Electricity consumption and GDP nexus in Bangladesh: a time series investigation

Sima Rani Dey and Mohammed Tareque
Bangladesh Institute of Governance and Management, Dhaka, Bangladesh

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Abstract

Purpose – The purpose of this paper is to assess the empirical cointegration, long-run and short-run dynamics as well as causal relationship between electricity consumption and real GDP in Bangladesh for the period of 1971–2014.

Design/methodology/approach – Autoregressive Distributed lag (ARDL) "Bound Test" approach is employed for the investigation in this study.

Findings – Both short-run and long-run coefficients are providing strong evidence of having positive significant association between electricity consumption and GDP. Our long-run results remain robust to different measurements and estimators as well. The study reveals the unidirectional causal flow running from per capita electricity consumption to per capita real GDP in the short run. The study result also yields strong evidence of bidirectional causal relationship between per capita electricity consumption and per capita real GDP in the long run with feedback. It is suggested that both electricity generation and conservation policy will be effective for Bangladesh economy.

Originality/value – In prior studies, lack of causality between electricity consumption and GDP is due to the omitted variables. Combined effects of public spending and trade openness on GDP and electricity consumption are also considerable.

Keywords Electricity consumption, GDP, ARDL bounds test, Causality test

Paper type Research paper

1. Introduction

Bangladesh has ensured its stable economic growth in the last decade, and it also has an aspiration to become a high-income country by 2,041. So, the development of energy and power infrastructure is inevitable to realize the long-term economic development. In the context of Bangladesh, the power sector is one of the largest sectors that consume primary energy. The relationship of GDP and electricity consumption has been immensely debated in the studied literature, yet their causal relationship directions are still unsolved. In the last decades, numerous researchers have attempted to address this issue and tried to investigate the association between electricity consumption and economic growth using both single-country and cross-country data. Plenty of literature exists on the causal relationship between electricity consumption and economic growth across the developing economies. Different countries, methodologies, time periods, even different proxy variables for energy consumption and income have been employed in different studies.

Causality bearing between power utilization and economic development has huge ramifications on political and economical strategy perspectives. The heading of causality can be abridged into four classes: growth hypothesis; conservation hypothesis; feedback hypothesis; and neutrality hypothesis. Single-direction causality from electricity

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consumption to financial development is a typical experimental finding for some Asian economies (Ho and Siu, 2007).

Studies those attempt to evaluate the connection between power utilization and GDP in setting of Bangladesh are sparse. Mozumder and Marathe (2007) led short-run Granger causality test for the time period of 1971–1999, whereas the examination by Ahamad and Islam (2011) assessed their short-run, long-run and joint causal relationship for the time period of 1971–2008 and Alam *et al.* (2012) examined the dynamic causality for the time period of 1972–2006. Most likely, above investigations are huge on their grounds, yet hardly any study, to date, has been led to survey the long-run relationship between power utilization and GDP with any control variable (considering the combined effects of public spending and trade openness on GDP and electricity consumption) along with their short-run, long- run and joint causal relationship. The sensitivity of our long-run estimates is verified by employing three alternative estimators.

Consequently, the paper examines the long-run association between electricity consumption and GDP in Bangladesh using ARDL bounds test approach. Again, the study investigates the presence and direction of causal relationship to take effective policy decision regarding electricity consumption. A vector error-correction model (VECM) based Granger causality test was employed to analyze the relationship; the *F*- and *t*-tests are carried out to gauge the joint significance levels of causality between the electricity consumption and GDP.

The rest of this paper is structured as follows: beginning with the introduction, Section 2 examines about the recent electricity scenario of Bangladesh and Section 3 depicts an outline of the literature review. Section 4 focuses on data and estimation procedures of the investigation. Section 5 examines the experimental outcomes; Section 6 reaches the inference of the study.

2. Recent electricity scenario of Bangladesh

Economic growth of a demand-driven economy like Bangladesh has always been linked with energy (mainly electricity) consumption. Unfortunately, the infrastructure of power sector is not sufficient to meet growing demands and is managed inefficiently. Moreover, the power demand of Bangladesh is increasing rapidly along with the increase of the per capita GDP over the last decades (Table II). Installed power generation capacity was 16046 MW (including captive power) as on December 2017 and 77 percent population had access to the electricity in Bangladesh (Table I).

To sustain the further economic growth, heavy dependence on labor-intensive industrial sector like readymade garment (RMG) is not sufficient and it is expected that it will shift to energy-intensive industries. Subsequently, energy utilization in the industrial sector is required to increment quickly. To manage the future fast development of vitality utilization in Bangladesh, government has detailed couple of compelling strategies. Without a doubt, for the seventh Five Year Plan (Power System Master Plan (PSMP) 2016), the objective by

Table I. Electric power utilization and GDP per capita, 1971–2014

Time periods	Electric power utilization (kWh per capita)	GDP per capita (constant 2010 US$)
1971–1980	16.67961	342.8396
1981–1990	35.45743	380.0094
1991–2000	76.0367	453.2003
2001–2010	173.8429	625.8588
2011–2014	283.9119	859.6671

Note: Average growth rate is a 10-year average except the last row, which is a four-year average

2020 is set as "power inclusion to be expanded to 96 percent with continuous supply to ventures" (Table II).

