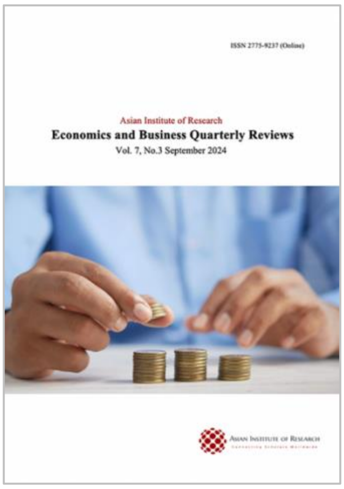

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Exploring the Relationship Between Energy Consumption and GDP: Evidence from Bangladesh

Md Atiqul Islam[1], Md. Al Zabir Hassan Mithen[2]

[1] Professor, Department of Economics, University of Rajshahi, Rajshahi-6205, Bangladesh
[2] Graduate Student, Department of Economics, University of Rajshahi, Rajshahi-6205, Bangladesh

Correspondence: Md Atiqul Islam, Professor, Department of Economics, University of Rajshahi, Rajshahi-6205, Bangladesh. Tel: +88001717138289. E-mail: atiqru@ru.ac.bd

Abstract
This research examines the causal relationship between per capita gross domestic product (PCGDP) and per capita energy consumption (PCEC) in Bangladesh over the period of 1971 to 2023. The ARDL bound testing approach indicates a statistically significant positive relationship between PCGDP and PCEC. The results also reveal that there is a one directional linkage running through PCEC to PCGDP. This indicates that an increase in energy consumption has a direct impact on GDP growth. This suggests that rather than energy conservation, priority to generate energy generation as a means of achieving higher GDP is needed for Bangladesh.

Keywords: Economic Growth, Energy Consumption, Autoregressive Distributive Lag Model, Bangladesh

1. Introduction

Energy consumption is a significant indicator of a country's level of development (Gozgor et al., 2018). It is also considered as one of the vital production factors for an economy. However, research on the topic of causal relation between energy consumption and income is enormous in the literature. Empirical studies vary on the basis of methodology, time periods considered, country or countries of study to considered and uses of proxy variables for energy consumption and income. Moreover, the results vary on the direction of causality and the long-term versus short-term impact. Depending upon the causal relationship of this, policy implications would be different for a country.

Bangladesh, a developing country is experiencing a growth in energy consumption as well as demand because of structural changes in the economy, population growth, urbanization, and industrialization (Debnath et al., 2015). For the future development of energy policy, the causal relation between energy consumption and GDP is required. This study attempts to examine this causal relationship. Our study raises some important questions: does long-term equilibrium relation exist between energy consumption and GDP in Bangladesh? How do they influence each other in the short-term? Answers to these questions are necessary to define and implement the appropriate energy development policies in Bangladesh.

The remainder of this paper is organized as follows: Section 2 provides a literature review. A detail description of the data and methodology of the study is presented in Section 3. Section 4 describes the findings of the study. The next section is a discussion related to the findings to provide the policy implications of the empirical results. Final section 6 gives conclusions for this study.

2. Review of the Literature

The causal relation between energy consumption and income is traced back to Kraft and Kraft (1978) in the literature. In their pioneering study for the United States, they utilized the technique of Sims (1972) and used annual data for the period of 1947-1974. This research found a unidirectional causality running from income to energy consumption. These findings implied that energy conservation policies may be initiated without deteriorating economic side effects. However, later on, Akarca and long (1980) pointed out that Kraft and Kraft's study suffers from temporal sample instability. Since then, a plethora of studies have dealt with the causal relationship between energy consumption and income in the literature of energy economics using different methodologies, different countries, different time periods, and different proxy variables for energy consumption and income. Menegaki (2014) provided a good review. However, for the simplicity of our analysis, we discussed further considering three issues, studies considering group of countries, studies on only one countries and studies related to Bangladesh. Some of this literature is highlighted here below in three different sub-groups.

2.1 Studies on Group of Countries

This group of studies tried to examine the relationship between energy consumption and income considering a group of countries. For example:

Soytas and Sari (2003) examined the causal relation between GDP and energy consumption considering the top 10 emerging markets and G-7 countries. Using cointegration and vector error correction techniques this study uses annual energy consumption and GDP per capita for the analysis. It is found that bi-directional causality exists in Argentina. For Italy and Korea, causality runs from GDP to energy consumption. On the contrary, causality runs from energy consumption to GDP in Turkey, France and Germany and Japan. Therefore, this study argued that energy consumption may harm economic growth for the last four countries where causality runs from energy consumption to GDP.

