Economic Growth, CO_2 Emissions, Electricity Production, and Consumption Nexus in Bangladesh

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ABSTRACT

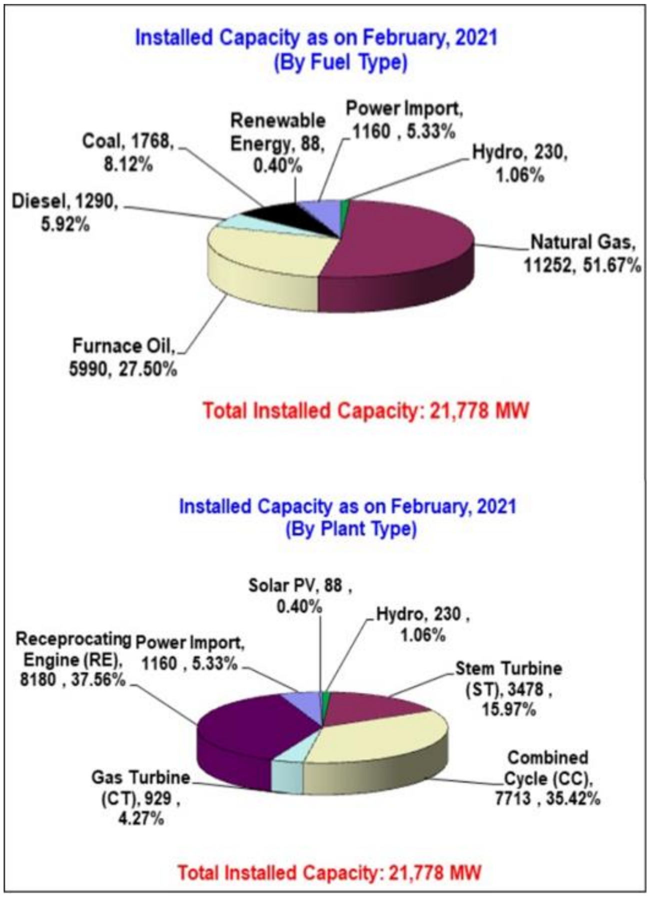
This paper seeks to find the causal relationship between economic growth, electricity consumption, carbon emissions, electricity production from oil, and electricity production from gas. The data were taken from World Development Index (WDI) for the period of 1972-2014. For stationarity checking, visualization and some econometrics techniques like ADF and Phillips-Perron test have been adopted. For testing the long-run relationships among the variables, the Johansen cointegration testing procedure has been considered. This test ensured that there are long-run relationships among the variables. To capture the short-run dynamics, a VECM test has been done, and to find the direction of causation, the Granger causality approach has been tested. The results find that there was a bidirectional causality from CO_2 emissions to gross domestic product (GDP) and from electricity production from gas to GDP where unidirectional causality was found from GDP to electricity consumption and electricity production from oil to GDP. CUMSUM and CUSUM approaches have also been considered to test the stability of the parameters. Policy implications of the research indicate that Bangladesh should give importance to low carbon emission technologies to reduce the CO_2 emissions level with a view to keeping Bangladesh safe from natural calamities along with economic growth.

Key words: Electricity Production, Electricity Consumption, CO_2, GDP, Causality

JEL Classifications: C32, O13, Q43

INTRODUCTION

Bangladesh is now a developing country and its economy is going through a paradigm shift. Over the last 10 years, GDP growth rate of Bangladesh averaged at 6.88%. The country is one of the disaster-prone countries in the world which faces extreme natural climatic disasters in each year. One of the Sustainable Development Goals (Goal 7) is to provide affordable and clean energy. According to United Nations Development Programme (UNDP), people who used electricity rose from 78 percent to 87 percent between 2000 and 2016. As the world's population grows, so will the demand for electricity, and the use of fossil fuels to generate energy will increase the likelihood of a massive change in our environment. Climate action is another key goal of the SDGs, which emphasizes on keeping global warming to 1.5 degrees Celsius, reducing global net CO_2 emissions by 45 percent between 2010 and 2030, and achieving net zero around 2050 (UNDP). If this is not controlled, sea levels will continue to increase, putting Bangladesh in jeopardy due to its location on the Bay of Bengal. Bangladesh is now a lower middle-income country that has a population of 161.4 million (Bangladesh census 2011). Its economic activities are expanding rapidly. Now, including captive power and renewable energy, total installed capacity is 21,778 megawatts (MW) from both public (50%) and private sector (50%). The important policy issue is whether a country needs to follow a strategy of reducing carbon emissions straight away regardless of the level of economic growth for keeping higher environmental quality, or it should not implement rapid and aggressive decrease of carbon emissions which may affect economic development and growth prospects. There are many ways of electricity generation in Bangladesh including electricity produced by oil, gas, coal, and diesel etc. Renewable energy sources include solar power, wind power, and hydroelectricity power etc. Electricity is produced by greater share equal of 51.67 percent by natural gas, 27.50 percent by furnace oil and 5.92 percent by diesel (Top panel of Figure 1).

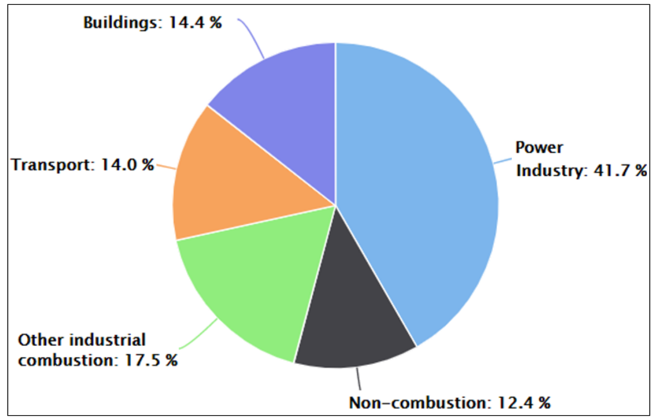


Source: Bangladesh Power Development Board (2021)

Figure 1: Electricity Production by Plant and Fuel Type

Again, lower panel of figure 1 shows plant type power production where reciprocating engine (RE) and combined cycle (CC) engine (Which run on the combustion of compressed natural gas (CNG), liquefied petroleum gas (LPG), diesel or petrol etc.) dominated the share of power production (37.56% and 35.42% respectively to total production). Plant for renewable energy (solar power) contributed only by 0.40 percent and hydro power by 1.06 percent. There have been many researches regarding the relationships among economic growth, energy consumption, and carbon emissions across the world. For Bangladesh, a large number of researchers have also worked with these variables. Also, there are a large number of researches which have covered electricity consumption. Some of these studies have proxied electricity consumption for energy consumption and some have tried to find the sole effect of electricity consumption in the development process and on environment of Bangladesh. Though there are some contemporary studies in the Bangladeshi context related with economic growth, electricity consumption and carbon emissions, it may be rare to find study which has considered the electricity production from gas and oil separately for Bangladesh. Therefore, this study considers electricity product from oil and gas along with the pre-examined variables for Bangladesh because still electricity generated using oil and gas have lion's share in total production. The study has also considered an expanded time period for the study.

