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ARTICLE

Economic growth and environmental pollution nexus in Bangladesh: revisiting the environmental Kuznets curve hypothesis

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ABSTRACT
The paper reports a re-examination of the environmental Kuznets curve (EKC) hypothesis for Bangladesh; considering economic growth and greenhouse gas (GHG) emissions (such as CO_2, CH_4, and N_2O). The autoregressive distributive lag (ARDL) model and VAR-based innovative accounting approach (IAA) with the combination of Variance Decomposition and Impulse Response Function are used to check cointegration among the variables using data from 1976 to 2014. This approach is specifically employed for variance analysis in order to measure causal association and regressors' shock to dependent variables. The EKC hypothesis is not supported because there is a positive association between economic growth and pollutants (CO_2 and CH_4 emissions) over time. However, the EKC is valid for N_2O emissions. IAA causal analysis reveals a bilateral causative relationship between GDP and CO_2 emissions, as well as a unilateral causal relationship between CH_4 emissions and GDP. Trade liberalisation, urbanisation, and financial liberalisation do not necessarily improve or save the natural environment. Bangladesh needs to use renewable energies and cut GHG emissions by abandoning fossil fuels.

KEYWORDS
Growth; EKC; GHG emissions; pollution; Bangladesh

Introduction

As COP26 has made clear, the world faces the rusk of climate change with multiple adverse effects [1]. In 2018, greenhouse gas emissions (GHG) amounted in total to 55.6 Gt CO_2 eq because of the continual growth in the global economy at an annual average of about 3.5% since 2012 [2]. CO_2 emissions represent the lion's share of anthropogenic GHG and the global total of CO_2 emissions from industry and energy increased in 2017, reaching a record high of 53.5 GtCO_2 eq. In addition, CH_4 (methane) and N_2O (nitrous

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oxide) contributed significantly to global warming and continued to increase from 2014 to 2016 [3]. These two greenhouse gases yielded a total 32% of GHG emissions throughout the last decade [4] mainly because of biogenic and fossil fuel emissions in the tropics and temperate areas, respectively [5].

The background to the present study is the structural transformation in the global economy, as well as energy policy and efficiency, and their relation to the intensity of global GHG emissions [6]. The environmental Kuznets curve (EKC) concerns the economic growth–environment nexus. This theorem is presented by an inverted U-shaped curve revealing the association between environmental deterioration and economic development [7]. The EKC hypothesis hints that if the per capita income of an economy increases through rapid industrialisation then the quality of the environment improves because of technological and financial capacities.

Many studies have tested the EKC hypothesis using various environmental degradation indicators: carbon dioxide (CO_2) emissions [8,9]; sulphur dioxide (SO_2) emissions [10,11]; nitrous oxide (NO_2) emissions [12]; methane (CH_4) emissions [13]; water and waste pollutants [10]; and ecological footprints [14], etc. Recent single country studies such as Expósito [15] tested it for urban water usage and found that EKC did not apply to Guadalquivir River, Spain. Usman et al. [16] confirmed the presence of the EKC hypothesis for India. Mahmood et al. [17] provided evidence of EKC in a quadratic restricted model but not in a cubic function while investigating the nexus between energy, environment, and industrial production for Pakistan. Egbetokun et al. [18] disclosed the presence of EKC for suspended particulate matter (SPM) and carbon emissions in Nigeria.

Some panel studies examined the EKC hypothesis using several extraordinary variables such as tourism, fossil fuel, ecological footprint, population and human development. Song et al. [19] investigated two-dimensional decoupling theories for China and US and noted the EKC for CO_2 emissions and GDP per capita in both economies. Kacprzyk and Kuchta [20] examined the EKC theorem between income and carbon emissions from fossil fuels for 161 panel economies for the years 1992–2012 and explored evidence of an EKC for CO_2 emissions. Altıntaş and Kassouri [21] used the heterogeneous panel model for 14 European economies during 1990–2014 and confirmed the EKC assumption could be applied to ecological footprint and carbon emissions. Asongu and Odhiambo [22] surmised that compared to CO_2 emissions, increasing both economic and population growth stimulates the U-shaped curve and that augmented inclusive human development confirms a Kuznets curve in 44 African countries during 2000–2012. Ike et al. [23] detected an inverted U-shaped relationship between carbon emissions and economic growth only at median, and consequently, the EKC theory applies to 15 oil-producing countries.

Sharker et al. [24] firstly tested the EKC hypothesis for Bangladesh, and used both classical and bootstrap techniques to examine the effect of CO_2 emissions but did not detect any grounds for the EKC hypothesis for the period 1972–2000. Miah et al. [11] focused on the GHGs and found that EKC for CO_2 follows a remorseless straight line in most cases. According to Koike et al. [10], the EKC for waste emissions and suspended particulate matter (SPM) is confirmed by a turning point concerning higher income per capita. Islam, Faridul and Shahbaz [25] showed that energy use makes a significant contribution to CO_2 emissions and found a long-term relationship between the variables for EKC. Rabbi et al. [26] reported the existence of a robust long-term association along with the short-run dynamic adjustment among carbon emissions, energy use, final output and trade liberalisation for Bangladesh during 1972–2008. Alam [8] asserted that EKC does not hold for CO_2 emissions and GDP per capita in Bangladesh for 1972–2010. Hussain [27] examined the EKC hypothesis in terms of higher CO_2 and N_2O emissions during 1981–2011 in India and Bangladesh. The inverted U-shape relationship is valid for Bangladesh in the preliminary model. In a robust quadratic approach to the Kuznets curve, energy consumption contributes significantly to rising carbon emissions for India but not Bangladesh.

Bangladesh has passed from the status of least developed to a developing country by maintaining a more than 6% growth rate over the last decade [28,29]. At the same time, energy use has been a determining factor for economic development in Bangladesh. Starting with agriculture, all production processes have become progressively energy-dependent in Bangladesh. For instance, the power sector relies mostly on two fossil fuels, namely natural gas and coal. About 62.90% of electricity is generated from natural gas, 10% from diesel, 5% from coal, 3.30% from renewable sources and 3% from heavy oil [30]. Observing this energy consumption pattern (non-renewables and renewables), most researchers investigating the EKC hypothesis in Bangladesh used CO_2 emissions as the proxy of environmental pollution. The major failure of these studies is using only CO_2 emissions as the factor of environmental pollution and a smaller range of data from 1972 to 2011. Previous researchers rarely incorporated other pollutants like CH_4 or N_2O emissions into their studies to check the EKC proposition for Bangladesh. Accordingly, this paper seeks to fill these research gaps by including other pollutants like CH_4 and N_2O emissions together with CO_2 emissions and extending the analysed period to 2014 within the robust econometric framework devised for Bangladesh.

The contribution of the present study is four-fold: firstly, unlike other Bangladesh studies such as Sharmin and Tareque [31], this study uses not only CO_2 emissions but also CH_4 and N_2O emissions to test the EKC hypothesis. Secondly, whereas Sharmin and Tareque [31] and Alam [8] covered the years 1980 to 2011, this analysis extends the data period and also considers the issues and variables that are in line with the goals of COP26. It is hoped that this study will help policy-makers, especially for Bangladesh. Thirdly, the methodology of this paper incorporates the Innovative Accounting Approach (IAA), which is the combined usage of both the Forecasting Error Variance Decomposition and Impulse Response Function. More importantly, exploring the causal association between the variables and predictors' shock detection on the predicted variables by using the Variance Decomposition and Impulse Response Function, respectively, is most scarce in the Bangladesh-focused EKC studies. Fourth and finally, the robustness check of empirical findings using Kernel fit-based scatter plots depicts the graphical assessment of the relationship between the variables. This emphasises the novel approach taken by the current study. Moreover, this study's findings on Bangladesh will provide practical insights for policymakers and environmentalists to determine the link between GDP growth and environmental deterioration in the light of GHG emissions and climate change in Bangladesh, and similar countries.

Methodology

Data and model

The study uses yearly time series data of per capita CO_2, CH_4, and N_2O emissions; and per capita GDP obtained from World Development Indicators (WDI) to reinvestigate the relevance of the EKC hypothesis. The data of Composite Trade Intensity (CTI) serve as a proxy of trade openness. To calculate CTI, the data of exports and imports are extracted from WDI whereas the KAOPEN index as the proxy for financial openness is obtained from Portland State University. In a developing economy like Bangladesh, data accessibility is a problem so the study period covers the period 1976 to 2014.

