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Energy consumption and economic growth nexus: New evidence from Pakistan using asymmetric analysis

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A B S T R A C T

This study contributes to the extant literature on the nexus among energy consumption, agriculture, capital and economic growth in Pakistan. We use time series data from 1971 to 2014 and employ the Non-linear Autoregressive Distributed Lag (NARDL) model. The NARDL testing results affirms asymmetric co-integration among the variables. Asymmetric causality is noted between positive shocks in energy consumption and economic growth running from energy consumption to economic growth. A feedback effect is found between agriculture and economic growth for positive shocks. A unidirectional nexus is noted between capital and economic growth for both positive and negative shocks. Similarly, the results of a Granger causality test indicate symmetric causality between energy consumption, agriculture, capital and economic growth. This research suggests that policymakers should revisit their policies regarding agriculture and energy sectors by attracting foreigner investors to build new hydropower dams to both affirm the availability of energy to the industrial sector and control the scarcity of water.

1. Introduction

Energy is considered as a basic resource in sustainable economic growth for both developed and developing countries. It is a key input in production processes and social development. In particular, manufacturing sectors rely heavily on energy for production purposes. Due to the importance of energy for economies, the link between energy and economic growth has been examined by numerous researchers (e.g., Refs. [1–6]). Indeed, the demand for energy increases day-by-day because of social economic development and rapid population growth. As a result, energy is considered a basic unit of domestic production, and it should be a component of production function, as are both capital and labour [7].

Over the last two decades, most countries have been facing insufficiency of energy sources. According to the International Energy Agency, the energy demand increased by 2.1% in 2017, which is more than twice that of 2016. According to Enerdata 2018, China (3105 Mtoe) is one of the largest energy consumers in the world. Since 2000, Asian countries – India Indonesia, Malaysia, and Japan – have increased their energy consumption. European countries, including Italy, Turkey, France, and Germany, have also increased their energy consumption. Meanwhile, energy consumption in the United States, the United Kingdom, Russia, and Canada has remained stable.

Pakistan's power sector is also now facing a critical situation. Approximately 140 million people either have no access to power or are facing more than 12 h' blackout daily. The total average shortfall in the power sector is approximately 4000 MW and approximately two billion cubic feet per day of natural gas. In Pakistan, 54% of the total energy is produced from natural gas and oil. The overall energy consumption is 37.7% in the industrial sector, 32.2% in the transport sector, and 22.2% in households. Meanwhile, the agriculture, government, and commercial sectors are consuming 2.6%, 2.5%, and 2.3%, respectively. Owing to the power crisis in terms of power outages and blackouts, Pakistan's economy lost more than 7% of GDP in 2015. In 2004, the GDP annual growth rate was recorded at 7.37%, and it was 7.66% in the following year; it has been increasing ever since 1982. In 2008, 2009, and 2010 the

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annual growth fell by 1.7%, 2.83%, and 1.6%, respectively, which was the lowest rate of the last two decades. The energy sector plays a vital role in the development of countries' economies. Unfortunately, the scarcity of energy sources has a negative impact on economic growth. Therefore, in this study, we discuss the link between energy and economic growth. The energy–growth nexus is presented in four hypothesis with implications for energy and growth policy: (1) The conservative hypothesis (unidirectional causality running from growth to energy); (2) The feedback hypothesis (bidirectional causality between energy and growth); (3) The growth hypothesis (indicates unidirectional causality flowing from energy to growth); and (4) The neutral hypothesis (means no causal effect). The feedback and growth hypotheses have revealed the link between economic growth and energy policies, whereas the conservative and neutral hypotheses have shown that there is no association between energy and economic growth [8].

The relationship between economic growth and energy consumption has been a debatable topic since the 1950s. In the mid-1950s, a few papers were published on this topic [9,10]. In later decades, the topic was studied broadly by Refs. [11,12], and [13] in the U.S. economy. The topic was extended to other countries following the study by Ref. [14], with numerous empirical methodologies being used in later periods. Because of the social consequences of this topic, an increasing number of researchers from numerous countries have conducted in-depth studies using larger data sets and stout econometric methods.

Owing to different factors, the topic has been discussed extensively. Firstly, in daily life, there are numerous issues pertaining to the environment and energy: in Rio de Janeiro in 1992, the United Nations conducted the first meeting about environmental degradation in many countries. Secondly, since 2010, the World Bank (World Development Indicator) has been publicising the financial data. Because of the online availability of this dataset, many studies on this topic have been conducted since 2010. Recently, some new studies have investigated the nexus between energy consumption and financial development ([15–20]).

In the last two decades, the causal relationships between energy consumption and economic growth has been a hotly-debated issue. In our literature review we found that the same causality methods have been employed, but the results vary [21]. revealed in their study that there is no significant relationship between energy consumption and economic growth in Indonesia for their dataset from 1971 to 2007 [22]. found neutral effect between energy and growth in Spain for a panel dataset from 1995 to 2012 [23]. found long-run causality between energy and growth and showed a short-run nexus growth of energy consumption for the economies of West African States [24]. uncovered some evidence of e short-run relationships between energy consumption and economic growth in both low- and high-income groups of countries. Unidirectional causality running from energy to income in India was found by Ref. [25] for a dataset from 1955 to 1990 [25,26]. demonstrated a dynamic causal relationship between energy and real GDP in India using time series data for 1971 to 2006 [27]. found unidirectional causality between natural gas consumption and economic development in China for the period from 1980 to 2012. In all those studies, we found that the results vary with different cases even though the same casualty tests were employed [14,28]. used the Granger causality test and found opposite causal relationships between energy and growth for the United States [29]. showed bidirectional causality between energy consumption and economic growth for 15 Asian countries for the period of 1980–2011 and [30] also showed bidirectional causality for India's agriculture sector for the period of 1972–2008 [3]. found bidirectional causality between electricity consumption and output in the coastal region in Turkey for a dataset from 1995 to 2013 [22]. showed a bidirectional causality between energy consumption and economic growth for Italy and USA for a panel dataset from 1995 to 2012. Since the 2000s, research has been focused on the impact of renewable energy consumption on economic growth.

