insufficiency of empirical research on the issue leads to uncertainty about the nature and magnitude of any such effect in real-life cases. Rehman et al. [50] mentioned the effect of corruption on environmental policy as one of the least researched topics that needs to be empirically tested for different regions. It is a general consensus that the total effect of corruption on the environment is ambiguous [45,53,54].

Moreover, no multivariate research work involving corruption has yet been done. This research is unique and significantly contributes to the literature, as it analyzes corruption and the aforementioned control variables by reducing the omitted variable bias.

Chandio et al. [28] conducted a research to examine the long run relationship between the financial development, economic growth, energy consumption in the form of electricity consumption in the agriculture sector, foreign direct investment, and population on the quality of environment in Pakistan during 1980-2016. The researchers chose CO_2 emissions from the agriculture sector as a substitute variable representing environmental quality. Chandio et al. [28] used various econometric tests (i.e., unit root tests, structural break unit tests, cointegration tests) to determine whether the concepts of stationary, structural break, and robustness of the results could apply to their collected data and the estimates, respectively. After implementing the aforementioned tests, Chandio et al. [28] found a long-term cointegration relationship between the variables. In addition, the findings of the study showed a positive between foreign direct investment and financial development with environmental quality in Pakistan. The researchers suggested that the government should make appropriate policies to encourage foreign investors to contribute more in the economy of the country. In addition, the reduction of using fossil fuels and replacing them by various renewable energies was recommended.

3. EMPIRICAL ANALYSIS

The model specification

We developed a dynamic econometric model to examine the long-run relationship between CO_2 emissions and their potentially contributing factors such as economic growth, energy consumption, population size, trade openness, financial development and corruption. Previous studies also used similar model specification in their empirical analyses [10,11,36]. In particular, we specified the model as:

$$PCO_{2it} = A_0 PGDP_{it}^{\alpha_{1i}} PEC_{it}^{\alpha_{2i}} POP_{it}^{\alpha_{3i}} TROP_{it}^{\alpha_{4i}} FD_{it}^{\alpha_{5i}} CPI_{it}^{\alpha_{6i}} \quad (1)$$

where PCO_{2it}, $PGDP_{it}$, PEC_{it}, POP_{it}, $TROP_{it}$, FD_{it} and CPI_{it} represent per capita CO_2 emissions, GDP per capita, per capital energy consumption, population, trade openness, financial development and corruption (measured by the corruption perception index-CPI, an index developed by Transparency International [55]) of the *i-th* country at *t* time, respectively. Since there is a direct relationship between PCO_2 with *PGDP*, *PEC,* and *POP* we would expect a positive sign for $\alpha_1, \alpha_2, and\ \alpha_3$. As mentioned earlier, the impact of trade openness, financial development and corruption on per capita CO_2 emissions is ambiguous. Therefore, we would not be able to take a guess about the signs of $\alpha_4, \alpha_5, and\ \alpha_6$.

Econometric methodology

We examined if any dynamic causal relationship exists between CO_2 emissions, economic growth, energy consumption, population size, trade openness, financial development and corruption. More specifically, the econometric methodology is four-fold. At first, all relevant variables are to be tested for stationarity status using a panel unit root test [1,56]. If these variables are found to be non-stationary, the second step employs a panel cointegration test to examine whether there is any long-run association between the series of these variables [1]. If any long-run association is not found between the series, the third step estimates the parameters of the long-run relationship between these variables, using the fully modified ordinary least square (FMOLS) method. Finally, the last step examines both the short-run and the long-run causal relationship between these variables through estimating a vector error-correction model (VECM). Previous studies have also used the aforementioned methodology in their empirical analysis [2]. In the followings we briefly explained our econometric methodology.

Step 1 – The panel unit root test

Stationary variables or stationarizing non-stationary variables are necessary for a meaningful time series econometric analysis. Therefore, the use of a unit root test for detecting unit root problems or testing stationarity properties of the variables has become a widespread practice in time series econometric literature [1]. The panel unit root test has higher power than the individual unit root test for maintaining persistence of individual time series regression errors across its cross sections [2]. There are several kinds of panel unit root tests; however none of them is free from statistical deficiencies. In this study, we used three types of panel unit root tests (i.e., the Levine-Lin-Chu test, the Breitung test, and the Im-Pesaran-Shin test) to detect unit root problems properly.

