Economics Bulletin

Volume 41, Issue 3

Dynamics of energy use, technological innovation, economic growth, and trade openness in Bangladesh

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Abstract

This empirical study uses the Marshallian demand function as the underlying framework to investigate the relationship between technological innovations and energy consumption in Bangladesh. The underlying theoretical framework argues that technological innovation, which is regarded as an exogenous variable, will increase energy efficiency and lead to reduced energy consumption up to a certain economic output. ARDL (autoregressive distributed lag) bounds testing approach is used with a sample period from 1980 to 2016 (37 years). This study empirically establishes the validity of the theoretical predictions both in the short and long run. Furthermore, the study identifies the Environmental Kuznets Curve (EKC) hypothesis and shows the dynamics of GDP per capita and trade openness on energy consumption in Bangladesh.

The author gratefully acknowledges two anonymous reviewers for their insightful comments that have significantly improved the quality of this paper. Special thanks to the editor, Prof. John P Conley, for his kind support towards this scholarly journey.
Citation: Md. Shafiqul Islam, (2021) "Dynamics of energy use, technological innovation, economic growth, and trade openness in Bangladesh ", *Economics Bulletin*, Vol. 41 No.3 pp. 997-1008.
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Submitted: March 01, 2020. **Published:** July 18, 2021.

1. Introduction

The development process entails a significant toll on the environment as massive industrialization increases the CO_2 emissions from fossil fuel consumption. If statistics on the post-implementation of the famous Kyoto Protocol are analyzed, an unfortunate result is vivid. The developed world witnessed a 7% rise in its CO_2 emission from 1990 to 2008 with no apparent sign of slowing down (Clark, 2012). A practical second step after the Kyoto Protocol calls for reducing the worldwide Greenhouse gas emission footprint. Higher energy demand and massive population burden are the primary sources of the rapid energy demand worldwide, as cited by the Intergovernmental Panel on Climate Change (IPCC, 2020). Thus, a growing concern over establishing an energy efficiency plan in lower fossil fuel combustion, reduced emission during extraction, conversion, and energy distribution is emphasized. Low carbon technologies[1] have to be implemented to reduce emissions from the energy sectors while tackling the paradox of economic development, environmental sustainability, and overall energy security. In this regard, developing countries are facing unique challenges of balancing their economic growth and, at the same time, maintaining an efficient level of energy use.

This study empirically investigates the dynamics of energy use, technological innovation, economic growth, and trade openness in Bangladesh, which is currently one of the fastest-growing economies globally with a robust economic expansion over the last 25 years. Recent fact book of Asian Development Bank (2020, October) reflects that the economy of Bangladesh grew by a staggering 8.20% which was the highest in Asia and the Pacific region. In 2015, Bangladesh achieved the lower-middle-income status and successfully met all the initial criteria to graduate from the status of a least-developed country in March 2018. According to the PwC, a global big-4 audit firm based in the UK, Bangladesh is now on the race to be the 23rd largest economy in the world by the year 2050 (Islam, 2020).

Apart from these recent developments, Bangladesh faces the threat of climate change which is crystal clear from the latest Global Climate Risk Index (CRI) 2021. Bangladesh ranks as the seventh most climate change vulnerable country, which is an added threat to the nation's economic sustainability. Bangladesh lost approximately $3.72 billion from 2000-2019 due to climate change-related issues, and in the future, this will only increase if the govt does not implement proper sustainable solutions. Therefore, Bangladesh faces a difficult challenge ahead of sustaining its promising economic outlook and ensuring that all the operations within the business environment are carried out with sustainability issues in mind (Islam, 2020). The incentive behind the undertaking of this study stems from the need to fill up the scholarly gap in the area of technological innovation and energy use in Bangladesh.

