Science of the Total Environment xxx (xxxx) 137364

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: http://ees.elsevier.com

Asymmetric impact of energy consumption and economic growth on ecological footprint: Using asymmetric and nonlinear approach

Khan Baz[a], Deyi Xu[a,*], Hashmat Ali[b], Imad Ali[c], Imran Khan[c], Muhammad Muddassar Khan[b], Jinhua Cheng[a]

[a] School of Economics and Management, China University of Geosciences, Wuhan, China
[b] Department of Management Sciences, Abbottabad University of Science and Technology, Pakistan
[c] College of Economics and Management, Northwest A&F University, China

ARTICLE INFO

Article history:
Received 31 December 2019
Received in revised form 14 Febraury 2020
Accepted 15 Febraury 2020
Available online xxx
Editor: Huu Hao Ngo

Keywords
Ecological footprint
Energy consumption
Environmental quality
Asymmetries
Nonlinear autoregressive distributed lag (NARDL)

ABSTRACT

The main objective of this article is to examine the impacts of energy consumption and economic growth on environmental quality in Pakistan. We use the ecological footprint (environmental quality) as a target variable, the control variables of gross domestic products are a proxy of economic growth, and energy consumption and gross fixed capital formation are proxies of capital from 1971 to 2014. For this purpose, a unit root test with break dates is employed for a stationary check, and a BDS test is used for nonlinearity. The nonlinear autoregressive distributed lag approach is employed to assess the asymmetric co-integration among the variables. These results confirm the asymmetric co-integration among the variables. The asymmetric causality technique is also applied to scrutinize the causal link between the variables. The asymmetric feedback effect is observed between positive shocks to environmental quality and energy consumption, and symmetrically, environmental quality causes energy consumption. By contrast, the neutral effect is observed among environmental quality, economic growth, and capital. Based on these findings, current energy portfolios should be diversified by either enhancing or incorporating renewable energy technologies, and this is indispensable to support the existing successful strides of environmental policies. Thus, policymakers must buttress their commitments to reduce emissions by sustaining and decarbonizing the trajectory of economic growth.

1. Introduction

The energy sector plays an essential role in sustainable economic growth for both developed and developing economies, and energy is a key input in production processes. Accordingly, because of the importance of energy in the economic growth, studies have investigated the nexus between energy and growth (Sarwar et al., 2017; Shahbaz et al., 2017a; Isik et al., 2018; Nordin and Sek, 2018; Tugcu and Topcu, 2018; Benkraiem et al., 2019). The manufacturing sector is heavily dependent on electricity availability. The consequences of greater energy demand are the substantial pressures on the environment and ecosystem and are pertinent to energy economists, environmentalists, and policymakers worldwide that design and implement friendly energy–environment policies. Although the energy–growth nexus is valid for sustainable growth, it is also true that energy use has been responsible for environmental degradation through carbon dioxide (CO_2) emissions, which are emitted from the burning of fossil fuels in industrial production. Rising energy demand and the concern for climate change caused by the massive consumption of fossil fuel sources have led many economic countries to shift toward renewable energy to upgrade environmental quality (Kuriqi et al., 2019a). Nevertheless, Ali et al.'s (2019) evidence has been presented on the negative impacts of hydropower on the ecosystem. However, an expectation is that energy consumption would have a positive impact on environmental pollution and that a strong relationship would exist between the environment and economic activities. For the purpose of this study, we focus on the relationship between ecological footprint (EF), economic growth, and energy consumption in Pakistan.

Our study investigates the environmental quality, energy consumption, and economic growth nexus by focusing on the Pakistan case. Investigations of environmental degradation are notable for many reasons. First, according to the World Bank (2016), there are critical, worrying situations in terms of global environmental pollution. Second, the Pakistan energy situation is critical because the total demand for energy is more than the supply. Therefore, the energy sector relies on fossil fuels to generate more electricity, disrupting the environment in terms of CO_2 emissions and increasing trade deficits because of fossil fuel imports.