[31] revealed the long-term effect of financial development on energy consumption but found no short-run relationship [30]. analysed the bidirectional causality between energy consumption and economic growth for Pakistan from 1972 to 2008 [19]. showed via economic growth that financial development has a positive and significant effect on energy consumption in Pakistan [32]. found a feedback effect between electricity consumption and economic growth in Pakistan. The outcomes of these studies vary according to the region studied and methods used. The nonlinearity methods were taken into account by Ref. [33] for panel of 53 countries and time series data for India [20]. To the best of our knowledge, asymmetry studies have not conducted in Pakistan so far.

Our study contributes to the existing literature on the growth–energy nexus by examining the asymmetric link between the pair of variables. We adopt an asymmetric approach because positive and negative variation in one variable does not have the same effect on the other variable. The presence of a nonlinear nexus between the variables can be affected by various factors, such as political changes, financial and economic issues, and technology innovations that bring either positive or negative variations in energy consumption and do not have the same impact on economic growth. For this purpose, the Cobb–Douglas production function is used to capture the asymmetric effect of energy consumption on economic growth in the case of Pakistan. The methods we have used in our study are as follows: (i) Because of low explanatory power, we have applied the Unit Root Test proposed by Ref. [34] to investigate the integration order and a single unknown structural break in the series (ii) The BDS [35]]; test has been applied to test whether nonlinearity exists in the series; (iii) We have employed the Non-Linear Auto-regressive Distributed Lag (NARDL) model, developed by Ref. [36], and the asymmetric causality test, proposed by Ref. [37], to enrich the existing literature on the growth–energy nexus. However [38], have identified two drawbacks of the NARDL model that are not applicable to the exchange market. The first drawback is the conventional threshold approach, which means that variables simply decompose into positive and negative. The other flaw in the model is that it ignores the expertise of planners and businessmen forecast analysis in the stock market. To the best of our knowledge, nonlinearity and asymmetrical methods have not been used so far for data collected in the case of Pakistan.

The rest of our study is organized as follows: Section 2 provides a description and primary analysis of the time series data, and the methodology used is developed in a subsection. Section 3 discusses the empirical outcomes. Section 4 concludes the study and provides energy policy implications.

2. Data and methodology

2.1. Data

Pakistan has the fifth-largest population in the world, behind China, India, the United States, and Indonesia (U.S. Census Bureau Population June 2019). According to the U.S. Energy Information Administration, in 2016, Pakistan's total primary energy usage was 3.115 Quadrillion Btu, ranking 33rd in the world, which is indicative of energy poverty in Pakistan. Over the last decade, Pakistan has suffered considerably from an energy crisis, as a result of increased circular debt, electricity shortages, and an incapable distribution system, leading to a 2–3% cut in GDP by in 2013 (Asian Development Bank). Various studies have investigated the relationship between energy consumption and economic growth in Pakistan

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[19,32] but studies of either asymmetry or nonlinearity have not yet been conducted. For these reasons, we decided to examine the case of Pakistan in our study.

The annual time series data have been collected from The World Bank online database. The analysis and descriptive statistics of variables are presented in Table 1. Table 1 consists of Energy use (kg of oil equivalent), GDP (in constant 2010 Pakistani currency), Gross fixed capital formation (in constant 2010 Pakistani currency), and Agriculture, value added (in constant 2010 Pakistani currency), from 1971 to 2014. All the variables have been transferred to per capita units by dividing the total population in each year. The Energy use (kg of oil equivalent per capita) is denoted by energy consumption, GDP per capita is denoted by economic growth, and agriculture per capita is a proxy for agriculture. Our variables are in annual frequency time series data over the period from 1970 to 2014, and these variables have been used to a large extent in previous studies [2,5,24]. To achieve accurate results, we have transformed all our variables to natural logarithm.

Table 1
Descriptive statistics and pair-wise correlations.

	Y_t	E_t	A_t	K_t
Mean	10.546	5.986	9.167	8.913
Median	10.617	6.033	9.134	8.941
Maximum	10.957	6.261	9.361	9.163
Minimum	10.061	5.653	8.980	8.555
Stand. Dev.	0.277	0.197	0.128	0.156
Skewness	−0.290	−0.319	0.193	−0.624
Kurtosis	1.882	1.639	1.508	2.697
Jarque−Bera	2.908	4.142	4.352	3.027
Probability	0.234	0.126	0.114	0.220
Sum	464.017	263.369	403.339	392.181
Sum Sq. Dev	3.307	1.670	0.703	1.050
Observations	44	44	44	44
Y_t	1			
E_t	0.985	1		
A_t	0.928	0.933	1	
K_t	0.773	0.774	0.593	1

Y denotes economic growth; E denotes energy consumption; A denotes agriculture; and K represents capital.

2.2. Methodology

2.2.1. The NARDL co-integration testing approach

Some hidden and unexpected events, such as financial and economic crises, revolutions, and political changes, which can lead the deficiency of linear approaches to capture the relationship among the economic time series data. To capture the nonlinear and asymmetric co-integration between the variables, we employed the multivariate NARDL model, which also distinguishes between long-run and short-run effects of the independent variables on dependent variables. Furthermore, this is a suitable instrument for time series data to test cointegration among the variables in a single equation [39]. Additionally, other cointegration models support only integrated order at either 1 or I(1) for all variables, whereas the NARDL test permits integrated orders of either I(0), I(1) or a combination of both. Here, the Vector Error Correction Model can be used, but it has a convergence problem due to the large number of parameters and, with same integration order of the time series, the NARDL model is free from the integration order restriction shown by Ref. [40].

