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Energy-output nexus in Bangladesh: A two-sector model analysis

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ABSTRACT

The relationship between energy and output is one of the key issues in economic literature. Existing empirical studies have mainly used the neoclassical one-sector aggregate production function to examine the energy-output nexus and revealed inconclusive results. To address this issue, in this paper, we develop a two-sector model differentiating the energy sector from the conventional production sector to study the energy-output linkage for the Bangladesh economy. Using the annual data from 1985 to 2018, we conduct several unit root tests and reveal that our variables are stationary at their first difference. We further use the Johansen-Juselius cointegration and the Autoregressive Distributed Lag (ARDL) bounds tests and find that the variables are cointegrated in the long-run. By using three robust estimators (Dynamic Ordinary Least Squares (DOLS), Fully Modified OLS (FMOLS), and Dynamic ARDL), we reveal that a 1% increase in energy can increase the output by 0.06–0.10% in the long-run. We also run the Granger causality test and Vector Error Correction Model (VECM) to check the long-run and short-run causality. Our results find a unidirectional causality running from energy to output in the long-run but not in the short-run. We recommend that a reliable supply of energy needs to be ensured for future sustainable development in Bangladesh.

1. Introduction

The significance of energy nowadays is undeniable as it plays a crucial role in both the demand and supply side of the economy. For instance, different types of household products, especially the durables, are completely energy-dependent. Energy is also a strategic determinant in the production process. Amin [1] argues that a minimum amount of energy is needed for a country to develop beyond a subsistence economy. Therefore, the policymakers always emphasize adopting an optimal energy policy for future energy security and sustainable development [2–4].

After the first oil crisis in 1973, the energy-output nexus gained much more research attention from many economists and policymakers. Since the pioneering work of Kraft and Kraft [5], a vast empirical literature has examined the relationship between energy consumption and economic growth using diverse methodologies. Among others, Amin and Khan [2]; Bekun et al. [6]; Gurus and Aydin [7]; Akalpler and Hove [8]; Carfora et al. [9]; Amin and Alam [10]; Sarkodie and Adom [11]; Fotourehchi [12]; Azam et al. [13]; Karantfil and Li [14]; Dagher and Yacoubian [15], Stern [16], Ouedrago [17] have focused on finding the relationship between energy and output growth for many countries.

However, the direction of causality between these two variables and coefficient estimation still remains an unresolved issue [1,18], and Bangladesh is no exception to this trend (Table 1). The determination of the explicit direction of causality and parameter coefficient is not merely an issue of empirical concern, but also for policy formulations [1]. Once the uniform features of most of the existing literature is that they consider energy augmented one-sector neoclassical aggregate production function to examine the energy-output linkage across the globe. However, Santos et al. [19] point out several criticisms of the one-sectoral production function and highlight the importance of a two-sector neoclassical model to study the exact relationship between energy and output.

Bangladesh, located in the north-eastern part of South Asia, has made significant progress over the last few years from a socio-economic standpoint such as increased per capita income level, life expectancy, literacy rate, and poverty reduction, etc. The country’s average GDP growth rate has increased by over 6.7% in the last 10 years, which was only 3.7% in the 1970s. With an aspiration to become a high-income country by 2041, Bangladesh now looks forward to sustained...
Given the electricity generation’s success, the Bangladesh government has already started adopting energy conservation policies to save 20% of total energy by 2030 [20]. However, the available statistics show a close association between per capita electricity use and per capita GDP growth (Fig. 2). Therefore, without knowing the results of the exact relationship between the energy and output, it would not be recommended to implement the energy conservation policies in Bangladesh. Previously, a few of the empirical studies attempted to know the energy-output nexus for Bangladesh’s economy using the conventional one-sectoral neoclassical production function; however, the studies found results in support for both the growth and the conservation hypothesis [10,21–23]. So, a rigorous re-examination of the relationship between energy and output growth in Bangladesh is necessary.

Therefore, this paper aims to analyse the energy-output nexus in economic growth by creating more jobs, improving the quality of health and education, developing energy and transport infrastructure, introducing energy conservation and efficiency policies, and ensuring good governance.