In the study, all the variables are converted into logarithmic form except financial openness (KAOPEN) having a negative value. The functional form of the association among the variables is specified in a linear model below:

$$\text{Pollutants} = f(\text{GDP}, \text{ CTI}, \text{ URB}, \text{ KAOPEN}) \tag{1}$$

Based on the linear form, the regression equation is depicted as follows:

$$Ln\text{Pollutant}_t = \alpha_0 + \alpha_1 ln\text{GDP}_t + \alpha_2 Ln\text{CTI}_t + \alpha_3 Ln\text{URB}_t + \alpha_4\text{KAOPEN}_t + \varepsilon_t \tag{2}$$

where, $Ln\text{Pollutant}_t$= log of GHG emissions, i.e. CO_2, CH_4 and N_2O emissions; $ln\text{GDP}_t$= log of GDP per capita (based on 2010); $Ln\text{CTI}_t$= CTI, i.e. trade openness; $Ln\text{URB}_t$= log of urban population (% of total population), i.e. urbanisation; KAOPEN_t= Chinn-Ito index, i.e. financial openness; and ε_t= error term. In the model, evidence of EKC requires α_1 to be negatively significant in both the short- and long-terms [9] or negative simply in the long term [58]. The specifications of the variables are described in Table 1.

Econometric assessments

Unit root test

Before undertaking ARDL estimation, it is required to do a stationarity check. The study employs three unit root tests, namely ADF – Augmented Dicky-Fuller, PP – Phillips-Perron and ERS – Elliott-Rothenberg-Stock tests. The rationale of employing the ERS unit root is that while the time series holds a linear trend, the ERS test can significantly improve the effectiveness of unit root test because it is superior to conventional tests, i.e. ADF, PP, etc [32].

Table 1. Specifications of variables.

Variables	Descriptions	Data Sources
*Ln*CO2	Carbon dioxide emissions (thousand metric tons per capita) in logarithmic form	World Bank, WDI, 2019
*Ln*CH4	Methane emissions in energy sector (thousand metric tons per capita of CO_2 equivalent) in logarithmic form	World Bank, WDI, 2019
LnN_2O	Nitrous oxide emissions (thousand metric tons per capita of CO_2 equivalent) in logarithmic form	World Bank, WDI, 2019
*Ln*GDP	GDP per capita (constant 2010 US$) in logarithmic form	World Bank, WDI, 2019
*Ln*CTI	Composite trade intensity (CTI) in logarithmic form	World Bank, WDI, 2019
*Ln*URB	Urban population (% of total population) in logarithmic form	World Bank, WDI, 2019
KAOPEN	Chinn-Ito index (financial openness)	Portland State University: http://web.pdx.edu/~ito/Chinn-Ito_website.htm

ARDL bounds test

The initial analysis seeks to check the F-statistic of the Wald test. The F-statistic is compared with the tabulated critical values. If the value of F-statistic is higher than the upper bound critical value, it is assumed that cointegration is present. If the value of F-statistic is lower than the lower bound critical values, then cointegration does not exist. Furthermore, if the Wald F-statistic stays between the upper and lower bounds' critical values, the finding is indecisive.

ARDL cointegration test

The study employs the logarithmic endogenous model within the ARDL approach to cointegration. The logarithmic transformation can transmute a much-skewed variable into more standardised data properties. In addition, the ARDL bounds testing technique [33] has some econometric advantages compared to the Johansen cointegration procedure. One significant feature of the ARDL model is that it measures the long-term association between the variables without satisfying the pre-check of time series data for the presence of unit roots [34]. Moreover, this procedure is suitable for time series data properties, which are of mixed integration order except for the variables which are integrated in order at $I(2)$. Therefore, checking the integrating order for time series data is indispensable since the ARDL procedure corrects the non-stationary problems in data. Another distinguishing characteristic of the ARDL model over other cointegration techniques is that it assesses both the short- and long-term effects of independent variables on the dependent variable simultaneously. To employ ARDL estimation of GHG emissions, the error correction model is written as:

$$\begin{aligned}\Delta Ln(Pollutant)_{i,t} &= \alpha_0 + \sum_{j=1}^{n1}\alpha_{1j}\Delta Ln(Pollutant)_{i,t-j} + \sum_{j=0}^{n2}\alpha_{2j}\Delta Ln(GDP)_{t-j} + \sum_{j=0}^{n3}\alpha_{3j}\Delta Ln(CTI)_{t-j} \\ &+ \sum_{j=0}^{n4}\alpha_{4j}\Delta Ln(URB)_{t-j} + \sum_{j=0}^{n5}\alpha_{5j}\Delta(KAOPEN)_{t-j} + \lambda_0 Ln(Pollutant)_{i,t-j} \\ &+ \lambda_1 Ln(GDP)_{t-1} + \lambda_2 Ln(CTI)_{t-1} + \lambda_3 Ln(URB)_{t-1} + \lambda_4 Ln(KAOPEN)_{t-1} \\ &+ \varepsilon_t\end{aligned} \tag{3}$$

where Δ stands for the first difference operator; α_0 denotes the drift instrument and ε_t is an error term. The coefficients $\alpha_1 - \alpha_6$ show the error correction mechanisms, and λ_0–λ_6 represents the long-run association among the variables. The next step is to explore the coefficients of the short-run dynamics that reveal the presence of the EKC hypothesis. The short-run equations for $CO_2, CH_4 and N_2O$ are written below:

$$\begin{aligned}\Delta Ln(CO_2)_{t-j} = \alpha_0 &+ \sum_{j=1}^{n1}\alpha_{1j}\Delta Ln(CO_2)_{t-j} + \sum_{j=0}^{n2}\alpha_{2j}\Delta Ln(GDP)_{t-j} + \sum_{j=0}^{n4}\alpha_{4j}\Delta Ln(CTI)_{t-j} \\ &+ \sum_{j=0}^{n5}\alpha_{5j}\Delta Ln(URB)_{t-j} + \sum_{j=0}^{n6}\alpha_{6j}\Delta(KAOPEN)_{t-j} + \varphi ECT_{t-1} + j_t\end{aligned} \tag{4}$$

$$\Delta Ln(CH_4)_{t-j} = \alpha_0 + \sum_{j=1}^{n1} \alpha_{1j}\Delta Ln(CH_4)_{t-j} + \sum_{j=0}^{n2} \alpha_{2j}\Delta Ln(GDP)_{t-j} + \sum_{j=0}^{n4} \alpha_{4j}\Delta Ln(CTI)_{t-j} + \sum_{j=0}^{n5} \alpha_{5j}\Delta Ln(URB)_{t-j} + \sum_{j=0}^{n6} \alpha_{6j}\Delta(KAOPEN)_{t-j} + \varphi ECT_{t-1} + j_t \quad (5)$$

$$\Delta Ln(N_20)_{t-j} = \alpha_0 + \sum_{j=1}^{n1} \alpha_{1j}\Delta Ln(N_20)_{t-j} + \sum_{j=0}^{n2} \alpha_{2j}\Delta Ln(GDP)_{t-j} + \sum_{j=0}^{n4} \alpha_{4j}\Delta Ln(CTI)_{t-j} + \sum_{j=0}^{n5} \alpha_{5j}\Delta Ln(URB)_{t-j} + \sum_{j=0}^{n6} \alpha_{6j}\Delta(KAOPEN)_{t-j} + \varphi ECT_{t-1} + j_t \quad (6)$$

where ECT, firstly, denotes the error correction mechanism and, secondly, indicates the adjustment speed of the variables from short-run imbalance to long-run equilibrium.

Innovative Accounting Approach (IAA)-based variance analysis

Within the framework of the Innovative Accounting Approach (IAA), this study uses the Variance Decomposition (e.g. forecast error variation) and Impulse Response Function (e.g. robustness) for Variance Analysis. As part of this analysis, the Variance Decomposition method serves to detect a causal association between the variables and Impulse Response Function measures regressors' shocks to the changes in the dependent variables. The traditional Granger causality test barely explains how much response occurs from one variable to another. Therefore, this study employs a VAR-based innovative accounting approach (IAA) to check the dynamic causal association among the variables as suggested by Shahbaz et al. [35]. More importantly, IAA adapts endogeneity and integrates the order of the data. This procedure determines the extent of causality between the variables ahead of the selected analysis period, whereas the VECM Granger causality test simply covers the selected sample period.

