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ENERGY CONSERVATION AND INVESTMENT IN RENEWABLE ENERGY IN BANGLADESH

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Abstract

This paper investigates the dynamic relationships between output, energy consumption, carbon emission and price levels of Bangladesh during the period 1973-2009 using multivariate vector error-correction model. To complement the findings of the co-integration analysis, this study performs various causality tests to shed light on the causal links between output-energy and output-pollution. The empirical results reveal that in Bangladesh there is short-run unidirectional causality from energy consumption to output. The direction of causality indicates that any energy conservation measure might be detrimental to the current Bangladesh economy. Since Bangladesh cannot aggressively implement energy conservation mechanisms, the only environment-friendly policy option could be to implement clean energy technologies. Therefore, this paper further investigates the prospects of clean energy technologies and offers some way forward in this regard for Bangladesh.

1. Introduction

Although the Copenhagen Accord 2009 (Conference of Parties or COP 15) laid out a framework for global emissions reduction, many countries were displeased with both the details of the agreement and the manner in which it was reached. The Accord was also not legally binding, with countries agreeing only to "take note" of it. For both the developed and the developing world, Copenhagen served only to create a weak agreement and put off all the tough decisions until Cancun Summit in 2010. Because of this, expectations leading into COP16 in 2010, which took place in Cancun and concluded on 10 December 2010, were relatively modest. Though there was no concrete achievement at the Cancun Summit, a general agreement was announced that echoed the Copenhagen Accord, urging developed countries to cut emissions and asking developing countries to start limiting their emissions growth and planning to

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reduce it in the future. Hence, with increasing economic activities and demand for energy, studies on identifying statistically significant association between energy consumption and economic activities in Bangladesh is worth pursuing. Furthermore, an in-depth investigation on the prospects and problems of clean energy technologies in Bangladesh is warranted at this point in time.

Standard economic theories do not provide any clear-cut answer to whether economic growth is the cause or effect of energy consumption. Although standard growth models do not include energy as an input of economic growth, the importance of energy in modern economy is undeniable. Different studies have reached at different conclusions on different countries with different study periods and various measures of energy. However, no consensus has yet been established. The popularity of these studies related to identifying the direction of causality emanates from its relevance in national policy-making issues regarding energy conservation.[1]

Two notable studies investigating the relationship between energy consumption and economic growth in Bangladesh are Salim, Rafiq and Hassan; and Mozumder and Marathe.[2] While the former investigates the relationship between energy consumption and output in a tri-variate model, the latter analyses the link between output and electricity consumption in a bi-variate model. As indicated by the works of Asafu-Adjaye, Masih and Masih and Stern studies concerning bi-variate models like Mozumder and Marathe suffer from omitted variable bias.[3] The study of Salim, Rafiq and Hassan includes price level as a

[1] For example see, David I. Stern, "Energy and Economic Growth." New York: Rensselaer working paper in Economics, 2004; James B. Ang, "Economic development, pollutant emissions and energy consumption in Malaysia," *Journal of Policy Modelling*, Volume 30, 2008, pp. 271-278; A. E. Akinlo, "Energy consumption and economic growth: evidence from 11 Sub-Sahara African countries", *Energy Economics*, Vol. 30, No. 5, 2008, pp. 2391-2400; Shuddhasattwa Rafiq and Ruhul A. Salim, "Temporal Causality between Energy Consumption and Income in Six Asian Emerging Countries", *Applied Economics Quarterly*, Vol. 55, No. 4, 2010, pp. 335-350; Shuddhasattwa Rafiq and Ruhul A. Salim, "The linkage between energy consumption and income: A multivariate cointegration analysis in Six Emerging economies of Asia", *Journal of Emerging Markets*, Vol. 6, No. 1, 2011, pp. 50-73.

[2] Ruhul A. Salim, Shuddhasattwa Rafiq and A. F. M. Kamrul Hassan, "Causality and dynamics of energy consumption and output: evidence from Non-OECD Asian countries", *Journal of Economic Development*, Vol. 33, No. 2, 2008, pp. 1-26; Pallab Mozumder and Achla Marathe, "Causality relationship between electricity consumption and GDP in Bangladesh" *Energy Policy*, Vol. 35, No. 1, 2007, pp. 395-402.

[3] John Asafu-Adjaye, "The relationship between energy consumption, energy prices and economic growth: Time series evidence from Asian developing countries", *Energy Economics*, Vol. 22, No. 6, 2000, pp. 615-625; Abul M. M. Masih and Rumi Masih, "Energy consumption, real income and temporal causality: Results from a multi-country study based on cointegration and error-correction modelling techniques", *Energy Economics*, Vol. 18, No. 3, 1996, pp. 165-183; David I Stern, "Energy and economic

third variable in analysing the economic activity and energy nexus in Bangladesh. The inclusion of price level in the model specification is a significant contribution of this paper. However, since carbon emission is one of the important bi-products of energy consumption, any model investigating the linkage between output and energy consumption should include pollutant emission within its framework. Therefore, this study intends to comment on the energy conservation policy in Bangladesh by analysing the linkage between energy consumption and economic activity in a multivariate model consisting of four macro level indicators like, output, energy consumption, carbon emission and price level. It would further investigate the prospects and problems of clean energy technologies in Bangladesh.

The article is structured as follows. Section 2 presents an overview of the energy consumption profile of Bangladesh. Section 3 provides a critical review of earlier literature, followed by the discussion of theoretical framework in section 4. A description of data sources and methodologies is presented in section 5. Section 6 presents an analysis of empirical results, while section 7 elaborates policy implications of the empirical study. Section 8 dicusses problems and prospects of clean energy technologies in Bangladesh. Conclusions and policy implications are given in the final section.

2. Demand for Energy Consumption in Bangladesh

Bangladesh boasts a growing economy in the frontier of global climate change. With an average Gross Domestic Product (GDP) growth rate of more than 6 per cent a year for last five years, it is, nevertheless, a densely populated country with more than a thousand people living in one square kilometer (Table 1). This increase in economic activities are contributed by substantial increase in net export, workers' remittances and foreign direct investment growths in recent years. As far as energy consumption is concerned, the increased economic activity is fueld by increased energy use and efficiency. Bangladesh is also experiencing accelerating pace in the adoption of modern information and communication technologies. With the help of all these recent positive trends, Bangladesh is now expected to be able to lift millions of people out of absolute poverty level in the coming years.

However, the growth of output and energy consumption has its consequences on environment. During this period of growth, pollutant emission has increased as well (Figure 1a). As indicated in Figure 1b, from 1980, Bangladesh has always been a net importer of energy and the gap between energy consumption and production is increasing as the years are going by.

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growth in the USA : A multivariate approach", *Energy Economics*, Vol. 15, No. 2, 1993, pp. 137-150; Pallab Mozumder and Achla Marathe, *op.cit.*, pp. 395-402.

Table1: Bangladesh at a Glance 2004-2008

Indicator (s)	2004	2005	2006	2007	2008	Average
Population density (people per sq. km)	1,158	1,176	1,194	1,212	1,229	1,194
GDP growth (annual %)	6.27	5.96	6.63	6.43	6.19	6.30
Net Export volume index (2000 = 100)	13.92	19.81	48.18	51.64	78.67	42.44
Workers' remittances and compensation of employees, received (% of GDP)	6.34	7.16	8.77	9.59	11.31	8.63
Foreign direct investment, net inflows (% of GDP)	0.79	1.35	1.13	0.95	1.22	1.09
Energy use (kt of oil equivalent)	21,738	22,538	23,896	24,635	25,759	23.713
GDP per unit of energy use (constant 2005 PPP $ per kg of oil equivalent)	6.69	6.86	6.85	7.09	7.21	6.94
Internet users (per 100 people)	0.20	0.24	0.29	0.32	0.35	0.28

Source: World Development Indicators (http://databank.worldbank.org/ddp/home).