Bangladesh was formerly known as an agrarian economy until the mid-90’s as the agriculture remained the most dominant sector of the Bangladeshi economy. However, during the last 3 decades, the country went through a sectoral transition process where the industrial and service sector started flourishing and became the major contributors to the national output (Fig. 1). Since both the service and industrial sectors are more energy-intensive than the agricultural sector, the use of energy and electricity started increasing sharply. This sectoral transition also exacerbated the historical energy crisis of Bangladesh till 2009 as the demand increased sharply, but supply-side remained sticky. Realising the crisis, the government started reforming the energy sector and achieved landmark success in the energy sector. For instance, installed generation capacity has increased from 5,272 Megawatt (MW) in 2009 to 20,618 MW in 2020, and nearly 95% of the population is now under electricity coverage.
Bangladesh with a newly developed energy augmented two-sector model. We use robust time series econometric techniques for conducting the empirical analysis using the annual dataset from 1985 to 2018. Several unit root tests (Augmented Dickey-Fuller (ADF), Phillips-Perron (PP), Kwiatkowski-Phillips-Schmidt-Shin (KPSS), and Dickey-Fuller-GLS (DF-GLS)) have been used to check the stationarity properties. Both Johansen-Juselius cointegration and Autoregressive Distributed Lag (ADRL) bounds tests based on surface regression have been used to check the long-run association among the variables. Long-run and short-run causalities have been checked by Granger causality and Vector Error Correction Model (VECM) tests. Finally, Dynamic OLS (DOLS), Fully Modified OLS (FMOLS), and recently developed Dynamic ARDL (DARDL) estimators have been employed to check the variables’ long-run coefficients.

Our results find that all the variables are stationary at the first difference, and long-run cointegration exists among them. We further reveal that the estimated long-run coefficient of energy for growth is inelastic and ranges between 0.06 and 0.10. Dynamic simulation results show that output growth significantly responds from the counterfactual changes in energy. On the other hand, causality results show that in the long-run, there is an existence of growth hypothesis. However, the neutrality hypothesis prevails in the short-run. Additionally, model stability tests show that the proposed two-sector model is stable.

The contribution of this paper is twofold. Firstly, instead of using a one-sector aggregate production function, we develop a novel two-sector model dividing the total economy into non-energy and energy sectors, where output produced in the energy sector acts as an additional factor of production in the non-energy sector to analysis the discussion.
of energy and output nexus (Methodological Contribution). Secondly, given the ambiguity of the empirical results, we use the model to re-examine the energy-output nexus for the Bangladesh economy. Our results are expected to guide the policymakers in formulating an optimal policy for the Bangladesh energy sector (Policy Contribution).

The rest of the paper has the following structure. The next section discusses the relevant literature; the methodology and data are presented in Section 3. Section 4 illustrates the results and relevant discussions. Finally, the last section brings the conclusion of the paper with policy suggestions.

2. Literature review

Several country-specific time series and panel studies have been conducted to examine the relationship between the energy and output earlier and found evidence for four important hypotheses: the conservation hypothesis, growth hypothesis, feedback hypothesis, and neutrality hypothesis. It is evident from the results that the energy-output nexus has been an equivocal issue as different studies with a variety of variables and methodologies gave mixed results [9,24–27]. Hence, this section’s discussion is presented in the following subsections sequencing to panel studies, country-specific studies, and the energy-output studies on Bangladesh. Besides, a summary of the literature is given in Table 1.

2.1. Literature on panel studies

Azam et al. [13] used the Granger causality test for five ASEAN countries and found that causality running from economic growth to energy consumption. They found no causality between energy consumption and economic growth for Indonesia, Thailand, Philippines, and Singapore, except Malaysia. On the other hand, Magazzino [27] revealed different results for ten Middle East countries as neither energy consumption nor CO₂ emissions impacted economic growth for non-Gulf Cooperation Council (GCC) countries, supporting the neutrality hypothesis.

Gorus and Aydin [7] investigated the causal relationship between energy consumption, economic growth, and CO₂ emissions for the Middle East and North African (MENA) countries, and the Granger causality analysis in the frequency domain showed unidirectional causality from energy consumption to economic growth for Egypt, Algeria, Iran, Oman, and Tunisia. Magazzino and Cerulli [28] examined the relationship among CO₂ emissions, GDP, and energy use for the MENA countries using the Responsiveness Score (RS) approach, and the empirical results suggested a positive response between GDP per capita and energy consumption. Besides, Magazzino [29] analysed the data for six GCC countries, and the analysis found that the growth hypothesis held for Kuwait, Oman, and Qatar as energy use caused the real GDP in the long-run. On the contrary, Carfora et al. [9] found no linkages among energy consumption, income, and price while incorporating the co-integration and Granger causality test.