The Levine-Lin-Chu (LLC) test for panel unit root allows detection of individual regression errors, the trend and intercept coefficient to move freely across the cross sections [57]. The test proposes the following hypothesis:

H_0: unit root – each series contains a unit root, i.e. $\beta_i = 0$

H_1: stationary – each series does not contain a unit root, i.e. $\beta_i < 0$

The Breitung test for panel unit root has been developed on the basis of de-trending methods and provides an unbiased class of *t*- test statistic [58]. The statistical test assumes the following hypothesis:

H_0: each series contains a unit root, i.e. $\sum_{k=1}^{p+1} \beta_{ik} -= 0$

H_1: each series does not contain a unit root, i.e. $\sum_{k=1}^{p+1} \beta_{ik} -< 0$

The Im-Pesaran-Shin (IPS) test for panel unit root proposes a standardized *t*- bar test to detect unit roots in dynamic heterogeneous panels. The test statistics is developed based on the mean of the individual Augmented Dickey Fuller statistic test and it is relatively less restrictive than the LLC test for panel unit root [33,59]. The hypothesis of the test is given as:

H$_0$: each series assumes an individual unit root process, i.e. $\beta_i = 0$

H$_1$: each series does not assume an individual unit root process, i.e. $\beta_i < 0 \; for \; i = 1, \ldots, N_1$ and $\beta_i = 0 \; for \; i = N_1 + 1, \ldots, N$.

Step 2: The panel cointegration test

The cointegration test in time series is used to examine whether there is any long-run association between variables when they are non-stationary. Amongst all the available cointegration statistical tests in time series the Pedroni and Kao's residual cointegration tests are widely used [1] which are briefly explained. Based on the residuals of the [60] cointegration regression, Pedroni [61,62] developed seven different statistical tests to examine if any cointegration relationship is available in heterogeneous panels. These seven tests are classified into two groups, within dimension and between dimension groups. The first group of statistical tests, also known as panel cointegration tests, includes panel v- statistic (Z_v), panel ρ -statistic (Z_ρ), panel *PP*-statistic (Z_{PP}), and panel *ADF*- statistic (Z_{ADF}). The second group of statistical tests, also known as group mean panel cointegration statistics consists of group ρ -statistic ($\widetilde{Z_\rho}$), group *PP*-statistic ($\widetilde{Z_{PP}}$), and group *ADF*-statistic ($\widetilde{Z_{ADF}}$). All the above statistical tests are used to test the following hypothesis:

H$_0$: No cointegration, i.e. $\rho_i = 0$

H$_1$: Cointegration exists, i.e. $\rho_i = \rho < 0$

Following the Dickey–Fuller (DF) and the augmented Dickey–Fuller (ADF) statistical tests to examine the no cointegration hypothesis in time series, Kao [63] developed a residual-based statistical test to investigate if any cointegration relationship exists in heterogeneous panels. Kasman and Duman [2] stated that the basic structure of the Kao's statistic test and the null and alternative hypotheses are similar to the Pedroni's.

Step-3: The panel cointegration estimates

Given the results of the cointegration statistical test in the second step, we estimated the parameters of the long-run association in the third step. Various techniques such as the ordinary least squares (OLS), fixed effect, random effect, generalized method of moments (GMM), and the fully modified ordinary least squares (FMOLS) methods are available to estimate the parameters; however all methods are not equally efficient. Many researchers argued that estimating parameters of the model by using the OLS, fixed effect, random effect, or the GMM methods will lead to inconsistence and bias estimates because of the presence of serial correlations in the panel data, and instead, the FMOLS method of Pedroni [62] was suggested. The main advantage of the FMOLS method is that it does not suffer from distortions in the presence of serial correlations, endogeneity, simultaneity bias and heterogeneous dynamics [1].