Figure 1a. Trend in output, energy consumption and pollutant emissions

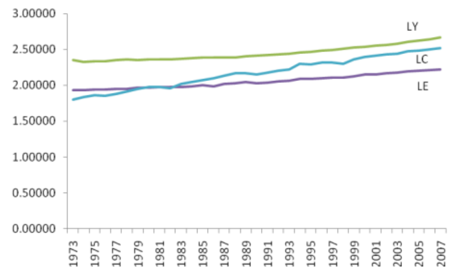
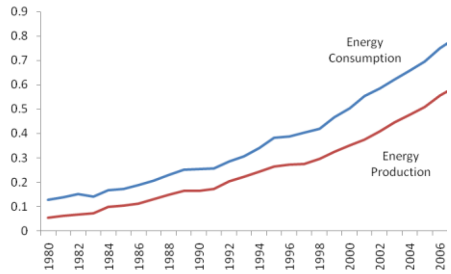


Figure 1b. Energy consumption, energy production and net import



Source: Energy Information Administration (http://tonto.eia.doe.) Note: 1a. *LY*, *LE* and *LC* represent natural log of output, energy consumption and pollutant emissions, respectively, 1b. Energy consumption and production figures are in quadrillion Btu.

3. Review of Literature

There is an impressive body of literature on the relationship between energy consumption and economic growth. Research on this issue has primarily been aimed at providing significant policy guideline in designing efficient energy conservation policies. The pioneering research in this area was conducted by Kraft and Kraft. The authors found a unidirectional causality running from national product to energy consumption in the US over the period 1947-1974. Following Kraft and Kraft, research on this subject has flourished in the context of both developed and developing countries. However, these studies do not arrive at any unique conclusion as to the direction of causality between energy consumption and economic growth. This may arise from three different sources: first, they differ in the econometric methodologies employed; second, they consider different data with different countries and time spans, and third, there may be possible problem created by non-stationarity of data.

Some studies find unidirectional causality running from output to energy consumption. Following Kraft and Kraft, Abosedra and Baghestani find unidirectional causality from output to energy consumption using extended data set on the US spanning from 1947 to 1987.[4] Unidirectional causality from output to energy has also been found in many other studies. For example, Narayan and Smyth examines Australia's data on electricity, GDP and employment; Al-Iriani examines energy consumption and GDP data of 6 Gulf Cooperation Council (GCC) countries over the period from 1971-2002; Mozumder and Marathe examines Bangladesh's data on electricity consumption and GDP from 1971-1999; and Mehrara examines the energy consumption and economic growth data of 11 oil exporting countries from 1971-2002 and so on.[5]

Contrary to the above, some studies find that there is unidirectional causal relationship that runs from energy consumption to output. Wolde-Rufael finds that over the period from 1952 to 1999 energy consumption in Shanghai Granger causes GDP growth. Morimoto and Hope came up with the same outcome on Sri Lankan data from 1960 to 1998 that electricity production causes economic growth.[6] Chen, Kuo and Chen use GDP and electric power consumption data of Asia's 10 newly industrialised countries (NICs) over the period from 1971 to

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[4] J. Kraft and A. Kraft, "On the relationship between energy and GNP", *Journal of Energy and Development*, Vol. 3, No.2, 1978, pp. 401-403; S. Abosedra and H. Baghestani, "New evidence on the causal relationship between United States energy consumption and gross national product", *Journal of Energy and Development*, Vol. 14, No. 2, 1989, pp. 285-292.

[5] Paresh Kumar Narayan and Russell Smyth, "Electricity consumption, employment and real income in Australia: evidence from multivariate Granger causality tests", *Energy Policy*, Vol. 33, No. 9, 2005, pp. 1109-1116; Mahmoud A. Al-Iriani, "Energy-GDP relationship revisited: An example from GCC countries using panel causality", *Energy Policy*, Vol. 34, No. 17, 2006, pp. 3342-3350; Mohsen Mehrara "Energy consumption and economic growth: The case of oil exporting countries", *Energy Policy*, Vol. 35, No.5, 2007, pp. 2939-2945.

[6] Yemane Wolde-Rufael, "Disaggregated industrial energy consumption and GDP: The case of Shanghai, 1952-1999", *Energy Economics*, Vol. 26, No. 1, 2004, pp. 69-75; Risako Morimoto and Chris Hope, "The impact of electricity supply on economic growth in Sri Lanka", *Energy Economics*, Vol. 26, No. 1, 2004, pp. 77-85.

2001.[7] Other studies like Masih and Masih, Stern and Shiu and Lam find the similar unidirectional causality from energy consumption to income.[8]

Bi-directional causality has also been found in some studies. Masih and Masih investigate causal link between energy and output for Korea and Taiwan over the period from 1955 to 1991 and 1952 to 1992 respectively, and conclude that there is bi-directional causal relationship between these variables.[9] Soytas and Sari examine G-7 and 10 emerging economy's data except China and find bi-directional causal relationship between per capita GDP and energy consumption in Argentina over the period from 1950 to 1990.[10] In case of Italy, from 1950 to 1992 and Korea, from 1953 to 1991 they find that causality runs from GDP to energy consumption, whereas the opposite was found in case of Turkey, Germany, France, and Japan over the period from 1950 to 1992. Other studies that also come up with same conclusions are Asafu-Adjaye, Oh and Lee, Yoo and Wolde-Rufael.[11] Although most of these studies find significant causal link between energy and output, some earlier studies, such as, Yu and Hwang's study on US data from 1947 to 1979, and Stern's study on US data from 1947 to 1990 conclude that there is no causal relationship between these two variables.[12]

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[7] Sheng-Tung, Hsiao- I. Kuo Chen and Chi-Chung Chen, "The relationship between GDP and electricity consumption in 10 Asian countries", *Energy Policy*, Vol. 35, No. 4, 2007, pp. 2611-2621.

[8] Abul M. M. Masih and Rumi Masih, "A multivariate cointegrated modeling approach in testing temporal causality between energy consumption, real income and prices with an application to two Asian LDCs", *Applied Economics*, Vol. 30, No. 10, 1998, pp. 1287-1298; David I. Stern "A multivariate cointegration analysis of the role of energy in the US macroeconomy", *Energy Economics*, Vol. 22, No.2, 2000, pp. 267-283; Alice Shiu and Pun-Lee Lam, "Electricity consumption and economic growth in China", *Energy Policy*, Vol. 32, No. 1, 2004, pp. 47-54.

[9] Abul M. M. Masih and Rumi Masih, "On the temporal causal relationship between energy consumption, real income, and prices: Some new evidence from Asian-energy dependent NICs Based on a multivariate cointegration/vector error-correction approach", *Journal of Policy Modeling*, Vol. 19, No. 4, 1997, pp. 417-440.

[10] Ugur Soytas and Ramazan Sari, "Energy consumption and GDP: Causality relationship in G-7 countries and emerging markets", *Energy Economics*, Vol. 25, No. 1, 2003, pp. 33-37.

[11] Wankeun Oh and Kihoon Lee, "Causal relationship between energy consumption and GDP revisited: The case of Korea 1970-1999", *Energy Economics*, Vo. 26, No. 1, 2004, pp. 51-59; Seung-Hoon Yoo, "Electricity consumption and economic growth: Evidence from Korea", *Energy Policy*, Vol. 33, No. 12, 2005, pp. 1627-1632; Yemane Wolde-Rufael, "Electricity consumption and economic growth: A time series experience for 17 African countries", *Energy Policy*, Vol. 34, No. 10, 2006, pp. 1106-1114.

[12] Eden S. H. Yu and Been-Kwei Hwang, "The relationship between energy and GNP: Further results", *Energy Economics*, Vol. 6, No. 3, 1984, pp. 186-190; David I Stern, "Energy and economic growth in the USA: A multivariate approach", *op.cit.*, pp. 137-150.