2.2. Literature on specific countries

Bekun et al. [6] assessed the energy-economic growth nexus for South Africa and found the energy-led growth hypothesis’s prevalence in the long-run. On the other hand, Magazzino et al. [36] also incorporated a study for South Africa using the Toda-Yamamoto Granger causality test and showed a feedback causality between economic growth and CO₂ emissions. The FMOLS long-run estimation showed the inverted U-shaped pattern between energy consumption and environmental degradation in South Africa.

Akalpler and Hove [8] conducted a study for India, and the ARDL results found a short-term relationship between Real GDP per capita and energy consumption and CO₂ emissions as well as gross fixed capital. For Tunisia, Farhani et al. [31] investigated the dynamic relationship between energy consumption and economic growth and some other control variables. The ARDL results revealed that unidirectional causalities were running from GDP and squared terms of GDP to energy consumption in the short-run.

2.3. Literature on Bangladesh’s case

A few of the studies have also been conducted to investigate the energy-output nexus for Bangladesh. Among others, Mozumder and Marathe [21] examined the causal relationship between electricity per capita consumption and the per capita GDP. They revealed a unidirectional causality running from per capita GDP to per capita electricity consumption in the short-run, but not vice versa. Similarly, Amin and Rahman [22] found a long-run unidirectional causality running from economic growth to energy consumption using the Granger causality test.

On the other hand, Ahmad and Islam [22] found short-run unidirectional causality running from per capita electricity consumption to per capita GDP, but not vice versa. In the long-run, however, they found bidirectional causality between electricity consumption and economic growth, validating the feedback hypothesis. Moreover, Amin and Alam [10] studied the relationship between sectoral output and energy consumption in Bangladesh. It was found that there existed a unidirectional causality from aggregate output to energy consumption in the long-run. In the short-run, however, the neutrality hypothesis existed at both aggregate and sectoral levels.

3. Methodology and data set

3.1. Theoretical underpinning

According to Ref. [32,33], a two-sector model based on neoclassical production functions has become a useful theoretical tool in economic analysis. The overall setup of the model provides a wide range of perspectives regarding economic growth and its relation to other factors. Therefore, following [1,33], we consider an economy with two sectoral production functions, one for the energy sector and the other for the non-energy sector.

\[
N = F(K_N, L_N, E) 
\]

\[
E = G(K_E, L_E, Q) 
\]

Where \( N \) and \( E \) represent the production functions of non-energy and energy sectors, respectively. \( K_N \) and \( K_E \) represent the capital stocks and \( L_N \) and \( L_E \) represent the labour forces in the respected sectors. The output of both sectors is a function of the factors (labour, capital, and energy) allocated to each sector. Since many developing and emerging countries import energy from the international market, we assume that a constant portion of energy (\( Q \)) has been imported at an international price of \( P \). Moreover, the output of the non-energy sector is dependent on the volume of energy being produced in the energy sector. The role of energy as a direct input in the non-energy sector further represents the beneficial effects of energy on the sectors, which formulate the non-energy sector. These effects can be considered as externalities as they

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3 Both the production functions are defined based on the arguments of Shinkai [34], Uzawa [35], and Solow [36]. Shinkai [34] first showed that in a two-sector setup, a stable, balanced growth could be achieved by assuming that each sector is endowed with a set of techniques. Given this assumption, he further showed that all the technical parameters become constant (or scalar) in both general and neutral cases described in Solow [36]. It should also be noted that constant technical parameter does not mean there is no technological impact; rather, it implies that technological change occurs without a trend mentioned in Solow [36]. Later, Uzawa [35], Ethier [32], and Feder [33] followed the same framework in their study, which is also followed in our paper.
are not reflected in terms of market prices.

Since the data about the sectoral allocations of primary factors are not available, we assume that the ratio of respective marginal productivities in the two-sectors deviates from unity by a factor \( \delta \). This implies:

\[
\frac{G_K}{F_K} = \frac{G_L}{F_L} = 1 + \delta \quad (3)
\]

If \( \delta > 0 \), the marginal productivity of the energy sector is greater than that of the non-energy sector and vice versa. A differentiation of equations (1) and (2) yields:

\[
\dot{N} = F_K \dot{K} + F_L \dot{L} + F_E \dot{E}
\]

\[
\dot{N} = F_K \dot{I} + F_L \dot{L} + F_E \dot{E}
\]

and. \( \dot{E} = G_K I + G_L \dot{L} + G_E Q \)

Since we assume that only a fixed portion of the energy is imported, therefore,

\[
\dot{E} = G_K I + G_L \dot{L}
\]