Under these circumstances, we consider EF as one unit of various natural areas that contribute to and support the national economy. This information and other information on the accessibility of forests, water, fresh air, grazing, and cultivation areas compose the EF. Thus, in this

* Corresponding author.
E-mail address: xdy@cug.edu.cn (D. Xu)

https://doi.org/10.1016/j.scitotenv.2020.137364
0048-9697/© 2018.

study, the EF is employed as a proxy of environmental quality for many reasons. Accordingly, during the process of economic activities, the carrying capacity of the earth, natural resource consumption, and the absorption capacity of ambient pollution. In addition, consideration of the EF is adopted to provide a broader prospective. Since the introduction of the EF, it has been continuously considered in relation to environmental quality. According to our review of the literature, several studies have investigated the EF in a linear, symmetric model for different regions. Furthermore, nonlinear and asymmetric techniques not have been adopted for the EF, energy consumption, and economic growth in Pakistan.

In the literature, empirical studies have investigated the interactions among economic activities, energy consumption, and environmental degradation. The literature is divided into two sections: the first section has considered economic–environment nexus. This link can has been demonstrated by investigating variability and using monotonic, quadratic, and cubic approaches. However, because of the economic situation of Pakistan, we use the nonlinear and asymmetric techniques to assess the relationship between the variables. The pioneer analysis (Grossman and Krueger, 1991; Grossman and Krueger, 1995) of growth in economies demonstrated that it might not affect the environment. Balado-Naves et al. (2018) also considered the idea that expending economic activities may produce new opportunities for a friendly environment and improve greener technical efficiency. In a literature review, the majority of studies the environmental quality as CO_2 emission, but recently, a few studies have used EF as a proxy of environmental quality (Lanouar, 2017; Bello et al., 2018). Yousefisahzabi et al. (2011) investigated the link between the CO_2 emission and economic growth by using a panel dataset to investigate the case of Iran. Unidirectional causality was noted by Lee and Yoo (2016)) after they ran economic growth and CO_2 emission in time series data in the case of Mexico. Chang (2010) also implied a causality that ran from economic growth to CO_2 in the case of China. The same results demonstrated by Saboori et al. (2012) for Malaysia. Galli et al. (2012) showed that economic activities affected environmental quality by using panel data in the case of India. Baloch et al. (2019) also implied a causal link between economic growth and environmental quality in a panel dataset of 59 Belt and Road countries. Notably, Ozturk and Al-Mulali (2015) showed unidirectional causality running from CO_2 emission to economic growth. The feedback effect was investigated by Menyah and Wolde-Rufael (2010); Shahbaz et al. (2013) between economic growth and CO_2 emission. Additionally, the neutral effect was implied by Kasman and Duman (2015) and Wang et al. (2016) between CO_2 emission and economic growth.

In the literature, the majority of researchers have solely relied on CO_2 emission as measure of environmental quality, and a small portion of literature has indicated that the EF is related to environmental quality (Ozturk and Al-Mulali, 2015; Bello et al., 2018; Alola et al., 2019b; Destek and Sinha, 2020). The two major problems of climate change and global warming have been hot topics of discussion, forethoughts, and concerns among economists, researchers, academic scholars, government and private institutions, and policymakers. As per the International Panel on Climate Change, the annual temperature increase has been within the range of 1–7 K during the span of 1960 to 2100 within various CO_2 emission abstracts (Solomon et al., 2007). Therefore, in the literature, energy use and economic growth have largely been used as a proxy of environmental quality.

Mrabet et al. (2017) employed the ARDL technique to investigate the nexus among trade openness, economic growth, oil prices, and environmental quality from 1980 to 2011 in the case of Qatar by using EF as a proxy of environmental quality. Their results showed that economic growth degrades environmental quality in the long run. Furthermore, Imamoglu (2018) revealed that gross domestic product (GDP) and energy consumption upgrade the EF, after investigating the formal and informal economy in Turkey. Destek et al. (2018) employed the EKC and EF as determinants of environmental quality degradation in the European Union region and found their nexus with renewable energy, non-renewable energy, trade openness, and economic growth. Kuriqi et al. (2019b) showed renewable energy should be developed in a sustainable manner to mitigate as much as possible the adverse impacts on the ecosystem. Bejarano et al. (2019) also showed the inverse effect between trade-off and environmental quality. The EKC hypothesis confirmed the existence of the nexus between the variables and indicated that an increase in non-renewable energy has positive impacts on the EF.