Following Pedroni [62], the panel FMOLS estimator is defined as:

$$\hat{\beta}^{*}_{FMOLS} = \frac{1}{N}\sum_{i=1}^{N}\left(\sum_{t=1}^{T}(X_{it}-\bar{X}_i)^2\right)^{-1}\left(\sum_{t=1}^{T}(X_{it}-\bar{X}_i)Y^{*}_{it}-T\hat{\gamma}_i\right)$$

Where $Y^{*}_{it} = Y_{it} - \bar{Y}_i - \left({\hat{\Omega}_{2,1,i}}/{\hat{\Omega}_{2,2,i}}\right)\Delta X_{it}$,

$\hat{\gamma}_i = \hat{\Gamma}_{2,1,i} + \hat{\Omega}^{0}_{2,1,i} - \left({\hat{\Omega}_{2,1,i}}/{\hat{\Omega}_{2,2,i}}\right)\left({\hat{\Gamma}_{2,2,i}}/{\hat{\Omega}_{2,2,i}}\right)$ and Ω_{it} is the long-run covariance matrix which can be further decomposed as; $\Omega_i = \Omega^{0}_i + \Gamma_i + \acute{\Gamma}_i$. The relevant *t*-test is specified as:

$t_{\hat{\beta}^{*}_{FMOLS}} = \frac{1}{\sqrt{N}}\sum_{i=1}^{N} t_{\hat{\beta}^{*}_{FMOLS},i}$; where $t_{\hat{\beta}^{*}_{FMOLS},i} = \left(\hat{\beta}^{*}_i - \beta_0\right)\left[\hat{\Omega}^{-1}_{1,1,i}\sum_{t=1}^{T}(Y_{it}-\bar{Y})^2\right]^{1/2}$

Step-4: The panel Granger causality analysis

The cointegrating relationship between variables indicates not only the existence of a long-run relationship but also the presence of a causal relationship between these variables, at least in one direction. However, the cointegration test results provide no information about the direction of the causal relationship. Thus, we estimated a panel vector error-correction model to examine the direction of the causal relationship. The direction of the short-run causal relationship is determined based on the *F*-test, whereas the error correction term provides information about the direction of the long-run causal relationship [2,11,20,56]. The panel VECM model is specified as:

$$\begin{pmatrix} \Delta lnPCO_{2it} \\ \Delta lnPGDP_{it} \\ \Delta lnPEC_{it} \\ \Delta lnPOP_{it} \\ \Delta lnTROP_{it} \\ \Delta lnFD_{it} \\ \Delta lnCPI_{it} \end{pmatrix} = \begin{pmatrix} \alpha_1 \\ \alpha_2 \\ \alpha_3 \\ \alpha_4 \\ \alpha_5 \\ \alpha_6 \\ \alpha_7 \end{pmatrix} + \sum_{k=1}^{P} \begin{pmatrix} \beta_{11k} & \beta_{12k} & \beta_{13k} & \beta_{14k} & \beta_{15k} & \beta_{16k} & \beta_{17k} \\ \beta_{21k} & \beta_{22k} & \beta_{23k} & \beta_{24k} & \beta_{25k} & \beta_{26k} & \beta_{27k} \\ \beta_{31k} & \beta_{32k} & \beta_{33k} & \beta_{34k} & \beta_{35k} & \beta_{36k} & \beta_{37k} \\ \beta_{41k} & \beta_{42k} & \beta_{43k} & \beta_{44k} & \beta_{45k} & \beta_{46k} & \beta_{47k} \\ \beta_{51k} & \beta_{52k} & \beta_{53k} & \beta_{54k} & \beta_{55k} & \beta_{56k} & \beta_{57k} \\ \beta_{61k} & \beta_{62k} & \beta_{63k} & \beta_{64k} & \beta_{65k} & \beta_{66k} & \beta_{67k} \\ \beta_{71k} & \beta_{72k} & \beta_{73k} & \beta_{74k} & \beta_{75k} & \beta_{76k} & \beta_{77k} \end{pmatrix} \begin{pmatrix} \Delta lnPCO_{2it-k} \\ \Delta lnPGDP_{it-k} \\ \Delta lnPEC_{it-k} \\ \Delta lnPOP_{it-k} \\ \Delta lnTROP_{it-k} \\ \Delta lnFD_{it-k} \\ \Delta lnCPI_{it-k} \end{pmatrix} + \begin{pmatrix} \omega_1 \\ \omega_2 \\ \omega_3 \\ \omega_4 \\ \omega_5 \\ \omega_6 \\ \omega_7 \end{pmatrix} ECM_{it-1} + \begin{pmatrix} \varepsilon_{1it} \\ \varepsilon_{2it} \\ \varepsilon_{3it} \\ \varepsilon_{4it} \\ \varepsilon_{5it} \\ \varepsilon_{6it} \\ \varepsilon_{7it} \end{pmatrix}$$