All variables are decompose into the positive and negative partial sums are given in the following manner.

$$x_t^+ = \sum_{j=1}^{t} \Delta x_j^+ = \sum_{j=1}^{t} \max(\Delta x_j, 0) \ and \ x_t^- = \sum_{j=1}^{t} \Delta x_j^- = \sum_{j-1}^{t} min(\Delta x_j, 0)$$

Where x_t denotes the independent variables. $E_t, A_t and\ I_t$.

To determine asymmetric long-term co-integration, we have employed the bound test, proposed by Ref. [36], which is a combined test for all repressors of all lagged levels. Two tests are employed, the null hypothesis in F-statistic test $\theta^+ = \theta^- = \theta = 0$, and in t-statistic the null hypothesis of $\theta = 0$ against the alternative hypothesis $\theta < 0$. In case of rejection of the null hypothesis it means accepts the alternative hypothesis revealing the long-term relationship among the variables. To estimate long-run asymmetric coefficients, we have used $Lmi^+ = \theta^+/\rho$ and $Lmi^- = \theta^-/\rho$,

$$\Delta Y_t = \alpha_0 + pY_{t-1} + \theta_1^+ E_{t-1}^+ + \theta_2^- E_{t-1}^- + \theta_3^+ A_{t-1}^+ + \theta_4^- A_{t-1}^- + \theta_5^+ K_{t-1}^+ + \theta_6^- K_{t-1}^- + \sum_{i=1}^{p} \alpha_1 \Delta Y_{t-1} + \sum_{i=0}^{q} \alpha_2 \Delta E_{t-1}^+ + \sum_{i=0}^{q} \alpha_3 \Delta E_{t-1}^- + \sum_{i=0}^{q} \alpha_4 \Delta A_{t-1}^+ + \sum_{i=0}^{q} \alpha_5 \Delta A_{t-1}^- + \sum_{i=0}^{q} \alpha_6 \Delta K_{t-1}^+ + \sum_{i=0}^{q} \alpha_7 \Delta K_{t-1}^- + D_t + \mu_t \quad (1)$$

where i = 1 …. 8., α_i represent short-run coefficients, and θ_i denotes long run coefficients. Here, short-run coefficients reveal the immediate effect of independent variables on dependent variables. On the other hand, long-run coefficients show the speed and reaction time of the adjustment towards an equilibrium level. By employing the Wald test to analyse the null hypothesis for short-run asymmetry is ($\alpha = \alpha^+ = \alpha^-$) and for long-run asymmetry ($\theta = \theta^+ = \theta^-$) for variables $Y_t, E_t, A_t \ and \ K_t$ which represent economic growth, energy consumption, agriculture, and capital, respectively. D_t is the dummy variable determined via a unit root test, which shows the structural break date (t). The optimal lags p and q will be determined by the Akaike information criterion for the dependent variable Y_t, and the independent variables. $E_t, A_t \ and \ I_t$.

where these long-term coefficients reveal the positive and negative changes of the exogenous variables and show the long-run relationship between the variables.

To estimate the asymmetric dynamic multiplier effects, we use the equation below:

$$m_h^+ = \sum_{j=0}^{h} \frac{\partial Y_{t+j}}{\partial E_t^+}, m_h^- = \sum_{j=0}^{h} \frac{\partial Y_{t+j}}{\partial E_t^-}, m_h^+ = \sum_{j=0}^{h} \frac{\partial Y_{t+j}}{\partial A_t^+}, m_h^- = \sum_{j=0}^{h} \frac{\partial Y_{t+j}}{\partial A_t^-}, m_h^+ = \sum_{j=0}^{h} \frac{\partial Y_{t+j}}{\partial K_t^+}, m_h^- = \sum_{j=0}^{h} \frac{\partial Y_{t=j}}{\partial K_t^-}$$

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If h→∞, $m_h^+ \rightarrow Lm^+ and\, m_h^- \rightarrow Lm^-$, it shows the asymmetric response of the exogenous variables to positive and negative changes in endogenous variables. We can observe dynamic adjustment from initial equilibrium to new equilibrium in system variables.

2.2.2. Asymmetric causality tests

The asymmetric causality test, recently adopted by Ref. [37], is used to determine the direction of the asymmetric causal relationship between the variables. The main reason for employing the [41] test is to check nonlinear effects and to discriminate between positive and negative shocks [37].J showed that the variables can be a random walk process, in the below form:

$$Y_t = Y_{t-1} + e_{1t} = Y_0 + \sum_{i=1}^{t} e_{1i} \; and \; X_t = X_{t-1} + e_{2t} = X_0 + \sum_{i=1}^{t} e_{2i} \tag{2}$$

Where t = 1, 2 …. T, Y_0 and X_0 are initial values, and e_{1t} and e_{2t} represent the error terms. The positive shocks are represented by $e_{1i}^+ = \max(e_{1i}, 0)$ and $e_{2i}^+ = \max(e_{2i}, 0)$, and the negative shocks are represented by $e_{1i}^- = \min(e_{1i}, 0)$ and $e_{2i}^- = \min(e_{2i}, 0)$.

The positive and negative shocks of the variables in an asymmetric framework are given below:

$$Y_t = Y_{t-1} + e_{1t} = Y_0 + \sum_{t=1}^{t} e_{1i}^+ + \sum_{t=1}^{t} e_{1i}^- \; and \; X_t = X_{t-1} + e_{2t} = X_0 + \sum_{t=1}^{t} e_{2i}^+ + \sum_{t=1}^{t} e_{2i}^-$$

In our analysis, the cumulative forms of both positive and negative shocks of the variables are used in the following equation:

$$Y_t^+ = \sum_{i=1}^{t} e_{1i}^+, Y_t^- = \sum_{i=1}^{t} e_{1i}^-, E_t^+ = \sum_{i=1}^{t} e_{2i}^+, E_t^- = \sum_{i=1}^{t} e_{2i}^-, A_t^+ = \sum_{i=1}^{t} e_{3i}^+, A_t^- = \sum_{i=1}^{t} e_{3i}^-, K_t^+ = \sum_{i=1}^{t} e_{4i}^+, K_t^- = \sum_{i=1}^{t} e_{4i}^- \tag{3}$$