Uncertainty remains regarding the function of energy consumption, economic growth, and capital growth in environmental quality mitigation. Nevertheless, the complexities comprise factors that have varied because of prescribed environmental regulations and the economic models among countries used to clear up the ambiguities of climate factors. To advance the literature, we consider EF against CO_2 because several countries are struggling with problems related to the ecological deficit. The main objective of our study is to propose econometric techniques that permit us to consider the nonlinear and asymmetric co-integration among environmental quality, energy consumption, economic growth, and capital in the case of Pakistan from 1971 to 2014. The idea behind the asymmetry and nonlinearity approaches, and the positive and negative changes in one exogenous variable, do not affect another variable in the same manner (Shahbaz et al., 2017b; Tugcu and Topcu, 2018; Baz et al., 2019). The existence of a nonlinear relationship among the variables is affected by several factors, for example, financial, economic, political, social, and international affairs, and technological advancement provides either negative or positive variation in energy use, which does not have the same impact on environmental quality. In this regard, we use the nonlinear autoregressive distributed lag (NARDL) model proposed by Shin et al. (2014) and the asymmetric causality test developed by Hatemi-j (2012) to enhance the literature on environmental quality and energy nexus. We also employ the unit root test (Kim and Perron, 2009) to find the integration order and unknown structural break date in the series. Notably, the BDS (Broock et al., 1996) test has been used to capture the presence of nonlinearity in series. As per the literature, and according to our review of the literature, asymmetric and nonlinear econometric techniques have not been investigated between environmental quality and energy consumption in Pakistan.

The remainder of our study is organized as follows. In Section 2, we examine the variables and explain the adopted methodology, asymmetry, and nonlinear approach, which have not been studied in either nexus. Section 3 presents the analysis of empirical results. In Section 4, we conclude our study by presenting policy suggestions based on empirical results.

2. Data and methodology

2.1. Data

Energy is an indispensable factor in socio-economic activities and economic transitions in developed and developing countries. This is cleared in the possibility of access to energy to increase well-being and livelihood. Nevertheless, the combustion of fossil fuels leading CO_2 emission has been recognized as a prime contributor to the degradation of the global environment. Thus, we attempt to investigate the nexus among a set of variables—EF, energy consumption, economic growth, and capital—for the set of annual time series data from 1971 to 2014 in the case of Pakistan. In this study, we examine the significant impact on environmental quality because of energy consumption and economic growth. The EF data is measured in global hectares (hga), which comprise both land and sea, and are collected from the Global Footprint network. The energy consumption (kg of oil equivalent), economic growth (real GDPs in constant 2010 local currency), and capital (real gross fixed capital formation in constant 2010 local currency) are from the World Bank Development Indicators. All comprise variables are transferred into per capita by dividing by the total population of each year. Further, to obtain accurate and precise empirical results, all variables are converted into natural logarithms from Shahbaz et al. (2017a). EFs have been discussed (Alola et al., 2019b; Saint Akadiri et al., 2019; Wang, 2019).

2.2. Methodology

2.2.1. The NARDL co-integration approach

In the section, we applied the multivariate NARDL model proposed by Shin et al. (2014) to capture the nonlinear and asymmetric relationships between the variables. The main idea behind the NARDL model is unexpected and hidden events, such as economic and financial crises, political changes, and other disasters, which lead to inadequacy in linear approaches to investigate the nexus among variables. In addition, the model distinguishes the short-run and long-run effects of exogenous variables on the dependent variables. Moreover, unlike other models, the integrated order of time series is considered the same, whereas the NARDL model accepts integration orders of *I* (*0*), *I* (*1*) or considers both. Shin et al. (2014) proposed that the multi-collinearity problem should be solved by selecting the appropriate lag order.