Technological innovation is regarded as a vital element in improving the energy efficiency of a country (Zhou et al., 2010; Fisher-Vanden et al., 2004; Hang and Tu, 2007). The magnitude of the impact of technological innovation is higher on energy efficiency than other methods of promoting energy efficiency, such as policies and controls (Sohag *et al.,* 2015). Advanced technologies allow producing a higher amount of goods at a lower amount of energy consumption. In Bangladesh, the author has noticed a significant increase in technological innovation, as evident from figure 1. This figure summarizes the energy use trend on the left side and patent application trend on the right side in the perspective of Bangladesh according to the WDI database:

[1] It includes low carbon power generation sources such as wind power, solar power, hydropower and nuclear power.

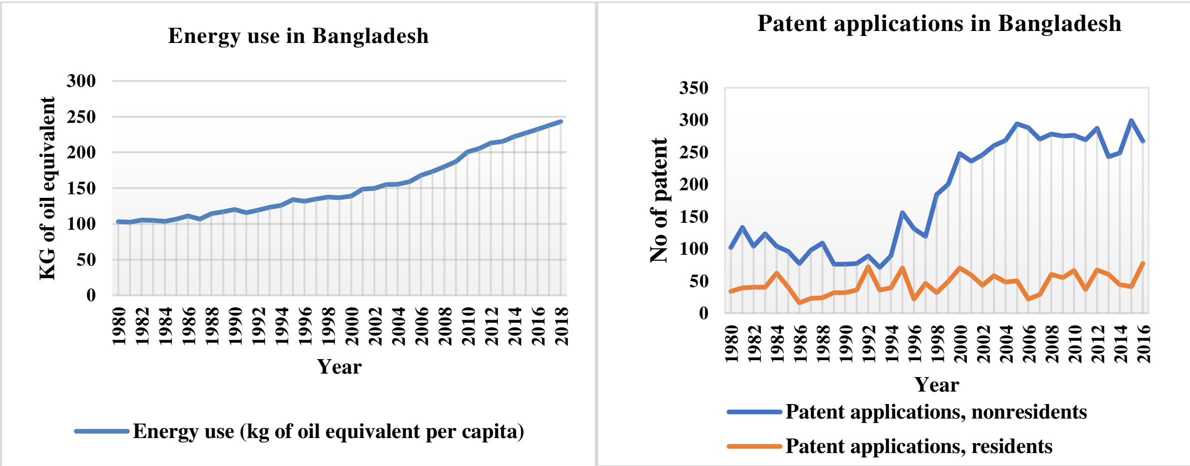

Figure 1: Trends of energy use and patent applications in Bangladesh

Thus, this empirical study uses the Marshallian demand function[2] as the basis of analysis to measure the impact of technological innovation on energy use in Bangladesh. To the best of the author's knowledge, no previous study empirically analyzed the dynamics of technological innovations on energy demand in the macroeconomic context of Bangladesh. Earlier, Sohag et al. (2015) researched the Malaysian economic context and led the author to implement a similar study in Bangladesh. This paper captured the impact of technology on energy efficiency by controlling some critical macroeconomic variables such as GDP per capita and trade openness. Kamal and Islam (2018) empirically found that GDP per capita and trade openness are two crucial variables of economic growth to be included in this type of research in Bangladesh. This study thus contributes significantly to the energy economics literature in Bangladesh by addressing the question of how technological innovations (proxied using patent applications- both residential and non-residential) leads to an increase in the energy efficiency of Bangladesh over the short and long run using the ARDL (autoregressive distributed lag) bounds testing approach.

The whole paper is organized as follows - Section 2 introduces the readers to the literature on the selected research topic. Section 3 describes the empirical model, data, and research methodology. Section 4 discusses the results of the analysis, and section 5 concludes the paper.