For different economic activities of a country, usage of various types of energy is very essential. With the development process of Bangladesh, both electricity production and consumption are increasing day by day which is contributing more carbon emissions in Bangladesh.



Source: Worldometer (2020)

Figure 2: Fossil CO_2 by Sector in Bangladesh in 2010

Figure 2 shows that carbon emitted by 41.7 percent only from power industry in 2010. Thus GDP, electricity production and consumption, and CO_2 emissions are much related variables. Therefore, the research seeks to explore the causal relations among the variables for the extended periods and considering two additional variables which are electricity product from oil and gas. This study tries to fill the research gap that electricity production at disaggregate level should be considered along with its consumption, GDP, and CO_2 emissions. As some types of electricity generation process started later in Bangladesh, all of those sources of production could not be incorporated within the period of 1972-2014. But those sources like hydro or solar energy do not contribute so remarkably in total production. Further research may seek casual relations among different variables incorporating electricity production at disaggregate level for Bangladesh.

Literature Review

Kraft and Kraft (1978) introduced the topic of energy consumption and economic growth first to examine the causal relationship between these two variables. Using causality tests, they studied relationship between GNP and energy consumption for the period of 1947 to 1974 in the US. The research found a unidirectional causality running from GNP to energy consumption. Later, many studies have been conducted regarding energy related variables, renewable energy related variables and other variables. Again, many studies regarding electricity consumption, economic growth and CO_2 emissions have also been done. These studies can be classified according to different criteria including methodology, region, variables considered and on hypothesis basis. Some studies found feedback effect and some found conservative hypothesis etc. Many studies have worked with only electricity consumption and economic growth and others have worked with electricity consumption, CO_2 emission and economic growth. There are many literatures in case of finding the relationships among the variables. Different results have come out from various studies. These results vary across countries, regions, different study periods, various variables and due to methodology varieties. Few of them are presented in the table 1.

In case of Bangladesh, numerous studies have been conducted on energy consumption and other variables but very few have considered electricity consumption as the contributing factor to the CO_2 emissions. Sarker & Alam, (2010) worked with economic growth and electricity generation data of Bangladesh for the period 1973 to 2006 to investigate the causal relationship between the variables. They found only undirected causality from electricity generation to economic growth. Their study recommended to increase electricity generation to promote economic growth of Bangladesh. Mozumder & Marathe (2007) conducted a research to find out the relationship between electricity consumption and economic growth and found that energy conservation would not affect growth and development of the economy and hence suggested energy conservation as a policy tool for Bangladesh. Being a developing country, Bangladesh is now doing well in the development perspectives and its economic activities are expanding gradually. Electricity is playing a great role in the development of Bangladesh. Economic activities in Bangladesh are directly affected by the increased electricity consumption (Golam Ahamad & Nazrul Islam, 2011). Some studies have been conducted regarding the relationships among the variables especially with energy consumption in Bangladesh. They found unidirectional or bidirectional causal relationship among energy related variables with economic growth and CO_2 emission (Jahangir Alam et al., 2012 & Masuduzzaman, 2011). Bangladesh is now experiencing a transition period where almost all of the aspects of the economy are being touched with development. With financial development, electricity consumption is being increased in Bangladesh which is causing CO_2 emissions (Shahbaz et al., 2014). Studies regarding GDP, ELC, and CO_2 and other variables in Bangladesh are shown in the table 1. Some mega projects are ongoing in Bangladesh. In the field of electricity, there has been development to a remarkable level. Nuclear power plant, coal power plant, hydroelectricity, oil and gas power plant sectors are also being developed. Perhaps, no studies have yet focused on the relationships among GDP, electricity production from oil and gas sources, electricity consumption, and carbon emissions together. This study, therefore, checks the causation relationships among the variables.

Table 1: Overview of Studies on Energy Consumption, Economic Growth and CO_2 Emissions

Author(s)	Country and Period	Methods	Variables	Causality
Shahbaz & Feridun (2012)	Pakistan (1971 - 2008)	ARDL bounds test, Toda-Yamamoto (TY) and Wald causality	EG and ELC	GDP → ELC
Dhungel (2019)	Five South Asian Countries (2000-2011)	Panel unit root and co-integration, FMOLS, Granger causality (GC)	GDP and ELC	GDP ←ELC
Ozturk & Acaravci (2011)	11 MENA countries (1971 – 2006)	ADF-WS, LS unit root, ARDL bounds test, VECM	EG and ELC	(Short Run) real GDP → ELC (Israel and Oman) ELC → real GDP (Egypt and Saudi Arabia) (LR) ELC → real GDP (Oman) (LR)
Lu (2017)	17 Industries in Taiwan (1998–2014)	Granger causality	EG and ELC	GDP ↔ ELC
Al-Mulali & Che Sab (2018)	Middle East Countries (1990–2008)	Panel unit root and Pedroni cointegration test, Panel Granger causality	EG, ELC and CO_2	ELC↔ CO_2 EG ↔ ELC
Ibrahiem (2018)	Egypt (1971–2013)	Johansen cointegration test, VECM, TY causality	Real GDP and ELC	real GDP ↔ ELC
Cowan et al. (2014)	BRICS Countries (1990– 2010)	Bootstrap panel causality	EG, ELC and CO_2	GDP↔ ELC (Russia) ELC→ CO_2 (India) GDP→ CO_2 (South Africa) GDP × CO_2 (India, China)