where $i = 1, 2, \ldots \ldots \ldots, n$; $t = P+1, P+2, P+3, \ldots \ldots \ldots, T$; Δ and *ECM* denote the first difference of the variable and the error-correction term, respectively. In addition, *K* represents the optimal lag length which is determined by the Schwarz Information Criterion (SIC). Finally, α*'s* and β*'s* are parameters of the model, and ω*'s* are the adjustment coefficients, which are unknown and have to be estimated

Data description

In this study we used a panel data consisting of seven variables: CO_2 emissions, economic growth, energy consumption, population size, trade openness, financial development and corruption. The CO_2 emissions were those emitted mainly from the burning of fossil fuels as well as from cement manufacturing plants measured in metric tons per capita. Economic growth was measured using GDP per capita in constant 2010 USD. Energy consumption represented the use of all primary energy before transformation to other types, the net import of energy and changes to existing stocks, and was measured in kilograms of oil equivalent per capita. The population variable represented the total human population regardless of legal status or citizenship. Trade openness was measured using the percentage of total trade in the GDP (i.e. total of exports and imports of goods and services). Similarly, financial development was measured using the percentage of domestic credit to the private sector in the GDP. According to Transparency International [55], the corruption variable was measured using the corruption perception index (CPI) which has a range of values from 0 (highly corrupt) to 100 (very clean). Data on all variables, except corruption, were collected from the World Development Indicators of the World Bank on January 3, 2017. Corruption data were obtained from the CPI scores of Transparency International on the same date. Transparency International has started estimating CPI scores based on a scale of 0 (highly corrupt) to 10 (very clean) since 1995 and later revised its scale with a range of 0 (highly corrupt) to 100 (very clean) in 2012 [55]. All CPI scores from 1995 to 2011 were multiplied by 10 to adjust the earlier scale with the recent one of 0 (highly corrupt) to 100 (very clean). The time length of observations began in 1995, because of unavailability of CPI scores at any previous period, and ended in 2013, as energy consumption data after 2013 were not available on January 3, 2017. Within this time frame, only 65 countries data across the observations were available. Therefore, the sample data set contains annual data on these variables from 65 countries during 1995 to 2013. The summary statistics of the sample data is available upon request.

4. EMPIRICAL FINDINGS AND DISCUSSION

All variables were tested whether they maintained stationary properties by using the three panel unit root tests- LLC, Breitung, and IPS. Table 1 summarizes the results of the unit root tests.

[Insert Table 1 here]

We failed to reject the null hypothesis indicating each series contains a unit root at level, but we rejected the same null hypothesis at the first difference with the 99 percent confidence. Thus, all variables under the panel were characterized as integrated of order one, i.e., I(1). We used the Pedroni and Kao residual cointegration tests to examine if the I(1) variables had any long-run relationship and showed the results in Table (2). As for the Pedroni residual cointegration test, most of the statistics such as panel PP-stat, panel ADF-stat, group PP-stat and group ADF-stat were found statistically significant with 99 percent confidence. The findings suggested that the I(1) variables were co-integrated implying that there was a long-run relationship between the variables. Similar results were found using the Kao residual cointegration test.

[Insert Table 2 here]