2. Literature Review

Recently, in Bangladesh, Fan *et al.* (2018) have taken the number of patents applied by residents and nonresidents as a proxy of technological innovation. They have found that infrastructure and technological innovation both positively and significantly impact industrial growth in Bangladesh in the short run. The reason for taking patents as the proxy for technological innovation is that innovation refers to the interest shown by the industrial and private sectors of a country to explore efficient technologies to emphasize the productive and allocative efficiency reflected in the quantitative indicators such as the number of patents. Before them, some other empirical studies that proxied technological innovation using patents are Ang (2009); Tang and

[2] In microeconomics, a consumer's Marshallian demand function (named after Alfred Marshall) specifies what the consumer would buy in each price and income or wealth situation, assuming it perfectly solves the utility maximization problem.

Tan (2013); Sohag et al. (2015); Cederholm and Zhong (2017) and hence it has also been incorporated in this study as well.

In the context of Malaysia, Sohag *et al.* (2015) showed that both per capita energy consumption and per capita GDP have a long-term positive impact on per capita carbon emissions, but the population growth rate has no significant impacts on per capita CO2 emissions. They suggested that economic growth may hurt CO2 emissions in the long run. Farhani and Ozturk (2015) test whether the EKC hypothesis exists when energy consumption, trade openness, and urbanization are incorporated in the environmental function. Dogan and Turkekul (2016) found that energy consumption and urbanization will increase environmental degradation over the long run while financial development will not affect it.

Mehrara (2007) and Salahuddin and Gow (2014) showed the existence of a unidirectional causal relationship between energy use and the economic growth in some selected oil export-based economies of the world. Alberini and Filippini (2011) studied the US economy and showed that energy prices are not positively related to the electricity and natural gas demand but with the income level by applying the static and dynamic panel models. Jamil and Ahmad (2011) show that the electricity demand is elastic in Pakistan, and due to the shortage of electricity supply, increasing income tax and reducing disposable income will lead to efficient use of energy.

Regarding the nexus between technological innovation and energy efficiency, Brock and Taylor (2005) found that production quality gets better due to energy efficiency lead by adopting new technologies. Wong et al. (2013) argued that OECD-based countries have higher energy efficiency gains from their sustainable technological innovations than other developing countries. Greening et al. (2000) pointed out that a rebound in overall energy use might be produced in absolute terms, though technology may marginally reduce energy use.

3. Empirical Model, Data, and Methodology

3.1 Empirical Model

In the theoretical literature, the energy demand of a country is linked with the income level and the price of energy. Assuming the equilibrium condition in the energy market where the demand of energy will exactly equal the energy consumption, the following energy demand function can be written based on the Marshallian demand function at time t:

$$E_{Dt} = f(Y_t, P_{et}) \tag{1}$$

Where E_{Dt} = energy demand at time t; Y_t = income at time t; P_{et} = energy price at time t

As discussed earlier, trade openness and technological innovation can influence a country's energy use in several possible ways. So, the modified version of the above equation (1) now becomes as follows:

$$E_{Dt} = f(Y_t, P_{et}, TI_t, TO_t) \tag{2}$$

Here, TI_t = technological innovation at time t and TO_t = Trade openness at time t.

One of the crucial reasons behind taking the variable technological innovation is that many studies found that this is a critical factor behind economic development as it ensures more efficient energy use. Besides being readily available, patents present the advantage of being a good indicator of innovative activity and tend to be highly correlated with many alternative measures of innovation (Wurlod and Noailly, 2018). One important aspect here is to measure the relationship between technological innovation and energy consumption; it is necessary to address how one should quantify technological innovation (Jin *et al.,* 2018). In this respect, worth mentionable research work that dictates the use of patents to measure innovation is Griliches (1990) that described some of the main characteristics of patents and patent data and hence proposed using patents as an indicator of technological change. Earlier studies such as Acs (2002) and Nagaoka *et al.* (2010) used patents to measure innovations from regions and firms. In the literature review section, the author further illustrated the rationale of his choice of patents as the proxy of technological innovation in the Bangladesh perspective. So, this study looks into more detail of the innovation and energy consumption relation and tries to find out the relationship between them, *ceteris paribus.*