Author(s)	Country and Period	Methods	Variables	Causality	
				GDP × ELC (Brazil, India, China) GDP →ELC (South Africa) ELC× CO_2 (Brazil, Russia, China, South Africa)	GDP↔ CO_2 (Russia) GDP← CO_2 (Brazil)
Anastacio (2017)	Canada, US and Mexico (1980-2008)	Pedroni cointegration tests, Panel FMOLS, Panel dynamic OLSs	ELC, EG and CO_2	ELC → CO_2 EG → CO_2	
Lean & Smyth (2010)	Five ASEAN countries (1980 – 2006)	IPS, MW-Fisher ADF, Johansen Fisher panel cointegration test, Panel DOLS and Granger causality	ELC, EG and CO_2	EG ←ELC (Long Run) EG ← CO_2 (LR) ELC ← CO_2 (SR)	
Gao & Zhang (2014)	14 Sub-Sahara African (SSA) Countries (1980 – 2009)	Panel cointegration and panel VECM	ELC, EG and CO_2	(Short run) EG → CO_2 EG→ ELC	(Long run) EG ↔ ELC ELC ↔ CO_2 EG ↔ CO_2
Njoke et al. (2019)	Cameroon (1971-2014)	ARDL, TY Granger causality (TYGC)	EG, ELC and CO_2	EG ← CO_2 EG × ELC	
Sharif Hossain (2012)	3 SAARC Countries (1976- 2009)	ADF, LLC, IPS, MW and Choi panel unit root test, Johansen Fisher panel cointegration and Kao tests, panel Granger F test	EG, ELC, Export values and Remittance	EG →ELC (Pakistan)	
Long et al. (2015)	China (1952 – 2012)	ADF, PP, Trace test, Max-Eigen test, Granger causality, static and dynamic regression analysis	EC, CO_2 and EG	GDP↔ CO_2 GDP↔ ELC	
Ahmad et al. (2016)	India (1971-2014)	ARDL, VECM	CO_2, EG, Energy at aggregate and disaggregated level	(Long run) ELC ↔ CO_2 EG ↔ ELC EG↔ CO_2 Short Run EG ↔ CO_2 (Agg. Level)	Disaggregate Level EG→ CO_2 ELC↔ CO_2 EG→ ELC EG → CO_2
Faisal et al. (2018)	Iceland (1965–2013)	ARDL bounds test, Granger causality	EG, ELC, trade and Urbanization	EG × ELC	
Khobai (2018)	BRICS Countries (1990–2014)	Kao panel and Johansen Fisher panel co-integration techniques, VECM, Granger-causality	ELC, EG, CO_2 and Urbanization	EG → ELC	
Algarini (2020)	Saudi Arabia (1990-2017)	VAR, Granger causality Wald test	EG, EC, CO_2, EPGas, and EPOil	EG ↔ ELC EG ↔ CO_2 EPG ↔ CO_2 gEPG → gCO_2	gEPG ←gCO_2 gEPG ← gELC gEPO → gCO_2
Mozumder & Marathe (2007)	Bangladesh (1971–1999)	ADF, Johansen cointegration, VECM, Pair-wise Granger causality	GDPpc and ELCpc	GDPpc → ELCpc	

Author(s)	Country and Period	Methods	Variables	Causality
Golam Ahamad & Nazrul Islam (2011)	Bangladesh (1971–2008)	Granger causality (VECM Specified)	GDPpc and ELCpc	(Short Run) GDPpc ← ELCpc, GDPpc ↔ELCpc
Masuduzzaman (2012)	Bangladesh (1981 – 2011)	ADF and PP test, Johansen co-integration test, Granger F approach	EG, ELC and Investment	GDP← ELC
Jahangir Alam et al. (2012)	Bangladesh (1972 – 2006)	Johansen bi-variate cointegration, ARDL, Granger causality	EC, ELC, CO_2 and EG	EGpc ↔ ELCpc (Long Run) EGpc ← CO_2pc (SR & LR)
Shahbaz et al. (2014)	Bangladesh (1975–2010)	ARDL bounds test, Innovative Accounting Approach (IAA)	ELC, CO_2 and Industrialization	ELC→ Energy Pollutants ELC →Industrial Growth ELC → Financial Development
Hossen & Hasan (2018)	Bangladesh (1972–2011)	ADF, PP, Johansen co-integration, Granger F-test	GDP, EC and CO_2	GDP← ELC ELC→ CO_2 GDP→ CO_2

Note: GDP stands for Gross Domestic Product, EG for Economic Growth, EC for Energy Consumption, ELC for Electricity Consumption, CO_2 for Carbon Emissions, EPGas for Electricity Production from Gas, EPOil for Electricity Production from Oil, SR and LR for short and long run respectively. Growth of respective variables has been indicated by g and pc has been added to show per capita to the specific variables. The signs → and ← denote unidirectional causality between the series where ↔ and × implies bi-directional and no causal relationship respectively.

Data and Methodology

Data

The research has used a yearly time series data for the period covering 1972-2014 taken from the World Development Indicators (WDI). The data include Gross Domestic Product (constant 2010 US$), Electricity Consumption (kWh per capita), Carbon Emissions (kt), Electricity Production from gas and Electricity Production from oil sources (% of total). These variables are expressed in logarithmic form and denoted as LGDP, LELC, LCO_2, LEPG and LEPO respectively. Initial year 1972 was chosen based on Bangladesh's independence period, and ending timeline 2014 was limited by the availability of data from secondary sources.

All the variables have trend pattern which implies significant and stable relationships among the variables gross domestic product (GDP), electricity consumption (ELC), CO_2 emissions and electricity production from gas (EPG) and oil (EPO).

Table 2: Descriptive Statistics

Variable	Observation	Mean	Std. Dev.	Minimum	Maximum
LGDP	43	24.65771	0.5656068	23.79019	25.71368
LCO_2	43	9.788076	0.8765803	8.163177	11.20081
LELC	43	4.163089	0.9819088	2.366175	5.768959
LEPO	43	2.423871	0.7983445	0.568387	3.763681
LEPG	43	4.2585	0.3002104	3.546354	4.529333

The descriptive statistics for all the variables have been presented in table 2. The statistical examination is for the 43 yearly observations. Standard deviation of electricity consumption is 0.98 which is very high and it may be due to the increased electricity consumption in Bangladesh. Again, the standard deviation of carbon emissions comes in the second place and it is also very high which denotes carbon emissions have also increased at a greater extent in Bangladesh.

The following Figure 3 includes 3 panels which show that all the variables show a trend during the period. Graphical visualizations reveal that gross domestic product, electricity consumption, carbon emissions and electricity production from gas have increased together over the period 1972-2014 where electricity production from oil has decreased over time.