Lee (2005) investigated the co-movement and causal relationship between energy consumption and GDP in 18 developing countries. Using data for the period 1975 to 2001 this study employed heterogeneous panel cointegration and panel-based error correction models. The empirical results showed that long-run and short-run causalities run from energy consumption to GDP, but not vice versa.

By examining 22 developed and 18 developing countries, Lee and Chang (2007) found that bidirectional causality between these two variables in developing countries, but a unidirectional causality from GDP to energy consumption in developing countries. For their analysis they applied a new panel data stationarity testing procedure with panel VARs that employ the GMM techniques and used per capita energy consumption and per capita real GDP as concerned variables.

Narayan and Popp (2012) examined whether there is long-run relationship between energy consumption and real GDP for 93 countries. Using panel cointegration and panel long-run Garnger causality model they found a mixed results on the impact of energy consumption on real GDP. In most countries energy does not have a long-run Granger causal effect on real GDP. However, where this relationship exists, the energy consumption has a negative impact on real GDP. The overall conclusion drawn from the panel level analysis of this study is that some countries will benefit from energy conservation policies and others will not.

Caraiani, Lungu and Dascalu (2015) investigated the causality between per capita energy consumption and economic growth of five emerging European economies (Bulgaria, Hungry, Poland, Romania and Turkey) considering data from 1980 to 2013. The causality analysis based on Engle and Granger model indicates that there is no possible impact of energy consumption on economic growth.

Al-mulali and Mohammad (2015) tested the causality between GDP by sector (agriculture, manufacturing, industrial and service sector) and energy consumption by type (oil, gas, coal and electricity) in 16 emerging countries considering panel model using data for the period of 1980-2010. The results of this study revealed that both bidirectional and unidirectional causality exist among different sectoral growth and different energy consumption. However, the major conclusion of this study is that countries should increase their renewable energy consumption to achieve their GDP growth.

2.2 Studies on Individual Country

Another group of studies tries to unfold the linkage between energy consumption and GDP for individual country. Some of them are as follows:

Lise and Montfort (2007) examined the causality between energy consumption and GDP for Turkey considering annual data over the period 1970-2003 using cointegration analysis. It is found that energy consumption and GDP are co-integrated and there is a unidirectional causality running from GDP to energy consumption. This research also tries to see the existence of energy Kuznets curve (EKC) for Turkey and finds the rejection of EKC hypothesis for Turkey.

Belloumi (2009) tested the causal relationship between per capita energy consumption (PCEC) and per capita GDP (PCGDP) for Tunisia during the 1971-2014 period using Granger causality and vector error correction model. The results indicated that the PCGDP and PCEC are related by one cointegrating vector. It is also found that long-run bi-directional causality runs between the two variables but short-run unidirectional causality runs from PCEC to PCGDP. The source of causation in the long-run was found to be the error-correction terms in both directions.

The study by Borozan (2013) used VAR and Granger causality tests covering the period between 1992 and 2010 in Croatia. They reported that the variables are not co-integrated. However, it was found that there was a unidirectional causality running from energy consumption to GDP. Furthermore, the impulse response function and variance decomposition analysis indicated that energy consumption was an important component determining economic growth in Croatia.

Mahalingam and Orman (2018) applied panel cointegration and panel causality test to examine the causal relationship between state energy consumption and state GDP for US economy for the period of 1978 to 2014. Their empirical estimates indicated a significant regional difference for two regions, the Rocky Mountain region and the Southwest region. Energy consumption Granger causes state GDP in the Rocky mountain region. Whereas, it was opposite in the Southwest region where GDP Granger caused energy consumption. Therefore, they suggested having a flexible federal energy policy to be most beneficial to the different regions of US.

2.3 Studies on Bangladesh

Two dimensions of studies found in the literature related to our topic on Bangladesh. First group of literature is found where relationship between GDP and energy consumption was examined. Considering data from 1980 to 2014, Amin and Alam (2018) found that there was a unidirectional causality from GDP to energy consumption. Similar findings were also found by Roy (2022) where they employed data from 1976 to 2014 considering per capita GDP to per capita energy consumption. On the contrary, considering data from 1981 to 2017, Sarker et al. (2019) found a bidirectional relationship. Even Islam and Ali (2011) did not find any direct relation between energy consumption and GDP growth. All of these studies used Johansen co-integration and Granger causality test for their analysis. However, using autoregressive distributive Lag (ARDL) bounds testing approach, Uddin et al. (2011) found a unidirectional causality running from energy consumption to GDP on 1971-2007 data.