Following Sohag et al. (2015), Farhani and Ozturk (2015), and Dogan and Turkekul (2016), the empirical model for the energy demand function of Bangladesh based on which the analysis is carried out is as follows:

$$LnEU_t = \beta_0 + \beta_1 LnGDPC + \beta_2 LnGDPC^2 + \beta_3 LnTI + \beta_4 LnTO + \varepsilon_t \quad (3)$$

where $LnEU_t$ = logarithmic form of energy use (per capita) at time t; $LnGDPC_t$ = logarithmic form of GDP (per capita) at time t; $LnGDPC^2$ = logarithmic form of GDP (per capita) squared at time t; $LnTI_t$ = logarithmic form of technological innovation at time t; and $LnTO_t$ =logarithmic form of trade openness at time t.

3.2 Data and Sources

This empirical study used annual time series data for Bangladesh from the year 1980 to 2016. World Development Indicators of World Bank was the primary data source. The dependent variable used is the energy use in kg of oil equivalent per capita. Explanatory variables used are real GDPC (GDP per capita), GDP (per capita) squared, level of technological innovation (total number of patent applications, both foreign and local). Trade openness (lnTO) is calculated as the total of real exports and imports divided by the real GDP.

3.3 Methodology

This paper uses the ARDL technique to estimate the empirical model shown in equation three earlier. The reason behind selecting ARDL is that it is a more efficient model than the other approaches to cointegration, such as Engle and Granger and Johansen (Sohag *et al.,* 2015). In Engle and Granger, multivariate analysis is excluded and can only analyze the case of bivariate technique. On the other hand, Johansen is another cointegration approach much more efficient than the Engle and Granger approach because it has multiple cointegrating vectors (Johansen, 1988). Johansen reduces omitted lag variables bias. However, this approach is criticized due to the lag selection's sensitivity, and the interpretation becomes difficult if there is more than one cointegrating vector in the model. In the presence of mixed order cointegration, the validity of Engel and Granger and Johansen approach are questioned and challenged. For all these reasons, the author has decided to go for the ARDL technique.

Several characteristics make the ARDL technique the better approach in this study. First of all, after choosing the appropriate lag order, this model uses the Ordinary Least Squares (OLS) estimation technique for the cointegration relationship prediction. Secondly, this technique remains statistically significant even if I(0); I(1) or mutual cointegration exists. Thirdly, this test is only valid for a finite and small sample size.

The Vector Error Correction Model (VECM) specification under the ARDL approach is as follows:

$$\Delta LnEU_t = \beta_0 + \beta_1 lnEU_{t-1} + \beta_2 LnGDPC_{t-1} + \beta_3 LnGDPC_{t-1}^2 + \beta_4 LnTI_{t-1} + \beta_5 LnTO_{t-1} + \sum_{i=1}^{p} \gamma_i \Delta lnEU_{t-i} + \sum_{j=1}^{q} \delta_j \Delta lnGDPC_{t-j} + \sum_{k=1}^{q} \partial_k \Delta lnGDPC_{t-k}^2 + \sum_{l=1}^{q} \varphi_l \Delta lnTI_{t-l} + \sum_{m=1}^{q} \vartheta_m \Delta lnTO_{t-m} + \varepsilon_t \quad (4)$$

Where $\Delta LnEU_t$ represents first difference term of logarithm form of energy use per capita. β_0 indicates the intercept. $lnEU_{t-1}, LnGDPC_{t-1}, LnGDPC_{t-1}^2, LnTI_{t-1}, LnTO_{t-1}$ indicate one-year lag of logarithm form of energy use per capita, GDP per capita, GDP per capita squared, technological innovation, and trade openness respectively, and $\beta_1, \beta_2, \beta_3, \beta_4$ *and* β_5 represent coefficient of $lnEU_{t-1}, LnGDPC_{t-1}, LnGDPC_{t-1}^2, LnTI_{t-1}, LnTO_{t-1}$ respectively.