On the other hand, the impulse response function (IRF) determines the time path of the consequence of any shock to predictors and their effect on predicted variables in the VAR model. It checks how a variable responds due to its own shock and shocks occurring in other variables. Since three models – CO_2, CH_4 and N_2O – are considered in this study, the VAR model can be written as follows:

$$V_t = \sum_{i=1}^{k} \delta_i V_{t-i} + \Delta_t \quad (7)$$

where for the Model including CO_2

$$V_t = (CO_22_t, GDP_t, CTI_t, URB_t, KAOPEN_t) \quad (8)$$

$$\Delta_t = (\Delta_{C0_2}, \Delta_{GDP}, \Delta_{CTI}, \Delta_{URB}, \Delta_{KAOPEN}) \quad (9)$$

where for the Model including CH_4

$$V_t = (CH_{4t}, GDP_t, CTI_t, URB_t, KAOPEN_t) \tag{10}$$

$$\Delta_t = (\Delta_{CH_4}, \Delta_{GDP}, \Delta_{CTI}, \Delta_{URB}, \Delta_{KAOPEN}) \tag{11}$$

where for the Model including N_2O

$$V_t = (N_2O_t, GDP_t, CTI_t, URB_t, KAOPEN_t) \tag{12}$$

$$\Delta_t = (\Delta_{N_2O}, \Delta_{GDP}, \Delta_{CTI}, \Delta_{URB}, \Delta_{KAOPEN}) \tag{13}$$

δ_i denotes the estimated coefficients and Δ shows a vector of error mechanisms.

Model robustness check

To check the model's robustness, the study employs some estimators including the structural break test (Chow break test), graphical assessment of the relationship between variables, and diagnostic tests. After confirming the non-existence of a structural break, checking the graphical representation of relationships between variables is required. In this case, scatter plots are mapped since they provide a better understanding of the integrity of the variables. To check the models' overall goodness of fit, Lagrange multiplier (LM) test for serial correlation, Jarque-Bera (JQ) test for residual's normality, Breusch–Pagan–Godfrey test for heteroskedasticity issue, and CUSUM and CUSUMSQ tests on the model's stability are conducted.

Empirical results

Descriptive statistics

Table 2 shows the summary statistics of the variables with 39 observations. In terms of GHG emissions, the average percentage of CO_2 (21.37) is higher than CH_4 (0.01) and N_2O (0.02), meaning that the CO_2 emissions contribute more than the other two GHGs (CH_4 and N_2O). The average per capita trade intensity is almost 20.57% and the annual average growth rate of urbanisation is 22.09%. Moreover, financial openness (Chinn-Ito index-CTI) is negative, amounting to −1.44, and its standard deviation is 0.46. This indicates an adverse financial openness as experienced by Bangladesh during the study period.

Table 2. Descriptive statistics.

Variables	Mean	Median	Max.	Min.	St. deviation
CO_2	21.37	19.60	47.37	7.77	11.79
CH_4	0.01	0.01	0.01	0.01	0.00
N_2O	0.02	0.02	0.02	0.01	0.00
GDP	52170.90	45,961.34	95,131.48	34,394.82	17,140.05
CTI	20.57	15.00	47.98	8.44	13.72
URB	22.09	21.69	33.53	10.70100	6.06
KAOPEN	−1.44	−1.21	−0.14	−1.91	0.46

Unit root test

To check for stationarity, three-unit root tests – ADF test, PP test and ERS test – are employed for all variables at a level and first difference. AIC selects the lag span for ADF test, whereas maximum lag order is nine. Table 3 reports the outcomes of unit root tests, which are virtually the same as those in the three estimation techniques. Overall the variables are of mixed order of integration.

ARDL bounds test

Table 4 represents the findings of the ARDL bounds testing approach, showing the cointegrating association among the variables. Here, the *F*-statistic is statistically significant at the 1% level and the values of *F*-statistic are greater than the upper bound critical values in three models. As well, the ECT_{t-1} coefficients are statistically significant and negative, indicating the speed of readjustment from short-run imbalance to long-run equilibrium.

Long-run and short-run estimations

According to Aung et al. [36], the short-run and long-run coefficients of GDP with reference to GHGs (CO_2, CH_4 and N_2O) are compared to check the EKC hypothesis (Table 5). The results of the models including CO_2 and CH_4 show that GDP has a significant positive impact on CO_2 and CH_4 emissions in the long-term, yet an insignificant effect in the short term. It implies the presence of no inverted U-shaped association between GDP and GHG (CO_2 and CH_4) emissions. The long-run positive effect between pollutants and economic growth reveals no likelihood of the EKC hypothesis and this is supported by Cederborg and Snöbohm [37]. Any increase in GDP does not contribute to reducing the CO_2 and CH_4 emissions in order to improve the environment. Trade openness (*Ln*CTI) has a statistically negative effect on CO_2 emissions in the long run, meaning that trade openness leads to less CO_2 emissions. Furthermore, urbanisation (*Ln*URB) and financial openness (KAOPEN) affect CO_2 emissions positively in the long run, strongly suggesting they do not favour any reduction in CO_2 emissions.

Apart from the model including CO_2, trade openness, urbanisation and financial openness are positively significant in the long run and insignificant in the short run in both models including CH_4 and N_2O emissions. These findings reveal that trade

Table 3. Unit root tests (ADF, PP, ERS).

	ADF test statistic		PP test statistic		ERS test statistic	
Variable	Level	First difference	Level	First difference	Level	First difference
$LnCO_2$	−2.02	−6.50***	−3.64**	−12.09***	1.79**	0.12***
$LnCH_4$	−0.50	−3.09**	4.57	−3.05**	0.29***	1.92**
LnN_2O	−3.09**	−4.92***	−1.63	−4.92***	1.15***	1.47**
LnGDP	5.16	−3.33*	7.53	−4.20***	35.49	2.11**
LnCTI	−0.34	−6.70***	−0.27	−6.67***	16.98	3.94
LnURB	−0.48	−3.58**	−3.24**	−3.69***	82.96	26.74
KAOPEN	−1.96	−5.94***	−1.96	−5.95***	5.98	1.25***

Note: ADF test stands for Augmented Dicky-Fuller test; PP test denotes Philips-Perron test; and ERS test indicates Elliott-Rothenberg-Stock test.

Table 4. ARDL bound test results.

Model including CO_2	F-statistics	8.55	
	ECT_{t-1}	−0.97*** (−7.82)	
	Critical value	Lower bound	Upper bound
	1%	3.29	4.37
	5%	2.56	3.49
	10%	2.2	3.09
Model including CH_4	F-statistics	14.20	
	ECT_{t-1}	−0.19*** (−10.32)	
	Critical value	Lower bound	Upper bound
	1%	5.14	6.61
	5%	3.57	4.66
	10%	3.03	3.99
Model including N_2O	F-statistics	5.45	
	ECT_{t-1}	−0.35*** (−6.22)	
	Critical value	Lower bound	Upper bound
	1%	3.29	4.37
	5%	2.56	3.49
	10%	2.2	3.09

Note: *** denotes significance at the 1% level.

Table 5. The long-run and short-run estimation results.

Models	Variable	Long-run coefficients	Variable	Short-run coefficients
Model including CO_2	*Ln*GDP	0.321* (1.811)	ΔLnGDP	–
	*Ln*CTI	−0.089* (−1.893)	ΔLnCTI	0.011 (0.354)
	*Ln*URB	1.96*** (9.84)	ΔLnURB	6.720*** (9.266)
	KAOPEN	0.096*** (4.40)	ΔKAOPEN	−0.069** (−2.776)
Model including CH_4	*Ln*GDP	0.638*** (0.00)	ΔLnGDP	0.079 (1.012)
	*Ln*CTI	0.025 (1.220)	ΔLnCTI	–
	LnURB	0.041 (0.500)	ΔLnURB	–
	KAOPEN	−0.041*** (−2.843)	ΔKAOPEN	−0.006 (−1.317)
Model including N_2O	LnGDP	−3.344**(−2.057)	ΔLnGDP	−1.586*** (−5.858)
	LnCTI	0.570* (1.849)	ΔLnCTI	−0.021 (−1.172)
	LnURB	1.216** (2.558)	ΔLnURB	–
	KAOPEN	0.195** (2.736)	ΔKAOPEN	0.003(0.321)

Note: ***, ** and * denote significance at the 1%, 5% and 10% levels, respectively. The values in () are the *t*-ratios.

openness, urbanisation and financial openness are not conducive to decreasing CH_4 and N_2O emissions and in turn improving the quality of the environment. On the contrary, GDP has a significantly adverse effect on N_2O emissions in both the short and long run in the model including N_2O. This negative relationship between pollution and economic growth in both the short- and long-terms confirms the applicability of the EKC hypothesis as found by Narayan and Narayan [7]. Therefore, N_2O emissions decline when incomes in Bangladesh increase.