The second group of literature is there where instead of energy consumption they used electricity consumption in their analysis and explored the relationship between energy consumption and GDP. Hossain and Hasan (2018) and Masuduzzaman (2012) found a unidirectional relation running from electricity consumption to GDP. On the contrary, Mozumder and Marathe (2007) found the same unidirectional causality but causality running from opposite directions, per capita GDP to per capita energy consumption. In addition, Ahmad and Islam (2011) found a bidirectional causality. Although these studies used cointegration and granger causality tests, they used different time span of data set.

Overall, from the above discussion on the literature, we have an apparently conflicting statistical findings on the relationship between energy consumption and GDP. Major reasons for these conflicting results seem to lie in methodological differences, time span of data used, and variables used as proxies for the interested variables. However, a country-specific causality study between energy consumption and economic growth can provide insight for designing future energy policies for that country. Moreover, it is also important to reach an unambiguous result for policy implementation.

3. Data and Methodology

3.1 Methodology

In order to determine the relationship and direction of causality between per capita energy (PCE) and per capita GDP (PCGDP) in Bangladesh, this research employs two stages. In stage one, the stationarity of the variables using the conventional Augmented Dickey Fuller (ADF) test and the Phillip-Peron (PP) test. The lag lengths are chosen using Akaike's information criterion. Stage two refers to testing the cointegration between variables. Based on the order of the time series we can use different techniques for testing the relationship between variables. Based on the existence of cointegration, the determination of the relationship is done either using Johansen cointegration or unrestricted VAR or ARDL cointegration technique (Nkoro and Uko, 2016). In this research we used ARDL bound testing approach for determining the relationship between PCEC and PCGDP.

3.2 Data

Empirical study here uses time series data of per capita GDP (PCGDP) and per capita energy consumption (PCEC) for the period of 1971-2023 in Bangladesh. PCGDP data are obtained from the data bank produced by the World Bank (World Bank, no date). Data on PCEC are obtained from processed data produced by Our World in Data (Our World in Data, no date). Per capita energy consumption is expressed in terms of kilowatt-hours and per capita GDP is expressed in constant 2015 US$. The historical trends of PCGDP and PCEC for Bangladesh are depicted in Figure 1.

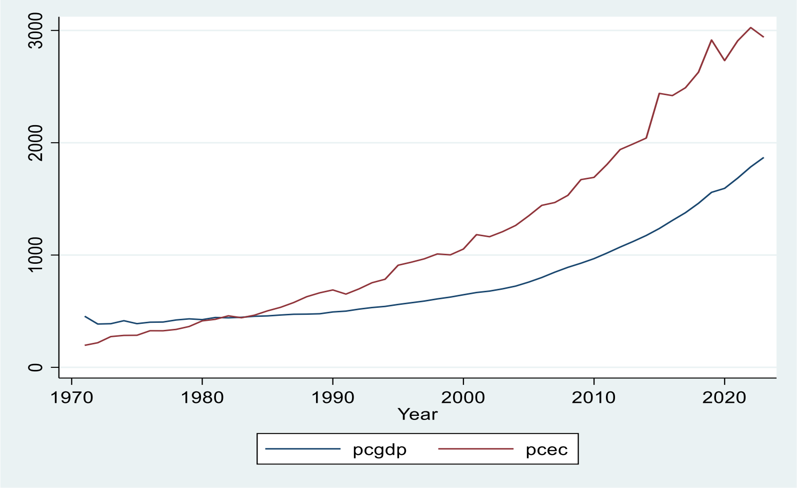

Figure 1: Per capita energy consumption and per capita GDP of Bangladesh

Source: Authors' construction using variable of interest

3.3 Descriptive statistics

Table 1 provides an insight into descriptive statistics of the variables used for this analysis. The correlation matrix indicates a significant positive relationship between the variables. The coefficient of correlation is equal to 0.98. Moreover, Figure 1 indicates that both variables exhibit an increasing trend in the period considered. All these suggest the possible existence of a strong link between them. However, before going into unveil the relationship and causality between them, a test for a unit root should be conducted.