If the total output is the sum of energy and non-energy sector, then we have:

\[
\dot{Y} = \dot{N} + \dot{E}
\]

\[
\dot{Y} = F_K \dot{I} + F_L \dot{L} + F_E \dot{E} + G_K \dot{I} + G_L \dot{L}
\]

\[
\dot{Y} = F_K \dot{I} + F_L \dot{L} + F_E \dot{E} + F_K (1 + \delta) \dot{I} + F_L (1 + \delta) \dot{L}
\]

\[
\dot{Y} = F_K (\dot{I} + I) + F_L (\dot{L} + L) + F_E \dot{E} + \delta \left(F_K \dot{I} + F_L \dot{L}\right)
\]

From equations (3) and (5), we derive:

\[
F_K \dot{I} + F_L \dot{L} = \frac{1}{1 + \delta} \left(G_K \dot{I} + G_L \dot{L}\right) = \frac{\dot{E}}{1 + \delta} \quad (8)
\]

Defining total investment \( I = \dot{I} + I \) and total growth of labour \( \dot{L} = \dot{L} + L \) and using equations (7) and (8), we get:

\[
\dot{Y} = F_K \dot{I} + F_L \dot{L} + \left(\frac{\delta}{1 + \delta} + F_K\right) \dot{E}
\]

If we assume a linear relationship between the real marginal productivity of labour in a given sector and average output per labour in the economy \( F_k = \beta \left(\frac{L}{Y}\right) \), denote \( F_k = \alpha \) and, then dividing equation (9) by \( Y \), we derive:

\[
\frac{\dot{Y}}{Y} = \alpha \left(\frac{I}{Y}\right) + \beta \left(\frac{L}{Y}\right) + \left(\frac{\delta}{1 + \delta} + F_K\right) \left(\frac{E}{Y}\right)
\]

\[
\frac{\dot{Y}}{Y} = \alpha \left(\frac{I}{Y}\right) + \beta \left(\frac{L}{Y}\right) + \gamma \left(\frac{E}{Y}\right)
\]

Equation (11) defines economic growth \( \left(\frac{Y}{Y}\right) \) as a function of the investment to output ratio \( \left(\frac{I}{Y}\right) \), growth of labour force \( \left(\frac{L}{Y}\right) \), and the multiple effects of the growth of energy sector \( \left(\frac{E}{Y}\right) \) and energy share in the GDP \( \left(\frac{E}{Y}\right) \). This formulation allows us to consider the externality effect of the energy sector when the marginal productivity of the energy sector is greater in the non-energy sector. From now on, we will refer to \( \frac{I}{Y}, \frac{L}{Y}, \frac{E}{Y} \) and \( \left(\frac{Y}{Y}\right) \) as YGR, I/Y, LGR, and EGR, respectively.

3.2. Unit root and cointegration analysis

We have performed the Augmented Dicky-Fuller (ADF) test to check the existence of unit root. In addition to the ADF unit root test, we have also used three other robust unit root tests, namely, Phillips-Perron (PP), Kwiatkowski-Phillips-Schmidt-Shin (KPSS), and Dickey-Fuller-GLS (DF-GLS). The Johansen-Juselius procedure [37] has been employed to test for cointegration by following [8,9]. However, Zhou [38] has argued that the asymptotic values of the Johansen-Juselius procedure for indicating cointegration tend to misinterpret the power performance when the sample size is small and lag order is high.

Therefore, to check whether Johansen-Juselius procedure is misinterpreting the long-run association, we have considered Autoregressive Distributed Lag (ARDL) bounds test procedure augmented with Kripganz and Schneider [39] critical values and approximate probability values derived from surface regressions.

3.3. DOLS estimation

The Dynamic OLS (DOLS) approach, as proposed by Stock and Watson [40] has been applied for the long-run estimation of the concerned variables. DOLS can deal with small sample size and dynamic sources of bias, which is also one of the major advantages of this technique [2]. Moreover, it is a robust single equation approach that corrects the regressor’s endogeneity by incorporating lags and leads on the first differenced regressor.

Besides, a sensitivity analysis has been carried out by re-estimating the model with Fully Modified OLS (FMOLS) proposed by Phillips and Hansen [41,44,45] and Dynamic ARDL (DARDL) proposed by Jordan and Phillips [42,50] based on the seminal work of Pesaran et al. [43]. The main idea behind such analysis is to obtain a convincing result for the energy-output nexus and ensure that it is not responsive to any estimation technique [47-49]. Furthermore, Stability test \(^5\) (CUSUM) has been applied to each of the variables to check the two-sector model stability.