The asymmetric error correction models are presented as follows:

$$\begin{aligned}\Delta EF_t = {} & \alpha_0 + \rho EF_{t-1} + \gamma_1^+ EC_{t-1}^+ + \gamma_2^- EC_{t-1}^- \\ & + \gamma_3^+ GDP_{t-1}^+ + \gamma_4^- GDP_{t-1}^- + \gamma_5^+ CAP_{t-1}^+ \\ & + \gamma_6^- CAP_{t-1}^- + \sum_{i=1}^{p} \alpha_1 \Delta EF_{t-i} + \sum_{i=0}^{q} \alpha_2 \Delta EC_{t-i}^+ \\ & + \sum_{i=0}^{q} \alpha_3 \Delta EC_{t-i}^- + \sum_{i=0}^{q} \alpha_4 \Delta GDP_{t-i}^+ \\ & + \sum_{i=0}^{q} \alpha_5 \Delta GDP_{t-i}^- + \sum_{i=0}^{q} \alpha_6 \Delta CAP_{t-i}^+ \\ & + \sum_{i=0}^{q} \alpha_7 \Delta CAP_{t-i}^- + Date_t + \epsilon_t\end{aligned} \quad (1)$$

where, γ_i represents long term, and α_i exemplifies short-term coefficients with i = 0, 1….7. In Eq. (1), the short-run analysis shows the instantaneous impacts of exogenous variables on the endogenous variable. Long-run coefficients indicate the reaction time of the adjustment in the direction of the equilibrium level. In this study, we employed a time series method to investigate how other independent variables, such as energy consumption, economic growth, and capital, explain the correspondence of the environmental quality as extended by EF. EF is represented by EF_t; energy consumption by EC_t; economic growth by GDP_t; and capital by CAP_t (for more details see the Data section). The dummy variable, structural break date, was identified through a unit root test (Kim and Perron, 2009) and is also used in the equation. We examined the long-run ($\gamma = \gamma^+ = \gamma^-$) and short-run ($\alpha = \alpha^+ = \alpha^-$) asymmetry for all variables by employing the Wald test. *p* and *q* denote the optimal lags for the endogenous variable (EF_t) and exogenous variables (EC_t, GDP_t, CAP_t), which are determined through the Akaike information criterion.

The exogenous variables were decomposed into positive and negative partial sums as follows:

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

where y_t denotes EC_t, GDP_t, and CAP_t.

The asymmetric co-integration was determined through a bound test proposed by Shin et al. (2014) for all regressors with lagged levels. We also applied the F statistic proposed by Pesaran et al. (2001) and the *t* statistic (Banerjee et al., 1998) to test the null hypothesis of no co-integration $\gamma = \gamma^+ = \gamma^- = 0$ and $\gamma = 0$, respectively.

2.2.2. Asymmetric Granger causality test

The process of Granger causality, a variable affects another variable, has attracted scholars attention since the forerunner study by Granger (1969). In the literature, symmetric techniques were used to determine the direction of the causal nexus between the variables, but recently, Hatemi-j (2012) proposed an asymmetric causality test between the positive and negative shocks of variables. The causality test works based on a theory in Toda and Yamamoto (1995), by incorporating non-leaner effects and differentiating between positive and negative shocks. The test serves as (Hacker and Hatemi-J, 2012) a causality test and helps investigate the asymmetric nexus between the variables.

First, Hatemi-j (2012) presumed that the integrated variables y_1 *and* y_2 work as follows:

$$y_1 = y_{t-1} + \varepsilon_{1t} = y_0 + \sum_{i=1}^{t} \varepsilon_{1i} \quad (2)$$

$$y_2 = y_{t-1} + \varepsilon_{2t} = y_0 + \sum_{i=1}^{t} \varepsilon_{2i} \quad (3)$$