Variance analysis

The variance analysis of this study encompasses two tests: causality analysis and regressors' shock analysis to the dependent variables. The causality direction between GHG emissions (CO_2, CH_4 and N_2O), GDP, trade openness, urbanisation and financial openness is checked by employing the Innovative Accounting Approach (IAA), which is a mixture of Variance Decomposition (VDC) and Impulse Response Function (IRF). Results of causal analysis using VDC are depicted in Tables A1-A3 for the three models, i.e. CO_2, CH_4 and N_2O, respectively.

CO_2 contributes 66.25% to its individual innovative shocks, and financial openness with one standard deviation shock determines CO_2 emissions by 16.09%, suggesting unidirectional causality is derived from financial openness to CO_2 emissions (Table A1). A 17.03% of GDP is described by own shock and GDP explains CO_2 emissions by 54.64% owing to innovative shocks arising in GDP which is higher. Confirmed here is the presence of a bilateral causal relationship between GDP and CO_2 emissions. A 46.43% share of trade openness is contributed by its own shock, and trade openness with one standard deviation shock explains CO_2 emissions by 31.75%, confirming the presence of a unilateral causal relationship from CO_2 emissions to trade openness. The own shock of urbanisation is explained by 6.69% and the contribution of urbanisation with one standard deviation shock is explained by 66.64% of CO_2 emissions, which is higher. Established here is the bidirectional causality between urbanisation and CO_2 emissions. A major contribution of financial openness with one standard deviation shock amounts to 74.92% while the share of trade openness is 10.73%, confirming the unidirectional causality from trade openness to financial openness.

Moreover, a 14.59% share of CH_4 emissions is explained by its individual shocks and one standard deviation shock in GDP interprets CH_4 emissions by 53.10% that is higher, indicating the unidirectional causality from CH_4 to GDP (Table A2). The portion of GDP (57.84%) is shared by its own shock and trade openness with one standard deviation shock interprets GDP by 18.22%, which is lower than the shock in GDP. Trade openness with its own innovative shock is explained by 36.34% and trade openness contributes 37.16% to GDP owing to one standard deviation shock, which is higher than the shock in trade openness, meaning there is evidence of bilateral causality between trade openness and GDP. A 14.81% share of urbanisation is described by its individual shock and one standard deviation shock in trade openness and GDP explains urbanisation by 14.84% and 52.64%, respectively. These percentages are higher than the own shock in urbanisation, confirming the bidirectional causality between urbanisation and trade openness, and urbanisation and GDP. The highest share (78.79%) in financial openness by its own shock and CH_4 with one standard deviation shock explains financial openness by 8.69%, which is lower than the innovative shock stemming from CH_4. Thus, there is unidirectional causality from CH_4 to financial openness.

Furthermore, 94.19% of N_2O emissions is shared by its own shock and the shock in financial openness illustrates N_2O emissions by 3.29%, which is lower than the shocks arising in N_2O emissions, meaning there is unilateral causality from financial openness to N_2O emissions (Table A3). The contribution made by GDP (62.09%) is interpreted by its own innovative shocks while trade openness with one standard deviation shock explains GDP by 17.25%, which is lower than the shock in GDP. Besides, trade openness by its own innovative shock contributes to 31.51% and one standard deviation shock in trade openness describes GDP by 39.30%, which is higher than the shock in trade openness. This means that the bidirectional causality is between trade openness and GDP. A 12.27% share of urbanisation is explained by its own shock and the contributions of GDP and trade openness are 54.89% and 15.60%, respectively. They are explained by one standard deviation shock in urbanisation. Since the shocks in

GDP and trade openness are higher than shocks in urbanisation, there is bilateral causation between urbanisation and GDP, and urbanisation and trade openness. Financial openness with its own innovative shock is explained by 66.95% (major contribution) and 27.59% of N_2O emissions is shared by one standard deviation shock in financial openness. This confirms the unidirectional causality from N_2O emissions to financial openness.

The impulse response function (IRF) is a substitute for the VDC approach. IRF illustrates the timeline and level of the response of dependent variables to the shock arising in the independent variables [38]. Figure B1 depicts CO_2 emissions as being positive over the 10-year period and the response in CO_2 emissions owing to forecast error arising in GDP mainly goes down and after the 3rd year period, it goes up until the 10-year time horizon. This does not mean that the EKC hypothesis is valid for GDP and CO_2 emissions. The share of trade openness in CO_2 emissions is negative over the 10-year period, showing the presence of EKC in the case of trade openness. The responses in CO_2 emissions are positive because of shock stemming from both urbanisation and financial openness. The responses in GDP, trade openness and urbanisation are positive owing to shock occurring in CO_2 emissions over the 10-year period, rejecting the EKC hypothesis. Financial openness responds adversely but positively after the 2nd year horizon because of forecast error resulting in CO_2 emissions. These results are entirely in line with the findings of the ARDL estimations and variance decomposition procedure.

The CH_4 emissions with own forecast error are positive during the 10-year period and the response in CH_4 emissions is positive for forecast error occurring in GDP for all of the 10-year time, nullifying the presence of the EKC hypothesis (see Figure B2). Besides, CH_4 emissions respond to trade openness and urbanisation positively in their forecast shocks over the 10-year phase. The response of CH_4 to financial openness owing to shock is initially positive but falls till the 5th year. Starting in the 6th year, it goes upward till the 10th year. The response of GDP is positive to CH_4 emissions owing to forecast error over the 10-year period, thus rejecting the EKC hypothesis. The responses in trade openness and urbanisation are positive all through this decade. Conversely, financial openness responds to CH_4 emissions negatively because of forecast error stemming from CH_4 emissions, establishing the viability of the EKC hypothesis regarding financial openness. These outcomes are identical to the results of the ARDL estimations and variance decomposition technique.

Moreover, N_2O is positive because of its own shock during the 10-year period and the response in N_2O emissions is negative for forecast error stemming from GDP over the 10-year period, confirming the validity of EKC between GDP and N_2O emissions (Figure B3). The reaction to N_2O emissions is mainly negative and positive after the 5th year period because of forecast error arising in trade openness; and the response from N_2O emissions is also negative initially and positive after the 7th year time horizon because of forecast shock stemming from urbanisation across the 10-year time period. The response from N_2O emissions is positively rudimentary till the 4th year and then negative over the 10-year period because of a shock happening in financial openness. Besides, the response from GDP is initially negative till the 2nd year period and then it remains positive till the 10th year time horizon. Meanwhile, the response in trade openness starts diminishing from the 2nd year to the 10th year, and the response in urbanisation is negative till the 3rd year period and then it becomes positive till the 10-year period because of innovative shock emanating in N_2O. The response in financial openness goes up till the 3rd year period and then starts declining over the 10-year time horizon because of forecast innovative shock to N_2O. This situation also rejects the EKC hypothesis since trade openness does not reach a peak in the long run. But, it begins declining from the 3rd year period in the short run. These findings are in line with the outcome of ARDL estimations and the variance decomposition technique.

Figure 1 shows the causality outcomes stemming from the innovative accounting approach (IAA). Figure 1 reveals that CO_2 emissions Granger cause all the variables except financial openness and all variables Granger cause CO_2 emissions except trade openness (CO_2 model). Apart from this, CH_4 emissions Granger cause GDP and financial openness, and no other variables Granger cause CH_4 emissions (CH_4 model). Finally, no variable Granger causes N_2O emissions but only N_2O emissions Granger cause financial openness. All the variables Granger cause each other except financial openness (N_2O model).

Model robustness check

Structural break check

The 2007 South Asian floods were a series of dreadful events and much of Bangladesh was greatly affected. UNICEF considered the situation as 'the worst flooding in living memory' [39]. So, the Chow test is applied to verify the presence of a structural break at the inquiry point and it confirms no existence of a break in 2007 (Table 6). As the *p*-value found in the Chow test is higher than the 5% significance level, the null hypothesis is accepted.