3.4. Causality analysis

Once the variables are found to be cointegrated, and long-run coefficients of the variables have been checked, the next step is to check the variables’ causal relationship. For long-run causality, we have used the Granger causality test [51]. On the other hand, for short-run causality, Vector Error Correction Model (VECM) has been applied as Engle and Granger [52] have showed that if two series are cointegrated, they can be expressed with an error correction mechanism. The VECM can infer both short-run and long-run causality among the variables. Deviations of the series from the long-run equilibrium relation are measured by the Error-Correction Term (ECT). Changes in an independent variable may be interpreted as representing the short-run causal

\(^4\) This specification allows the estimation of sectoral marginal productivities using aggregate data.

\(^5\) For more details about CUSUM, please see Ref. [46].
impact while the error-correction term provides the adjustment for long-run equilibrium.

3.5. Data sources

The paper is based on annual data covering the period of 1985–2018. Data on the total labour force, Gross capital formation as a proxy of investment (Constant $US), GDP (Constant $US), electricity sector’s growth, and share of the electricity sector in GDP of Bangladesh are taken from the World Development Indicator (WDI) and the Statistical Yearbook of Bangladesh (SYB) of different years respectively. We have considered electricity as a proxy of energy in our analysis for two reasons. Firstly, electricity is the most widely used form of energy and is known as the energy carrier [1]. Secondly, due to the data unavailability of the shares of different energy sectors to GDP in Bangladesh, we considered electricity as a proxy of energy in our analysis for two reasons.

4. Results and discussions

4.1. Unit root test results

At first, we check the stationarity properties of the concerned variables. Table 3 shows the results of the unit root tests at the level and first differenced forms. 6 From the results of the ADF unit root test, we can see that all the variables are stationary at their first differenced form or integrated at order one, I (1). Similarly, PP, KPSS, and DF-GLS unit root tests also justify the integration order of all the variables is I (1).

4.2. Cointegration test results

The results of Table 3 allow us to proceed to check the existence of the long-run cointegrating relationship among the variables of interest. Table 4 shows that both Maximum eigenvalue and Trace test statistics reveal the evidence of a long-run association among the variables in the Johansen test results. According to the ARDL bounds test results (Table 5), the F-statistics is well above the upper bound [I (1)] critical values and validated by significant p-values. Thus, a meaningful long-run cointegrating relationship is validated among the variables in the two-sector model.

Note: ***,* *, and * show significance at 1%, 5%, and 10% respectively. ADF, PP and DF-GLS perform under null hypothesis where series is non-stationary against alternative hypothesis of series is stationary. KPSS performs under null hypothesis where series is stationary against alternative hypothesis of series is not stationary.

Table 4

| Hypothesised No. of CE (s) | Trace Test | Probability Max Eigen Test | Probability |
|---------------------------|------------|-----------------------------|-------------|
| None                      | 65.18      | 0.00                        | 35.24       | 0.00 |
| At most 1                 | 29.93      | 0.04                        | 20.67       | 0.10 |
| At most 2                 | 9.26       | 0.34                        | 8.90        | 0.29 |
| At most 3                 | 0.36       | 0.55                        | 0.36        | 0.55 |

Note: The test is run on intercept but no trend configuration.

4.3. DOLS estimation results

Table 6 shows the long-run estimation results from both the two-sector model and the conventional one-sector model. Our results reveal that the explanatory variables in the two-sector model are highly significant (at 1%) in comparison to the variables (except investment) used in the one-sector model (at 10%). Furthermore, it is observed that the one-sector model overestimates the coefficients that the two-sector model to a certain degree, which supports the result of [53] where the analysis is based on the one-sector framework. It is also worth mentioning that the variables’ standard errors are considerably low in the two-sector model.

According to the two-sector model’s estimation, in the long-run, a 1% increase in energy will lead to a 0.10% increase in output growth. However, the one-sector model result indicates that a 1% increase in energy will bring about 0.20% of output growth. Besides, a 1% increase in investment and labour will lead to a 0.21% and 0.78% increase in the output growth, respectively, in the two-sector framework. The labour growth coefficient also indicates that Bangladesh is still a labour-oriented economy. In other words, following the argument of [33], we can assert that surplus labour does not exist for Bangladesh in the sample period.