Table 1: Summary statistics for both series

Variables	Description	Mean	S.D.	Min.	Max.
PCGDP	Per capita GDP (in constant 2015 US$)	767.24	414.53	385.84	1869.16
PCEC	Per capita energy consumption (in kilowatt-hours equivalent)	1196.72	855.35	196.08	3025.79
Correlation	Pearson correlation coefficient	0.98***			
Observations		53			

Note: *** indicates the 1% level of significance

3.4 Unit Root

The results of ADF and PP unit root tests are summarized in Table 2. The results indicate that all variables are non-stationary in level. By taking first-difference of the variables, PP test indicates that the null hypothesis of a non-stationary process is rejected at the 5% significance level. That means that according to PP unit root test, the variables are I(1). However, ADF test does not indicate the so. Moreover, in the second difference of the variables, both test result indicates that for both the variables the null hypothesis of a non-stationary process is rejected at the 5% significance level. This indicates that the PCGDP and PCEC variables of Bangladesh are individually I(2).

Table 2: Unit root test

Variables	ADF			PP		
	Constant	Constant and Trend	Decision	Constant	Constant and Trend	Decision
$pcgdp$	3.539 (4)	3.533 (4)	UR	3.683 (4)	2.236 (4)	UR
$pcec$	2.91 (3)	-0.32 (3)	UR	1.41 (3)	-1.47 (3)	UR
Δpchdp	1.126 (3)	-0.932 (3)	UR	-13.87** (3)	-54.67***(3)	S
Δpcec	-1.86 (4)	-2.54 (4)	UR	-74.56***(4)	-66.73***(4)	S
2Δpchdp	-3.498***(4)	-4.225***(4)	S	-56.83***(4)	-56.45***(4)	S
2Δpcec	-4.09***(3)	-4.09***	S	-66.73***(3)	-65.71***(3)	S

Note: *, **, and *** indicate 10%, 5% and 1% levels of significance respectively; Lag order is shown in parentheses; This optimum lag length found here is shown in the parentheses; UR and S represent unit root and stationary respectively.

There are several cointegration techniques are available to us to reveal the long run relationships among time series variables, like Johansen cointegration and unrestricted VAR. However, all of these techniques required that all series have same ordered integrations as well as should not be more than I(1). In this respect, another approach developed by Pesaran et al. (2001), namely autoregressive-distributed lag (ARDL) also known as the bounds test which withdraws these restrictions. Because of this convenience, ARDL method has been used in many studies and in our study here we also used this technique to obtain the long-run relationship among the series.

3.4 Model Specification

The model that relates GDP and energy consumption is:

$$PCGDP = f(PCEC) \tag{1}$$

where PCGDP is the per capita gross domestic product and PCEC is the per capita energy consumption.
Equation (1) can be written as an ARDL formula as the model in equation (2) as follows:

$$\Delta pcgdp_t = \alpha + \sum_{i=1}^{k} \beta_{1i} \Delta pcgdp_{t-i} + \sum_{i=1}^{k} \beta_{2i} \Delta pcec_{t-i} + \beta_3 pcgdp_{t-1} + \beta_4 pcec_{t-1} + u_t \quad (2)$$

Where α is the drift component and u_t is white noise. The terms with summation signs represent the error correction dynamics, while the terms without summation represent to the long-run relationship. Long run relationship among these variables is examined by bound test.

According to the test, null hypothesis in the equation is $H_0: \beta_3 = \beta_4 = 0$. This indicates the existence of no cointegration. The alternative hypothesis is $H_1: \beta_3 \neq \beta_4 \neq 0$. According to Pesaran et al. (2001), if the calculated F statistic is higher than the upper bound critical value I(1) for the number of explanatory variables (k), null hypothesis will be rejected. If the F statistic is lower than the lower bound critical value I(0), null hypothesis cannot be rejected. The F statistic being between I(0) and I(1) puts for then indecision about cointegration. The optimal lag value k in equation (2) is chosen by the model selection criteria such as AIC and BIC. If there is cointegration then in the next step of ARDL process holds the long-run ARDL equation as follows:

$$pcgdp_t = \beta_0 + \sum_{i=1}^{p} \beta_{1i} pcgdp_{t-i} + \sum_{i=0}^{q} \beta_{2i} pcec_{t-i} + e_t \quad (3)$$

The selection of lag values of p and q in equation (3) is done using AIC and adjusted R-squared value. The best estimates model is the model with minimum AIC or maximum R-squared value. Finally, short-run estimation of ARDL also known as error-correction model is also known as error correction model is estimated in the equation below

$$pcgdp_t = \delta_0 + \sum_{i=0}^{p} \delta_{1i} pcgdp_{t-i} + \sum_{i=0}^{q} \beta_{2i} pcec_{t-i} + \lambda ECM_{t-1} + e_t \quad (4)$$

The coefficient of the error-correction term (ECM_{t-1}) λ in Eq. (4) is the speed of adjustment parameter which shows how quickly the series attains a long-run equilibrium. Based on the model we decide the relationship and the direction of causality between the variables here.