Graphical assessment of the relationship between variables

Based on Kernel fit lines, the scatter plots drawn to show the upward slope between GDP and two pollutants (CO_2 and CH_4). This situation reveals a positive connection between the variables. Therefore, a positive relationship between two pollutants (CO_2 and CH_4) and GDP does not confirm the existence of the EKC hypothesis. Meanwhile, the nexus between GDP and N_2O exhibits a decrease-increase-decrease trend, implying a negative

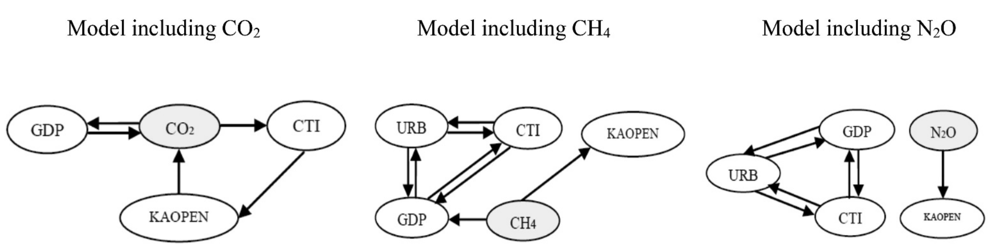

Figure 1. Direction of the causality for the CO_2, CH_4, N_2O models.

Table 6. Chow test for structural break in 2007.

F-statistic	1.736332	Prob. F(4,30)	0.1681
Log likelihood ratio	8.121432	Prob. Chi-Square(4)	0.0872
Wald Statistic	6.945329	Prob. Chi-Square(4)	0.1388

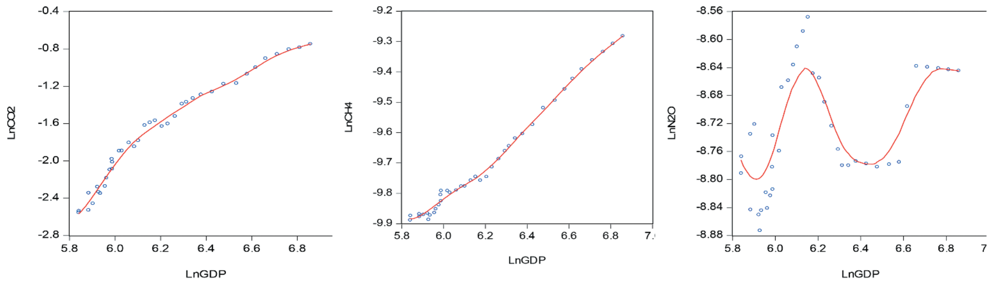

Figure 2. Scatter plots of *Ln*GDP together with pollutants (CO_2, CH_4 and N_2O).

link between the variables. This negative relationship in both the short and long runs suggests the EKC hypothesis is valid. These findings are entirely consistent with ARDL estimations (Figure 2).

Model diagnostic tests

Table 7 presents the diagnostic statistics of ARDL models for the three models. Lagrange multiplier (LM) tests depict evidence of no serial correlation in the time series at the 5% level of significance. The JB test results reveal that all residuals in the models are distributed normally. Further, the Breusch–Pagan–Godfrey test confirms that variables used in the models are homoscedastic.

Further, the stability of the three models is confirmed by CUSUM and CUSUMSQ tests where the lines drawn lie within the critical bounds at the 5% level of significance (Figure 3).

Discussion

The results report that the EKC hypothesis is partly valid between environmental pollutants (GHG emissions) and GDP growth in Bangladesh. Moreover, EKC is not observed between CO_2 emissions and GDP growth. It is supported by Sharker et al. [24] who used classical and bootstrap approaches for Bangladesh for the years 1972–2000, and the outcome is also in line with: Saboori et al. [40] on Indonesia; Lacheheb et al. [41] on Algeria; Aung et al. [36] on Myanmar; and Sohag et al. [42] on 83 middle-income countries. Yet our finding contradicts Rabbi et al. [26] who detected evidence of an inverted U-shaped relationship between GDP growth and CO_2 emissions in Bangladesh. Outside Bangladesh, a host of previous studies such as Saboori et al. [40] on Malaysia, Dávalos [43] on the Dominican Republic, Ali et al. [44] on Pakistan, Taguchi [12] on

Table 7. Diagnostic tests results.

Models	LM Test	JB Test	Heteroscedasticity Test
Model including CO_2	0.68 (0.51)	1.64 (0.44)	0.94 (0.51)
Model including CH_4	1.18 (0.35)	0.25 (0.88)	1.03 (0.43)
Model including N_2O	2.06 (0.12)	1.78 (0.41)	0.76 (0.68)

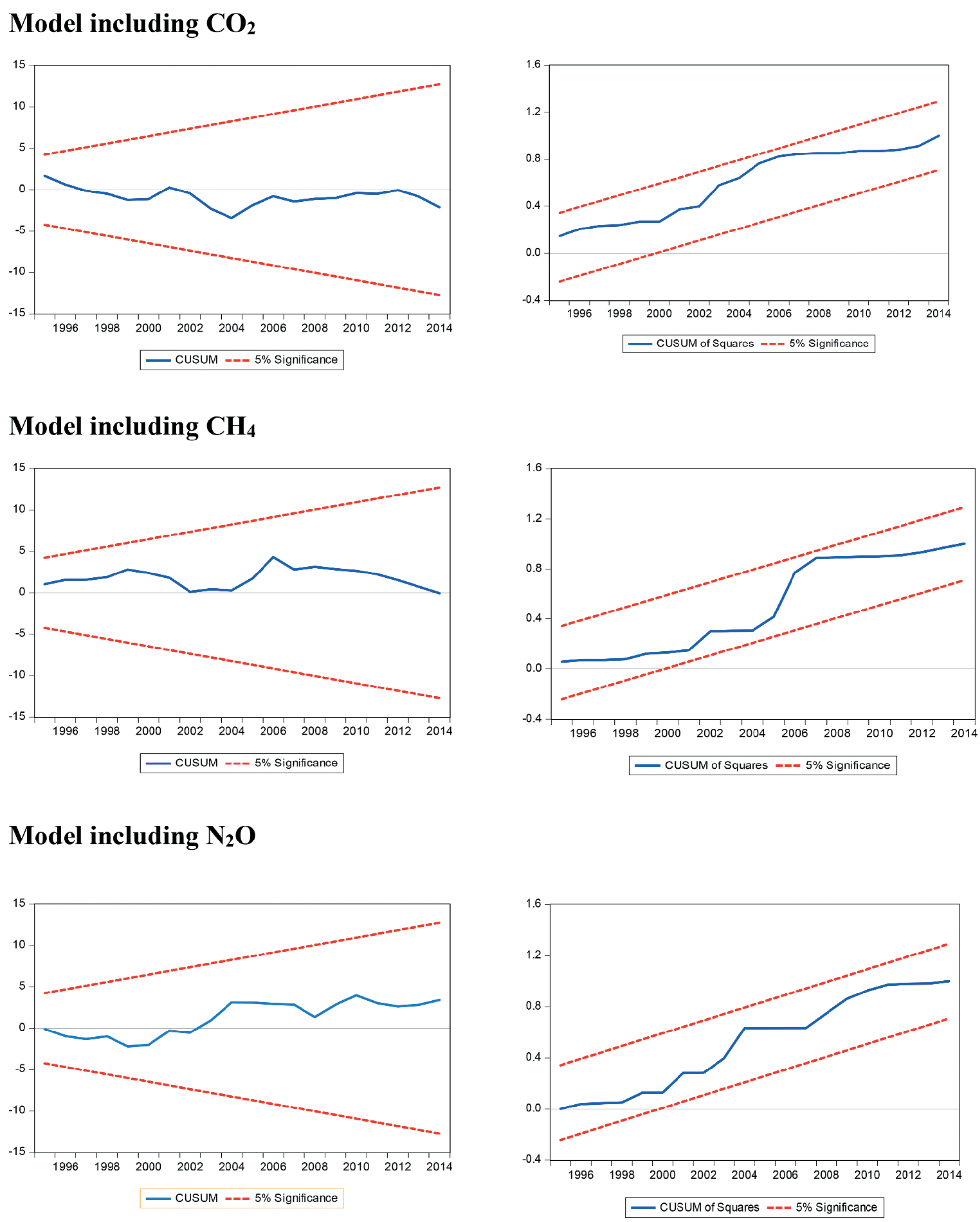

Figure 3. CUSUM and CUSUMSQ tests.