We further discuss that the policymakers can consider the high significance level of the long-run coefficients of energy (EGR) for...
implementing sustained energy policies. It is also worth noting that almost in all the existing literature of energy-output nexus, the conventional variables like energy use per capita or total energy uses are used as a proxy to study the impact of energy on output. However, in the two-sector model, we argue that output should not depend on conventional variables solely, rather depend on a multifaceted structure to include the multiple effects of energy. The energy variable (equation (11)) is defined as a combination of both the energy sector share in GDP in measuring the output may give us a misleading conclusion. However, the one-sectoral model considers only energy sector’s share in GDP distinctly. For instance, the absence of the energy sector share in GDP in measuring the output may give us a misleading conclusion. However, the one-sectoral model considers only the energy use at a level and overlooks the combined effect of both growth of the energy sector and its share in the GDP. This is the reason why the one-sector model misjudges (i.e., overestimates) the energy impact on output. For instance, in Bangladesh, the growth in the energy sector refers to all sorts of improvements in sector-level activities (i.e., generation, transmission, distribution, and innovation) [54].

The multiplicative term also helps us understand the actual change of output in detail. The term includes both the changes in the energy sector’s growth and share in GDP distinctly. For instance, the absence of the energy sector share in GDP in measuring the output may give us a misleading conclusion. However, the one-sectoral model considers only the energy use at a level and overlooks the combined effect of both growth of the energy sector and its share in the GDP. This is the reason why the one-sector model misjudges (i.e., overestimates) the energy impact on output. For instance, in Bangladesh, the growth in the energy sector on average has increased at a very higher speed (over the last 30 years) than the increase in the energy sector’s share in GDP.

### 4.4. Sensitivity analysis

A sensitivity analysis has been carried out to check the robustness of the model. The results of the sensitivity analysis is shown in Table 7. It can be depicted from the table that the DOLS, FMOLS, and DARDL estimation approaches show the same pattern in the estimation result. For instance, the impact of LGR on YGR is consistently higher in all three methods. Furthermore, the coefficient of I/Y stays between 0.20 and 0.25. Lastly, the coefficient of EGR ranges between 0.06 and 0.10 overall; the sensitivity analysis confirms the robustness of the two-sector model.

### 4.5. Counterfactual analysis

DARDL is capable of simulating responses of the dependent variable from the counterfactual changes in regressors. We have conducted an exercise through which we have checked the effect of counterfactual shocks in EGR, I/Y, and LGR on YGR. The outcome of the exercise can be seen in Fig. 3. We can observe that a positive shock in EGR intensifies YGR in the long-run. A negative shock in EGR does not adversely affect YGR in the very short-run but significantly lowers YGR in the long-run. Responses from both of the shocks tend to alleviate after t = 20. Therefore, it is clear that the YGR of Bangladesh depends on EGR. Any distortions in the energy sector or energy conservation policies that interrupt the availability of energy access will hamper the long-term growth pattern.

### 4.6. Causality test results

The results of both long-run and short-run causalities are shown in Tables 8 and 9, respectively. From Table 8, we can see that there is a unidirectional causality running from EGR to YGR. However, no causality has been observed in the short-run (Table 9). The existence of such unidirectional causality, in the long-run, confirms the growth hypothesis meaning that consumption of more energy will speed up the output growth in the long-run but not vice versa. The long-run causality result is different from the studies based on a one-sector model, for instance Refs. [10,22,23,55], where the first three studies have found the opposite causality implies the existence of conservation hypothesis, and the last study has found the existence of feedback hypothesis.

On the other hand, the short-run result also differs from Ref. [23,53] who have found a growth hypothesis. Furthermore [21], have found a conservation hypothesis in the short-run. The long-run causality direction is consistent with our estimation results and makes the two-sector model robust in capturing energy and output nexus. One of the possible reasons for not having any causality between EGR and YGR in the short-run is that the effect of energy on the production process is subject to time lag [2,7]. In the long-run, I/Y causes YGR but not vice versa. Furthermore, bidirectional causality is present between YGR and LGR. However, in the short-run, YGR causes I/Y and LGR, respectively, indicating that in the shorter period due to market power, growth itself stimulates investment and labour within the economy.