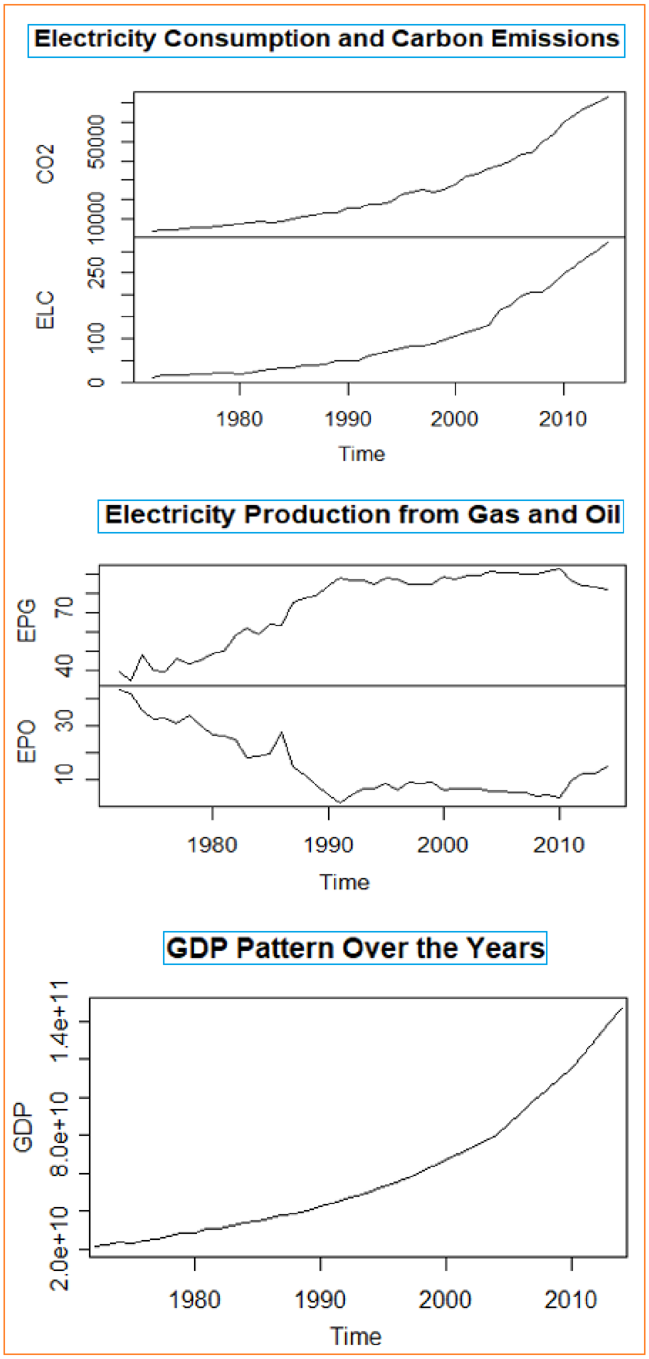


Figure 3: Graphical View of the Variables

Methodology

Augmented-Dickey Fuller and Phillips Perron Test

The presence of a justifiable long-term relation among the various variables depends heavily on the state of stationarity of the variables. Being the variables non-stationary, ordinary least square estimates may cause spurious regression difficulties and some tests like t and F may become inapplicable. If any time series variable is non-stationary, then it may be of trend stationary process (TSP) or difference stationary process (DSP). De-trending process for trend stationary variables and differencing process for the difference stationary process are required to make the variables stationary. The Unit Root tests are considered as the formal tests for checking whether the variables are TSP or DSP. For all the variables LGDP, LELC, LCO_2, EPG and LEPO, Augmented Dickey Fuller and Phillips-Perron tests have been used to check stationarity of the variables. Augmented Dickey- Fuller (ADF) test (Dickey and Fuller, 1981) is as follows.

$$\Delta Y_t = \alpha + \beta Y_{t-1} + \sum_{i=1}^{n} \delta_i \Delta Y_{t-i} + \rho T + u_t$$

Where, α, β, δ, ρ are the parameters to be estimated, ΔY_{t-1} denotes the lagged of a time series variable like GDP, $\delta_i \Delta Y_{t-i}$ indicates lagged values of the first differenced series, T shows deterministic time trend, and u_t is for normally distributed white noise error term. An optimal lag length is selected using the Akaike information criterion. Again, for time series variables, serial correlation may cause problems. In ADF test, lags of the first differences of the series are added for eliminating the difficulties. When it is the case that the error term u_t is serially correlated and there is possibility of heteroskedasticity, Phillips-Perron (1988) test is applied which generalises the results of the regression equation for ADF test. The PP test can be shown as

$$u_t = \theta(L) e_t = \sum_{i=0}^{n} \theta_j e_{t-1}$$

PP tests are robust to general forms of heteroskedasticity in the error term u_t and there is no need to determine optimal lag length for the test regression.

Johansen Cointegration Test

To check multiple cointegrating vectors, Johansen cointegration test (Johansen, 1988) and (Johansen & Juselius, 1990) is applied. This approach includes the estimation of the vector autoregressive (VAR) model in the following form:

$$\Delta X_t = \alpha + \sum_{i=1}^{k} \Gamma_i \Delta X_{t-i} + \Gamma X_{t-1} + \varepsilon_t$$

Where Γ and Γ_i are n×n matrices of unknown parameters, X_t denotes n endogenous variables as a column vector, and ε_t is a n×1 column vector error term. In this study, X_t stands for a 5×1 vector of the time series variables gross domestic product (GDP), carbon emissions (CO_2), electricity consumption (ELC), electricity production from gas (EPG), and electricity production from oil (EPO), α is for a 5×1 vector of constant terms, Γ and Γ_i are 5×5 matrix of coefficients, and ε_t indicates a 5×1 vector of error terms which are white noise in nature. The matrix Γ show long run information regarding the relationship among the variables. The rank of the impact matrix may be different. Full column rank of the matrix Γ indicates stationarity of all the variables in X. Zero rank of the matrix Γ implies that the process is a conventional first differenced vector auto regression (VAR) which contains no long run relationship elements. But existence of r cointegrated vectors can be ensured if the rank of Γ is in between the full column and zero column rank, that is $0 < \text{rank}(\Gamma) = r < n$, which makes the linear combinations of the time series variables X_t stationarity or cointegrated. Johansen and Juselius provides two tests i.e., the Trace test and the Maximal Eigen value test. Depending on the comparison of some selection criteria like adjusted R^2 value, Akaike Information Criterion (AIC) and Schwarz Bayesian Criterion (SIC), the autoregressive order of VAR is to be chosen. The null hypothesis for both the test is that there is no cointegrating relationship against the alternative that there is at least one cointegrating relationship among the variables.