Ecuador, and Saboori et al. [40] on Malaysia found that the EKC hypothesis applied to income and CO_2 emissions. There is no evidence for the EKC hypothesis because there is a long-term positive connection between CO_2 emissions and GDP.

CO_2 is associated with economic growth directly through the consumption of fuels, i.e. gas, oil and coal, for industry [45]. The energy supply structure and structural changes may also illustrate changes in the link between emissions and income [46]. Since CO_2

emissions will damage the environment in Bangladesh, policy-makers should implement and enforce a policy that will reduce this pollutant (CO_2) without compromising economic progress.

Likewise for CO_2 emissions, the EKC hypothesis does not apply to the link between CH_4 emissions and GDP growth. This finding is similar to that of Roca et al. [46] who studied Spain but is incompatible with Aung et al. [47] who studied Myanmar. For these economies, the fundamental sources of CH_4 emissions are cattle-raising and agriculture-related activities together with waste management [46]. In Bangladesh, agriculture is the major contributor to GHG emissions (especially CH_4) and this sector will not make environmental protection possible [48]. Devising alternative sources for agricultural production is critical to saving the environment [31].

More importantly, the EKC hypothesis applies for N_2O emissions and GDP growth, whereas GDP impacts N_2O emissions adversely in both the long-run and short-run. This finding is consistent with Alam [27] who assessed Bangladesh and India. Earlier, Aung et al. [47] on Myanmar, Zambrano-Monserrate and Fernandez [12] on Germany, and Luo et al. [49] on selected Chinese provinces have evidence supporting this study's findings but differ from Roca et al. [46] for Spain. N_2O emissions are predominantly caused by fertiliser use in agriculture. Bangladesh, despite its push to be more industrialised, is largely agriculture-dependent and the average value of agriculture's contribution during 1960–2018 amounted to 34.23% [50]. The transport sector is triggering more N_2O emissions but transport-based income is one of the important sources of economic development in Bangladesh; transport and communication sectors contribute 10.98% to the economy [51]. This is evidence for EKC for N_2O (non-CO_2 emissions) being instrumental in achieving potential monetary and technical capacities to manage livestock and agriculture industrial water and waste as the economy seeks to grow even more [38].

Trade openness helps the quality of the environment but it affects CO_2 emissions negatively. This finding is inconsistent with Shahbaz et al. [52], who studied trade and transport-related activity in Bangladesh [53]. In the case of CH_4 and N_2O emissions, trade openness is positively correlated; these two pollutants do not diminish when trade openness increases. The growth of Bangladesh largely depends on trade (exports and imports). Moreover, the trade liberalisation policies enhanced logistics and raw materials for export-related industries, which contributed to consumer and non-production-type imports [54]. This suggests that Bangladesh adopted export-related policies without regard for the environment.

On the other hand, urbanisation and financial openness do not improve the environment because they simply add to the amount of CO_2 emissions, which contradicts the findings of Islam, Faridul and Shahbaz [25]. These two indicators influence N_2O emissions positively and they do not favour a reduction in N_2O emissions. Financial openness affects CH_4 negatively, which indicates that an increase in financial openness reduces CH_4 emissions as well as environmental degradation. CH_4 emissions and urbanisation are positively linked and generally, urbanisation greatly influences the migration of people and migration influences GHG emissions and especially from CO_2. So, policy-makers should emphasise the use of clean or renewable energy to reduce GHG emissions. On the other hand, financial development contributes to the increase or decrease of GHG emissions. A better functioning financial sector can fund strategies to curtail environmental hazards, thus cutting GHG [36]. In the case of Bangladesh, there is no alternative to developing a sound financial sector that can help preserve the environment.

The results of this study have substantial policy implications for Bangladesh which faces a serious climate change problem, with finite resources and a degraded environment [55]. This paper thus suggests pursuing policies to reduce the damage being done to the environment by choosing alternative sources of energy. A policy of sustainable energy management would augment alternative energy production and reduce the need for subsidies to control the energy price.

Conclusion

The Bangladesh government should consider policies that require GHG emissions reductions for saving the environment. The Kyoto Protocol of 1997 and the United Nations Climate Change Conference in Glasgow in 2021 both encouraged rich and developing countries to forego higher income and economic growth in favour of a more sustainable approach. Policymakers in Bangladesh should develop policies that ensure that Bangladesh's economic success is not at the expense of its natural environment. Bangladesh should rely on renewable energy sources rather than non-renewable sources of energy. The EKC hypothesis, according to this study, should be re-examined when developing long-term development policies.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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Appendix A

Table A1. Variance decomposition method (Model including CO_2).

Period	*Ln* CO_2	*Ln*GDP	*Ln*CTI	*Ln*URB	KAOPEN
1	100.0000	0.000000	0.000000	0.000000	0.000000
3	78.96392	0.206975	0.825878	7.371557	12.63168
5	72.30626	0.387408	1.287685	8.981624	17.03702
7	72.51185	0.897040	1.818663	9.026345	15.74610
9	71.80852	1.879513	1.736727	8.979441	15.59580
11	71.01274	3.342607	1.588419	8.534595	15.52164
13	70.06889	4.975769	1.712939	7.872744	15.36965
15	68.85375	6.506631	2.084026	7.145026	15.41056
17	67.67982	7.781434	2.491920	6.443427	15.60340
19	66.68078	8.772642	2.801023	5.831108	15.91444
20	66.25071	9.176943	2.907577	5.565140	16.09963
Variance decomposition of *Ln*GDP					
1	1.063845	98.93616	0.000000	0.000000	0.000000
3	6.527361	68.66838	18.30875	1.123948	5.371561
5	20.72258	46.94848	25.57575	0.812480	5.940707
7	30.87141	34.90317	24.24848	0.497009	9.479928
9	38.68881	27.94822	20.23701	0.565664	12.56030
11	44.31290	23.65791	16.40643	0.853464	14.76929
13	48.08681	20.94434	13.45617	1.198763	16.31392
15	50.71469	19.20634	11.29758	1.502428	17.27896
17	52.61996	18.07559	9.717038	1.736885	17.85053
19	54.05332	17.31860	8.543452	1.904525	18.18011
20	54.64493	17.03058	8.070668	1.967567	18.28626
Variance decomposition of *Ln*CTI					
1	4.815128	1.045509	94.13936	0.000000	0.000000
3	10.31033	5.181655	77.11337	0.047869	7.346785
5	20.32409	5.342006	66.09743	0.073174	8.163304
7	24.40250	5.059351	59.51308	0.383304	10.64177
9	25.86251	4.921118	55.84081	0.698940	12.67663
11	27.12906	4.930565	53.67830	0.900211	13.36187
13	28.09568	5.070285	52.03938	1.046847	13.74781
15	29.02075	5.327939	50.53997	1.134712	13.97663
17	30.03332	5.664235	48.99597	1.190059	14.11641
19	31.14815	6.042094	47.32769	1.232750	14.24931
20	31.75072	6.237426	46.43661	1.252582	14.32266
Variance decomposition of *Ln*URB					
1	37.26471	10.00797	3.117124	49.61019	0.000000
3	56.32126	3.210802	15.79456	24.20891	0.464463
5	69.69799	1.598318	9.161758	18.66328	0.878655
7	74.53030	1.777480	6.000197	16.11935	1.572679
9	74.81620	2.941923	4.609886	14.53390	3.098085
11	73.89143	4.764491	3.770409	12.89546	4.678215
13	72.34051	6.775841	3.417123	11.22390	6.242628
15	70.46662	8.565104	3.478888	9.645790	7.843597
17	68.70049	9.927657	3.699287	8.272936	9.399633
19	67.24465	10.86774	3.875615	7.158680	10.85332
20	66.64381	11.21133	3.922417	6.696319	11.52613
Variance decomposition of KAOPEN					
	0.836848	0.000668	3.193463	2.158385	93.81064
3	4.262430	0.995535	3.822618	3.212998	87.70642
5	7.009130	1.712757	6.083761	3.559357	81.63500
7	7.355014	2.250492	8.165610	4.328044	77.90084
9	7.189535	2.446395	9.757496	4.592127	76.01445
11	7.123975	2.491441	10.51720	4.626738	75.24064
13	7.174177	2.489372	10.67715	4.620446	75.03885
15	7.222982	2.486931	10.66983	4.613477	75.00678
17	7.232875	2.493064	10.67761	4.613438	74.98301
19	7.228735	2.502556	10.71255	4.614105	74.94205
20	7.228442	2.506970	10.73017	4.613775	74.92064

Table A2. Variance decomposition method (Model including CH_4).