### 4.7. Model Stability Diagnostics results

Fig. 4 illustrates the CUSUM test results of each variable used in the two-sector model. The CUSUM test results of each variable show that the plots stay within the corridor of 5% critical value, indicating that the

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### Table 5

| Criteria | Value | 10% | 5% | 1% | P-Value |
|----------|-------|-----|----|----|---------|
| Model F-Statistics | 6.57 | 2.98 | 4.30 | 3.70 | 5.24 | 5.53 | 6.50 | 0.00 | 0.02 |

### Table 6

| Variables | Long-run Coefficients | Conventional One-Sector Model | Long-run Coefficients |
|-----------|------------------------|-------------------------------|-----------------------|
| I/Y       | 0.21*** (0.02)         | K 0.96*** (0.16)              | K 0.96*** (0.16)      |
| LGR       | 0.78*** (0.06)         | L 1.25* (0.62)                | L 1.25* (0.62)       |
| EGR       | 0.10*** (0.01)         | E 0.20* (0.14)                | E 0.20* (0.14)       |
| Adj-R²    | 0.97                   | Adj-R² 0.85                   | Adj-R² 0.85          |
| J-B       | 1.26                   | J-B 1.04                      | J-B 1.04             |
| AC        | 4.59                   | AC 1.58                       | AC 1.58              |

Note: Standard errors are in parenthesis. ***, **, and * show significance at 1%, 5%, and 10% respectively. J-B and AC refer Jarque-Bera and Autocorrelation Tests. Both tests have been done in the residuals of the regressions.

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8 The energy sector’s share in GDP captures the sectoral contribution/size in the economy.

9 On average, $\frac{E}{E}$ increased at 0.03% point whereas, $\frac{E}{Y}$ increased at 0.21% point (Statistical Year Books of Bangladesh).
model is stable both in terms of systematic and sudden movements. The estimated two-sector model has been verified with conventional diagnostics tests reported in Tables 6 and 7.

5. Conclusions and policy implications

In this paper, we have developed a novel two-sectoral model to re-examine the energy-output nexus in Bangladesh by dividing the economy between the energy sector and the non-energy sector. [1] argues that a two-sectoral model provides more robust and significant results reflecting the real-life frictions. Our estimation results reveal that energy significantly influences economic activities at the aggregate level in the long-run in Bangladesh. On the other hand, labour and investment output ratio have a positive impact as well. Furthermore, a

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Fig. 3. Effects on YGR due to counterfactual changes in regressors.
90% of the electricity is generated mainly from fossil fuels: natural gas and imported oil. So far, only 628 MW of electricity (3% of the total investment-growth nexus, and a bidirectional causality is seen for the generation capacity) has been produced from renewables, which is far less than the actual target of generating 10% of electricity from renewable energies. The global Covid-19 pandemic also expedites urban and rural migration and mobilises economic activities in rural areas. Therefore, increasing renewable energy integration while maintaining electricity supply stability, investments in the Research and Development (R&D) to check up on the feasibility of the renewables projects, infrastructural development, and the diffusion of modern and advanced technologies to the rural areas are highly recommended.

Another area of focus can be the enhancement of skills in the energy sector workforce. Improvement in sector-specific skills can certainly increase efficiency as well as productivity in the sectoral activities [56]. From the statistics of labour force surveys in Bangladesh [57–59], it is observed that 75% of the energy sector’s workforce falls under the low and medium-skilled category, whereas only 25% fall under the highly skilled category. As a result, policies that focus on developing knowledge-based skills in the workforce of the energy sector should be implemented.

It is also argued that any growing economy like Bangladesh may be constrained by politics, weak infrastructure, and resource mismanagement. So, institutional reform is also a crucial factor in increasing sectoral capacity. [60] argues that a better institution can help the different stakeholders in a society adopt optimal decisions and implement effective policies. However, Bangladesh still faces institutional barriers that hinder the development process of the energy sector and the other sectors. Therefore, the government should adequately identify the problems associated with different institutions in the energy sector and introduce coordinated institutional reform policies for future energy security.

We also argue that any shock to the energy sector or reduced availability of energy supply will ultimately hurt economic growth, and our results did not support the conservation hypothesis. Recently, there is a growing belief among the energy experts and the environmentalists that Bangladesh should immediately focus on energy conservation and efficiency policies as it is cheaper to save one unit of energy than to supply an additional unit. The government also plans to consider energy conservation measures as an integral part of the national energy development programme. However, we recommend focusing on the alternative policy initiatives mentioned above rather than adopting conservative energy policies. The multiplicative term in the two-sector model further highlights that, given the small share of the energy market, a sizeable growth of energy use is essential to achieve sustainable economic growth.

This paper can be further extended by disaggregating both energy and non-energy sectors to explore the relationship’s nature from an even more in-depth perspective. Besides, the model can also be reconstructed by augmenting environment-related variables to observe the effect of pollution on the output. Furthermore, region wise comparison can be another continuation of this paper through which a set of fundamental policies can be formulated for specific regions.