[37] reveals asymmetric causality among the variables of both positive and negative shocks. To determine an asymmetric causal relationship, we need to adopt the vector autoregressive (VAR) model with order p. The lag-based criterion suggested by Refs. [42,43] used to select the optimal lag order for the VAR model. The following Hatemi-J Criterion (HJC) model is adopted for lag selection:

$$\mathrm{HJC} = \ln(|A_j|) + q\left(\frac{n^2\, lnT + 2n^2 \ln(lnT)}{2T}\right), q = 0\,, \ldots\ldots p \tag{4}$$

The symbols used in the equation are described below:

Where *ln* represents the natural logarithm and $|A_j|$ represents the determinant of the estimated variance-covariance matrix of the error terms in the VAR model with using lag order q and number of equations, and n represent the number of variable that are used in the VAR model, and 'T' shows the number of observation (sample size). The null hypothesis represented by k^{th} element of $\sum X_{it}^+$ does not Granger-cause the ω^{th} element of Y_{it}^+. The null hypothesis H_0 :row ω, column k element in A_r equal to zero were r = 1, …,p.

3. Results

In this part, we illustrate the descriptive statistics and unit root tests for all variables and we employ the NARDL asymmetric cointegration test. Finally, we estimate the asymmetric causal association between the variables by employing asymmetric causality tests proposed by Ref. [37].

3.1. Descriptive statistics and unit root tests

In Table 1, we present descriptive statistics and pair-wise correlations of all the variables. Our results showed that economic growth, energy consumption, and capital are negatively skewed, while agriculture is positively skewed, meaning that tails are longer than normal distribution. The kurtosis test shown light tailed than a normal distribution for all variables. The Jarque–Bera test rejects the null hypothesis of normality for economic growth, energy consumption, capital, and agriculture. Moreover, strong and positive correlation is found between economic growth and energy consumption. Capital and agriculture are also positively correlated with economic growth. In addition, energy consumption is also positively correlated with agriculture and capital, which leads to high economic growth.

In this section, the unit root test to be performed because of the NARDL model [36] requires ensuring that all variables are stationary and that none of them is integrated at order 2 or $I(2)$. In Table 2, the unit root test shows that all the variables are stationary and integrated at order $I(0)$ or $I(1)$ to investigate cointegration between the variables. To examine the variability of the variables we employed KPSS [44] and PP [45] unit root tests. The results reveal that variables, economic growth, energy consumption, agriculture, and capital are stationary at level and 1st difference with intercept and trend in the KPSS test, whereas, under the PP test, at first difference all variables are found to be either stationary or integrated at order I(1).

In econometrics [46], discovered an unexpected structural change in time series that can cause errors in forecasting. The unit root test accepts the null hypothesis and reveals that the series is stationary, while unknown structural breaks exist [34]. stated that the unit root test provides vague results due to weak distribution size and low explanatory power. To remove the unknown structural change, we employed the breakpoint unit root test, proposed by Ref. [34]. In Table 3, by employing structural break unit root test considering with both intercept and trend to find structural break. All variables are found to be non-stationary, but structural break exists in 1992, 2002, 1995, and 1998 for economic growth, energy consumption, agriculture, and capital, respectively. Actually, over the last three decades, Pakistan has faced numerous issues in terms of energy, economic, and financial policies. For example, during the 1990s, foreign remittances decreased, the trade deficit rose and, in turn, the growth rate was affected badly. Furthermore, after 9/11, petroleum production declined, oil prices jumped to $27.39/barrel,

Table 2
Unit root analysis without structural break.

Variable	KPSS		PP	
	Level	1st Diff.	Level	1st Diff.
Y_t	0.1609(5) **	0.0743(2) ***	−1.5100(3)	−5.8920(1) ***
E_t	0.1816(5) **	0.1396(1) *	0.3390(0)	−5.6973(0) ***
A_t	0.1463(4) **	0.1518(15) **	−3.2845(4) *	−9.8371(8) ***
K_t	0.1842(5) **	0.0484(2)	−1.2136(0)	−5.5920(5) ***

*, **, and *** denote significance levels of 1%, 5%, and 10%, respectively, for the null hypothesis. Values in brackets () represent lag order. The optimal lag length for testing unit root test of the variables shown in the parentheses.

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Table 3
Perron unit root analysis with structural break.

Variable	Trend and intercept		With only intercept	
	Statistics	Break Date	Statistics	Break Date
Y_t	−3.2334	1992	−3.4149	1979
E_t	−2.9893	2002	−2.6545	2007
A_t	−4.2478	1995	−4.4275	1995
K_t	−3.0834	1988	−2.3212	1981

*, **, and *** denotes significance levels of 1%, 5%, and 10%, respectively, for the null hypothesis.

and, in consequence, the energy supply to the manufacturing sector was affected. The existence of structural break unit root lead us to apply the NARDL bound test to investigate asymmetric cointegration among the variables.

To detect nonlinearity in our variables we have used the BDS test [35]. The BDS test results (Table 6) confirm nonlinearities in energy consumption, economic growth, agriculture, and capital. The null hypothesis of linearity is rejected, and the alternative hypothesis for nonlinearities of all variables is accepted. Moreover, Figs. 4–6 CUSUM also confirms nonlinearity, which indicating that the applied NARDL model is properly specified for energy consumption, economic growth, agriculture, and capital.