There are some studies that also find mixed conclusions for different countries. While examining the energy-income relationship in India, Indonesia, the Philippines and Thailand, Asafu-Adjaye considers a tri-variate model comprised of energy, income, and prices. In this study, the author uses annual data covering the period of 1973 to 1995 for India and Indonesia, while for Thailand and the Philippines the sample period spans from 1971 to 1995. Based on Granger causality and error correction mechanisms, this paper outlines that, for India and Indonesia, a uni-directional Granger causality runs from energy to income in the short-run. For Thailand and the Philippines, there exists bi-directional causality in the shorter time horizon. On the contrary, in the long-run, uni-directional Granger causality runs from energy and price level to income for India and Indonesia, while for Thailand and the Philippines, energy, income, and prices are mutually causal.

Chiou-Wei, Chen and Zhu examine the relationship between energy consumption and economic growth by using both linear and nonlinear Granger causality tests for a sample of newly industrialised Asian countries along with the US.[13] This study finds energy neutrality for Thailand, South Korea and the US, while there is a uni-directional causality running from economic growth to energy consumption for the Philippines and Singapore. For Taiwan, Hong Kong, Malaysia, and Indonesia, causality is running from energy consumption to economic growth.

Salim, Rafiq and Hassan examine the short and long run causal relationship between energy consumption and output in six non-OECD Asian developing countries. This study finds a bi-directional causality between energy consumption and income in Malaysia, while a uni-directional causality from output to energy consumption in China and Thailand and energy consumption to output in India and Pakistan. Bangladesh remains as an energy neutral economy confirming the fact that it is one of the lowest energy consuming countries in Asia. In a similar study, Rafiq and Salim also finds mixed results for the major developing economies of Asia.

In addition to causality analysis, some studies examine whether the underlying time series data have undergone any structural break. For example, Lee and Chang examines Taiwan’s data and find the structural break in gas and GDP data.[14] With regard to causality they conclude that energy causes growth and energy conservation may harm economic growth. Altinay and Karagol

[13] Song Zan Chiou-Wei, Ching-Fu Chen, and Zhen Zhu, “Economic growth and energy consumption revisited - Evidence from linear and non-linear Granger causality” *Energy Economics*, Vol. 30, No. 6, 2008, pp. 3063-3076.

[14] Chien-Chiang Lee and Chun-Ping Chang, “Structural breaks, energy consumption, and economic growth revisited: Evidence from Taiwan”, *Energy Economics*, Vol. 27, No. 6, 2005, pp. 857-872.

examines Turkish data and find similar result to that of Lee and Chang.[15] They find structural break in the electricity and income series and unidirectional causality running from electricity consumption to income. This finding also implies that energy conservation may be harmful for future economic growth.

Some of the previous studies in this field performs bivariate Granger causality test to ascertain the direction of causality. However, in one of the pioneering works in multivariate studies, Stern questions the appropriateness of such bivariate approach in the light of omitted variable problems. The traditional bivariate causality tests may fail to identify additional channels of impact and can also lead to conflicting results. Afterwards, multivariate studies in this field take two different dimensions: supply or production-side approach with energy consumption, GDP, capital and labour; and demand-side approach with energy consumption, GDP and prices. Nevertheless, none of the previous demand-side studies included carbon emission output in their studies although carbon emission has always been an important by-product of energy consumption.

Ang includes carbon emission as the third variable in his studies in the context of Malaysian and French economies.[16] However, since prices are not included, the approach that the author has taken cannot be termed as a complete demand-side analysis. Halicioglu studies the Turkish economy to investigate the dynamic causal relationship between carbon emissions, energy consumption, income and foreign trade from 1960 to 2005.[17] One of the most significant findings of this study is that income seems to be the most significant variable in explaining the carbon emissions in Turkey which is followed by energy consumption and foreign trade.

Pointing out the increased number of empirical studies on energy consumption and economy relationship, recently Karanfil questions the appropriateness of the policy implications proposed by studies considering small number of variables in a small sample by using conventional econometric methods.[18] One of the future directions suggested by the author in this study is to include variables like carbon emission in a comprehensive framework. The article in hand also identifies some of the limitations of the conventional studies investigating in energy-economy relationships and tries to make some significant

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[15] Galip Altinay and Erdal Karagol, "Electricity consumption and economic growth: Evidence from Turkey", *Energy Economics*, Vol. 27, No. 6, 2005, pp. 849-856.
[16] James B. Ang, "CO2 emissions, energy consumption, and output in France", *Energy Policy*, Vol. 35, No. 10, 2007, pp. 4772-4778.
[17] Ferda Halicioglu, "An econometric study of CO_2 emissions, energy consumption, income and foreign trade in Turkey", *Energy Policy*, Vol. 37, No. 4, 2009, pp. 1156-1164.
[18] Fatih Karanfil, "How many times again will we examine the energy-income nexus using a limited range of traditional econometric tool", *Energy Policy*, Vol. 37, No. 4, 2009, pp. 1191-1194.

improvements in the light of the limitations in its analysis of identifying the impact of energy consumption on economic activities in Bangladesh.

From the above discussion some important conclusions emerge. First, the relationship between energy consumption and economic growth is not unique. Second, very few of the previous studies include carbon emission in their models although pollutant emission is an important outcome of demand for energy. More importantly, there is no comprehensive study on identifying the link between energy consumption and economic activities in Bangladesh. The present article is an attempt to overcome some of these deficiencies in the earlier studies.

This study, therefore, differs from previous studies on the following grounds. This is the first study to analyse energy consumption and growth relationship in Bangladesh by implementing a comprehensive analysis including carbon emission within its model. This is also the first study which presents possible clean technology options for Bangladesh based on extensive econometric excercise. From the econometric point of view, the importance of this paper lies in four points. Firstly, prior to analysing the econometric model this study performs a battery of pre-testing procedures one of which is the test of unknown structural break in the underlying time series data. Secondly, instead of using Engel-Granger two step method, this study employs cointegration test proposed by Johansen and Johansen and Juselius.[19]Thirdly, this study examines causality among the variables within the error correction model formulation to identify both the direction of short and long run causality and within-sample Granger exogeneity and endogeneity of each variable. And fourthly, for testing the robustness of results, this study presents variance decompositions and impulse response functions which provide information about interaction among the variables beyond the sample period.

4. Theoretical Settings

The usual approach to modelling energy consumption demand is to hypothesise a model that relates energy consumption to its price, income, and the price of a substitute. Like Sadorsky, the variables employed in this research are selected in accordance with economic theory and data availability.[20] Real GDP is included in the model to measure income. Since there is no unique price for the energy as a whole this study consideres GDP deflator to indicate overall price level of the economy. Following Rafiq and Salim and in accordance with societal

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[19] Søren Johansen, "Statistical analysis of cointegration vectors", *Journal of Economic Dynamics and Control*, Vol. 12, No. 2-3, 1988, pp. 231-254; S. Johansen and Katarina Juselius, "Maximum likelihood estimation and inference on cointigration with applications to the demand for money", *Oxford Bulletin of Economics & Statistics*, Vol. 52, No. 2, 1990, pp. 169-210.

[20] Perry Sadorsky, "Renewable energy consumption, CO_2 emissions and oil prices in the G7 countries", *Energy Economics*, Vol. 31, No. 4, 2009, pp. 456-462.

concerns over greenhouse effects, CO_2 emissions are included in the model as an important additional explanatory variable. Hence, the equation for energy consumption demand would take the following form:

$$LE_{it} = \beta_{0i} + \beta_{1i} LY_{it} + \beta_{2i} LC_{it} + \beta_{3i} LP_{it} + e_{it} \quad (1)$$

where, i = 1, ..., 7 denotes the country , t = 1980, 1981, ...2006 denotes the time period, e_{it} the vector of serially and mutually uncorrelated structural innovations. *LY*, *LE*, *LC* and *LP* stands for real GDP, energy consumption, carbon emission and price level, respectively.