However, we discussed above only for the situation where PCGDP is considered a dependent variable. The same procedure will be followed for PCEC variable taking it into the dependent variable.

4. Empirical Findings

The ARDL Bounds testing approach was employed here to determine the presence of cointegration among the variables.

Before performing the cointegration test, it is necessary to determine the optimal lag length and then formulate the optimal model for the deterministic components in the system. Table 3 shows the results of the different lag order selection criteria. Most of the criteria suggested that for PCGDP and PCEC the optimal lag length order is 4 and 3 respectively. Therefore taking the maximum value, the maximum lag length was selected for equation (2) to be $k = 4$.

Table 3: Lag Order Selection Criteria

Lag	Endogenous variable					
	PCGDP			PCEC		
	AIC	HQIC	SBIC	AIC	HQIC	SBIC
0	14.92	14.94	14.96	16.33	16.34	16.37
1	7.75	7.78	7.82	11.73	11.76	11.81
2	7.69	7.73	7.81*	11.61	11.65	11.73
3	7.71	7.77	7.87	11.48*	11.54*	11.64*
4	7.63*	7.71*	7.83	11.52	11.59	11.71

Note: * indicating lag order selected by specific criteria. AIC= Akaike information criterion, SBIC= Schwarz's Bayesian information criterion, HQIC= Hannan–Quinn information criterion. Exogenous variable: C. Sample: 1971 to 2023.

Then from the model, optimum lag is obtained relying on the minimizing the Akaike Information Criterion (AIC) when the lag value k was equal to 4. According to AIC criterion the best model like equation (2) for PCGDP is

ARDL (2, 1) model which means $p = 2$ and $q = 1$. Similarly, model for PCEC is ARDL (3, 1). The results are presented in Table 4 for both the equations. The non-significant estimated F-statistics for PCEC cannot reject the null hypothesis of no cointegration and suggested no integration in PCEC model. On the contrary, for model PCGDP estimated a significant F-statistics suggested a cointegration in PCGDP equation over the period of 1971-2023 in Bangladesh. In this model, diagnostic tests like Lagrange multiplier test for serial correlation, Ramsey's RESET test for functional form results shown well.

Table 4: ARDL cointegration analysis

Model for	F-statistics	Critical Values Lower-Upper	Diagnostic test: No Serial Correlation (Breush-Godfrey LM test)	Diagnostic test: Het. (White test)	Diagnostic test: Ramsey RESET test	Cointegration
PCGDP	39.475***	4.124 – 8.463	4.794* (0.0286)	32.77 (0.0031)	3.54* (0.0224)	Yes
PCEC	2.377	4.109 – 8.501	0.284 (0.5944)	17.63 (0.6119)	5.54 (0.0028)	No

Note: *** and * indicate significant at 1% and 5% levels respectively. Het. indicates Heteroscedasticity. Diagnostic test results for no serial correlation and Heteroscedasticity are based on chi-square statistic and Ramsey RESET test of omitted variable test is based on F-statistics. Figures in the parenthesis represent probability values.

Table 5 provides the estimated results of the ARDL model that found the existence of cointegration. The long-run estimated results are shown here. It indicates that per capita GDP is determined by its lagged values, per capita energy consumption and its lagged values. Relating to our interest we can say that per capita energy consumption is a determinant of per capita GDP. In other words, per capita energy consumption Granger causes per capita GDP.

Table 5: ARDL (2, 1) Model Results

Dependent variable: PCGDP	Coefficient	St. error	T-ratio	Prob.
$PCGDP_{t-1}$	0.917***	0.1047	8.76	0.000
$PCGDP_{t-2}$	0.124	0.1026	1.22	0.230
$PCEC_t$	0.069***	0.0176	3094	0.000
$PCEC_{t-1}$	-0.055**	0.0217	-2.53	0.015
Intercept	-20.455***	5.5687	-3.67	0.001
$R^2 = 0.99, F(4,46) = 21565.68\ (Prob = 0.0000)$				

Note: ** and *** indicate significance at 5% and 1% levels respectively.