$\sum_{i=1}^{p} \gamma_i \Delta lnEU_{t-i}$, $\sum_{j=1}^{q} \delta_j \Delta lnGDPC_{t-j}$, $\sum_{k=1}^{q} \partial_k \Delta lnGDPC_{t-k}^2$, $\sum_{l=1}^{q} \varphi_l \Delta lnTI_{t-i}$, *and* $\sum_{m=1}^{q} \vartheta_m \Delta lnEU_{t-m}$ indicate the summation of the coefficients γ_i, δ_j, ∂_k, φ_l, and ϑ_m for the values of lag difference $(\Delta) lnEU_{t-1}, LnGDPC_{t-1}, LnGDPC_{t-1}^2, LnTI_{t-1}, LnTO_{t-1}$ respectively, where optimum lag is 1 to p for the dependent variable and 1 to q for the explanatory variable. Finally, ε_t indicates the error terms.

3.4 Estimation Procedure

The process starts with equation (4) using OLS to examine the possibility of long-run relationships among the variables. Wald Test verifies the null hypothesis of the existence of no cointegrating relationship among the dependent and independent variable (H_0: $\beta_1 = \beta_2 = \beta_3 = \beta_4 = \beta_5 = 0$) against the alternative hypothesis of the existence of a cointegration (H_a: $\beta_1 \neq \beta_2 \neq \beta_3 \neq \beta_4 \neq \beta_5 \neq 0$). For comparison of the F-stat against the calculated critical values of the upper and lower bounds provided by Pesaran et al. (2001), the rules followed are: if the F-stat becomes higher than the critical values, the corresponding null hypothesis of no cointegration is rejected, similarly if the F-stat becomes lower than the critical values then the null hypothesis is accepted and finally if the F-stat is observed to be in between the lower and upper critical values then the test is not conclusive enough. After this, long-run coefficients are estimated using the ARDL model following equation (5) below:

$$LnEU_t = \beta_0 + \sum_{i=1}^{p} \gamma_i lnEU_{t-i} + \sum_{j=0}^{q1} \delta_j lnGDPC_{t-j} + \sum_{k=0}^{q2} \partial_k lnGDPC_{t-k}^2 + \sum_{l=0}^{q3} \varphi_l lnTI_{t-l} + \sum_{m=0}^{q4} \vartheta_m lnTO_{t-m} + \varepsilon_t \quad (5)$$

Where $LnEU_t$ represents the logarithm form of energy use per capita. β_0 indicates the intercept. $\sum_{i=1}^{p} \gamma_i lnEU_{t-i}$, $\sum_{j=0}^{q1} \delta_j lnGDPC_{t-j}$, $\sum_{k=0}^{q2} \partial_k \Delta lnGDPC_{t-k}^2$, $\sum_{l=0}^{q2} \varphi_l lnTI_{t-i}$, *and* $\sum_{m=0}^{q3} \vartheta_m lnTO_{t-m}$ indicate the summation of the long run coefficients γ_i, δ_j, ∂_k, φ_l, and ϑ_m for the values of $lnEU_{t-1}, LnGDPC_{t-1}, LnGDPC_{t-1}^2, LnTI_{t-1}, LnTO_{t-1}$ respectively, where optimum lag is from 1 to p for the dependent variable and from 0 to q for the explanatory variable. Finally, ε_t indicates the error terms.

After this, the estimation goes for the error correction model as specified in equation (6) below; the purpose is to investigate the short-run behavior of the respective variables and figure out the rate of adjustment towards the long run after an economic shock.

$$\Delta LnEU_t = \beta_0 + + \sum_{i=1}^{p} \gamma_i \Delta lnEU_{t-i} + \sum_{j=1}^{q} \delta_j \Delta lnGDPC_{t-j} + \sum_{k=1}^{q} \partial_k \Delta lnGDPC_{t-k}^2 + \sum_{l=1}^{q} \varphi_l \Delta lnTI_{t-l} + \sum_{m=1}^{q} \vartheta_m \Delta lnTO_{t-m} + \omega ecm_{t-1} + \varepsilon_t \quad (6)$$