The installed capacity and maximum generation of electricity are increasing over the last few years, but the state is struggling to meet the demanded electricity. Currently, many of power plants in Bangladesh cannot generate electricity as specified in terms of power for each unit. So, hydro power generation studies have become an urgent issue through the government's renewable energy promotion policy. Hopefully, the new Power System Master Plan study will cover previous challenges and will provide feasible proposal and action plans for implementation as well (Figure 1).

So, the development of energy and power infrastructure, therefore, pursues not only the quantity but also the quality to realize the long-term economic development. Therefore, power proficiency may end up being the most essential alternative to deal with the tremendous neglected power request in the future relying upon the causality directions. Hence, the direction of relationship should be examined cautiously to determine right policy for accelerating economic growth and development.

3. Literature review

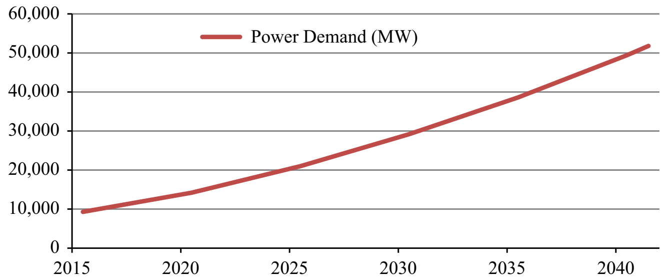
The association of energy consumption with economic growth is a special matter of interest and a series of literature on energy consumption and economic growth is available. The relationship between energy consumption and economic growth was first studied by Kraft and Kraft (1978), then the research works had been extended from energy consumption to electricity consumption. A short synopsis of those particular written works on electricity consumption and economic development point of view has been introduced in Table III.

The causal linkages' nature and directions of the above-mentioned literature vary across countries due to econometric techniques and variables used on different time series in their studies. Causality tests give us the insights about whether the information of past electricity movements improves conjectures of developments in economic growth and the other way around.

Year	Installed capacity (MW)	Maximum demand (MW)	Maximum peak generation (MW)
1995–1999	3,084	2,439	2,151
2000–2004	4,262	3,682	3,187
2005–2009	5,293	5,207	3,903
2010–2014	8,274	7,671	5,870
2015–2017	12,485	11,444	8,777

Note: Average growth rate is a five-year average except the last row, which is a three-year average

Table II. Electric power consumption scenario, 1995–2017



Source: JICA Survey Team

Figure 1. Forecasted power demand up to 2041

No.	Authors	Countries	Study period	Used variables	Causality directions
1	Altinay and Karagol (2005)	Turkey	1950–2000	Logarithm of electricity consumption and real GDP	EC→Y
2	Aqeel and Butt (2001)	Pakistan	1955–1996	Logarithm of per capita real GDP, energy consumption and employment	EC→Y
3	Shiu and Lam (2004)	China	1971–2000	Electricity consumption and real GDP	EC→Y
4	Narayan and Singh (2007)	Fiji Islands	1971–2002	Logarithm of GDP, electricity consumption and labor force	EC→Y
5	Yuan *et al.* (2007)	China	1978–2004	Electricity consumption and real GDP	EC→Y
6	Chandran *et al.* (2010)	Malaysia	1971–2003	Electricity consumption, price and real GDP	EC→Y
7	Odhiambo (2009)	Tanzania	1971–2006	Logarithm of per capita electricity consumption, energy consumption and real GDP	EC→Y
8	Ho and Siu (2007)	Hong Kong	1966–2002	Electricity consumption and real GDP	EC→Y
9	Acaravci (2010)	Turkey	1968–2005	Per capita electricity consumption and real GDP	EC→Y
10	Iyke (2015)	Nigeria	1971–2011	Per capita electricity consumption, inflation and real GDP	EC→Y
11	Morimoto and Hope (2004)	Sri Lanka	1960–1998	Electricity consumption and real GDP	EC→Y
12	Ghosh (2002)	India	1951–1997	Logarithm of per capita electricity consumption and real GDP	Y→EC
13	Jamil and Ahmad (2010)	Pakistan	1960–2008	Electricity consumption, electricity price and real GDP	Y→EC
14	Ciarreta and Zarraga (2010)	Spain	1971–2005	Logarithm of electricity consumption and real GDP	Y→EC
15	Mozumder and Marathe (2007)	Bangladesh	1971–1999	Per capita electricity consumption and real GDP	Y→EC
16	Narayan and Smyth (2005)	Australia	1966–1999	Real income, electricity consumption and employment	Y→EC
17	Tang (2008)	Malaysia	1972:Q1–2003:Q4	Logarithm of per capita Electricity consumption and real GNP	EC↔Y
18	Oh and Lee (2004)	Korea	1970–1999	Logarithm of Real GDP, capital, labor and divisia energy	EC↔Y(LR); EC→Y(SR)
19	Alam *et al.* (2012)	Bangladesh	1972–2006	Per capita electricity consumption, energy consumption, CO2 emissions and real GNP	EC↔Y(LR); EC↮Y(SR)
19	Polemis and Dagoumas (2013)	Greece	1970–2011	Residential electricity consumption, electricity price, GDP, employment, light fuel price, heating and cooling degree days	EC↔Y
20	Tang *et al.* (2013)	Portugal	1974–2009	Electricity consumption per capita, real GDP per capita, relative price, trade openness, foreign direct investment and financial development	EC↔Y
21	Hamdi *et al.* (2014)	Bahrain	1980:Q1–2010;Q4	Logarithm of per capita electricity consumption and real GDP, foreign direct investment and capital	EC↔Y
22	Yoo (2005)	Korea	1970–2002	Logarithm of electricity consumption and real GDP	EC↔Y
24	Ahamad and Islam (2011)	Bangladesh	1971–2008	Per capita electricity consumption and real GDP	EC↔Y
25	Belloumi (2009)	Tunisia	1971–2004	Per capita energy consumption and real GDP	EC↔YLR); EC→Y(SR)
26	Stern (1993)	USA	1947–1990	Logarithm of GDP, capital, labor and energy	EC↮Y