3.2. Asymmetry co-integration results

The NARDL results are given below in Table 4. The energy consumption, agriculture and industries explain $R^2 = 0.9342$ (93.42%) of economic growth, and the remaining amount is error term, 6.56% is the variation in economic growth. The results of a Durbin Watson test (2.3005) shows that there is no autocorrelation between the independent variables and economic growth. Moreover, we also note the absence of serial correlation (χ^2_{SC}) and White heteroscedasticity (χ^2_{HET}). The Wald test also reveals significant asymmetry co-integration for both the short-run and the long-run for all variables. And more importantly, the F-statistic value is above the upper critical limit; all these reliability tests confirm co-integration among economic growth, energy consumption, agriculture, and capital for the period from 1971 to 2014 for Pakistan. The F-statistics (F_{pss}) also confirm asymmetric co-integration among energy consumption, agriculture, capital, and economic growth. The detailed results are given below.

Table 4
Co-integration results.

Dependent variable: Y_t			
Variable	Coefficient	T-values	Probability
Constant	6.2524***	5.5697	0.0000
Y_{t-1}	−0.6214***	−5.5685	0.0000
E^+_{t-1}	0.5306***	3.8347	0.0012
E^-_{t-1}	0.6001**	2.0063	0.0601
A^+_{t-1}	−0.3904***	−6.3618	0.0000
A^-_{t-1}	−0.1668	−1.3440	0.1956
K^+_{t-1}	0.3242***	4.4505	0.0003
K^-_{t-1}	0.2057***	−3.8102	0.0013
D_{1979}	−0.0472***	−3.8101	0.0000
ΔE^+_t	0.4934***	3.8910	0.0011
ΔE^-_t	1.1250***	4.0656	0.0007
ΔE^-_{t-1}	0.8368***	3.2418	0.0045
ΔE^-_{t-2}	0.6399**	2.4005	0.0274
ΔA^-_t	**0.1162**	1.5414	0.1406
ΔA^-_{t-1}	0.2312**	2.4235	0.0261
ΔA^-_{t-2}	**0.1288**	1.4214	0.1723
ΔK^+_t	0.2199***	4.1954	0.0005
ΔK^+_{t-1}	−0.1755***	−3.1366	0.0057
ΔK^+_{t-2}	−0.0956*	−1.7616	0.0951
ΔK^-_t	**−0.0971**	−1.5978	0.1275
ΔK^-_{t-2}	0.2132***	3.8817	0.0011
R^2	0.9342		
Adj- R^2	0.8537		
D-W Stat	2.3005		
χ^2_{SC}	3.5644	[0.1683]	
χ^2_{HET}	19.0097	[0.6447]	
χ^2_{FF}	1.7306	[0.2058]	
L^+_E	0.8539***	L^-_E	0.9657*
L^+_A	−0.6283***	L^-_A	−0.2684
L^+_K	0.5217***	L^-_K	0.3310***
$W_{LR.E}$	12.2084***	$W_{SR.E}$	10.8926***
$W_{LR.A}$	18.5852***	$W_{SR.A}$	3.7659**
$W_{LR.K}$	13.1502***	$W_{SR.K}$	5.9902***
F_{PSS}	13.7522***		
T_{BDM}	−4.8620**		

"+" and "-" denote positive and negative variations, respectively, and D_{1979} represents the dummy variable of structural break for economic growth. χ^2_{HET}, χ^2_{SC} and χ^2_{FF} denote LM tests for heteroscedasticity, serial correlation and functional form, respectively. L^+ and L^- are the estimated long-run coefficients associated with positive and negative changes, respectively, defined by $\beta = -\theta/\rho$. The Wald test for the null hypothesis of long-run W_{LR} and for short-run FPSS shows the statistics from the [47] bounds test. TBDM shows the statistics from Ref. [48]. The p-values appear in brackets. ***, **, and * indicate significance levels of 1%, 5%, and 10%, respectively.

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3.3. Long-run and short-run co-integration

To determine the results in Table 4, we estimated that a long-term positive shock to energy consumption has a positive effect on economic growth (coefficient of 0.5306 with 1% significance), which indicates that a positive shock to energy consumption has a positive impact on economic growth in the Pakistan economy. In our result, a negative shock has positive impact on economic growth (coefficient 0.6001 at 10%). In the last part of the table, a one percent increase or decrease in energy consumption will increase economic growth by 0.8539 and 0.9657, respectively. By employing the Wald test for the null-hypothesis of no co-integration are rejected for short-run and long-term asymmetry energy consumption 10.8926 and 12.2084 at 1% significant, respectively. Both energy demand and economic growth are highly correlated and have a long-run relationship. Pakistan is one of the countries that has not had surplus energy since 1947. The renewable energy policy of 2006 and renewable energy technology have introduced energy production through utilising renewable resources. Pakistan is rich in renewable energy resources and can easily fulfil its energy demands by proper utilisation of these resources.

In the long-run coefficient, a positive shock to agriculture has a negative effect on economic growth (−0.3904 at 1% significance), and a negative shock to agriculture also has a negative effect on economic growth (−0.1668, not significant). The null-hypothesis and co-integration are both rejected for both the long-term and short-term at 18.5852 and 3.7659, at 1% and 5%, respectively. In the short-run assessment, we found an adverse effect on economic growth (0.2312 at 5% on lag 1).

In the long-run, positive and negative shocks to capital have a positive impact on economic growth (0.3242 and 0.2057 both at the 1% significance level), respectively. In the very short-term, a positive shock to capital has a positive effect on economic growth (coefficient 0.2199 at 1% significance), but a positive shock (at lag 1 and 2) and a negative shock (lag 0) have a negative effect on economic growth (positive lag 1−0.1755 at 1% and lag 2−0.0956 at 10%), and a lag 2 negative shock to capital has an inverse relationship with economic growth. From the results, we infer an adverse relationship between capital and economic growth.

Finally, the results of applying the dynamic multiplier adjustments, show in Figs. 1–3 that the economic growth adjustment is towards long run equilibrium in terms of positive and negative shocks in agriculture, energy consumption, and capital. Fig. 1 shows that initially positive change in energy consumption which dominate on negative change but afterward negative shocks dominate on positive change. However, a positive link is seen between energy consumption and economic growth. At the start of the period, negative and positive changes in agriculture are found significant in third quarter but onward the impact noted insignificant on economic growth in Fig. 2. The positive change is more dominate its negative shocks in capital and results implies that the positive nexus noted between capital and economic growth.