where y_1 *and* y_2 represent the initial values, and t = 1, 2, …. . , T, and the two white noise disturbance terms are denoted by ε_{1i} and ε_{2i}. Onward, these error terms are decomposed into positive and negative shocks: $\varepsilon_{1i}{}^+ = \max(\varepsilon_{1i}, 0)$ and $\varepsilon_{2i}{}^+ = \max(\varepsilon_{2i}, 0)$ denote positive changes, and $\varepsilon_{1i}{}^- = \min(\varepsilon_{1i}, 0)$ and $\varepsilon_{2i}{}^- = \min(\varepsilon_{2i}, 0)$ represent negative changes. After we decomposed the initial values into positive and negative shocks, the following was observed: $\varepsilon_{1i} = \varepsilon_{1i}{}^+ + \varepsilon_{1i}{}^-$ and $\varepsilon_{1i} = \varepsilon_{1i}{}^+ + \varepsilon_{1i}{}^-$. The variables are presented in asymmetric form as follows:

$$y_1 = y_{t-1} + \varepsilon_{1i} = y_0 + \sum_{i=1}^{t} \varepsilon_{1i}^+ + \sum_{i=1}^{t} \varepsilon_{1i}^- \quad (4)$$

$$y_2 = y_{t-1} + \varepsilon_{2i} = y_0 + \sum_{i=1}^{t} \varepsilon_{2i}^+ + \sum_{i=1}^{t} \varepsilon_{2i}^- \quad (5)$$

Further, each variable is fractionated into positive and negative shocks and presented in cumulative form as $y_{1t}{}^+ = \sum_{i=1}{}^t \varepsilon_{1i}{}^+$, $y_{1t}{}^- = \sum_{i=1}{}^t \varepsilon_{1i}{}^-$, $y_{2t}{}^+ = \sum_{i=1}{}^t \varepsilon_{2i}{}^+$, and $y_{2t}{}^- = \sum_{i=1}{}^t \varepsilon_{2i}{}^-$. We captured the asymmetric causality between the variables to be estimated under the vector autoregressive (VAR) model proposed by Hatemi-j (2012) within the order of *p*. For the optimal lag length selection, we used the HJC model proposed by Hatemi-J (2003) and Hatemi-J (2008) as follows:

$$\text{HJC} = \left(\left|\hat{A}_j\right|\right) + q\left(\frac{n^2 \ln T + 2n^2 \ln(lnT)}{2T}\right), \text{q} = 0, \ldots\ldots.\text{p} \tag{6}$$

The symbol $\left|\hat{A}_j\right|$ denotes the determinant of the variance–covariance matrix of white noise disturbance terms in the VAR model, where q is lag order, *ln* represents natural logarithm, and total observations are denoted by T.

After the selection of optimal lag order, we specified the null hypothesis of the k^{th} element of y_2, which does not cause the w^{th} element of y_1 in the causality test. The hypothesis is tested under the Wald test (Hatemi-j, 2012). H_0: w^{th} row, k^{th} column in A_r is equal to zero for $r = 1\ldots$ p.

The null hypothesis of no causality by using Walt test is$H_0 = C\hat{\beta} = 0$:

$$\text{Wald} = \left(\text{C}\beta\acute{}\right)\left[C\left(\left(ZZ\right)^{-1} \bigotimes S_U\right)\acute{C}\right]^{-1}(C\beta) \tag{7}$$

where β = vec(D) represents the column-stacking operator, and C denotes the p x n(1 + np) indicator matrix. ⨂ represents the Kronecker product, and S_U indicates the estimated VAR covariance matrix of the unrestricted VAR model as $S_U = \frac{\acute{\delta_U}\delta_U}{T-q}$ in each equation of VAR model, and q represents the number of parameters. The hypothesis is rejected for no causality if the calculated values of the Wald statistic are beyond the bootstrap critical values.