As mentioned earlier, the parameters of the regression model, i.e., equation [1], were estimated using the FMOLS estimation technique and the estimates were shown in Table 3. Since all the data were converted into logarithmic form, the parameters of the equation express the long-run elasticities of the per capita CO_2 emissions with respect to the independent variables. We found a direct relationship between economic growth and CO_2 emissions (i.e., 0.348), as the coefficient shown in table 3 is statistically significant with 99 percent confidence. It means that a one per cent increase in GDP per capita requires producing more goods and services using the existing technology that results in an additional CO_2 emission of 0.35 percent. This finding is consistent with [33] and [2], but inconsistent with [1]. As for energy consumption, we found a statistically significant direct relationship with CO_2 emissions that is also consistent with precedent studies [1, 2,11]. In particular, we found that the long-run elasticity of CO_2 emissions and energy consumption is 0.606 implying that an increase in per capita energy consumption of one per cent emits an additional per capita CO_2 amount of 0.606 percent. According to the economic theories, the demand for durable goods increases due to increase in economic growth. Consumption of durable goods uses more energy and results in more emissions. As for population variable, we found a direct relationship between CO_2 emissions and population growth (0.174), and the finding was statistically significant (*p-value* 0.026). Any increase in human population requires more production of economic output necessary for consumption by the additional population, and eventually leads to more CO_2 emissions. In this study, we found that a one percent increase in population results in additional CO_2 emissions of 0.174 percent. Table 3 shows an inverse relationship between CO_2 emissions and trade openness, which was statistically significant (*p-value* 0.034). Specifically, the long-run elasticity of CO_2 emissions and trade openness was -0.072. It implies that a one percent increase in trade openness reduces per capita CO_2 emissions by 0.072 percent. The coefficient of the financial development was -0.051 and statistically significant with 99 percent confidence. It indicates that a one per cent increase in financial development reduces per capita CO_2 emissions by 0.051 percent. The finding is consistent with studies by [31,37] which argued that countries with well-developed financial systems tend to grow faster in terms of per capita income which, according to the EKC hypothesis, will eventually improve environmental quality. This study also shows another positive relationship between corruption and CO_2 emissions. Table 3 shows that the long-run elasticity of CO_2 emissions and corruption was 0.155 which is statistically significant with 99 percent confidence. It indicates that a one percent increase in corruption results in 0.155 percent increase in per capita CO_2 emissions. Greater corruption does not only weaken the stringency of environmental regulations, but also delays a nation in achieving the turning point of economic growth which, according to the EKC hypothesis, is required to improve environmental quality [45,51,52]. In conclusion, CO_2 emissions have a long-run relationship with economic growth, energy consumption, population growth, trade openness, financial development and corruption.

[Insert Table 3 here]

The long-run relationship between variables in this study is found from the long-run estimates; however, these estimates do not provide information about causal relationships between these variables. Table 4 presents the results of the panel Granger causality test which provides the information about the causal relationship. As mentioned earlier, the statistical significance of coefficients of variables as well as of the lagged error correction terms in the model present evidence of the existence of a short-run and a long-run causal relationship, respectively. Table 4 shows that there is a short-run bidirectional causal relationship between economic growth and CO_2 emissions. Economic growth is the dominant factor that leads to more CO_2 emissions. The primary objective of the economic growth is to ensure well-being for societies. However, unlimited economic growth or increase in wealth which disregards the objective of conserving the earth ecosystem does not entirely bring well-being. It is a general consensus that GDP fails to measure economic activity accurately as it does not contemplate other dimensions of economic activity [64]. We recommend that other related factors of well-being such as life expectancy, scholastic achievements should be considered while measuring economic growth. For instance, countries are urged to count their Gross Sustainable Development Product (GSDP) or the Genuine Progress Indicator (GPI) rather than conventional GDP. In this study we found a short-run bidirectional causal relationship between population growth and CO_2 emissions, which is consistent with the findings of previous studies [20]. Other short-run bidirectional causal relationships were also found between economic growth and financial development; energy consumption and corruption; and energy consumption and population growth.

The findings of this study showed that there was a short-run unidirectional causality running from economic growth to energy consumption, which was consistent with the findings of previous studies [2,24,36,65,66,67]. It indicates that an increase in GDP enables households to purchase more durable goods that require energy to be operated, and thus accelerate CO_2 emissions [38]. As we mentioned earlier, we hypothesized energy consumption to represent the use of all primary energy forms which are mostly from pollution intensive sources (e.g. fossil fuels), before their transformation to other types. Countries should take policy initiatives to reduce pollution intensive energy consumption through increasing the energy efficiency of consumption, decreasing the energy intensity of production, and focusing on transition to renewable energy sources. Countries could adopt energy saving strategies to improve their energy efficiency without risking economic development, as this study does not find any causality running from energy consumption to GDP. With the aim to deter misuses of pollution intensive energy, e.g. fossil fuels, countries may impose carbon pricing, in the form of pollution or emissions taxes on fossil fuels, specifically targeting the big industrial polluters (such as electricity producers), and invest a portion of the tax revenue for research and development on discovering more energy efficient technologies and finding alternative energy sources. In the developing countries, part of the tax revenue could be spent to make the supply of renewable and energy efficient technologies available at subsidized prices, to alleviate the burden of taxation for poor households. Moreover, countries could use a portion of the tax revenue to educate their population and make them mindful about the consequences of excessive energy uses.