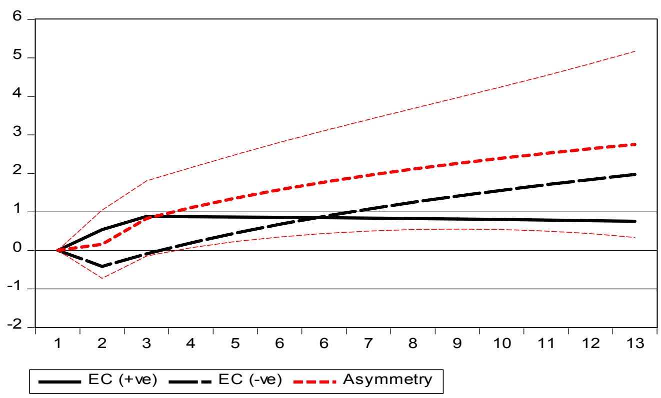

Fig. 1. Cumulative effect of energy consumption to economic growth. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

3.4. Asymmetric causalities between energy consumption and economic growth

To determine the casual relationship among the variables and their cumulative coefficient we employed the asymmetric causality test, proposed by Ref. [37]. At the very start of Table 5, it can be

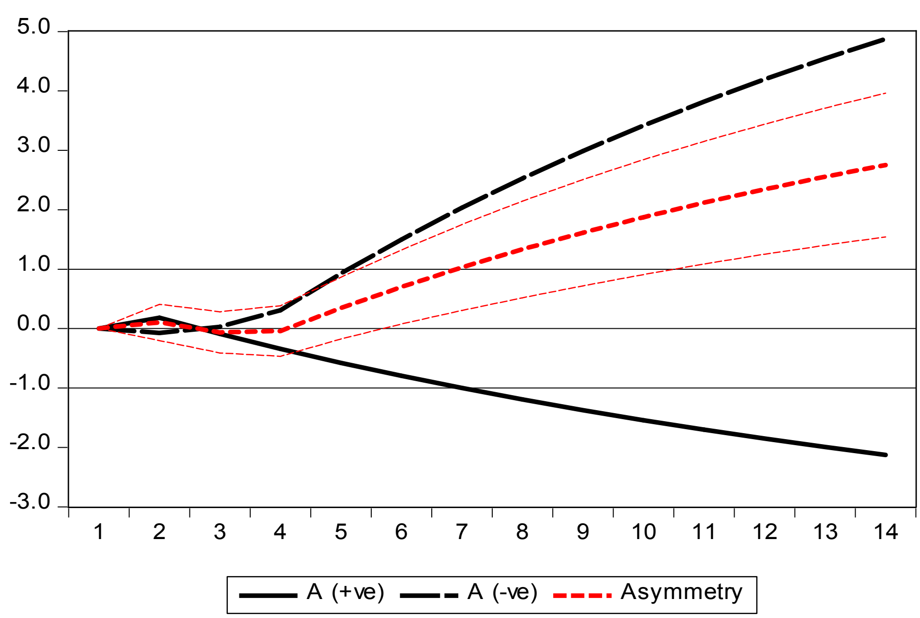

Fig. 2. Cumulative effect of agriculture to economic growth. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

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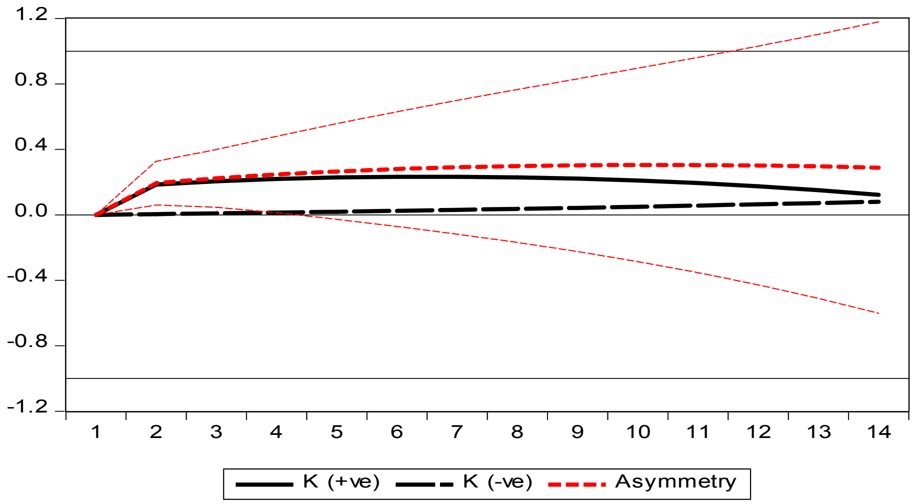

Fig. 3. Cumulative effect of capital to economic growth. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