### Table 8
Long-run causality test results.

| Variable | Null Hypothesis | F-Statistic | P-Value | Conclusion |
|----------|-----------------|-------------|---------|------------|
| Causality tests statistics between YGR and I/Y | YGR I/Y does not cause | 5.66 | 0.07 | I/Y Causes YGR |
| | YGR I/Y does not cause | 0.90 | 0.34 | No Causality |
| | YGR I/Y does not cause | 0.90 | 0.41 | No Causality |
| | YGR I/Y does not cause | 0.90 | 0.41 | No Causality |
| | YGR I/Y does not cause | 0.90 | 0.41 | No Causality |

unidirectional causality is found for the energy-growth and the investment-growth nexus, and a bidirectional causality is seen for the labour-growth nexus in the long-run. However, no causality has been found between energy and output growth in the short-run. Moreover, in the short-run, unidirectional causalities are present among output, investment, and labour. Finally, our results support that Bangladesh is a labour-oriented country, as the coefficients of the two-sector model are significant and greater than the coefficients of the other two variables.

We find that energy can play a significant role in the Bangladesh economy. A 1% increase in energy can increase the GDP by 0.09% on an average. This also supports the belief that the landmark success in the energy sector played an important role in maintaining an impressive GDP growth rate for the last decade. Therefore, it is crucial to reform the energy sector for future energy security and economic stability. Although Bangladesh has achieved great success, the transmission and distribution sector is yet to develop to transfer the electricity to the end consumer through the country. Due to the improper transmission and distribution infrastructures, a considerable amount of energy is lost while transmitting to the consumers-a phenomenon known as system loss. Given the stable generation capacity, it is now time to unbundle and privatise the transmission and distribution systems to attract investments for reducing the system loss and extending the grid capacity.

Besides, Bangladesh’s performance in improving off-grid electrification by expediting renewable energy is still unsatisfactory. More than 90% of the electricity is generated mainly from fossil fuels: natural gas and imported oil. So far, only 628 MW of electricity (3% of the total generation capacity) has been produced from renewables, which is far less than the actual target of generating 10% of electricity from renewable energies. The global Covid-19 pandemic also expedites urban and rural migration and mobilises economic activities in rural areas. Therefore, increasing renewable energy integration while maintaining electricity supply stability, investments in the Research and Development (R&D) to check up on the feasibility of the renewables projects, infrastructural development, and the diffusion of modern and advanced technologies to the rural areas are highly recommended.

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We also argue that any shock to the energy sector or reduced availability of energy supply will ultimately hurt economic growth, and our results did not support the conservation hypothesis. Recently, there is a growing belief among the energy experts and the environmentalists that Bangladesh should immediately focus on energy conservation and efficiency policies as it is cheaper to save one unit of energy than to supply an additional unit. The government also plans to consider energy conservation measures as an integral part of the national energy development programme. However, we recommend focusing on the alternative policy initiatives mentioned above rather than adopting conservative energy policies. The multiplicative term in the two-sector model further highlights that, given the small share of the energy market, a sizeable growth of energy use is essential to achieve sustainable economic growth.

This paper can be further extended by disaggregating both energy and non-energy sectors to explore the relationship’s nature from an even more in-depth perspective. Besides, the model can also be reconstructed by augmenting environment-related variables to observe the effect of pollution on the output. Furthermore, region wise comparison can be another continuation of this paper through which a set of fundamental policies can be formulated for specific regions.

### Table 9
Short-run causality test results.

| Variable | Null Hypothesis | Chi Square Statistic | P-Value | Conclusion |
|----------|-----------------|----------------------|---------|------------|
| Causality tests statistics between YGR and LGR | YGR LGR does not cause | 3.75 | 0.15 | No Causality |
| | YGR LGR does not cause | 0.38 | 0.68 | No Causality |
| | YGR LGR does not cause | 0.38 | 0.68 | No Causality |
| | YGR LGR does not cause | 0.38 | 0.68 | No Causality |

Credit author statement

Sakib Bin Amin: (the corresponding author) generates the idea of the paper, formulates the theoretical framework, conducts the empirical part, prepares part of the chapters, and supervises the paper. Foqoruddin Al Kabir: reviews the literature, collects data and prepares part of the chapters. Farhan Khan: conducts the empirical part, and prepares part of the chapters.

Declaration of competing interest

The authors declare that they have no known competing financial
interests or personal relationships that could have appeared to influence the work reported in this paper.

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Fig. 4. Stability diagnostics of the variables used in the Two-Sector Model.
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