Vector Error Correction Model (VECM)

If each series is integrated of the same order, there is a long-term association between two series in a bivariate relationship. If co-integration is identified between the series, then there is a long-term equilibrium association between the series. Therefore, the study conducts VECM model in order to estimate the short run integration. VECM refers to a constrained vector auto regression having co-integration restrictions designed into the framework, so that it can deal with non-stationary time series variables which are supposed to be cointegrated or are in long run association. The long-term characteristics of the endogenous variables are restricted moves towards their integrating associations while a broader range of the short-term dynamism are allowed. The cointegration term shows speed of adjustments towards long run relationship which is regarded as the error correcting term (i.e., ε_{t-1}). And as any divergence from the deep-term equilibrium gets adjusted step by step after completion of a rounds of partial short-term corrections. In case of no co-integration case, VECM isn't needed and then Granger causality tests is investigated to find out the causal association between the related variables. The regression equation structure of VECM is as follows:

$$\Delta Y_t = \mu_1 + p_1\varepsilon_1 + \sum_{i=0}^{k}\theta_i\,\Delta Y_{t-i} + \sum_{i=0}^{k}\Psi_i\,\Delta X_{t-i} + \sum_{i=0}^{k}\Phi_i\,\Delta Z_{t-i}$$

$$\Delta X_t = \mu_2 + p_2\varepsilon_{t-1} + \sum_{i=0}^{k}\theta_i\,\Delta Y_{t-i} + \sum_{i=0}^{k}\Psi_i\,\Delta X_{t-i} + \sum_{i=0}^{k}\Phi_i\,\Delta Z_{t-i}$$

Where ΔY_t and ΔX_t are the first differenced dependent variables, μ_1 and μ_2 are the intercept terms, ε_{t-1} is the error correction term, ΔY_{t-i} and ΔX_{t-i} are the lagged differenced terms of the dependent variables respectively, and ΔZ_{t-i} are the control variables used as independent variables.

Granger Causality Test

This study uses Granger causality test (Granger, 1969) to check the causal association between GDP, CO_2, ELC, EPO, and EPG of Bangladesh respectively. From the five variables, if GDP and CO_2 are considered, there may be four probable relationships related to causality analysis which are as follows: unidirectional causal relationship from GDP to CO_2 or vice-versa, two-sided causal association and finally no causality between the two variables.

The regression equations of usual Granger causality test can be written as follows:

$$LNGDP_t = \lambda + \sum_{i=1}^{p}\delta_i\,LNCO_{2t-i} + \sum_{i=0}^{p}\gamma_i\,LNELC_{t-i} + \sum_{i=0}^{p}\pi_i\,LNEPG_{t-i} + \sum_{i=0}^{p}\tau_i\,LNEPO_{t-i} + e_{1t} \quad (1)$$

$$LNCO_{2t} = \lambda + \sum_{i=1}^{p}\alpha_i\,LNGDP_{t-i} + \sum_{i=0}^{p}\gamma_i\,LNELC_{t-i} + \sum_{i=0}^{p}\pi_i\,LNEPG_{t-i} + \sum_{i=0}^{p}\tau_i\,LNEPO_{t-i} + e_{2t} \quad (2)$$

$$LNELC_t = \lambda + \sum_{i=1}^{p}\alpha_i\,LNGDP_{t-i} + \sum_{i=0}^{p}\delta_i\,LNCO_{2t-i} + \sum_{i=0}^{p}\pi_i\,LNEPG_{t-i} + \sum_{i=0}^{p}\tau_i\,LNEPO_{t-i} + e_{3t} \quad (3)$$

$$LNEPG_t = \lambda + \sum_{i=1}^{p}\alpha_i\,LNGDP_{t-i} + \sum_{i=0}^{p}\delta_i\,LNCO_{2t-i} + \sum_{i=0}^{p}\gamma_i\,LNELC_{t-i} + \sum_{i=0}^{p}\tau_i\,LNEPO_{t-i} + e_{4t} \quad (4)$$

$$LNEPO_t = \lambda + \sum_{i=1}^{p}\alpha_i\,LNGDP_{t-i} + \sum_{i=0}^{p}\delta_i\,LNCO_{2t-i} + \sum_{i=0}^{p}\gamma_i\,LNELC_{t-i} + \sum_{i=0}^{p}\tau_i\,LNEPO_{t-i} + e_{5t} \quad (5)$$

Where, i and j represent lag length.

According to Sim (1980), a time series variable can be considered as causal for another different time series variable if the first one plays role in contributing to forecast error variance of the second time series. Different studies like Jbir and Zouari (2009) and Belloumi (2009) have contributed to develop the hypothesis testing procedures.

To find different causal relationship, this paper has run regressions in many ways and set different hypothesis. For example, in equation 1, unidirectional causality relationship from CO_2 to GDP can be found if the hypothesis $\sum_{i=1}^{p}\delta_i \neq 0$, $\sum_{i=0}^{p}\gamma_i = \sum_{i=0}^{p}\pi_i = \sum_{i=0}^{p}\tau_i = 0$ exists. Again, the inverse directed causality from GDP to CO_2 is also found by setting $\sum_{i=1}^{p}\alpha_i \neq 0$, $\sum_{i=0}^{p}\gamma_i = \sum_{i=0}^{p}\pi_i = \sum_{i=0}^{p}\tau_i = 0$. And if both the hypotheses are satisfied simultaneously, then there exists bidirectional causality between variables GDP and CO_2. And lastly, if both the parameter vectors are simultaneously equal to zero, that is $\sum_{i=1}^{p}\delta_i = \sum_{i=1}^{p}\alpha_i = 0$, then GDP and CO_2 are said to be independently related and there exists no relationship between the two variables.

Empirical Results and Discussion

Results of ADF and PP Tests

Table 3 shows the results of unit root tests i.e., ADF and PP, for all the variables at their level and first difference form so that the order of integration of the variables can be determined. According to Engle and Granger (1987), a time series is considered to be integrated of order *d* [symbolically denoted as $\sim I(d)$] if the series is necessary to be differenced d times for becoming stationary. For the ADF test, the null hypothesis is that there is a unit root in the sample data considered against the alternative hypothesis that there is no presence of unit root in the data.

Table 3: Augmented Dickey Fuller (ADF) Test

Variable	Without trend		With trend	
	Level	First Difference	Level	First Difference
LNGDP	1.61 (2)	-2.66* (2)	-0.01 (2)	-7.60 *** (1)
$LNCO_2$	-0.65 (4)	-5.14*** (4)	-0.86 (3)	-5.17*** (4)
LNELC	0.42 (3)	-5.04*** (2)	-1.23 (1)	-5.02*** (2)
LNEPO	-1.99 (1)	-5.88*** (0)	-1.53 (1)	-6.07*** (0)
LNEPG	-1.23 (4)	-6.30*** (1)	-0.743 (4)	-7.59*** (1)

Notes: (a) figures within the parentheses indicate lag lengths chosen by the Akaike Information Criterion (AIC); (b) *, **, and *** denote rejection of the null hypothesis of unit root at the 10%, 5%, and 1% significance level respectively.