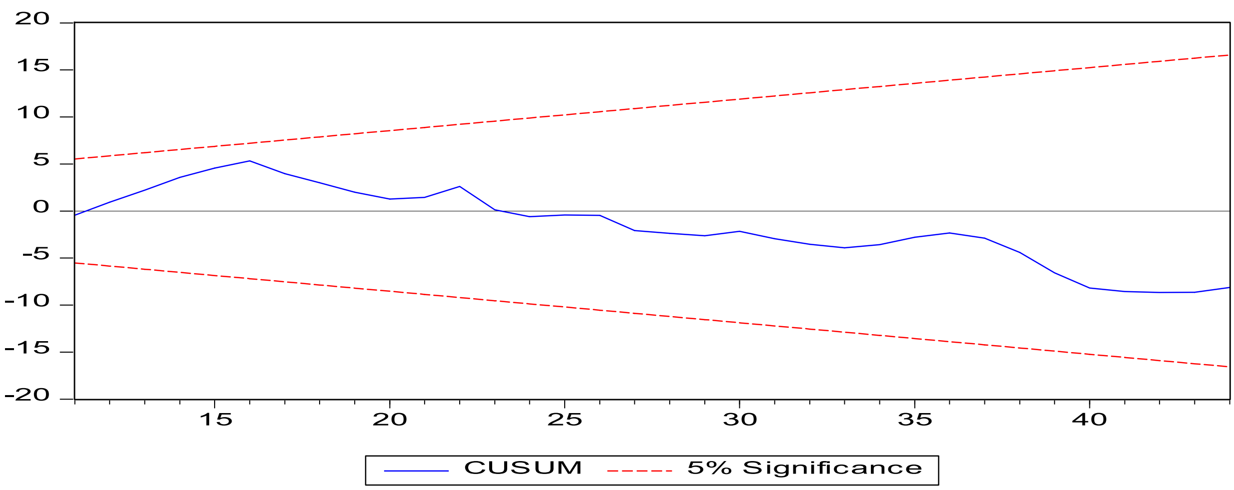

Fig. 4. Cumulative sum (CUSUM) test on energy. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

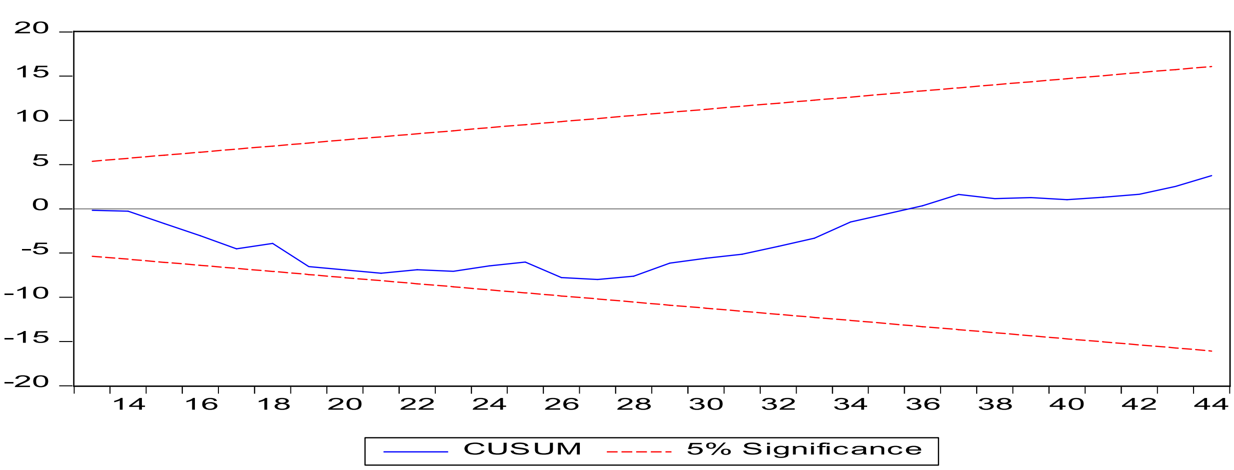

Fig. 5. Cumulative sum (CUSUM) test on Agriculture. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

noted that there is no causal effect of symmetric value (row 1). The neutral effect is noted between positive shocks in economic growth and positive shocks in energy consumption (row 2), and a similar result is noted for negative shocks of economic growth on energy consumption (row 3). The neutral effect is found for both the symmetric and asymmetric nexuses running from economic growth to energy consumption [5]. In (row 4), running from energy consumption to economic growth, we found symmetric causality as

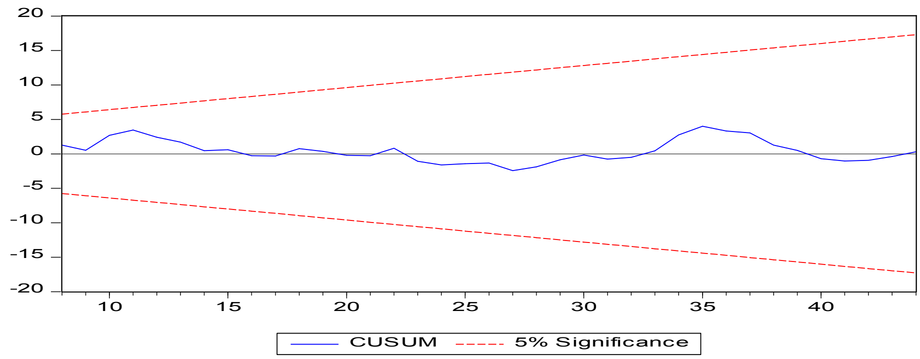

Fig. 6. Cumulative sum (CUSUM) test on Capital. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 5
Asymmetric and non-asymmetric Causality test.

Variables	Test Value	CV at 10%	CV at 5%	CV at 1%
(1) $Y_t \nRightarrow E_t$	0.178	4.200	6.011	10.009
(2) $Y_t^+ \nRightarrow E_t^+$	0.756	3.525	5.163	9.138
(3) $Y_t^- \nRightarrow E_t^-$	0.294	2.643	5.424	17.828
(4) $E_t \Rightarrow Y_t$	5.610**	3.276	4.745	8.371
(5) $E_t^+ \Rightarrow Y_t^+$	6.942**	3.250	4.818	8.865
(6) $E_t^- \nRightarrow Y_t^-$	2.557	5.261	7.079	12.367
(7) $Y_t \Rightarrow A_t$	7.338***	2.891	4.233	7.333
(8) $Y_t^+ \Rightarrow A_t^+$	3.794*	2.909	4.158	7.691
(9) $Y_t^- \nRightarrow A_t^-$	2.993	6.286	8.590	14.706
(10) $A_t \Rightarrow Y_t$	9.308*	8.030	12.890	18.803
(11) $A_t^+ \Rightarrow Y_t^+$	6.830**	3.393	4.494	8.742
(12) $A_t^- \nRightarrow Y_t^-$	0.096	3.338	4.960	10.667
(13) $Y_t \nRightarrow K_t$	0.747	2.989	4.297	7.763
(14) $Y_t^+ \nRightarrow K_t^+$	0.032	3.097	4.427	7.959
(15) $Y_t^- \nRightarrow K_t^-$	0.221	2.861	4.256	8.865
(16) $K_t \Rightarrow Y_t$	5.908**	2.944	4.267	7.581
(17) $K_t^+ \Rightarrow Y_t^+$	4.516**	3.024	4.448	8.366
(18) $K_t^- \Rightarrow Y_t^-$	10.906**	5.397	7.346	11.958