Where $\Delta LnEU_t$ represents first difference term of logarithm form of energy use per capita. β_0 indicates the intercept. $\sum_{i=1}^{p} \gamma_i \Delta lnEU_{t-i}$, $\sum_{j=1}^{q} \delta_j \Delta lnGDPC_{t-j}$, $\sum_{k=1}^{q} \partial_k \Delta lnGDPC_{t-k}^2$, $\sum_{l=1}^{q} \varphi_l \Delta lnTI_{t-i}$, $and\ \sum_{m=1}^{q} \vartheta_m \Delta lnEU_{t-m}$ indicate the summation of the coefficients γ_i, δ_j, ∂_k, φ_l, and ϑ_m for the values of lag difference $(\Delta) lnEU_{t-1}, LnGDPC_{t-1}, LnGDPC_{t-1}^2, LnTI_{t-1}, LnTO_{t-1}$ respectively, where optimum lag is 1 to p for the dependent variable and 1 to q for the explanatory variable. ε_t indicates the error terms. Finally, ω is the coefficient of the one-year lag values of error correction mechanism (ecm_{t-1}).

The analysis employs the cumulative sum of squares of recursive residuals (CUSUMSQ) tests to examine the stability of the coefficients following Pesaran and Pesaran (1997).

4. Results and Discussion

4.1 Order of integration of the respective variables

To justify the use of the ARDL approach, this study, before testing the cointegration, goes for the order of integration test for the variables using the ADF (Augmented Dickey-Fuller), DFGLS (Dickey-Fuller Generalized Least Squared), and Phillips-Perron (P-P) tests. The tests validate the variables being limited within the boundary of the order of integration I (1).

Table I: Results of Augmented Dickey-Fuller (ADF), Dickey-Fuller Generalized Least Squared (DFGLS), and Phillips-Perron (P-P) unit root tests.

Log levels				**Log 1st Difference**			
Variable	**ADF**	**DFGLS**	**P-P**	**Variable**	**ADF**	**DFGLS**	**P-P**
LGDPC	0.986739	-0.667294	1.028849	LGDPC	-7.744968**	-4.481464**	-7.534407**
$LGDPC^2$	1.643752	-0.912133	1.672644	$LGDPC^2$	-7.257027**	-4.292804**	-7.093592**
LNEU	-2.202088	-1.695822	-2.089130	LNEU	-8.225289**	-8.256662**	-9.480769**
LNTO	-0.780258	-0.705724	-0.808601	LNTO	-6.470787**	-5.518033**	-6.334455**
LTI	-2.884333	-2.474522	-2.681019	LTI	-7.123870**	-6.374028**	-7.982432**

4.2. Cointegration and long-run impact of technological progress and control variables

From the previous analysis, suitable conditions for applying the bounds testing approach to cointegration are evident. For estimating equation (4), the identification of optimum lag is essential here. Using the VAR model optimum lag taken for the testing is 1, chosen based on Schwarz's Information Criterion (SIC).

Table II: Selection criteria of VAR lag order.

Lag	LogL	LR	FPE	AIC	SIC	HQ
0	156.2380	NA	9.42e-11	-8.896353	-8.671888	-8.819804
1	411.0200	419.6409	1.29e-16	-22.41294	-21.06615*	-21.95365
2	444.4176	45.18502*	8.74e-17*	-22.90692	-20.43780	-22.06488*
3	460.2192	16.73112	1.99e-16	-22.36583	-18.77440	-21.14105
4	503.9257	33.42262	1.25e-16	-23.46622*	-18.75246	-21.85869

The Wald joint significance test (F-statistic) on the coefficients of the lagged variables is needed to examine the cointegrating relationship. The null hypothesis to test here ($\beta_1 = \beta_2 = \beta_3 = \beta_4 = \beta_5 = 0$) is of no-cointegration against the alternative hypothesis of the presence of cointegration in the model. Thus, the paper has calculated the F-stat by normalizing all the variables as the dependent variable, and the total number of cointegrating vectors is determined as such. Finally, all calculated F-stat is compared with critical values provided by Pesaran et al. (2001).