Notes: EC and *Y* represent electricity (energy) consumption and GDP, respectively. →,↔ and ↮ represent unidirectional, bi-directional and neutral causality, respectively
Source: Author compilation

Table III.
Summary of selected observational studies

We can categorize our selected research works into four gatherings. First, an extensive number of studies found unidirectional causality running from electricity (or energy) consumption to GDP. These include Altinay and Karagol (2005) and Acaravci (2010) for Turkey, Aqeel and Butt (2001) for Pakistan, Shiu and Lam (2004) and Yuan *et al.* (2007) for China, Narayan and Singh (2007) for Fiji Islands, Chandran *et al.* (2010) for Malaysia, Odhiambo (2009) for Tanzania, Ho and Siu (2007) for Hong Kong, Iyke (2015) for Nigeria and Morimoto and Hope (2004) for Sri Lanka.

The investigations that found unidirectional causality running from GDP to electricity (or energy) consumption comprise the second group. These include Ghosh (2002) for India, Jamil and Ahmad (2010) for Pakistan, Ciarreta and Zarraga (2010) for Spain, Mozumder and Marathe (2007) for Bangladesh and Narayan and Smyth (2005) for Australia.

The studies that found bidirectional causality comprise the third group. These include Tang (2008) for Malaysia, Oh and Lee (2004) and Yoo (2005) for Korea, Polemis and Dagoumas (2013) for Greece, Tang *et al.* (2013) for Portugal, Hamdi *et al.* (2014) for Bahrain, Jumbe (2004) for Malawi, Ahamad and Islam (2011) for Bangladesh and Belloumi (2009) for Tunisia. The fourth group comprises studies that found no causal linkages between electricity consumption and GDP, such as Stern (1993) for USA.

The summary of above writing audit reflects on the causal relationship between electricity (or energy) consumption and GDP, but the existing research works fail to provide clear evidence on the direction of causality between them. The inconsistency of the causality findings may attribute to the different data span and source, alternative econometric techniques, different countries' characteristics and omitted relevant variables (Chen *et al.*, 2007). The causal relationship between energy consumption and economic growth has strong implications from theoretical, practical and policy points of view (Fuinhas and Marques, 2012).

4. Data and estimation techniques

Following Mazumder and Marthe (2007) and Ahamad and Islam (2011), we used both electricity consumption and GDP data for Bangladesh in per capita form. Clearly, besides per capita electricity consumption, different factors could have extraordinary effect on economic growth. Thus, exclusion of those factors could lead to inclination of the estimation results and causality direction of the factors. In this point of view, we included government spending (GE) but in per capita form and trade openness as controlled variable to avoid omitted variable bias and simultaneity bias in our regression following Akinlo (2008) and Tang *et al.* (2013). Table IV provides the descriptive statistics of the studied variables.

Annual data on PCEC and PCGDP are covering the time period of 1971–2014 and collected from the World Bank[1]. All data are in real form. The historical data of per capita GDP and per capita electricity consumption for Bangladesh are portrayed in Figure 2.