5. Data Sources and Analytical Framework

Data Sources: This study uses annual data from as early as Bangladesh's inception, from 1973 to 2009. Different data series are obtained from various sources. Real GDP and GDP deflator data with base year of 2005 are collected from World Development Indicators (WDI). Energy consumption and carbon emission data are extracted from British Petroleum (BP) Statistical Review, 2010. Units for energy consumption and carbon emission are million tonnes oil equivalent and million tonnes, respectively.

Analytical Framework: The empirical estimation undertaken in this paper has three objectives. The first is to examine how the variables are related in the long run. The second is to identify the dynamic causal relationship between the variables. And the third is to investigate the robustness of the causality directions and magnitude.

To perform the above mentioned tasks, this study first constructs a reduced form Vector Auto Regression (VAR) model with four variables namely, output, energy consumption, carbon emission and price level. A VAR approach serves this paper's estimation purpose since it avoids the endogeneity problems by treating all variables to be endogenous. Accordingly, the reduced form level VAR is presented below:

$$z_t = \alpha_0 + \sum_{j=1}^{p} A_j z_{t-j} + \varepsilon_t \quad (2)$$

where, $z_t = [Y_t E_t C_t P_t]'$. The series Y_t, E_t, C_t and P_t can be either *I(0)* or *I(1)*. α_t is a vector of constant terms or $\alpha_0 = [\alpha_Y \alpha_E \alpha_C \alpha_{P_t}]'$ and A_j is a matrix of VAR parameters for lag *j*. The vector of error terms $\varepsilon_0 = [\varepsilon_Y \varepsilon_E \varepsilon_C \varepsilon_{P_t}]' \sim IN(0, \Omega)$. Before implementing the model it is imperative to ensure first that the underlying data are non-stationary or I (1) and there exists at least one cointegrating relationship among the variables. Three of the most widely used unit root tests in this regard are Augmented Dickey-Fuller (ADF), Phillips Perron (PP) and Kwiatkowski-Phillips-Schmidt-Shin (KPSS) unit root tests. However, these standard tests may not be appropriate when the series contains structural break.[21] To account for such structural breaks, Perron (1997) develops a procedure that allows endogenous break points in series under consideration.[22] Thus, this paper employs ADF, PP and KPSS unit root testing procedure as well as the test for unknown structural break.

Engle and Granger suggest that a vector of non-stationary time series, which may be stationary only after differencing, may have stationary linear combination without differencing and then the variables are said to have cointegrated relationship.[23] If the variables are non-stationary and not co-integrated, the estimation result of regression model gives rise to what is called 'spurious regression'. The traditional Ordinary Least Square (OLS) regression approach to identify cointegration cannot be applied where the equation contains more than two variables and there is a possibility of having multiple cointegrating relationships. In that case, VAR based cointegration test is appropriate.

As Engle and Granger reveal, cointegrated variables must have an error correction representation in which an error correction term (ECT) must be incorporated into the model. Accordingly, a vector error correction model (VECM) is formulated to reintroduce the information lost in the differencing process, thereby allowing for long run equilibrium as well as short run dynamics. For illustration, assuming that there is only one cointegrated relationship; the VECM constructed for this study can be expressed as follows:

$$\Delta LE_t = \mu_1 + \alpha_{11} ECT_{t-1} + \sum_{j=1}^{p-1} \beta_{1j} \Delta LE_{t-j} + \sum_{j=1}^{p-1} \gamma_{1j} \Delta LY_{t-j} + \sum_{j=1}^{p-1} \delta_{1j} \Delta LC_{t-j} + \sum_{j=1}^{p-1} \theta_{1j} \Delta LP_{t-j} + \varepsilon_{1t} \quad (3)$$

$$\Delta LY_t = \mu_2 + \alpha_{21} ECT_{t-1} + \sum_{j=1}^{p-1} \beta_{2j} \Delta LE_{t-j} + \sum_{j=1}^{p-1} \gamma_{2j} \Delta LY_{t-j} + \sum_{j=1}^{p-1} \delta_{2j} \Delta LC_{t-j} + \sum_{j=1}^{p-1} \theta_{2j} \Delta LP_{t-j} + \varepsilon_{2t} \quad (4)$$

$$\Delta LC_t = \mu_3 + \alpha_{31} ECT_{t-1} + \sum_{j=1}^{p-1} \beta_{3j} \Delta LE_{t-j} + \sum_{j=1}^{p-1} \gamma_{3j} \Delta LY_{t-j} + \sum_{j=1}^{p-1} \delta_{3j} \Delta LC_{t-j} + \sum_{j=1}^{p-1} \theta_{3j} \Delta LP_{t-j} + \varepsilon_{3t} \quad (5)$$

$$\Delta LP_t = \mu_4 + \alpha_{41} ECT_{t-1} + \sum_{j=1}^{p-1} \beta_{4j} \Delta LE_{t-j} + \sum_{j=1}^{p-1} \gamma_{4j} \Delta LY_{t-j} + \sum_{j=1}^{p-1} \delta_{4j} \Delta LC_{t-j} + \sum_{j=1}^{p-1} \theta_{4j} \Delta LP_{t-j} + \varepsilon_{4t} \quad (6)$$

where ε_t's are Gaussian residuals and

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[21] Ruhul A. Salim and Harry Bloch, ""Business expenditure on R & D and trade performances in Australia: Is there a link?" *Applied Economics*, Vol. 32, No. 11, 2007, pp. 1-11.

[22] Pierre Perron, "Further evidence on breaking trend functions in macroeconomic variables", *Journal of Econometrics*, Vol. 80, No. 2, 1997, pp. 355-385.

[23] R. F. Engle and C. W. J. Ganger, "Cointegration and error correction representation, estimation and testing", *Econometrica*, Vol. 55, No. 1, 1987, pp. 26.

$$ECT_{t-1} = LE_{t-1} + (\beta_{21}/\beta_{11})LY_{t-1} + (\beta_{31}/\beta_{11})LC_{t-1} + (\beta_{41}/\beta_{11})LP_{t-1}$$

is the normalised cointegrated equation. There are two sources of causation, *i.e.*, through the ECT, if $\alpha \neq 0$, or through the lagged dynamic terms. The ECT shows the long run equilibrium relationship while the coefficients on the lagged difference terms indicate short term dynamics. The statistical significance of the coefficients associated with the ECT provides evidence of error correction mechanism that drives the variables back to their long run equilibrium.

Given two separate sources of causality, we can perform three different causality tests, i.e., short run Granger non-causality test, weak exogeneity and strong exogeniety tests. In Eq. (3), to test ΔLY_t does not cause ΔLE_t in the short run, the statistical significance of the lagged dynamic terms is examined by testing the null H_0: all γ_{1j} = 0 using the Wald test. Non-rejection of the null implies ΔLY_t does not cause ΔLE_t in the short run. The weak exogeneity test, which is a notion of long run non-causality test, requires satisfying the null H_0: $\alpha_{11}=0$. It is based on a likelihood ratio test which follows a χ^2 distribution. Finally, strong exogeneity test which imposes stronger restrictions can be performed by testing the joint significance of both the lagged dynamic terms and ECT.[24] This requires satisfying both Granger non-causality and existence of weak exogeneity. In particular, ΔY_t does not cause ΔE_t if the null H_0: all $\gamma_{1j} = \alpha_{11} = 0$ is not rejected. The strong exogeneity test does not distinguish between the short run and long run causality, but it is a more restrictive test which indicates the overall causality in the system. It is important to highlight that this paper uses the concept of causality in the *predictive* rather than in the *deterministic* sense. As Deibold put forward, '*X* causes *Y*' is simply the abbreviated expression for '*X* contains useful information for predicting *Y*'.[25] Hence, the causality results are interpreted in the Granger sense.