From table 3, it is observed that for the case of without trend, all the variables are non-stationary. But all the variables become stationary at their first differenced form in the case of without trend. That is the variables are integrated of order 1 i.e., [~I(1)]. From the graphical analysis, (Figure no. 3), it is observed that the data follow trend. Adding trend in the ADF test equation at level form, no variables are observed to be stationary. But considering trend and first differenced form of the variables, it is clear that all the variables are stationary. So we can conclude from the ADF test that, $LNCO_2$, LNELC, LNGDP, LNEPG, and LNEPO are I(1). The null hypothesis is that the time series variable has a unit root where the alternative is that the series was generated by a stationary process.

Table 4: Phillips-Perron (PP) Test

Variable	Without Trend		With Trend	
	Level	First Difference	Level	First Difference
LNGDP	1.730	-8.165***	.286	-12.092 ***
$LNCO_2$	-1.654	-11.065 ***	-2.312	-10.901***
LNELC	-1.050	-9.037***	-1.67	-8.903***
LNEPO	-1.934	-5.874***	-1.490	-6.062***
LNEPG	-2.103	-9.956***	-0.763	-13.264***

Notes: *, **, and *** denote rejection of the null hypothesis of unit root at the 10%, 5%, and 1% significance level respectively.

Table 4 exhibits output of Phillips-Perron test where similar results like ADF have been obtained. That is all the variables are stationary at first difference form. Being the variables integrated of order 1, there may be cointegrating relationship among the series being considered.

Johansen Cointegration Test

Table 5: Johansen Cointegration Test

H_0	Trace Statistics	5% Critical Value	Max Statistics	5% Critical Value
r = 0	101.8518*	68.52	54.9990*	33.46
r ≤ 1	46.8527	47.21	21.7693	27.07
r ≤ 2	25.0834	29.68	15.7383	20.97
r ≤ 3	9.3452	15.41	9.0842	14.07
r ≤ 4	0.2610	3.76	0.2610	3.76

Notes: (1) r denotes the number of cointegrating equation. (2) The lag order for each VAR is chosen by AIC. (3) '*' denotes the rejection of the null hypothesis of unit root at 5% significance level.

Table 5 shows the result of Johansen cointegration test. For both the Trace and Maximal Eigenvalue tests, null hypothesis of no cointegration is strongly rejected here indicating that there exists one cointegrating relationship. All the variables LNGDP, $LNCO_2$, LNELC, LNEPG and LNEPO have long run relationship and they move together. The availability of a cointegration ties shows that long-run equilibrium relationships are present among the variables in the model and there is minimum one cause and effect relationship among the chosen variables but the orientation of the causal association cannot be identified clearly.

Vector Error Correction Model (VECM)

Table 6: Long Run Estimation of the Vector Error Correction Model (VECM)

Long Run Relationship Dependent Variable: LNGDP				
Variable	Coefficient	Standard Error	Z-value	P>|z|
Constant	-28.88	-	-	-
LNGDP	1.00	-	-	-
$LNCO_2$	0.8520218**	0.3715022	2.29	0.022
LNELC	-1.592075***	0.3142479	-5.07	0.000
LNEPO	0.0911077	0.0788028	1.16	0.248
LNEPG	0.4634373	0.2957437	1.57	0.117

Notes: *, **, and *** denote rejection of the null hypothesis of unit root at 10%, 5%, and 1% significance level respectively.

The table 6 shows that carbon emissions have significant and positive long run relationship with gross domestic product (GDP) at 5% level of significance. Bangladesh is experiencing many development activities with many institutional developments which is contributing in emitting carbon. Again, when institutional developments and other activities take place, GDP of Bangladesh increases. Hence, it is like the case that CO_2 is associated with GDP. The study finds long run negative association of electricity consumption with gross domestic product. As electricity consumption increases, GDP decreases. This may happen due to misuse of electricity, corruption in the power distribution sectors and other activities. The results also reveal that electricity production from gas and oil have no significant impact on GDP in the long run. Bangladesh imports oil, and day by electricity production from oil is decreasing. That may be one of the causes of no long run relationship of electricity production from oil with GDP. And electricity production from gas is not also associated with GDP in the long run and it may happen due to the fact that electricity is being generated in many other different ways. Development of various alternative renewable sources for power may be an example.

Table 7: Short Run Estimation of the Vector Error Correction Model (VECM)

Short Run Relationship Dependent Variable: LNGDP				
Variable	Coefficient	Standard Error	Z-value	P>|z|
ETC_{t-1}	-0.0450427***	0.0154982	-2.91	0.004
LNGDP LD.	-0.4076102***	0.1562484	-2.61	0.009
$LNCO_2$ LD.	0.0433902	0.0450618	0.96	0.336
LNELC LD.	0.0264091	0.0340966	0.77	0.439
LNEPO LD.	-0.0004253	0.0083219	-0.05	0.959
LNEPG LD.	-0.0707024*	0.0410994	-1.72	0.085
Constant	0.0460508	0.0077357	5.95	0.000

Notes: *, **, and *** denote rejection of the null hypothesis of unit root at 10%, 5%, and 1% significance level respectively.

When the variables are cointegrated, there is long run relationship among the variables. But sometimes due to shocks to the economy, this equilibrium situation or relationship may get disrupted. If there is really deviation of the variables from the stable relationship, adjustments in the way of reaching the equilibrium relationship take place. Vector autoregressive error correction model is applied to capture this short run dynamics of the variables. ETC is the lagged error correction term which indicates speed of adjustments, and it shows how quickly the variables carbon emissions, electricity consumption, and electricity production from gas and oil respond to a deviation from the long run equilibrium. The error correction term here shows that almost 4.5 months needed to reach the long run equilibrium if there is really any deviation from the long run stable relationship. In short run, only electricity production from gas has negative impact on GDP. But due to lack of some essential things and having some difficulties, there are no short run impacts of some variables.

Granger Causality Test

This study employs Granger causality test to find the relationship among the variables gross domestic product (GDP), Carbon emission (CO_2), electricity consumption (ELC), electricity production from gas (EPG) and electricity production from oil (EPO). Table 8 shows the empirical results of the test where the null hypothesis that carbon emissions does not cause GDP and vice-versa is rejected at 5% level of significance.

So, this paper finds a bidirectional causality between CO_2 emissions and GDP. The GDP of Bangladesh mostly depends on agriculture and manufacturing sector along with service sector. Various types of fertilizer, and insecticides are used in the agriculture sector and there are different types of chemical industries in the manufacturing sector which contribute a lot in emitting carbon. Moreover, different types of energy like coal, oil or various fossil energy intensive resources are used in different industries which also emit CO_2 and thus such emissions are linked with increase in GDP.