The functional form of the model to satisfy the prime objective of the study is as follows:

$$PCGDP = f(PCEC,\ PCGE,\ TO).$$

Variable	Definition	Mean	SD	Min.	Max.
PCEC	Per capita electricity consumption (in kWh)	94.45	87.28	10.50	310.39
PCGDP	Per capita GDP (in constant 2010 US$)	487.67	164.77	317.70	922.16
PCGE	Per capita general government final consumption expenditure (in constant 2010 US$)	22.66	10.22	3.999	46.09
TO	Trade openness	0.2135	0.1378	0.0844	0.4797
Observations			44		

Table IV. Descriptive statistics of studied variables

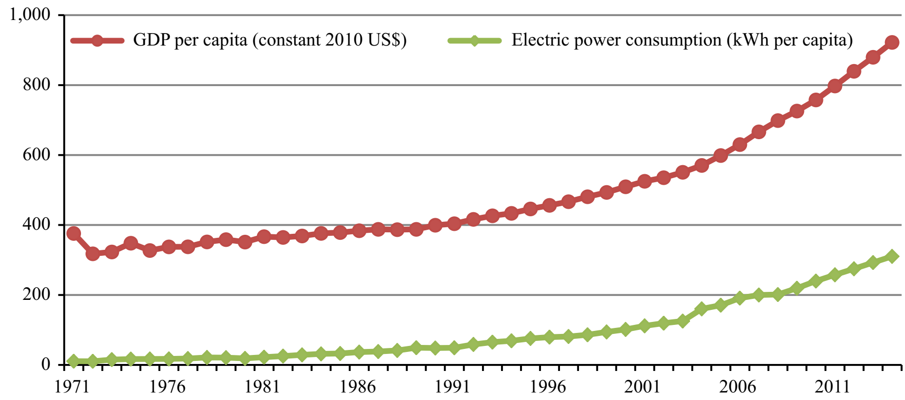


Figure 2.
Trend of per capita electricity consumption and per capita GNI in Bangladesh

The econometric form of the above model relating to electricity consumption and GDP, once stationarity or cointegration is verified:

$$PCGDP_t = \alpha + \beta_1 PCEC_t + \beta_2 PCGE_t + \beta_3 TO_t + \varepsilon_t, \tag{1}$$

where all the variables are discussed above, α is the intercept, β_1–β_3 are the coefficients of exogenous variables and ε is the error term.

A multivariate framework is used in this paper to examine the linkage between electricity consumption and GDP. To analyze the long-run relationship between the studied variables, the study employed autoregressive distributed lag (ARDL) "Bound Test" approach introduced by Pesaran and Shin (1999) and Pesaran *et al.* (2001)[2]. To correct residual serial correlation and problem of endogenous variables, appropriate modification of the orders of ARDL model is sufficient (Pesaran and Shin, 1999).

Although pre-testing of unit root is not necessary to proceed with ARDL bounds testing approach as it can test the cointegration existence between a set of variables of $I(0)$ or $I(1)$ or blender of both, there is a risk of invalid estimation if any variable comes out as integrated of order two or $I(2)$. It is, therefore, essential to test the stationarity properties of each variable before proceeding to the econometric analyses. The augmented Dickey–Fuller (ADF) and the Phillip–Perron unit root testing methods will be used for test unit root of the variables under study.

In ARDL cointegration technique, the existence of cointegration or possession of long-run relationship among the variables is primarily determined. At that point, the short- and long-run parameters extraction is done in the second step. The bound test approach is mainly based on an estimate of unrestricted error-correction model (UECM) by using ordinary least squares (OLS) estimation procedure. ARDL is easy to clarify, gives unprejudiced estimation of the long-run relationship and dynamics as well as the issues of serial correlation and endogeneity are taken care of.

The presence of causality and its direction will be assured by the existence of cointegration of the variables. The bound testing approach to cointegration involves investigating the presence of a long-run equilibrium relationship using the error-correction model (UECM) frameworks:

$$\Delta PCGDP = \alpha_{10} + \sum_{i=1}^{k} \alpha_{1i} \Delta PCGDP + \sum_{i=0}^{l} \alpha_{2i} \Delta PCEC + \sum_{i=0}^{m} \alpha_{3i} \Delta PCGE + \sum_{i=0}^{n} \alpha_{4i} \Delta TO,$$

$$+ \alpha_5 PCGDP_{t-1} + \alpha_5 PCEC_{t-1} + \alpha_5 PCGE_{t-1} + \alpha_5 TO_{t-1} + \varepsilon_{1t} \tag{2}$$

$$\Delta PCEC = \alpha_{20} + \sum_{i=0}^{k} \alpha_{1i} \Delta PCGDP + \sum_{i=1}^{l} \alpha_{2i} \Delta PCEC + \sum_{i=0}^{m} \alpha_{3i} \Delta PCGE + \sum_{i=0}^{n} \alpha_{4i} \Delta TO,$$

$$+ \alpha_5 PCGDP_{t-1} + \alpha_5 PCEC_{t-1} + \alpha_5 PCGE_{t-1} + \alpha_5 TO_{t-1} + \varepsilon_{2t} \tag{3}$$

$$\Delta PCGE = \alpha_{30} + \sum_{i=0}^{k} \alpha_{1i} \Delta PCGDP + \sum_{i=0}^{l} \alpha_{2i} \Delta PCEC + \sum_{i=1}^{m} \alpha_{3i} \Delta PCGE + \sum_{i=0}^{n} \alpha_{4i} \Delta TO,$$