Period	*Ln*CH4	*Ln*GDP	*Ln*CTI	*Ln*URB	KAOPEN
1	100.0000	0.000000	0.000000	0.000000	0.000000
3	80.05745	13.99571	2.548358	0.254414	3.144069
5	60.53604	22.90046	13.64385	0.275260	2.644392
7	45.43300	32.25725	19.79940	0.663852	1.846492
9	34.73533	39.43200	21.79037	1.144058	2.898241
11	27.57271	44.32160	21.76796	1.504955	4.832776
13	22.74096	47.62005	21.12330	1.732473	6.783212
15	19.40563	49.88143	20.46355	1.878,569	8.370826
17	17.03495	51.47146	19.95643	1.989577	9.547586
19	15.29485	52.63112	19.60489	2.088269	10.38087
20	14.59113	53.10136	19.47343	2.135098	10.69898
Variance decomposition of *Ln*GDP					
1	2.422081	97.57792	0.000000	0.000000	0.000000
3	5.777995	77.21376	9.904173	0.110806	6.993263
5	8.140395	64.14377	15.35727	0.895753	11.46282
7	8.977322	59.15549	17.53215	1.850692	12.48435
9	9.093265	57.72655	18.23491	2.472229	12.47305
11	8.915860	57.60087	18.35431	2.747637	12.38132
13	8.684581	57.77743	18.30160	2.819545	12.41685
15	8.499466	57.89924	18.23988	2.809312	12.55211
17	8.380830	57.91408	18.21391	2.781701	12.70948
19	8.312982	57.86934	18.21839	2.760016	12.83928
20	8.290872	57.84071	18.22672	2.752572	12.88912
Variance decomposition of *Ln*CTI					
1	5.163592	0.205756	94.63065	0.000000	0.000000
3	11.34080	16.36100	57.43881	3.194842	11.66455
5	9.704605	21.52896	50.12962	4.444787	14.19203
7	9.124292	24.77803	47.65585	4.399264	14.04256
9	8.700309	27.23955	45.62170	4.177366	14.26107
11	8.431614	29.21980	43.78569	3.941904	14.62100
13	8.373882	30.95765	42.04479	3.711414	14.91227
15	8.441481	32.64242	40.38679	3.550200	14.97911
17	8.513965	34.39327	38.76702	3.456551	14.86920
19	8.536659	36.22861	37.15275	3.390613	14.69137
20	8.529411	37.16454	36.34496	3.358877	14.60221
Variance decomposition of *Ln*URB					
1	0.041892	0.001240	12.29449	87.66238	0.000000
3	4.617213	4.210142	21.32235	67.71598	2.134317
5	4.162542	11.62806	13.69254	65.63755	4.879307
7	3.457008	19.76261	10.61116	61.62641	4.542823
9	3.213693	29.04511	9.165065	53.93034	4.645797
11	3.517797	37.68688	8.978729	44.10394	5.712663
13	4.381779	43.91992	10.03629	34.32834	7.333673
15	5.412118	47.78184	11.66271	26.37383	8.769508
17	6.255390	50.22641	13.19162	20.56979	9.756792
19	6.822356	51.95115	14.37838	16.43406	10.41406
20	7.018796	52.64669	14.84520	14.81794	10.67137
Variance decomposition of KAOPEN					
1	3.981823	4.664661	0.015611	2.277885	89.06002
3	8.093368	4.111644	0.195541	4.058347	83.54110
5	8.643020	3.890629	1.227015	4.970960	81.26838
7	8.716189	4.037561	2.414251	5.121935	79.71006
9	8.669298	4.201967	2.884332	5.095478	79.14892
11	8.653059	4.250409	2.963172	5.082471	79.05089
13	8.671609	4.250605	2.963149	5.082459	79.03218
15	8.691216	4.258979	2.974053	5.090863	78.98489
17	8.699722	4.292216	2.991494	5.101738	78.91483
19	8.700214	4.348127	3.008012	5.109114	78.83453
20	8.698908	4.383199	3.016043	5.110942	78.79091

Table A3. Variance decomposition method (Model including N_2O).

Period	*Ln*N_2O	*Ln*GDP	*Ln*CTI	*Ln*URB	KAOPEN
1	100.0000	0.000000	0.000000	0.000000	0.000000
3	94.43668	0.300886	1.120173	0.261849	3.880416
5	94.89127	0.235697	0.920244	0.720140	3.232653
7	94.60539	0.218859	0.986769	0.871354	3.317624
9	94.49418	0.216102	1.132621	0.867594	3.289502
11	94.36980	0.215580	1.215849	0.918261	3.280505
13	94.27881	0.217244	1.230093	0.996327	3.277529
15	94.23019	0.220461	1.230157	1.039596	3.279598
17	94.20459	0.222073	1.234018	1.051321	3.287995
19	94.19434	0.222168	1.236804	1.052773	3.293914
20	94.19259	0.222625	1.237096	1.052836	3.294856
Variance decomposition of *Ln*GDP					
1	4.925630	95.07437	0.000000	0.000000	0.000000
3	4.478887	82.57546	8.496213	0.077279	4.372158
5	5.204154	70.84001	13.64957	0.574007	9.732255
7	5.405913	64.89889	15.68179	1.364415	12.64899
9	5.265700	62.50806	16.54238	1.992957	13.69090
11	4.968479	61.80586	16.88462	2.355732	13.98531
13	4.641476	61.77677	17.02734	2.517156	14.03726
15	4.349378	61.91856	17.10562	2.568034	14.05841
17	4.114148	62.03389	17.16889	2.573237	14.10983
19	3.933707	62.08474	17.22852	2.566550	14.18648
20	3.860365	62.09218	17.25656	2.563158	14.22774
Variance decomposition of *Ln*CTI					
1	12.58121	3.576140	83.84265	0.000000	0.000000
3	5.551389	19.97488	50.26016	3.222172	20.99141
5	4.490213	21.65606	41.86254	4.976607	27.01458
7	4.249448	23.81894	40.35368	5.310162	26.26776
9	4.074812	26.14426	39.16208	5.147351	25.47149
11	3.874823	28.65178	37.90516	4.893208	24.67503
13	3.672951	31.22836	36.51835	4.589919	23.99042
15	3.531070	33.68361	35.05535	4.309454	23.42051
17	3.450025	35.99177	33.60036	4.098786	22.85906
19	3.397944	38.21387	32.19428	3.942056	22.25186
20	3.375366	39.30757	31.51192	3.873587	21.93155
Variance decomposition of *Ln*URB					
1	3.192514	0.219224	11.87868	84.70958	0.000000
3	1.269910	5.007162	25.20500	66.74327	1.774651
5	2.691349	10.59258	17.38652	63.15157	6.177980
7	4.887821	16.95350	13.95725	58.35835	5.843075
9	6.680349	25.74790	12.40510	50.13294	5.033720
11	7.557616	35.45926	12.02424	40.05537	4.903519
13	7.632594	43.40768	12.65835	30.42166	5.879721
15	7.266000	48.61364	13.69970	22.89685	7.523809
17	6.747618	51.84186	14.64341	17.65602	9.111096
19	6.215429	54.02444	15.34139	14.08326	10.33547
20	5.962223	54.89648	15.60671	12.72218	10.81240
Variance decomposition of KAOPEN					
1	0.019551	2.490951	1.126586	0.787063	95.57585
3	11.17581	1.614949	0.931695	2.669754	83.60779
5	23.23735	1.375203	0.884907	3.167277	71.33527
7	27.01640	1.372866	0.869340	3.108894	67.63250
9	27.57132	1.431485	0.896451	3.059161	67.04158
11	27.59317	1.452697	0.902555	3.051333	67.00024
13	27.59562	1.454957	0.902453	3.050568	66.99640
15	27.59697	1.455045	0.904478	3.057817	66.98569
17	27.59603	1.456900	0.906389	3.068860	66.97182
19	27.59514	1.461161	0.907481	3.076697	66.95952
20	27.59460	1.464534	0.907968	3.078950	66.95395