Table 8: Granger causality (Wald Test)

Null Hypothesis	χ^2-value	$P > \chi^2$	Decision
$LNCO_2$ does not granger cause LNGDP	5.90**	0.018	CO_2 ↔GDP
LNGDP does not granger cause $LNCO_2$	13.96***	0.000	
LNELC does not granger cause LNGDP	1.23	0.267	
LNGDP does not granger cause LNELC	12.00***	0.001	GDP→ELC
LNEPO does not granger cause LNGDP	3.24*	0.072	EPO→GDP
LNGDP does not granger cause LNEPO	2.33	0.127	
LNEPG does not granger cause LNGDP	15.24***	0.000	EPG↔GDP
LNGDP does not granger cause LNEPG	21.83***	0.000	
LNELC does not granger cause $LNCO_2$	0.009	0.922	
$LNCO_2$ does not granger cause LNELC	0.0001	0.989	
LNEPO does not granger cause $LNCO_2$	1.84	0.176	
$LNCO_2$ does not granger cause LNEPO	0.009	0.920	
LNELC does not granger cause LNEPO	2.14	0.143	
LNEPO does not granger cause LNELC	0.927	0.336	
LNEPG does not granger cause LNELC	1.89	0.170	
LNELC does not granger cause LNEPG	1.973	0.160	
LNEPG does not granger cause LNEPO	2.363	0.124	
LNEPO does not granger cause LNEPG	0.0198	0.888	

Notes: *, **, and *** denote rejection of the null hypothesis of unit root at 10%, 5%, and 1% significance level respectively.

Bangladesh as a developing country is now going through a paradigm shift with gradual increment in the GDP. When the economy expands having increased GDP, different branches of the economy also expand with increased output. Thus, expansion of the economy will increase the demand for electricity and other energy usage which will induce increase in the CO_2 emissions level. So, these processes explain the bidirectional causality between GDP and CO_2 emissions in Bangladesh. But for Bangladesh, unidirectional causality from GDP to CO_2 were found by (Hossen and hasan, 2018), unidirectional causality from

CO_2 emissions to GDP by (Jahangir Alam et al., 2012), no significant relationship between economic growth and carbon emission by (Chandra Ghosh, 2014). Similar category results were found for Russia (Cowan et al., 2014), Sub-Sahara African countries (Gao & Zhang, 2014), China (Long et al., 2015), Saudi Arabia (Algarini, 2020) and India at aggregate level (Ahmad et al., 2016). The null hypothesis that electricity does not cause GDP is not rejected but the inverse relationship exits. This implies that Bangladesh is an energy independent country. The table 8 presents that the null hypothesis of GDP causes electricity consumption is statistically significant at 1%. So, there is a unidirectional causality running from GDP to electricity consumption which favours the conservation hypothesis. This implies that energy conservation strategies may have less or no adverse impact on economic development. Financial growth causes development in the industrial as well as commercial sectors where electricity acts as a basic input. Increase in overall economic development contributes to higher disposable earnings, creating higher demand for household electronic products. This creates greater levels of electricity usage in the country. Additionally, the unidirectional causal relationship may mean that the consumption of electricity is not strong enough to impact growth in the economy; rather it may be due to inadequate infrastructure, insufficient power facilities or poor management of power to meet the increased demand from economic growth. This finding is similar to (Mozumder & Marathe, 2007) but contrary to (Jahangir Alam et al., 2012) who found bidirectional causality implying that Bangladesh is an energy dependent country. Hossen and Hasan (2018) and Masuduzzaman (2012) found growth hypothesis for Bangladesh. Study of Golam Ahamad & Nazrul Islam (2011) reveals a growth hypothesis in the short run and a feedback hypothesis in the long run for Bangladesh. Other literatures including the developing economies show that conservation hypothesis holds for Pakistan (Shahbaz & Lean, 2012), Israel and Oman (Ozturk & Acaravci, 2011), Turkey (Pempetzoglou, 2014), South Africa (Cowan et al., 2014), Uganda (Sekantsiand & Motlokoa, 2016), and Brazil, India and China (Khobai, 2018). Recent studies show that this result also holds for the developed economies like Germany (Ikegami & Wang, 2016), and Czech Republic, Latvia, Lithuania as well as the Russian Federation (Wolde-Rufael, 2014).

The study finds no causality between electricity consumption and carbon emissions which supports neutrality hypothesis. This result may be the fact that Bangladesh is endowed with natural gas reserves which is being used for electricity generation and for other commercial or industrial purposes. This finding may also be the result of the major initiatives that Bangladesh is taking in respect of installation and increased usage of cleaner and renewable energy sources, especially hydroelectricity and wind power. Hossen and Hasan (2018) and Shahbaz et al. (2014) found unidirectional causality from electricity consumption to CO_2 emissions for Bangladesh. Such types of results were found for Brazil, Russia, China, and South Africa (Cowan et al., 2014). There is a unidirectional causality from electricity product from oil to GDP and not the reverse. Electricity generation creates employment opportunities and other sources of earnings for the govt. which contributes in GDP. Expansion of the economy requires more energy, but this research finds that GDP does not cause electricity product from oil. This may be fact that the country imports oil and is diversifying power generation capacity and installation from various sources. Electricity production from gas causes GDP and vice versa implying a feedback hypothesis. Electricity generation from gas, creating working opportunities, contributes to national earnings. Financial developments in the economy need energy for different sectors and thus GDP causes electricity production from Gas but does not cause electricity generation from oil. This may happen as electricity generation from gas still dominates while that from oil is on the declining path.