$$+ \alpha_5 PCGDP_{t-1} + \alpha_5 PCEC_{t-1} + \alpha_5 PCGE_{t-1} + \alpha_5 TO_{t-1} + \varepsilon_{3t} \tag{4}$$

$$\Delta TO = \alpha_{40} + \sum_{i=0}^{k} \alpha_{1i} \Delta PCGDP + \sum_{i=0}^{l} \alpha_{2i} \Delta PCEC + \sum_{i=0}^{m} \alpha_{3i} \Delta PCGE + \sum_{i=1}^{n} \alpha_{4i} \Delta TO,$$

$$+ \alpha_5 PCGDP_{t-1} + \alpha_5 PCEC_{t-1} + \alpha_5 PCGE_{t-1} + \alpha_5 TO_{t-1} + \varepsilon_{4t} \tag{5}$$

where Δ is the difference operator; the existence of long-run equilibrium relationship is tested by limiting the lagged level variables $PCGDP_{t-1}$, $PCEC_{t-1}$, $PCGE_{t-1}$ and TO_{t-1} in Equations (2)–(5). Decisions of bound test are made on the basis of F-statistic value that helps to draw conclusion about the long-run relationship of the variables.

The causal relationship among the studied series exists if the presence of cointegration is confirmed, but it does not demonstrate the direction of the causal relationship. The VECM model derived from the long-run cointegrating relationship can be utilized to catch the dynamic Granger causality (Granger, 1988). Engle and Granger (1987) demonstrated that if the series are cointegrated, the VECM model for the series can be written as follows:

$$\Delta PCGDP = \alpha_{10} + \sum_{i=1}^{k} \alpha_{1i} \Delta PCGDP + \sum_{i=0}^{l} \alpha_{2i} \Delta PCEC,$$

$$+ \sum_{i=0}^{m} \alpha_{3i} \Delta PCGE + \sum_{i=0}^{n} \alpha_{4i} \Delta TO + \delta_{11} ECT_{t-1} + \varepsilon_{5t} \tag{6}$$

$$\Delta PCEC = \alpha_{20} + \sum_{i=0}^{k} \alpha_{1i} \Delta PCGDP + \sum_{i=1}^{l} \alpha_{2i} \Delta PCEC,$$

$$+ \sum_{i=0}^{m} \alpha_{3i} \Delta PCGE + \sum_{i=0}^{n} \alpha_{4i} \Delta TO + \delta_{21} ECT_{t-1} + \varepsilon_{6t} \tag{7}$$

$$\Delta PCGE = \alpha_{30} + \sum_{i=0}^{k} \alpha_{1i} \Delta PCGDP + \sum_{i=0}^{l} \alpha_{2i} \Delta PCEC,$$

$$+ \sum_{i=1}^{m} \alpha_{3i} \Delta PCGE + \sum_{i=0}^{n} \alpha_{4i} \Delta TO + \delta_{31} ECT_{t-1} + \varepsilon_{7t} \tag{8}$$

$$\Delta TO = \alpha_{40} + \sum_{i=0}^{k} \alpha_{1i}\Delta PCGDP + \sum_{i=0}^{l} \alpha_{2i}\Delta PCEC,$$

$$+ \sum_{i=0}^{m} \alpha_{3i}\Delta PCGE + \sum_{i=1}^{n} \alpha_{4i}\Delta TO + \delta_{41}ECT_{t-1} + \varepsilon_{8t} \quad (9)$$

where ECT_{t-1} represents the error-correction term (ECT) derived from the long-run cointegrating relationship to capture long-run effects, and ε_{1t}, ε_{2t} are the serially uncorrelated error terms.

In Equations (6)–(9), changes in the dependent variable are caused not only by their lags, but also by the previous period's disequilibrium in level, ECT_{t-1}. Given such a specification, the presence of short- and long-run causality can be tested. The error-correction model results indicate the speed of adjustment back to the long-run equilibrium after short-run shocks.

The ECM coordinates the short-run coefficient with the long-run coefficient without losing long-run data. Under ECM technique, the long-run causality is delineated by the negative and significant value of the ECT coefficient δ and the short-run causality appears by the noteworthy estimation of coefficients of other informative factors (Rahman and Mamun, 2016; Shahbaz *et al.*, 2013). Equation (6) can be considered. If the estimated coefficients on lagged values of per capita electricity consumption (α_2s) are factually noteworthy, then the implication is that electricity consumption Granger causes per capita real GDP in the short run. However, long-run causality can be found by testing the criticality of the assessed coefficient of ECT_{t-1}.

5. Empirical results

In this section, we present the empirical results from various approaches. Table IV demonstrates that all variables are non-stationary in their dimensions, yet they turned out to be stationary after first differencing and the results are outlined underneath.

From the above estimates, it can be inferred that both ADF and PP (Table V) test results reveal that the variables are non-stationary at 5 percent level of significance, but they became stationary at the first difference level. Thus, all the variables are integrated of order one, that is $I(1)$, and both possibilities with intercept as well as with intercept and trend are considered.