6. Empirical Analyses

Augmented Dickey-Fuller (ADF), Phillips Perron (PP) and Kwiatkowski-Phillips-Schmidt-Shin (KPSS) unit root tests are first employed to examine the stationarity of underlying time series data. In Table 1, it is evident that all unit root tests remarkably yield similar results: LY_t, LE_t, LC_t and LP_t are non-stationary in their levels but become stationary after taking the first difference. Hence, from the unit root tests results it could be inferred that all series are $I(1)$ at the 5 per cent level of significance.

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[24] W. W. Charemza and D. F. Deadman, *New Direction in Econometric Practice: General to Specific Modelling, Cointegration and Vector Autoregression*, 2nd ed, Glos, UK: Edward Elgar Publishing, Inc, 1992; R. F. Engle, D.F. Hendry and J. F. Richard, "Exogeneity", *Econometrica*, Vol. 51, No. 1, 1983, pp. 277-304.

[25] F. Deibold, *Elements of Forecasting*, Ohio: Thompson Learning, 2004.

Table 1: Unit Root Tests

	ADF[a]		PP[a]		KPSS[b]	
	Intercept	Trend and Intercept	Intercept	Trend and Intercept	Intercept	Trend and Intercept
LY_t	3.356	-1.692	12.128	3.409	0.682**	0.202**
ΔLY_t	-4.692*	-12.278**	-6.244**	-17.169**	0.176	0.050
LE_t	1.591	-2.446	3.258	-2.262	0.702**	0.213**
ΔLE_t	-8.193**	-8.752**	-8.507**	-28.120	0.339	0.127
LC_t	-0.637	-1.028	-1.480	-2.979	0.714**	0.135*
ΔLC_t	-5.036**	-5.009**	-14.425**	-16.239**	0.300	0.021
LP_t	-1.218	-2.265	-1.111	-2.971	0.674**	0.208**
ΔLP_t	-3.335*	-5.201**	-5.729**	-7.279**	0.172	0.110

Note: (*) and (**) indicate 10 and 5 per cent level of significance, respectively.
[a] H_0 = the series has a unit root. Schwarz Info Criterion (SIC) is used to select the lag length. The maximum number of lags is set to be 4.
[b] H_0 = the series is stationary. Barlett-Kernel is used as the spectral estimation method. The bandwidth is selected using Newey-West method.

However, as mentioned earlier, the traditional unit root tests cannot be relied upon if the underlying series contains structural break(s). Many authors discuss this limitation of the conventional unit root tests.[26] Following Perron and Zivot & Andrews, a number of empirical studies were conducted in recent years.[27] This study uses Perron unit root test that allows for structural break and the test results are summarised in Table 2. When the underlying series is found non-stationary the selected value of T_b is likely to no longer yield a consistent estimate of the break point. Therefore, it may be concluded that the underlying data are non-stationary at level but stationary at their first differences.

[26] Pierre Perron, “The great crash, the oil price shocks, and the unit root hypothesis”, *Econometrica*, Vol. 57, No. 6, 1989, pp. 1361-1401; E. Zivot and D. W. K Andrews, “Further evidence on the great crash, the oil-price shock, and the unit-root hypothesis”, *Journal of Business and Economic Statistics*, Vol. 10, No. 3, 1992, p. 20.
[27] A. K. Salman and G. Shukur, “Testing for Granger causality between industrial output and CPI in the presence of regime shift: Swedish data”, *Journal of Economic Studies*, Vol 31, No. 5-6, pp. 492-499; Hacker R. Scott, and A. Hatemi-J., “The effect of regime shifts on the long run relationships for Swedish money demand,” *Applied Economics*, Vol. 37, No. 2, 2005, pp. 1131-36.

Table 2: Perron Innovational Outlier model with change in both intercept and slope

Series	T	T_b	k^1	$t_{\hat{\beta}}$	$t_{\hat{\theta}}$	$t_{\hat{\gamma}}$	$t_{\hat{\delta}}$	$\hat{\alpha}$	t_{α}	Inference
LY_t	13	1989	0	2.29	1.67	-1.32	-3.01	0.732	-2.288	NS
LE_t	13	1989	0	3.93	3.63	-4.17	3.39	0.522	-3.741	NS
LC_t	15	1991	0	2.73	0.38	1.34	-0.89	0.498	-3.169	NS
LP_t	26	2002	0	2.43	1.52	-1.47	-0.98	0.846	-1.845	NS

*Note***:** 1, 5 and 10 per cent critical values are -6.32, -5.59 and -5.29, respectively (Perron, 1997). The optimal lag length is determined by Akaike Information Criterion (*AIC)* with $k_{\max} = 10$. NS stands for Non-stationary at levels.

As the variables are level non-stationary and first difference stationary, the Johansen, and Johansen and Juselius maximum likelihood co-integration test is employed to examine if the variables are co-integrated and the test results are reported in Table 3. The superiority of Johansen's approach compared to Engle and Granger's residual based approach lies in the fact that Johansen's approach is capable of detecting multiple cointegrating relationships among variables. This study accepts the optimum lag lengths provided by *AIC*. In Table 3, both the results of trace tests and maximum eigen value tests unanimously point to the same conclusion that there are at least three cointegrated relationships, at the 5 per cent level of significance.

Table 3: Johansen cointegration test

Hypothesised no. of CE(s)	$r = 0$	$r \leq 1$	$r \leq 2$	$r \leq 3$
Trace statistic (λ *trace*)	46.282**	36.336**	24.673**	7.281
Hypothesised no. of CE(s)	$r = 0$	$r \leq 1$	$r \leq 2$	$r \leq 3$
Maximum eigen value statistic (λ *max*)	125.112**	78.830**	42.493**	7.820

Note: (*), (**) and (***) indicate 10, 5 and 1 per cent level of significance, respectively. Optimum lag length selected by *AIC* is 4.

Table 4 presents the cointegrating vectors and the speed of adjustment coefficients. By normalising LY_t to one, all the coefficients in the long-run for each of the cointegrating vectors are statistically significant. It is evident that LE_t, LC_t and LP_t are positively related to LY_t in the long run. The long run elasticities of LE_t, LC_t and LP_t with respect to LY_t are 1.460, 0.588, and 0.407, respectively.

Hence, the highest impact in output comes from energy consumption in the long run. The loading factors, which measure the speed of adjustment back to the long run equilibrium level, are statistically significant and correctly signed (negative). This implies that error correction mechanisms exist so that the deviations from long run equilibrium have significant impacts on economic growth. This provides further support for the use of error correction framework. According to Vector 1, for example, output adjusts at a speed of 47 per cent every year, or it takes about 2.1 years, to restore equilibrium when there is shock on the steady-state relationship. This speed of adjustment, nevertheless, is considered relatively high for a developing country like Bangladesh.

Table 4: Cointegrating Vectors

Vector	Cointegrating equations	Coefficient
1	$LY_t = 0.553 + 1.460\ LE_t$	-0.470
	(1.524) (7.546***)	(17.105***)
2	$LY_t = 1.066 + 0.588\ LC_t$	-0.306
	(3.206**) (3.379**)	(3.801**)
3	$LY_t = 1.558 + 0.407\ LP_t$	-0.792
	(3.853**) (3.558**)	(9.492***)

Note: Maximum likelihood estimates subject to exactly identifying restrictions. LY is the normalized dependent variable. Conitegration with restricted intercepts and no trend in the VAR. 32 observations from1973 to 2008. Order of VAR is 4. r = 3. Variables included are, *LY*, *LE*, *LC*, *LP* and intercept. (***) and (**) denote parameters are significant at or below 1 and 5 per cent, respectively. P-values in brackets.