3. Co-integration results and discussion

3.1. Stationary unit root test and descriptive statistics

The correlation and descriptive statistics are presented in Tables 1 and 2. The mean, median, and standard deviation figures of all variables are uniform. The Jarque-Bera value reveals that corresponding variables are normally distributed and that none of them are outliers. In the correlation analysis, EF is positively correlated with energy consumption, economic growth, and capital. A positive correlation is observed among energy consumption, capital, and economic growth. Before estimations and conducting the NARDL model, we must examine the order of integration of the variables to ensure that all included variables are not integrated at order 2. The stationary tests (Dickey and Fuller, 1979; Phillips and Perron, 1988) must be performed because of the NARDL (Shin et al., 2014) that the variables follow at order I (0) and I (1) or both. The unit root tests are reported in Table 3 and show that EF, energy consumption, economic growth, and capital have unit roots at levels associated with intercept, and at first difference, the included variables are stationary at I(1) for both the ADF and PP unit root tests. Somehow, Perron (1989) demonstrated that traditional unit root tests have biased empirical results. Because all unit root tests accept the null hypothesis of stationary, the series may exit the structural break. This problem is resolved by Kim and Perron (2009), by accommodating structural break dates (Table 3). Accordingly, the variables are noted as non-stationary in the existence of the structural break dates 1984, 2003, 1986, and 1974 for EF, economic growth, energy consumption, and capital, respectively. Many economic policies have been implemented in Pakistan over the span of the data that have improved macroeconomic performance. For example, Faruqee and Carey (1995) noted that first-time agriculture credit was disbursed to sectors by lending agencies in Pakistan, which increased cultivation land and environmental quality. Furthermore, after the 9/11 attacks, Pakistan was one the most affected states in terms of its economy from 2000 to 2019. Similarly, the ongoing power generation projects were completed in the 1990s, the total supply increased from 1863 to 4123 MW, which increased energy consumption. The presence of a unit root in the variables leads us to apply NARDL model to investigate asymmetric co-integration among environmental quality, economic growth, energy consumption, and capital. (See Fig. 1.)

Table 1
Description of the variables.

Variables	EF_t	EC_t	GDP_t	CAP_t
Mean	18.2343	5.9856	6.0563	4.2335
Median	18.3058	6.0326	6.0157	4.2659
Maximum	18.8492	6.2610	7.1318	5.2093
Minimum	17.4595	5.6531	7.1318	2.4397
Std. Dev	0.4554	0.1970	0.6146	0.6489
Skewness	−0.2135	−0.3193	−0.1253	−0.6534
Kurtosis	1.6313	1.6393	2.6896	3.3875
Jaeque-Bera	3.7685	4.1420	0.2917	3.4064
Probability	0.1519	0.1261	0.8642	0.1821

Note: EF denotes ecological footprint; EC denotes energy consumption; GDP denotes economic growth; and CAP denotes by capital.

Table 2
Correlation of the variables.

Variables	EF_t	EC_t	GDP_t	CAP_t
EF_t	1.000			
EF_t	0.9929	1.000		
EF_t	0.9352	0.9167	1.000	
EF_t	0.9110	0.9012	0.9830	1.000

Note: EF denotes ecological footprint; EC denotes energy consumption; GDP denotes economic growth; and CAP denotes by capital.

3.2. Diagnostic statistics

For policy inferences and sound empirical estimation, we conducted sensitivity (diagnostic) tests on time series data (Table 4). According to the estimated model, all diagnostic results show that the null hypothesis could not be rejected for no serial correlation, white heteroscedasticity, and functional form (Ramsay reset test). The value of coefficient (R^2 = 0.9381) of the NARDL indicates that energy consumption, economic growth, and capital explain the speedy adjustment toward the equilibrium of the environmental quality model for both the long and short run in a single equation. Furthermore, Figs. 2 and 3 show that the cumulative sum of square (CUSUMSQ) and cumulative (CUSUM) of the test statistics of the recursive residuals are within the critical values at 5% significance. Hence, indications of graphical plots of the series are stable in the error correction model.

The test statistics of Durbin Watson also confirm the absence of autocorrelation in the estimated model. More importantly, the asymmetric Wald test is significant for both the short run and long run, when we used asymmetric and nonlinearity as the link among environmental quality, energy consumption, and economic growth. Notably, the T_{BDM}

Table 3
Unit root test (stationary).