Since our variables are integrated, so it needs to be found whether the variables are cointegrated or not. To explore the long-run relationship between electricity consumption and GDP, ARDL model to cointegration and error correction is employed.

The ARDL bound tests affirms the existence of long-run association between the factors in Equations (2)–(5) and the outcomes are presented in Table VI. The computed F-statistic of above equations exceeded the upper bounds at 1 percent level of significance except the

Variables	Augmented Dickey–Fuller test Intercept	Intercept and trend	Phillips–Perron test Intercept	Intercept and trend	Order of integration
PCEC	6.7943 (1.000)	1.5231 (0.999)	8.8005 (1.000)	2.4461 (1.000)	
PCGDP	6.8645 (1.000)	1.0661 (0.999)	7.5856 (1.000)	1.4502 (1.000)	
PCGE	3.5628 (1.000)	0.2469 (0.997)	0.4495 (0.983)	−1.0411 (0.927)	
TO	−0.9994 (0.745)	−2.6061 (0.279)	−1.1302 (0.695)	−2.7575 (0.220)	
ΔPCEC	−1.8714 (0.342)	−6.3111 (0.000)	−3.6226 (0.009)	−6.3111 (0.000)	$I(1)$
ΔPCGDP	−1.9286 (0.316)	−8.5691 (0.000)	−5.0928 (0.000)	−7.8121 (0.000)	$I(1)$
Δ PCGE	−5.6785 (0.000)	−5.6688 (0.000)	−5.6785 (0.000)	−5.6688 (0.000)	$I(1)$
ΔTO	−5.4138 (0.000)	−6.2424 (0.000)	−5.4900 (0.000)	−6.2429 (0.000)	$I(1)$

Table V.
Unit root tests

second equation when per capita electricity consumption is the dependent variable. As per the rule, the higher F-statistic value supports the non-acceptance of null hypothesis that confirms the long-run relationship between the factors, which implies that the variables will move together. So the cointegration results lead us to contend that electricity consumption and GDP have a long-run affiliation.

The AIC lag length criterion statistic indicates that ARDL (3,1,3,1) model is the best lag orders combination and the estimation results are reported in Table VII. The result showed that a statistically significant association exists between electricity consumption and economic growth. Intercept term also becomes significant at 5 percent level of significance (Table VIII and Figures 3 and 4).

Both short-run and long-run coefficients are providing strong evidence of having positive significant association between electricity consumption and GDP at 5 percent level of significance. The value of ECT coefficient in GDP equation is –0.12 which indicates that the alteration coefficient (speed of convergence) to reestablish the equilibrium in the long run by around nine years.

To check the robustness of our long-run results, we employed three alternative estimators: the Phillips and Hansen's (1990) fully modified OLS (FMOLS) procedure, the Stock and Watson's (1993) dynamic OLS (DOLS) and the Park's (1992) canonical cointegration regression (CCR). Although the electricity consumption coefficients in three alternatives are smaller than the ARDL coefficient estimate, but our findings of positive electricity consumption–economic growth nexus remain robust to all these three estimators (Table IX).

ARDL models	Dependent variable	F-statistic	Decision
Equation (6)	$F_{PCGDP}(PCGDP\backslash PCEC, PCGC, TO)$	32.64	Cointegration
Equation (7)	$F_{PCEC}(PCEC\backslash PCGDP, PCGE, TO)$	3.35	No cointegration
Equation (8)	$F_{PCGE}(PCGE\backslash PCGDP, PCEC, TO)$	10.35	Cointegration
Equation (9)	$F_{TO}(TO\backslash PCGDP, PCGE, PCEC)$	8.90	Cointegration
Lower bound critical value at 1 percent		3.65	
Upper bound critical value at 1 percent		4.66	

Table VI.
Bound test results

Variable	Dependent variable: D(PCGDP) ARDL(3, 1, 3, 1) selected based on AIC Coefficient	Prob.*
Constant	24.31690	0.2030
PCGDP(−1)*	−0.120875*	0.0481
PCEC(−1)	0.367475**	0.0026
PCGE(−1)	0.770739**	0.0093
TO(−1)	22.76833	0.1267
D(PCGDP(−1))	−0.350540**	0.0087
D(PCGDP(−2))	−0.373907**	0.0000
D(PCEC)	0.029607	0.8231
D(PCGE)	1.131274*	0.0494
D(PCGE(−1))	−1.319006**	0.0009
D(PCGE(−2))	1.473489**	0.0003
D(TO)	−18.17714	0.4241
Adjusted R^2	0.999576	
F-statistic	8571.084 (0.0000)	
DW-statistic	1.499099	

Notes: Figures in ( ) represent probability values. *, **Represent significance at 5 and 1 percent level, respectively