The short-run estimated results are shown in Table 6. The coefficient of the error correction term is positive as well as insignificant. That means when per capita GDP is far away from their equilibrium level, it cannot adjust. It means that the process here not converging. However, as our interest is in PCEC, it is shown as significant here. Now to add little bit more, a simple OLS estimate of a model from equation (1) is also done here.

Table 6: Short-run Estimation

Dependent variable: $\Delta PCGDP$	Coefficient	St. error	T-ratio	Prob.
$\Delta PCGDP_{t-1}$	-0.1249	0.1026	-1.22	0.230
$\Delta PCEC_t$	0.0551**	0.0217	2.53	0.015
Constant	-20.455*	5.5687	-3.67	0.001
ECM_{t-1}	0.0425	0.0240	1.77	0.083
$R^2 = 0.88$				

Note: ** and *** indicate significant at 5% and 1% level respectively.

The OLS estimates are shown in Table 7. As we found that our variables are $I(2)$, therefore to avoid the spurious regression we use the variables after making it stationary. The results here also indicate that the per capita energy consumption is a significant determinant of the per capita GDP.

Table 7: OLS Estimation Results

Dependent variable: $PCGDP$	Coefficient	St. error	T-ratio	Prob.
$PCEC$	0.071***	0.0198	3.58	0.001
$Constant$	3.148	2.5601	1.23	0.225
$R^2 = 0.20, Adj\ R^2 = 19, F(1,49) = 12.80\ (Prob = 0.0008)$				

Note: *** indicates significant at 1% level.

5. Discussion

Overall, from the above findings we may concluded that there is evidence of a unidirectional causal linkage that runs from per capita energy consumption to per capita GDP. Similar unidirectional causality running from energy consumption to GDP was found by Borozan (2013) in the case Croatia. In the case of Bangladesh, our result supports findings of the study done by Uddin et al. (2011). From this causality patterns, we may advocate the argument that more energy consumption refers to more value addition and consequently increase GDP of Bangladesh.

These findings again confirm the narrative that energy is an important factor in production. Therefore, energy is an important component determining economic growth for Bangladesh. Therefore, as policy perspective for the economic prosperity of the country, energy prices, availability of energy, technological progress need to considered seriously. Energy consumption is affected by all of these variables and it is possible to affect the economic growth of the country by their changes. However, for more useful policy suggestions, future research can be done analyzing disaggregated total energy consumption for coal, liquid fuel, natural gas, hydropower and electricity.

The findings again imply that because of energy-dependent economy, at first glance, a conservation policy may have an adverse effect on economic growth in Bangladesh. Consequently, it leads to a decrease in income and an increase in unemployment. Therefore, Bangladesh needs to formulate an efficient and effective energy policy that may also facilitate substitutions among sources towards cleaner and renewable energy forms of higher quantity. Moreover, no matter what kind of relationship exists between GDP and energy consumption, economic growth may be stimulated by improving efficiency in production and avoiding wasteful uses that may lead to increase in productivity of energy consumption which in turn may stimulate economic growth. Thus, energy conservation policies would not necessarily hinder economic growth in Bangladesh. We just need to formulate and implement energy policy judiciously.

6. Conclusion

Energy sector is very important for an economy. Scarce domestic resources and an unstable world energy market concern knowledge demanding for Bangladesh energy relation with GDP. Moreover, energy sources and policy are important issues for this.

This study investigated the relationship between per capita energy consumption (PCEC) and per capita GDP (PCGDP) in Bangladesh, focusing on the period from 1971 to 2023. To better understand the potential causal relationship between these two variables, the study employed relevant econometric techniques, the ARDL bound testing approach. The analysis indicates a statistically significant positive long-run relationship between PCGDP and PCEC. Moreover, the findings indicate a unidirectional causal relationship running from PCEC to PCGDP. The relationship indicating that per capita energy consumption has a significant impact on per capita GDP. In other words, per capita energy consumption is found to predict per capita GDP.

The study highlights the necessity of sufficient amount of energy production to ensure sustainable economic growth in Bangladesh. This suggests that the government ought to prioritize energy generation as a means of achieving greater per capita GDP in Bangladesh. The challenges for energy policy maker are to secure enough energy, maintain prices of energy, production and consumption of energy efficiency, and create new energy sources. It could also be suggested that Bangladesh should explore energy generation from renewable resources, such as solar, hydroelectric, and wind energy.

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