Evidence of cointegration implies the existence of causality, at least in one direction. However, it does not indicate the direction of causal relationship. Hence, to shed light on the direction of causality, this study performs ECM-based causality tests. The results of the causality tests are reported in Table 5.

Table 5: Causality tests

Hypothesis	Short-run Granger non-causality	Long-run weak exogeneity test	Overall strong exogeneity test
H_0: $\Delta LY \not\rightarrow \Delta LE$	0.3855	1.574	0.3694
H_0: $\Delta LE \not\rightarrow \Delta LY$	18.342***	0.185	17.904***
H_0: $\Delta LY \not\rightarrow \Delta LC$	0.0010	0.3291	0.0005
H_0: $\Delta LC \not\rightarrow \Delta LY$	12.234***	0.185	13.430***

Note: (***) indicates rejection of the null hypothesis of non-causality at 1 per cent level of significance. All statistical tests are performed using Wald $\chi 2$ tests.

According to the causality results it can be inferred that in the short run both energy consumption and carbon emission Granger causes output. However, there is no feedback from the opposite side and more significantly the tests point out that the causality relationships identified are only a short run phenomenon; no long run linkages are evident.

Granger causality test suggests which variables in the models have significant impacts on the future values of each of the variables in the system. However, the result will not, by construction, be able to indicate how long these impacts will remain effective in the future. Variance decomposition and impulse response functions give this information. Hence, this paper conducts generalised variance decompositions and generalised impulse response functions analysis proposed by Koop et al., and Pesaran and Shin.[28] The unique feature of these approaches is that the results from these analyses are invariant to the ordering of the variables entering the VAR system.

The generalised impulse response functions trace out responsiveness of dependent variables in the VAR to shocks to each of the variables. For each variable from each equation separately, a unit shock is applied to the error, and the effects upon the VAR system over time are noted.[29] The results of the impulse response functions are presented in Figure 2. According to the results of impulse responses, there is not much happening in response to one standard error (S.E.) shocks in both *LY* and *LP* equations. However, in response to one unit S.E. shocks in *LE* and *LC*, *LY* increases positively and indefinitely into the future. This upward trend in responses from *LY* indicates the appropriateness of the causality results which pointed out unidirectional causality from energy and carbon emission to output.

Variance decomposition gives the proportions of the movement in the dependent variables that are due to their "own" shocks, versus shocks to the other variables. The results of variance decomposition over a period of 20-year time horizon are presented in Table 6. The results indicate that after five years, only 8.16 per cent of the variations in *LY* are explained by its own innovation, whereas 75.36 per cent and 62.09 per cent of the variations are explained by *LE* and *LC*, respectively. After 20 years, the explanation from *LY* to its own innovation drops down to 0.20 per cent and *LE* and *LC* explains 77.85 per cent and 58.99 per cent, respectively. Hence, the results of the variance decompositions also confirm the fact that both energy consumption and carbon emission impacts output of Bangladesh.

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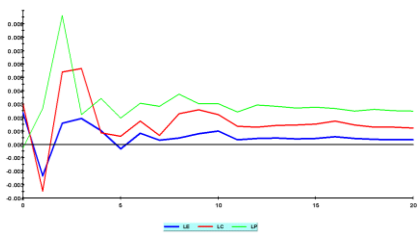
[28] G. Koop, M. H. Pesaran, and S. M. Potters, "Impulse response analysis in nonlinear multivariate models", *Journal of Econometrics*, Vol. 74, No. 1, 1996, pp. 119-147; M. H. Pesaran, and Yongcheol Shin, "Generalized impulse response analysis in linear multivariate models", *Economics Letters*, Vol. 58, No. 3, 1998, pp. 17-29.

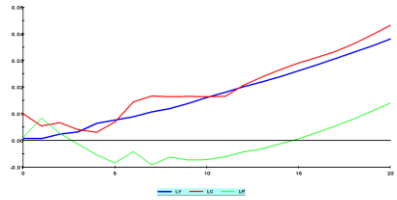
[29] Chris Brooks, *Introductory Econometrics for Finance*, Cambridge, UK: Cambridge University Press, 2002.

Figure 2: Generalised Impulse Response Functions

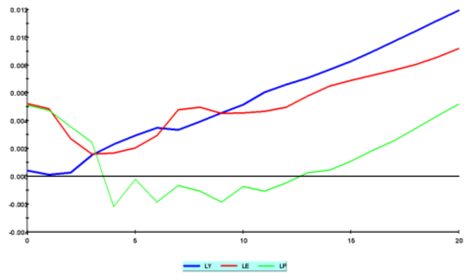
Generalised Impulse Response(s) to one S.E. shock in the equation for LY



Generalised Impulse Response(s) to one S.E. shock in the equation for LE



Generalised Impulse Response(s) to one S.E. shock in the equation for LC



Generalised Impulse Response(s) to one S.E. shock in the equation for LP

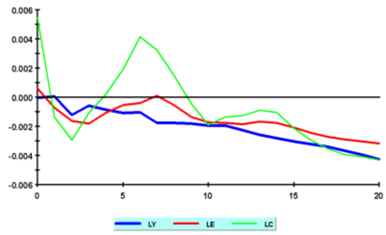


Table 6: Findings from Forecast Error Variance Decomposition

Years	Variance Decompositions of LY				Variance Decompositions of LE			
	LY	LE	LC	LP	LY	LE	LC	LP
1	0.9650	0.1045	0.0215	0.0041	0.0834	0.7823	0.3836	0.0071
5	0.0816	0.7536	0.6209	0.0272	0.0550	0.8306	0.2020	0.0253
10	0.0152	0.7874	0.5007	0.0179	0.0165	0.8808	0.1297	0.0108
15	0.0049	0.7844	0.5944	0.0134	0.0068	0.8796	0.1047	0.0096
20	0.0020	0.7785	0.5899	0.0119	0.0032	0.8759	0.0941	0.0101
	Variance Decompositions of LC				Variance Decompositions of LP			
	LY	LE	LC	LP	LY	LE	LC	LP
1	0.0467	0.2876	0.8969	0.0699	0.0143	0.1406	0.0957	0.8562
5	0.1277	0.3806	0.6495	0.0695	0.0959	0.1452	0.0578	0.7102
10	0.0502	0.7515	0.3063	0.0382	0.0922	0.2332	0.0441	0.5712
15	0.0219	0.8421	0.1815	0.0171	0.1027	0.2462	0.0415	0.5357
20	0.0095	0.8677	0.1269	0.0124	0.0975	0.3719	0.0617	0.4404

Note: All the figures are estimates rounded to four decimal places.

7. Policy Implications of the Empirical Study

In the previous empirical sections, this paper investigates the dynamic relationships between output, energy consumption, carbon emission and price levels for Bangladesh during the period of 1973-2008 using multivariate vector error-correction model. To complement the findings of the cointegration analysis, this study performs various causality tests to understand the causal links of output-energy and output-pollution. This study, further, employs impulse response functions and variance decompositions analyses to test the robustness of the causality results. The empirical results reveal that in Bangladesh there are short-run unidirectional causalities from energy consumption to output and pollutant emission to output.

The findings of uni-directional causality from energy consumption to economic activities imply that Bangladesh is an energy-dependent economy. The results are sensible given that a significant amount of economic growth in Bangladesh has been fuelled by industrial growth recently, which requires intensive use of energy. Since energy is a stimulus for economic development, the implementation of energy conservation policies may severely affect economic performance and retard economic development. Energy conservation can be defined as measures that either increases the efficiency of how we use energy or reduce our energy consumption. Although energy conservation measures may help slow down the pace of environmental degradation nevertheless, the Bangladesh economy may also be subject to energy shocks in which an energy shortage may adversely affect GDP growth.