Table VII.
ARDL Regression outputs

Table VIII.
Estimated ARDL long-run and short-run coefficients

Long-run coefficient estimates				
	Constant	PCEC	PCGE	TO
	201.1741 (0.0033)	3.040130 (0.0002)	6.376337 (0.0962)	188.3628 (0.2890)
Short-run coefficient estimates				
Lag order	0	1	2	
ΔPCEC	0.029607 (0.7716)			
ΔPCGE	1.131274 (0.0010)	−1.319006 (0.0002)	1.473489 (0.0000)	
ΔTO	−18.17714 (0.2353)			
ECT_{t-1}	−0.120875 (0.0000)			
Short-run diagnostic tests				
Adjusted R^2	Jarque–Bera normality test	Breusch–Godfrey Serial Correlation LM	Heteroskedasticity Test: ARCH	Ramsey RESET test
0.958779	1.64901 (0.4384)	1.51090 (0.1075)	2.46798 (0.1183)	0.45095 (0.5074)

Notes: Diagnostic tests results are based on F-statistic and figures in ( ) represent probability values

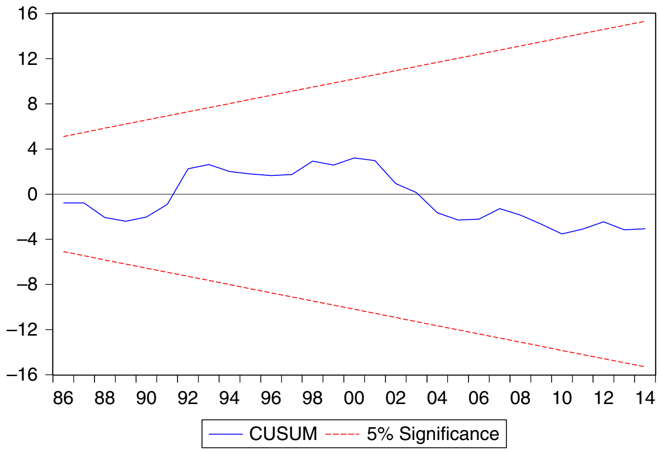


Figure 3.
Plot of CUSUM test

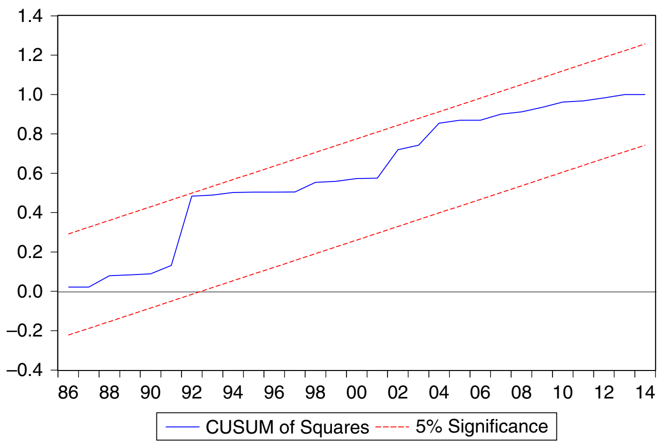


Figure 4.
Plot of CUSUM of Sq. test

Granger causality test is used to identify the causal relationship between the variables. Existence of long-run relationship leads to expect either unidirectional or bidirectional causal relationship between the series. The dynamic Granger causality test results (Table X) indicate that there is a unidirectional short-run causal relationship running from per capita electricity consumption to per capita GDP at 1 percent level of significance. The reverse causality, that is PCGDP Granger causes PCEC, is not significant even at 10 percent level. This result is similar to those obtained by Oh and Lee (2004) and Ahamad and Islam (2011), but it is converse of Mazumder and Marthe (2007).

Turning to the long-run causality, the ECT coefficients were rejected in all equations except trade openness, though per capita spending coefficient was not significant. The result implies that electricity consumption, GDP and trade openness have bidirectional causality in the long run. In addition, PCGDP and PCEC variables are not weakly exogenous, proposing bidirectional long-run causality (feedback relationship) between PCGDP and PCEC. Our outcome is additionally in accordance with findings by Oh and Lee (2004), Ahamad and Islam (2011) and Alam *et al.* (2012); they likewise uncovered feedback hypothesis in the long run between per capita electricity consumption and per capita GDP (Figure 5).

Moreover, a joint F-test confirms the bi-directional long-run causality between electricity consumption and GDP because we reject the null hypothesis at the 1 percent level (the null

	ARDL		FMOLS		DOLS		CCR	
Variable	Coefficient	Prob.*	Coefficient	Prob.*	Coefficient	Prob.*	Coefficient	Prob.*
PCEC	3.04013**	0.0002	1.83555**	0.0000	1.84628**	0.0000	1.85862**	0.0000
PCGE	6.37633*	0.0962	0.968885	0.3588	2.16904*	0.0747	0.735028	0.4858
TO	188.3628	0.2890	−22.47856	0.6051	−51.74164	0.2537	−14.40794	0.7326
Constant	201.1741	0.0033	296.6130	0.0000	281.4285	0.0000	299.0104	0.0000