$\nRightarrow$″ and ″$\Rightarrow$″ represents no causlity and unidircetional causlity, respectively.
***, and ** indicate signaficance levels of 1% and 5%, respectively. Numbers in brackets represents rows. The HJC information is used for lag selection, while unrestricted extra lag is included in the VAR model for unit root effect, proposed by Ref. [41].

Table 6
Nonlinearity BDS test [35].

Variable	m = 2	m = 3	m = 4	m = 5	m = 6
Y_t	0.1991***	0.3389***	0.4362***	0.5057***	0.5557***
E_t	0.2027***	0.3412***	0.4373***	0.5051***	0.5528***
A_t	0.1457***	0.2402***	0.3008***	0.3435***	0.3715***
K_t	0.1660***	0.2837***	0.3605***	0.4092***	0.4382***

Note: The results indicate the BDS test based on residual values of all variables within VAR, with m dimension. *, **, and *** represent rejection of the null hypothesis of residuals *iid* at 10%, 5%, and 1%, respectively.

same revealed by Refs. [2,5]. The asymmetric nexus is noted running from energy consumption to economic growth in a positive shock of energy consumption and economic growth (row 5) [39]. also revealed asymmetric causality between energy consumption and economic growth for positive shocks. A neutral effect is noted for negative shock in energy consumption and economic growth (row 6). Policymakers should attract new investors to build more energy plants in a country to accelerate energy production and ensure an energy supply for industries.

There are causal relationship between economic growth and agriculture (for both asymmetric and symmetric) running from economic growth to agriculture (row 7 to 8). Further, there is a neutral effect noted for positive shocks in agriculture and economic growth (row 9). The asymmetric nexus is found between positive shocks in agriculture and economic growth (row 11), whereas no causal relationship is noted in negative shocks to agriculture and economic growth (row 12) running from agriculture to economic growth. In (row 10) a symmetric causal relationship is noted from agriculture to economic growth. These findings imply that an asymmetric feedback effect is found between positive shocks in agriculture and economic growth, and similarly symmetric results also confirm the feedback effect.

From economic growth to capital, neutral effects are noted for both between positive and negative shocks to capital and economic growth (row 14 and 15). The same result is noted for the symmetric nexus between capital and economic growth (row 13). In (row 16) we find symmetric causality between capital and economic growth, running from capital to economic growth [20,49]. revealed a symmetric causality between capital and economic growth for India. Finally, we note the asymmetric causal relationship between capital and economic growth in both negative and positive shocks, running from capital to economic growth (row 17 and 18). The same asymmetric causalities were found by Ref. [39] for both positive and negative shocks in the case of Portugal.

4. Conclusion

By employing production function as a Non-linear Auto-Regressive Distributed Lag (NARDL), we examine the nexus between economic growth, energy consumption, agriculture, and capital for time-series data from 1971 to 2014 in the case of Pakistan. By using a non-linear ECM under the NARDL developed by Ref. [36], we investigate the long-term and short-term equilibrium relationship. Our findings reveal that a strong asymmetric co-integration relationship exists between the variables. Moreover, asymmetric causality is investigated for energy consumption, agriculture, capital, and economic growth. From these findings, we infer that, due to bad governance and erroneous policy, Pakistan's energy sector has never fulfilled the energy demand in the country. Among the economic sectors, agriculture plays a vital role in Pakistan's economy. An economy like Pakistan's can never meet its targets without an agriculture sector. For long-run economic growth, the state should invest more to build better infrastructure. The government authorities and policymakers should attract new investors to invest more in Pakistan to boost the country's economy.

Our main conclusion is that energy policy plays a significant role in sustainable development and promotes growth in Pakistan. However, the energy sector alone is not sufficient to boost the country's revenues. This research will support policymakers in attracting foreign and local investors to invest in energy, to encourage electricity production, to overcome environmental issues, and to design new technologies for saving energy. Pakistan is currently facing energy and water crises. These two problems can be dealt with simultaneously by building new hydropower dams in the country. These can offer cheap electricity to consumers and will also provide water reservoirs for the agriculture sector. Future studies on this subject should consider the asymmetric relationship between variables and choose an empirical approach accordingly.

Declaration of competing interest

The authors declare that there is no conflict of interest, and is approved by all authors for submission to your esteem journal.

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Appendix A

Variables	Description and treatment	Source
Economic growth (Y)	Real gross domestic products (GDP) taken in constant 2010 Pakistani currency and annual frequency. The data transferred to per capita units by dividing the total population in each year. The data transformed into natural logarithm.	The World Bank - World Development Indicators database (1971–2014).
Energy consumption (E)	Energy consumption is measured by kg of oil equivalent and transferred into per capita by dividing the total population in each year. And also converted into natural logarithm.	The World Bank - World Development Indicators database (1971–2014).
Agriculture (A)	Agriculture is measured in value added (constant 2010) in Pakistani currency. The data transferred into per capita by dividing the total population in each year. And also converted into natural logarithm.	The World Bank - World Development Indicators database (1971–2014).
Capital (*K*)	Capital is proxy of Gross fixed capital formation in annual frequency and Pakistani currency. The data transferred into per capita by dividing the total population in each year. And also converted into natural logarithm.	The World Bank - World Development Indicators database (1971–2014).

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