From table III, calculated F-statistics are found for different variables being used as the dependent variable. The calculated F-statistic is 4.3943** {F_{lnEU} (lnEU

1,0,0,0,0 in table IV. Table IV represents several exciting findings of the ARDL framework. First, the author observes that in the long run, the coefficient of GDP per capita is 4.1485, which is significant at the 1% level. This implies that a 1-unit increase in the GDP per capita is associated with an increase in energy consumption per capita of 4.1485 units, keeping all other things constant. Both theoretical (the Marshallian demand function) and empirical evidence (for instance, Sohag et al. (2015), Asafu-Adjaye (2000) and Tang et al. (2013)) support this finding.

Then the second variable, GDP per capita squared, shows a negative sign that reflects the Environmental Kuznets Curve (EKC)[3] hypothesis in Bangladesh. This reflects that GDP per capita growth will cause an increase in the energy demand but up to a certain level. When the level is reached, then the GDP per capita increase will decrease energy use. This may happen due to the country's environmental consciousness and the technologically superior infrastructures being developed. Let us now move to the third variable, technological innovations. As expected, this variable shows a negative coefficient and implies that superior technology in the country leads to a decrease in the country's overall energy consumption. The author finds that technological progress reduces energy consumption at a 5 percent level of significance. So, this validates and strengthens the author's claim at a higher probability. Finally, trade openness shows a positive coefficient here, and this is insignificant, which contrasts with the findings of Zhou and Teng (2013), where they showed a negative coefficient. This can be attributed to the fact that as trade openness leads to more foreign direct investment, this increases the local energy demand.

Table IV: Long run coefficients using the ARDL approach, (1,0,0,0,0) selected based on SIC; the dependent variable is LnEU.

Regressor	Coefficient	Standard Error	T-Ratio [Prob]
lnGDPPC	4.1485***	1.1605	3.5746[.001]
$lnGDPPC^2$	-.26380***	.087541	-3.0135[.005]
lnTI	-.054295**	.026123	-2.0785[.046]
lnTO	.083226	.057515	1.4470[.158]
C	-10.6139***	3.6635	-2.8972[.007]

(**) and (***) represent 5% and 1% level of significance respectively

4.3. Short-run impact of technological innovation and other control variables

The paper analyzed the short-run elasticities using equation (6) mentioned earlier. The author has identified almost similar results compared to the result achieved in the long run. GDP per capita has a significant positive impact on energy use in the short run but up to a certain level. After that level, there is a negative impact on energy use, implying the EKC hypothesis in Bangladesh. Technological innovation has a negative coefficient as expected, and it was significant at the 10% level. Trade openness increases energy use in the short run, which is supported by the positive statistically significant coefficient shown in Table V. The author has found a negative and highly significant coefficient of the error correction mechanism (ECM),

[3] The Environmental Kuznets curve (EKC) is a hypothesized relationship between environmental quality and economic development: various indicators of environmental degradation tend to get worse as modern economic growth occurs until average income reaches a certain point over the course of development. The solution to pollution is economic growth is put forward by EKC hypothesis

and the result shows that short-run disequilibrium will adjust by 68% towards the long-run equilibrium.

Table V: Error Correction Representation of ARDL Model, (1,0,0,0,0) selected based on SIC: Dependent variable is Δ lnEU.