Notes: *,**Significant at 10 and 1 percent level, respectively

Table IX.
Estimated long-run coefficients

	Source of causation								
	Short run				Long run	Joint (short run and long run)			
	ΔPCEC	ΔPCGDP	ΔPCGE	ΔTO	ε_{t-1}	ΔPCEC, ε_{t-1}	ΔPCGDP, ε_{t-1}	ΔPCGE, ε_{t-1}	ΔTO, ε_{t-1}
Dept. variable	F-statistic				t-statistic	F-statistic			
ΔPCEC	–	1.2772	0.3071	0.5304	−8.472***	–	7.360***	5.7321***	5.8525***
		(0.2981)	(0.8201)	(0.6645)	(0.0000)		(0.0021)	(0.0069)	(0.0063)
ΔPCGDP	6.7740***	–	10.055***	2.4106*	−3.382***	58.060***	–	37.874***	36.209***
	(0.0011)		(7.E-05)	(0.0845)	(0.0017)	(0.0000)		(0.0000)	(0.0000)
ΔPCGE	0.45460	9.088***	–	4.0212**	−0.7636	0.9394	0.5119	–	0.3017
	(0.7158)	(0.0002)		(0.0152)	(0.4501)	(0.4002)	(0.6037)		(0.7414)
ΔTO	3.0890**	1.1267	0.7416	–	3.0146***	4.7341**	7.807***	4.5771**	–
	(0.0404)	(0.3524)	(0.5349)		(0.0047)	(0.0150)	(0.0015)	(0.0169)	

Notes: *,**,***Significant at 10, 5 and 1 percent level, respectively

Table X.
Causality test results based on the error correction model

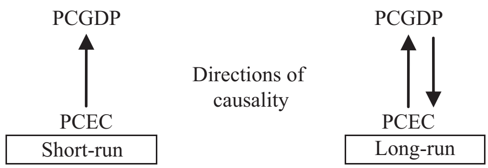


Figure 5.
Causal channels

hypothesis that the coefficients on the ECTs and the interaction terms are jointly 0 in both the PCGDP and the PCEC equation).

In this way, overall study findings imply that feedback hypothesis (which states that bidirectional causality runs from electricity consumption to GDP) exists both in the short-run and long-run, indicating that when economy grows, electricity demand increases and the reverse is true as well in Bangladesh.

A series of diagnostic tests were conducted on the ARDL model and the model is found to be robust against residual correlation, and the ARCH test confirms the homoskedasticity of the residuals. At the same time, Jarque–Bera normality test ensured that estimated residuals are normal, and the CUSUM and CUSUM of Sq. test also confirmed the correct functional form of the model.

6. Conclusion and policy implications

This study examines the causal linkage between electricity consumption and gross domestic product (GDP) in Bangladesh. In this regard, along with two control variables (per capita government spending and trade openness), the study used essential econometric techniques to comprehend the source and direction of conceivable causal connection between them. Cointegration test result establishes the presence of long-run equilibrium relation between PCEC and PCGDP series. Moreover, the robustness of the long-run result is verified by other alternative estimators. For the validation of the causal relationship, VECM-based Granger causality test is led and the results reveal unidirectional short-run causal relationship running between per capita electricity consumption and per capita GDP, whereas bidirectional long-run and joint causal relationship also exists between per capita electricity consumption and per capita GDP, which demonstrates that electricity consumption can animate economic growth and the reverse is also true. Our study findings might have a considerable impact on the making of essential short-run and long-run policy insights.

The study findings clearly exhibit that electricity consumption can be considered as a important factor for achieving higher growth of GDP in the short run. So, policy regarding electricity generation, distribution, management and conservation should be given priority to ensure higher economic growth in the short run for Bangladesh economy. On the contrary, long-run bidirectional causal relationship (greater access to electricity and high per capita GDP influence each other) indicates that adequate investment is required for strengthening the electricity supply and also for those factors that will influence the GDP growth.

Notes

1. According to World Bank collection of development indicators (2017).
2. ARDL approach has several advantages over other previous and traditional methods. The first is that it is flexible, as it allows the analysis with $I(0)$, $I(1)$ or a combination of both data. The second is that ARDL test is relatively more proficient in case of small and finite sample data.

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About the authors

Sima Rani Dey is currently working as Assistant Professor in Bangladesh Institute of Governance and Management (BIGM) located in Dhaka. She has completed her graduation and post-graduation in Statistics; she did another masters in macroeconomic policy as well later on. Her research interests are mainly the macroeconomic issues including consumption expenditure, energy, external debt, trade and financial development. Carbon emission, urbanization and migrants are the recent contents of her research. She also has an interest to work on human capital development and poverty in order to examine their impact on the economic growth of Bangladesh. Sima Rani Dey is the corresponding author and can be contacted at: simabd330@gmail.com

Mohammed Tareque is Director of Bangladesh Institute of Governance and Management (BIGM) located in Dhaka, capital of Bangladesh. He is a postgraduate of economics and has completed his PhD from Boston University. He has served the Government of Bangladesh as Senior Secretary of Finance Division and possesses a vibrant career for his great contribution in Finance ministry. His research interests are the macroeconomic issues of Bangladesh.