The results have important implications for policy makers in Bangladesh who aspire to transform the economy into a fully industrialised one in the near future. Economic growth is the outcome of growth in inputs and increases in the productivity of the inputs. Therefore, rapid industrialisation requires higher and/or more efficient consumption of energy products. Given that, over-consumption of resources can have negative impacts on the environment, there is much scope for the development of energy conservation strategies.

The evidence also suggests that the degradation of the environment precedes economic growth. In Bangladesh, an increase in pollution level induces economic expansion which is not surprising given the fact that much energy inputs have been consumed in the production (which have resulted in more pollution) to promote heavy industry. This pattern of development is consistent with the experiences of many developing countries. However, despite the above findings, policy makers should be mindful that a persistent decline in environmental quality will exert a negative externality to the economy through affecting human health, thereby reducing productivity in the long run.[30] Hence, it is of utmost importance that the country should start investigating the prospect of clean energy technologies and adopt a policy for a way forward in this respect. In the

[30] Some regulatory controls can be imposed to reduce pollution and ensure sustainable development. For an assessment of the effects of different tax instruments on controlling the emissions of carbon dioxide, see D. W Jorgenson and P. J. Wilcoxen, "Reducing U.S. carbon dioxide emissions: An assessment of different instruments", *Journal of Policy Modeling*, Vol. 15, No. 1, 1993, pp. 491-520.

next section, this study therefore, would explore some of those technologies and offer some recommendations thereof.

8. Clean Energy Technologies

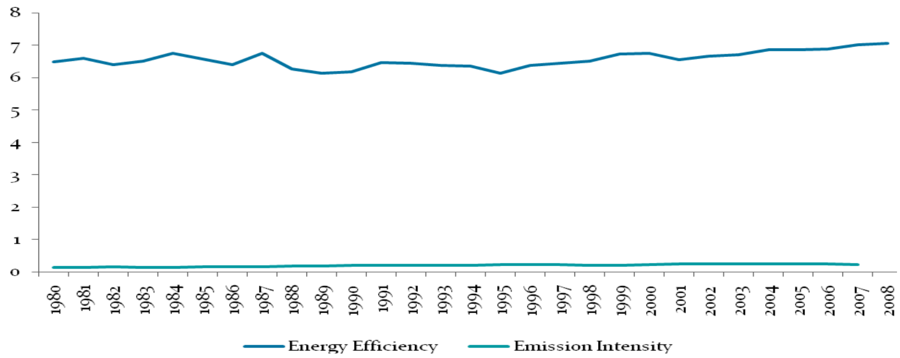
The paradigm of clean energy technologies can be divided into two separate energy regimes. The first one is energy efficiency, i.e., using less energy resources to meet the same energy need. The second one is renewable energy, i.e. using non-depleting natural resources to meet energy needs. The outcome of our empirical study indicates that at this state of economic development of Bangladesh both of these initiatives seem to be more logical than straightforward energy conservation measures.

Clean energy technologies have several advantages related to environmental, economic, and social performances of a country. From environment perspective, clean energy technologies will actively avoid and mitigate the adverse impacts of climate change and reduce pollutions at local level. Economically, these technologies will reduce the rate of fossil fuel depletion and would minimise the cost of clean energy technologies in the life-cycle basis. That is, although innovating clean energy technologies require substantial primary investment, over the life of this technology it would prove to be hugely profitable in the forms of patent and other property right mechanisms. As far as social impacts are concerned, the introduction of clean energy will generate local employment, reduce drain of local currency and essentially satisfy the growing energy demand from industrial and agricultural sector.

8.1 Trends in Energy Efficiency and Energy Intensity

Figure 3 presents energy efficiency and emission intensity trends in Bangladesh from 1980 to 2008. Here, energy efficiency represents GDP per unit of energy use (constant 2005 PPP US$ per kg of oil equivalent) while Emission Intensity represents CO_2 emissions (kg per 2005 PPP US$ of GDP).

Figure 3: Trends in Energy Efficiency and Energy Intensity



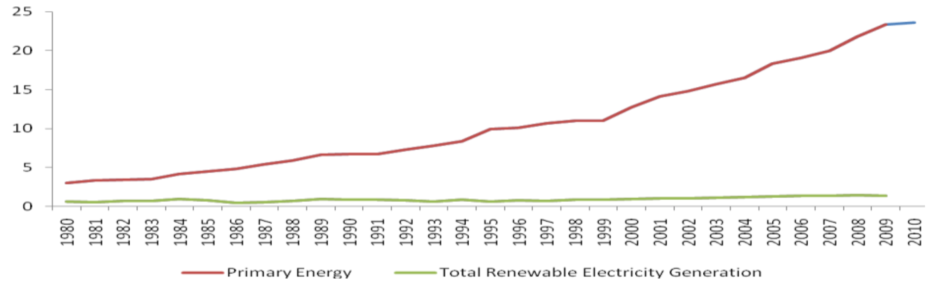
Data Source: World Development Indicators 2011.

As Figure 4 depicts, from 1980 through the adoption of modern technologies in industrial and agricultural sectors, Bangladesh is steadily improving energy efficiency performance. However, the rate of improvement is much flatter than the growth in energy consumption. Another alarming indication is that according to the graph the pollutant intensity is also growing in a stable pace. Both of these indicate that the country needs to increase its endeavour to adopt different energy efficiency measures in commercial, industrial and agricultural sectors.

8.2 Trends in Renewable Energy

Figure 4 shows the trends in primary energy consumption and total renewable electricity generation in Bangladesh from 1980 to 2009. Here, primary energy consumption is represented in million tonnes oil equivalent while total renewable electricity generation is in billion kilowatt hours.

Figure 4: Trends in Renewable Energy Adoption

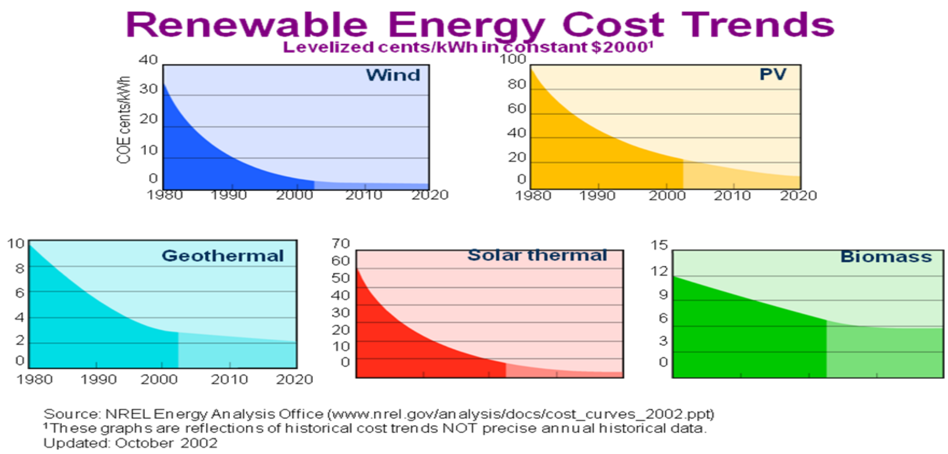


Data Source: World Development Indicators 2011.

According to Figure 4, total renewable electricity generation has increased steadily throughout the years. The rate nevertheless is very slow in relation to the growth of primary energy consumption which reveals the need for greater initiative to accelerate the adoption of renewable energy in Bangladesh.

Major Sources of Renewable Energy: Some of the major sources of renewable energy are: (a) Solar (Solar Photovoltaic and Solar Thermal/Concentrating Solar Power), (b) Wind, (c) Biogas and Biomass, and (d) Hydro-electricity. Common characteristics of these renewable energy technologies are: (a) renewable technologies typically have higher initial cost of development and introduction, (b) eventually they would have lower operating cost, (c) they are environmentally cleaner, and (d) they are often cost effective on a life-cycle basis. Hence, investment in innovating even a smallest renewable technology might open up an avenue for Bangladesh for a profit generating market for the future. It is to be noted here that, worldwide the cost of renewable energy technologies are falling rapidly as shown in Figure 5.