Variables	ADF test		ADF break date		PP test	
	Level	1st diff	Statistic	Date	Level	1st diff
EF_t	−1.253	−7.662***	−2.432	1984	−1.386	−7.657***
GDP_t	−0.173	−5.739***	−1.596	2003	−0.156	−5.757***
EC_t	−1.880	−5.160***	−3.213	1986	−1.771	−5.185***
CAP	−0.972	−4.951***	−2.983	1974	−0.930	−4.858***

The significance level represents ***, **, and * for 1%, 5%, and 10%, respectively.

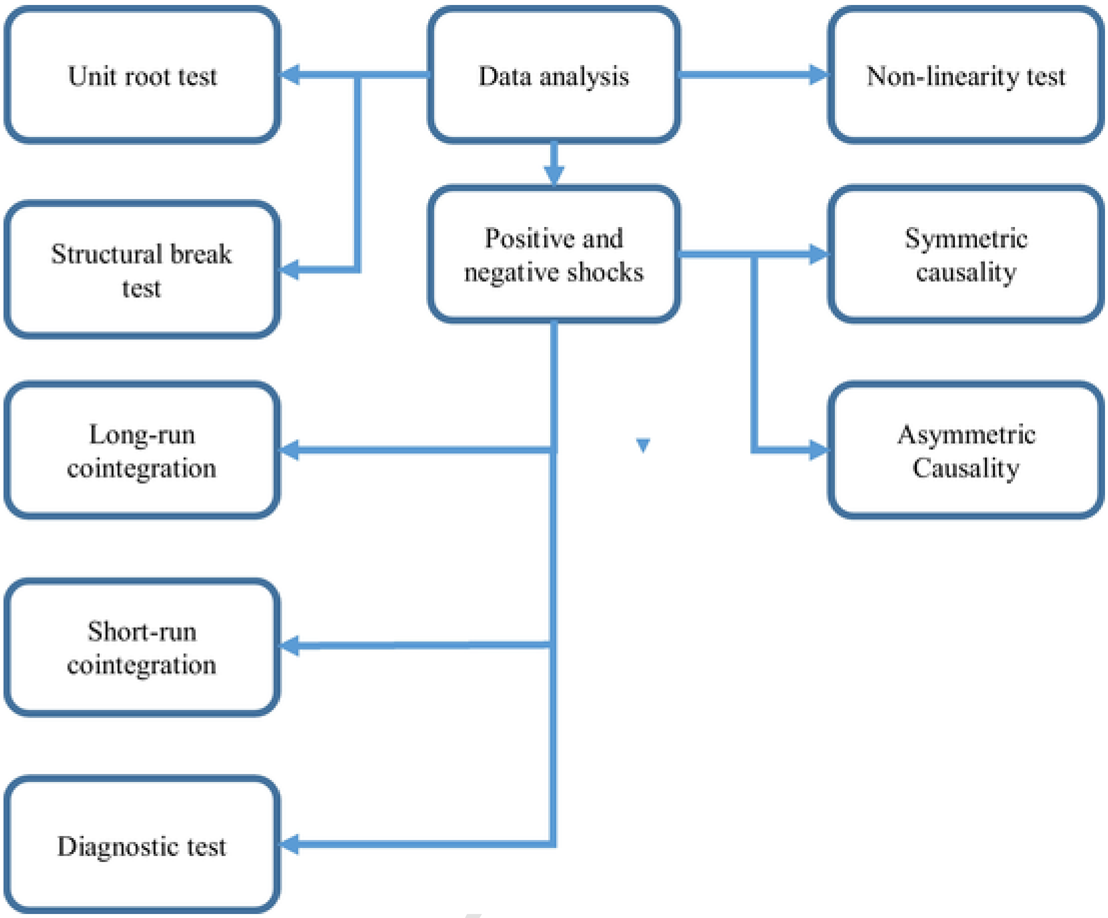

Fig. 1. Research design and methodology framework.

Table 4
Diagnostics and Wald test.