[Insert Table 4 here]

The findings of this study showed that there was another short-run causality running from energy consumption, corruption and financial development to CO_2 emissions, which is, to some extent, consistent with the findings of [11] and [2]. It indicates that in addition to economic growth and energy consumption, corruption and financial development substantially affect CO_2 emissions. As for corruption, it does not only weaken the stringency of environmental policy measures, but also drags economic development down. The lower level of economic development delays a nation to reach the turning point in its EKC curve. In this study, the presence of Granger causality, running from corruption to energy consumption, indicated that the energy sector amongst the sample countries was less transparent and misuses of energy due to corruption were common. For example, the loss in the energy distribution system, locally called '*system-loss*' in the energy sector in Bangladesh was 28 per cent during 2001 to 2002 [68]. To reduce CO_2 emissions by promoting stringent environmental policy regulations, and economic development with an efficient energy sector, countries should develop anti-corruption strategies by initiating an independent anti-corruption commission, or by strengthening the activities of the commission if it had already been established. In addition, countries should promote green banking and encourage investors to invest into green technologies. Nations are urged to develop an appropriate combination of policy tools to address the root cause of CO_2 emissions and improve their environmental quality. As mentioned earlier, we found other short-run unidirectional causal relationships in this study that were running from population growth to financial development; from economic growth and trade openness to corruption; and from economic growth to population growth. Finally, the findings of this study showed a couple of long-run unidirectional causal relationships. The first one was running from CO_2 emissions, economic growth, energy consumption, population growth, trade openness and corruption to financial development that was consistent with findings by [11]. The second one was running from CO_2 emissions, economic growth, energy consumption, trade openness, financial development and corruption to population growth.

5. CONCLUSION

Human activities alter the carbon cycle by increasing the concentration of CO_2 in the atmosphere and by lowering the earth's capacity to absorb CO_2 from the atmosphere. The anthropogenic CO_2 emissions continue to create diverse socio-economic complications. The reduction of CO_2 emissions is necessary to mitigate their adverse effects on natural and human systems. Therefore, the study of factors that potentially contribute to CO_2 emissions is required in order to formulate appropriate policies that aim to reduce CO_2 emissions. In this study, we have developed several dynamic econometric models and used data from the World Development Indicators of the World Bank and Transparency International to examine the long-run relationships between CO_2 emissions and economic growth, energy consumption, population growth, trade openness, financial development and corruption. Based on the results of the Granger causality test, we have concluded that the main potential factors driving global CO_2 emissions were economic growth, energy consumption, corruption and financial development. Therefore, we have suggested that nations should develop their own CO_2 emissions reducing policies combining proper mix of policy tools, such as regulation, economic, voluntary and educational/ informational instruments to address their environmental pollution. Moreover, they could consider other dimensions of well-being beyond GDP, when measuring their economic development. Imposing pollution taxes on fossil fuel based energy supplies, developing emissions standards, strengthening anti-corruption strategies and educating people about the adverse effects of CO_2 emissions on the natural environment and human health are such potential policy measures.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Table 1. Panel unit root test results