Figure 5: Cost of Renewable Energy Technologies World-Wide



Furthermore, there have been some developments in different renewable energy sources in Bangladesh recently. However, they are scattered endeavour from some esteemed entrepreneurial bodies without much collective efforts. Brief statements on some of these initiatives and their key features are offered below.

Solar Energy: The greatest amount of solar energy is available between two broad bands encircling the earth between 15″ and 35″ latitude north and south. Fortunately, Bangladesh is situated within this band and as such Bangladesh is in a very favourable position in respect of the utilisation of solar energy. So far, solar energy is the most explored option amongst the renewable energy sources in Bangladesh. More than 450,000 solar home systems have been installed in the country. One million systems are expected to be installed further by 2012. Government has in principle decided to install solar power in all public and semi-public offices. Recently, solar power equipment is made locally. Only the panels are imported. Government hopes that solar panel manufacturing/assembling will soon take place in Bangladesh.

In Bangladesh major initiatives in solar energy adoption have been taken by Rural Electrification Board (REB), Atomic Energy Commission, Local Government Engineering Department (LGED), and Grameen Shakti. They have installed a number of solar PV systems in different parts of the country. Institute of Fuel Research and Development (IFRD) of Bangladesh Council of Scientific and Industrial Research (BCSIR) and Centre for Mass Education in Science (CMES) are engaged in the development and dissemination of Solar Cookers. Different models of Solar Ovens have already been designed and constructed with locally available raw materials. Solar Water Heater is designed and constructed by IFRD as well.

Wind Energy: Wind Energy does not offer a very encouraging picture for Bangladesh as far as climatic facts are concerned. Hence, quite reasonably wind is one of the least explored forms of energy in Bangladesh. Country wide wind studies in heights up to 6 meters have been carried out and indicate that onshore wind speed is too slow (3.5-4.5 m/s) to pass significant commercial potential. Furthermore, the wind season in Bangladesh stays for a short period, only 3-4 months.

There are some industries along the Bay of Bengal coastline which uses wind power for electricity generation. They are shrimp farming, fish processing, and ice making industries. These are all electricity intensive and represent major industries along the coast, especially in the Cox's Bazar, Chokoria, Chittagong, and Khulna areas of Bangladesh.

Biogas and Biomass: These are other renewable sources where Bangladesh along with its neighbours has substantial expertise. In Bangladesh, commonly known Biomass fuels are: fuel wood, rice husk, jute stick, sugarcane bagasse, agriculture residual and animal dung. Bangladesh has naturally strong potential for biomass gasification based electricity. This technology can be disseminated on a large scale for electricity generation. In IFRD, BCSIR both single and multiple stoves have been modified to save fuel up to the extent of 50-70 per cent.

Bangladesh has huge potential in these sources. Firstly, we have noteworthy experience in these technologies among our rural mass. Secondly, innovating effective and efficient small scale technologies in this sector requires very little investment. Thirdly, for our own use there are huge stocks of some of these indigenous sources in our cities and villages. According to a study by LGED, some of the facts about biomass and biogas are as follows:

- Biomass
    - Fuel Wood: 8 million m^3/y
    - Agricultural Residues: 12,021,201 metric ton
    - Animal Dung: 27,202,000 tons
    - Bagasse, rice husk
- Biogas
    - 22 million cows and buffaloes produce 2.9×10^9 cubic meter of gas equivalent 3.04 million tons of coal
    - 4 million biogas plants can be installed
    - Poultry farms can produce aggregate 100 MW of electricity using biogas based electric generator.

Small Hydro: Except Chittagong and the Chittagong Hill Tracts, microhydro and minihydro have limited potential in Bangladesh. There is one hydro power plant at Kaptai established in 1960 with an installed capacity of 230 MW.

8.3 Some Challenges for Renewable Energy Adoption in Bangladesh

Some of the reasons behind the low renewable energy deployment identified in Bangladesh are:

1. The true potential has not been determined.
2. The prevalence of extreme poverty in precisely the areas of the country where renewable energy can be deployed.
3. Subsidised or "no tax" fossil fuel supply.
4. Lack of capacity within the country to deploy new and emerging technologies; and,
5. Neglecting attitude of the past governments.

The above reasons are fairly generic, and apply equally well to all developing countries to a greater or lesser degree. But for Bangladesh all the five factors are significant and highlight the general level of indifference towards renewable energy. For example, if Bangladesh is compared to India, factors 2 and 3 apply to both country situations, but with respect to the other three factors, India is far ahead of Bangladesh, which is reflected in the higher level of renewable energy deployment in India. However, given all the challenges, in the light of some of the major developments in international energy scenarios presented bellow, Bangladesh has to increasingly accelerate its adoption of renewable energy technologies in its energy supply.

8.4 A Few National and International Realities

Future energy policies for Bangladesh should be based on some of the present national and international energy scenarios and future energy outlooks. Fossil fuel price is going to keep on soaring because of greater investment for exploration in the global context. The future of fossil fuel lies in carbon pricing resulting in higher prices for non-renewable and larger global market for renewable technologies. In this regard, Bangladesh's strength is our market. This huge market could eventually make any new innovations feasible. Hence, a possible strategy for Bangladesh could be to start selling carbon intensive energy sources at good price and invest good sum of that money along with climate funds in renewable energy technologies and get ready for the future.

9. Conclusions and Policy Recommendations

This paper is divided into two separate parts. The basic objective of the first part is to identify the energy conservation possibility for Bangladesh. Therefore it investigates the dynamic relationships between output, energy consumption, carbon emission and price levels for Bangladesh during the period of 1973-2009, using multivariate vector error-correction model. The empirical results reveal that in Bangladesh there are short-run unidirectional causalities from energy consumption to output and pollutant emission to output.

The findings of uni-directional causality from energy consumption to economic activities imply that Bangladesh is an energy dependent economy. As energy is a stimulus for economic development, the implementation of energy conservation policies by reducing fossil fuel consumption may severely affect economic performance and retard economic development. The economy of Bangladesh may also be subject to energy shocks in which an energy shortage may adversely affect GDP growth.

To balance the often conflicting objectives of greater economic emancipation and introduction of environmental friendly energy technologies the clean energy options include: energy efficiency and mass adoption of renewable energy technologies. The second part of this paper performs the task of developing a future outlook for clean energy based on a reflection of the past energy uses.

Some specific policy recommendations emerged from this analysis. First, aggressively encourage R&D endeavours for inventing cheaper and efficient renewable energy technologies. Second, search and develop markets for small solar items as well as biomass and biogas know-how around the world. Third, benchmark investment and production cost for renewable energy technologies in Bangladesh. Fourth, formulate renewable energy regulations. Fifth, develop a central database for energy statistics to facilitate energy research. Sixth, develop energy economics research wing to design a Renewable Energy Target (RET) mechanism as well as a path for introducing carbon tax.

One of the main contributions of this study is that for the first time an attempt is made to examine the dynamic relationships between economic development, energy consumption and carbon emission for Bangladesh. Although the findings of this analysis may be unique to Bangladesh due to its institutional and structural characteristics, the econometric technique employed in this study can be readily extended to include other less developed countries. The econometric specification is subject to tests for serial correlation and normality. The test results support the paper's relatively parsimonious specification. However, it is important to know that given the small sample nature of this analysis, the results are to be interpreted with due caution. Another major contribution of this paper is that this is the first effort in Bangladesh energy literature to develop an outlook for future clean energy technologies based on empirical evidences of the past.