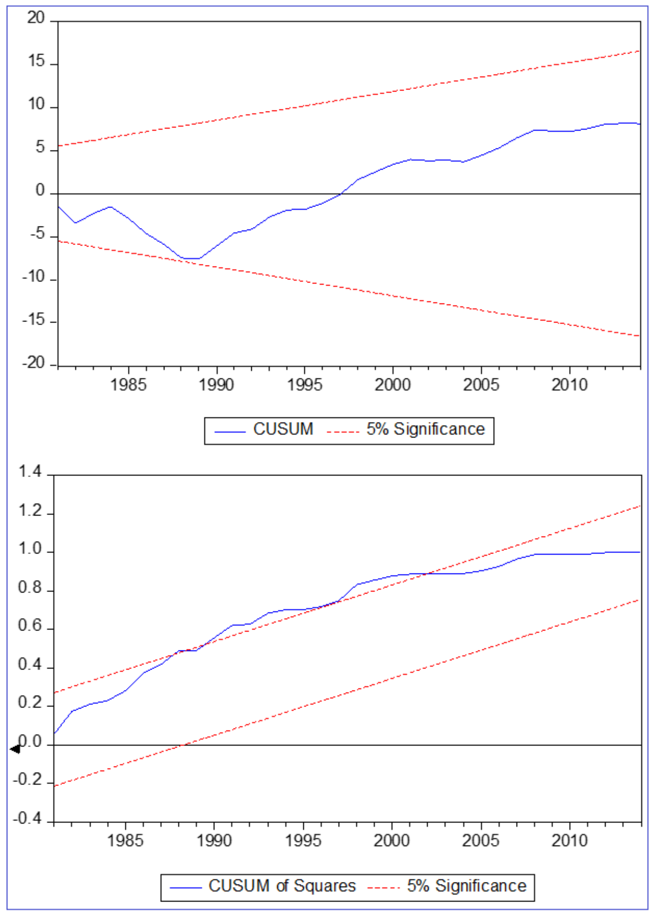


Figure 3: Plots of Cumulative Sum (CUSUM) and Cumulative Sum of Square (CUSUMSQ)

This research tried to find out whether electricity production from either gas or oil is contributing in carbon emissions and found that there is no causal association between carbon emissions and electricity production from gas or oil. Increasing infrastructural development for the energy sector, reducing unnecessary wastages of power supply, taking planned strategies and good management of the electricity production sector can promote economic development. But the less polluting sources like production from hydro, wind, nuclear or gas should get priority. To examine the relationship between electricity consumption and electricity product from oil and from gas, the study found no causal relationship between the variables. But Sarker & Alam (2010) found one sided causality from electricity generation to economic growth in the short run for Bangladesh where the researcher used electricity generation at an aggregate level and not at disaggregate level segregated by fuel type power production. Algarini (2020) found bidirectional causality between electricity production from gas and CO_2 emissions, unidirectional causality from electricity consumption and CO_2 emissions to electricity production from gas and from electricity production from oil to CO_2 emissions for Saudi Arabia. The results are different due to the fact that Saudi Arabia exports oil whereas Bangladesh does not, rather it imports oil.

To examine stability of the coefficients of any model, CUSUM and CUSUMSQ can be applied (pesaran and pesaran, 1997). After estimating the VECM model, the cumulative sum of recursive residuals (CUSUM) as well as the CUSUM square (CUSUMSQ) tests have been used to examine the stability of the parameters. The figure 3 plots CUSUM and CUSUMSQ test results. As the CUSUM statistic graph lies within the critical bands at 5% confidence interval of parameter stability, there is no parameter instability of the coefficients. Mapping of CUSUMSQ shows that the CUSUMSQ statistic falls inside the critical bands initially and then fall slightly outside for few years and then comes back again inside the bands.

Conclusion and Policy Implications

Bangladesh is experiencing a massive transition in the path of development. Electricity production and consumption is playing a vital role in this process. As each and every year, this country gets affected by various natural calamities, it is very essential to go in a much sustained way towards development progress. Taking time series data for GDP, carbon emissions, electricity consumption, and electricity production from gas and oil for the periods 1971 to 2014, this paper has tried to explore whether there exists any relationship among the variables. To find this, different testing procedures including ADF and Phillips-Perron tests for stationarity checking, Johansen and Juesilus test for finding cointegrated vector, and vector error correction model for error adjustment process have been applied. Finally, this research goes through Granger causality test to check the directions of causal effect among the variables. This study finds a unidirectional causality from GDP to electricity consumption and not vice versa. It is often argued that energy conservation will have detrimental impacts on economic development. An undirected causality from GDP to consumption of electricity implies that energy consumption is driven by GDP and not vice versa. This means the conservation of energy does not affect economic activity and production. A well-designed recycling strategy can play an important role in energy management. Obtaining energy efficiency by implementing multiple energy saving initiatives would reduce wastages and emissions associated with electricity consumption and provide more energy for economic operation and decrease financial losses caused by the energy supply wastages. So, this research suggests that Bangladesh can have its economy and environment in a better condition by ensuring energy efficiency and conservation. This policy suggestion is also given by (Mozumder & Marathe, 2007) (Chandra Ghosh et al, 2014). It has been found that electricity production from oil causes GDP and not vice versa. Again, there is bidirectional causality between electricity production from gas and GDP. As electricity production from gas and oil contributes a lion's share in total production, we can say that electricity production causes GDP in Bangladesh. So, the electricity production should be kept uninterrupted in line with its demand to keep the economic development unaffected. Again, GDP causes electricity production from gas and not from that of oil. This may be the case that there are many sources of electricity production though the other sources do not contribute to a greater extent. Again, Bangladesh is an oil importing country, and because of that, share of electricity from oil is decreasing gradually. As a result, electricity production from oil can not affect GDP so significantly. Neutrality hypothesis exist in the electricity consumption and CO_2 emission relationship. This may be due to the fact that emission level by electricity consumption is at very marginal level compared to total CO_2 emissions in Bangladesh. So, efficient use of electricity power may play effective role in reducing CO_2 emissions along with economic development.

As there is feedback hypothesis in GDP and CO_2 emission nexus, strategies to reduce CO_2 emissions may affect economic development adversely. But excessive level of CO_2 emissions due to economic development might have adverse consequences on human health with gradual decline in productivity. With an advancement in production technologies, CO_2 emission limits can be reduced, these improvements will help enhance production efficiency whilst reducing rates of pollution. Different alternative efficient strategies of energy production and consumption may help in decreasing the emission levels. As Bangladesh is very vulnerable to disaster, it should have policies to develop its economy in such a way that it can achieve sustainable development in all the spheres of the economy. As per the agenda of becoming a developed country by 2041, necessary steps need to be taken without deteriorating environmental quality. For achieving sustainable development target by 2030, Bangladesh needs more dependencies on different renewable energy sources like solar, wind, hydro or nuclear energy to keep energy consumption uninterrupted with lower-level carbon emissions. Moreover, efficiency in electricity production and usage of electricity in low carbon emitting production process may be environmentally sustainable towards the path of higher development. The study recommends some policy suggestions. Firstly, efficient usage of and prevention of the wasteful use of energy (conservation policy) should be ensured which will facilitate to have continuing availability of energy. If efficiency in case of energy usage can be ensured, it will help to decrease carbon emissions without affecting development of the country. Secondly, to keep economic growth stable, electricity production should be maintained uninterrupted as per demand. And finally, the basic environmental considerations of the total planning methodology of power generation and usage should be taken into account.

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