Variable → / Test ↓		$LNPCO_2$	LNPGDP	LNPEC	LNPOP	LNTROP	LNFD	LNCPI
LLC t^*-Stat	At L	-2.72** (0.003)	-22.45** (0.000)	-2.35** (0.009)	-6.18** (0.000)	-5.77** (0.000)	0.03 (0.513)	-2.24 (0.012)
Breitung t-Stat	At L	4.87 (1.000)	4.42 (1.000)	2.80 (0.997)	12.49 (1.000)	-3.03 (0.011)	4.97 (1.000)	-0.19 (0.421)
IPS W-Stat	At L	0.05 (0.520)	-0.98 (0.163)	0.65 (0.743)	-5.61 (0.100)	-3.18 (0.100)	0.31 (0.623)	-2.73** (0.003)
LLC t^*-Stat	At Δ	-19.82** (0.000)	-17.08** (0.000)	-19.76** (0.000)	-4.02** (0.000)	-21.98** (0.000)	-16.41** (0.000)	-18.45** (0.000)
Breitung t-Stat	At Δ	-10.61** (0.000)	-10.32** (0.000)	-5.97** (0.000)	-0.05 (0.476)	-15.48** (0.000)	-8.21** (0.000)	-6.41** (0.000)
IPS W-Stat	At Δ	-18.77** (0.000)	-11.69** (0.000)	-17.33** (0.000)	-6.93** (0.000)	-17.78** (0.000)	-13.02** (0.000)	-19.39** (0.000)

Note: *L, Δ and ** stand for level, first difference and 0.01 level of significance, respectively. All unit root tests have the same null hypothesis which examines the presence of unit root in the variables. Lag length is selected automatically based on Schwarz Information Criteria-SIC.*

Table 2. Cointegration test results

Pedroni Residual Cointegration Test							Kao Residual Cointegration Test
Within-dimension				Between-dimensions			
Panel v-stat	Panel rho-stat	Panel PP-stat	Panel ADF-stat	Group rho-stat	Group PP-stat	Group ADF-stat	
-3.69 (0.99)	6.38 (1.00)	-7.70** (0.00)	-8.92** (0.00)	9.66 (1.00)	-18.81** (0.00)	-11.37** (0.00)	-4.89** (0.00)

Note: *** 0.01 level of significance. All cointegration tests have the same null hypothesis of not cointegration. Lag length is selected automatically based on Schwarz Information Criteria-SIC.*

Table 3. Panel FMOLS results ($LNPCO_2$ is the dependent variable)

LNPGDP	LNPEC	LNPOP	LNTROP	LNFD	LNCPI
0.348** (0.000)	0.606** (0.000)	0.174* (0.026)	-0.072* (0.034)	-0.051** (0.006)	0.155** (0.000)

Note: *** 0.01 level of significance. Lag length is selected automatically based on Schwarz Information Criteria-SIC.*

Table 4. Panel Granger causality test results

Y↓ X⟶	$\Delta LNPCO_2$	ΔLNPGDP	ΔLNPEC	ΔLNPOP	ΔLNTROP	ΔLNFD	ΔLNCPI	ETC
$\Delta LNPCO_2$	------	33.143** (0.000)	11.544* (0.021)	14.797** (0.005)	3.095 (0.541)	13.472** (0.009)	8.686** (0.006)	[0.42] (0.67)
ΔLNPGDP	14.607** (0.005)	------	1.031 (0.904)	7.328 (0.119)	2.875 (0.579)	19.327** (0.000)	1.631 (0.803)	[-1.43] (0.15)
ΔLNPEC	4.871 (0.300)	30.603** (0.000)	------	35.837** (0.000)	8.431 (0.077)	11.824* (0.018)	9.800* (0.043)	[1.84] (0.06)
ΔLNPOP	18.095** (0.001)	28.377** (0.000)	28.580** (0.000)	------	0.597 (0.963)	4.128 (0.388)	0.877 (0.927)	[-2.38] (0.01)
ΔLNTROP	7.579 (0.108)	39.809** (0.000)	11.910* (0.018)	4.968 (0.290)	------	1.661 (0.797)	9.305 (0.053)	[2.36] (0.01)
ΔLNFD	8.247 (0.082)	35.642** (0.000)	8.259 (0.082)	11.208* (0.024)	8.327 (0.080)	------	6.009 (0.198)	[-5.54] (0.00)
ΔLNCPI	8.598 (0.071)	33.694** (0.000)	10.480* (0.033)	2.444 (0.654)	25.864** (0.000)	4.363 (0.359)	------	[1.34] (0.17)

Note: *The p-values are presented in parentheses while t-statistics are in brackets. ** and * denote statistical significance at 1% and 5% level, respectively.*