Regressor	**Coefficient**	**Standard Error**	**T-Ratio [Prob]**
Δ lnGDPPC	2.8239*	1.0256	2.7534[.010]
Δ $lnGDPPC^2$	-.17957	.072232	-2.4861[.019]
Δ lnTI	-.036959 ***	.019416	-1.9035[.066]
Δ lnTO	.056653*	.037456	1.5125[.141]
ECM (-1)	-.68071*	.16348	-4.1639[.000]
*ECM = LNEU -4.1485*LNGDPC + .26380*LNGDPC2 + .054295*LNPAT -.083226*LNTO + 10.6139*C*			

(*), (**) and (***) represent 1%, 5% and 10% level of significance

4.4. Diagnostic test results of the model

The author has checked the validity of the long-run ARDL model estimated using equation (5), as mentioned earlier. R^2 and adjusted R^2 are .9946 and .9937, respectively, which means the model fits very well. From table VI, the author sees that the model is not affected by serial correlation, normality, functional, and heteroscedasticity problem.

Table VI: Diagnostic test of ARDL model

	Test -statistic	**P-value**
R-squared	.99463	
R-bar-squared	.99377	
Functional form χ^2 (1)	.43227	.511
Serial correlation χ^2 (1)	1.2713	.260
Normality χ^2 (1)	1.1204	.571

Figure 2 shows the CUSUMQ (cumulative sum of squares) test, and it also shows that the model used is stable under the process of recursive residuals at a 5% level of significance.

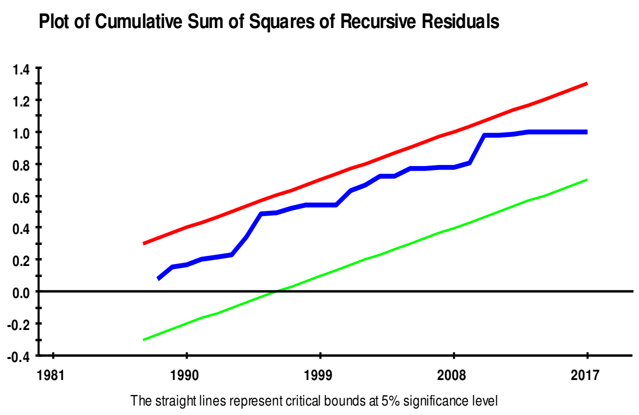

Figure 2: Stability test

5. Conclusion

The author has gone for an in-depth review of the dynamics of GDP per capita, trade openness, and technological innovations on the energy use of Bangladesh. The author finds GDP per capita and trade openness is the main factors behind the increased energy consumption in Bangladesh. Nevertheless, in line with previous findings, the author has found that innovation in technology helps to reduce the increased consumption of energy as a more efficient form of energy utilization is becoming prevalent in Bangladesh. To clarify more on the proxy of technological innovation used in this study, a patent represents the number of applications accepted and granted for the patent right. More specifically, this refers to the exclusive right of ownership by the inventors or designers of the creation of inventions, which the patents office issues after the due process of assessment and approval following the patent law of the country and in appropriate cases, the international body The World Intellectual Property Organization (WIPO). Patents are granted for inventions, utility models, and designs. This indicator reflects the achievements of science and technology and design with independent intellectual property (Wurlod and Noailly, 2018).

The empirical investigation has uncovered some interesting points. First, the author notices a higher impact of GDP per capita on energy use in the long run than in the short-run (coefficient being 4.14 in the long run and 2.82 in the short run). Second, according to the analysis, there is a presence of the EKC hypothesis as GDP per capita squared has a negative coefficient both in the long and short run, which implies that people become more conscious in using energy-efficient technologies due to economic betterment. Third, the author finds that trade openness positively impacts energy use, and as Bangladesh moves toward a more open market-based economy, the demand for energy consumption and production will increase. Finally, the author has found that technological innovation reduces energy consumption as it increases the efficiency of the devices and reduces system losses in the related manufacturing process. Thus, the author proposes that achieving sustainable energy security in Bangladesh can be made possible by replacing the old technologies with more upgraded energy-efficient technologies. This can be efficiently planned and executed by implementing public-private partnerships in technological investment and increasing renewable energy-efficient technologies.

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