Appendix B

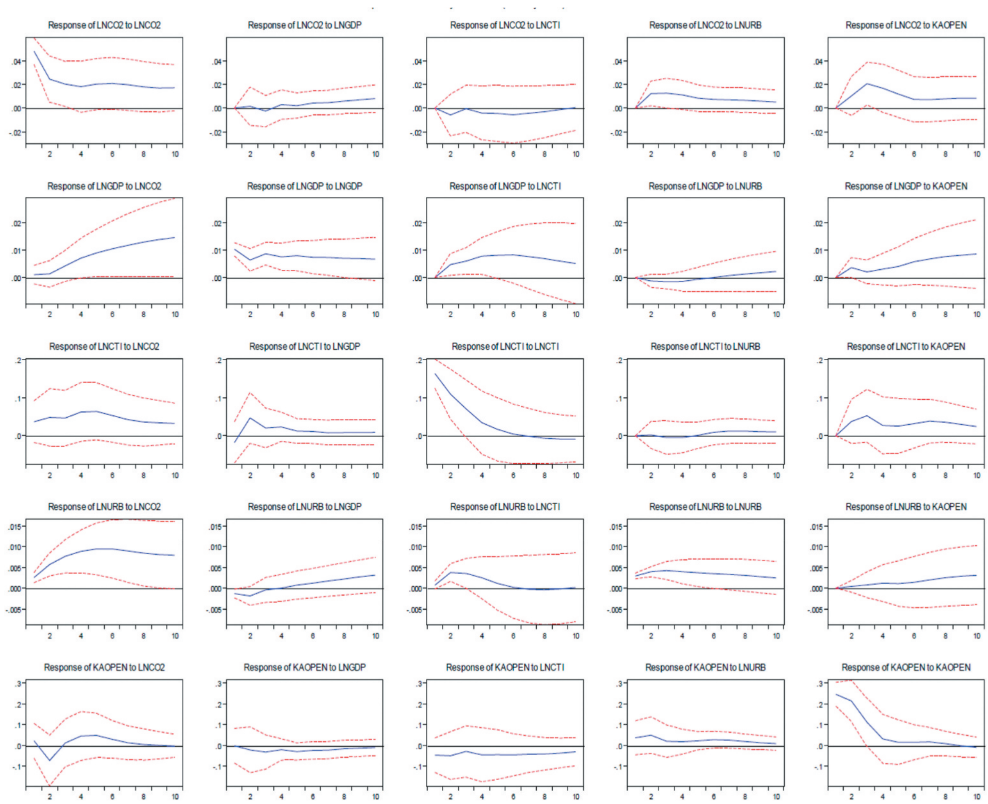

Figure B1. Impulse response function (Model including CO_2).

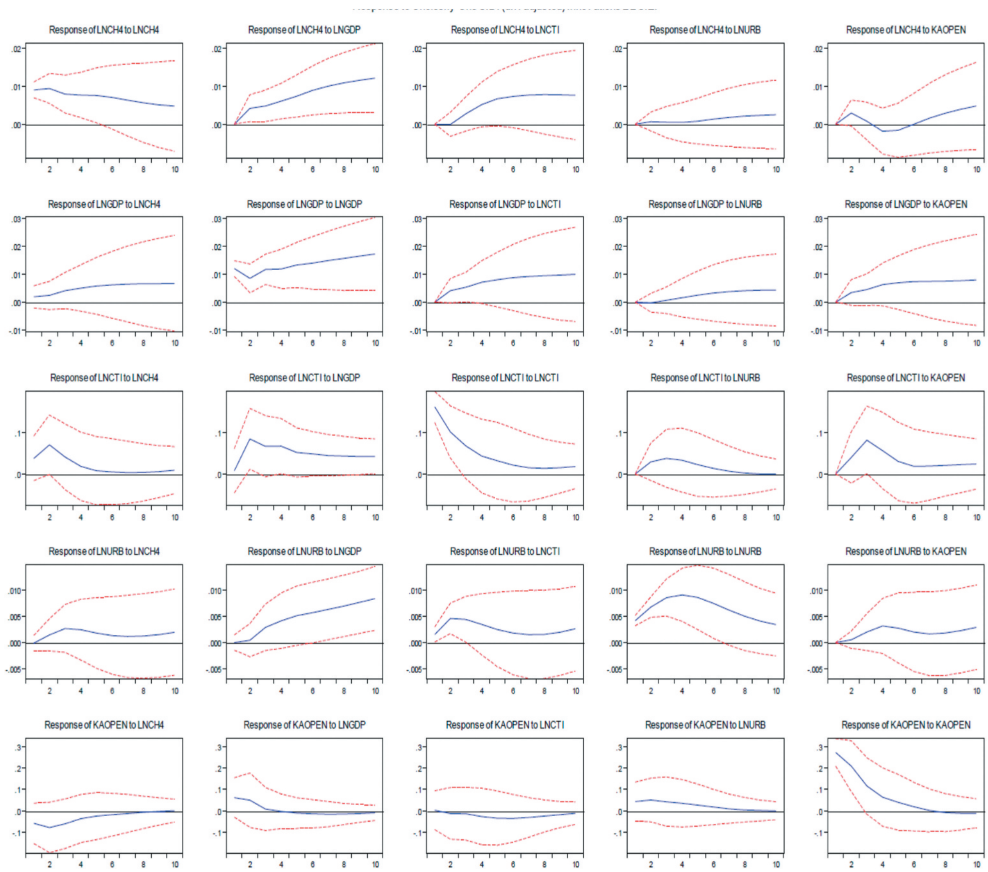

Figure B2. Impulse response function (Model including CH_4).

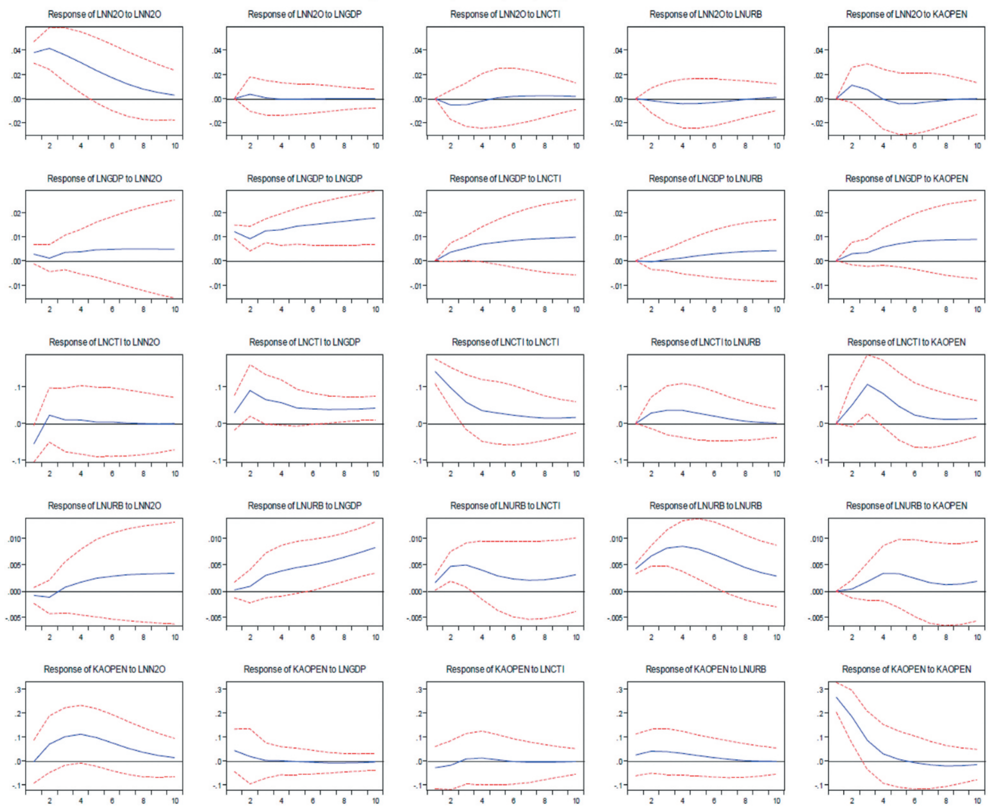

Figure B3. Impulse response function (Model including N_2O).