Asymmetric co-integration			Diagnostic test	
Variables	Wald (long run)	Wald (short run)	Tests	Result
GDP_t	17.8568***	8.5967***	Heteroscedasticity	25.0373 (0.572)
EC_t	29.9280***	8.8316***	Functional form	0.4309 (0.5250)
CAP_t	17.2276***	11.1302***	Serial correlation	0.7029 (0.7037)
F_{PSS}	11.3202***		R^2	0.9381
T_{BDM}	−6.0433***		D-Watson	2.1080

Note: significance level represents ***, **, and * for 1%, 5%, and 10%, respectively.

and F_{PSS} *t* statistic both confirm the co-integration among the variables developed by Banerjee et al. (1998) and Shin et al. (2014), respectively. Finally, we conducted a nonlinear BDS test (Broock et al., 1996); thus, the null hypothesis of linearity is rejected and suggests that all included variables are nonlinear, confirming the chaotic behavior in the time series data (Table 5). These findings demonstrated the consistency and reliability of the results and confirm that the model is well designed. More importantly, the specified model of environmental quality is revealed to be appropriate for policymaking.

3.3. Co-integration analysis

Long-term and short-term results are presented in Table 6, which indicates that positive shocks in energy consumption have a positive, significant impact on EF, and similarly, negative shocks to energy consumption positively affect the EF. These results show that a one unit increase in the use of energy positively affects environmental quality; by contrast, a 1% decrease in energy consumption, a slight increase, has been noted in environmental pollution. In the short-run, a slight increase in energy consumption has a positive significant impact on environment quality at lag 0 with a coefficient 1.8560, but at lag (1 and 2), a downward shift is observed in environmental quality (coefficient –2.9149 and –1.9979, respectively). By contrast, a negative change in energy consumption has a negative significant effect on environmental quality at lag 1 and 3 with the coefficients −4.4932 and –4.7936, respectively. This segment resonates with the evidence that has been presented by Aşıcı and Acar (2018), Sarkodie and Strezov (2018) and Ulucak and Bilgili (2018) for EFs and energy consumption. However, a study contradicted the findings of Charfeddine and Mrabet (2017) and Destek and Sinha (2020), and many others. Notably, an increase in energy consumption helps EFs to be wavelike. These findings show that increases in energy consumption result in an upsurge in the environmental quality in the case of Pakistan. From a policy prospective, government authorities should reduce energy consumption to contribute to environment quality and ensure the supply of energy to consumers by shifting toward renewable energy generation, which will not affect economic activities.

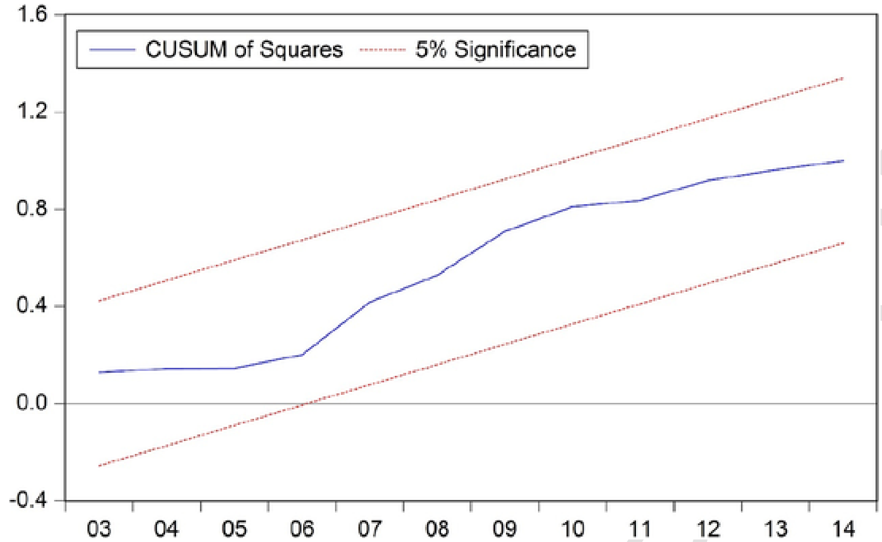

Fig. 2. Cumulative sum of square test.

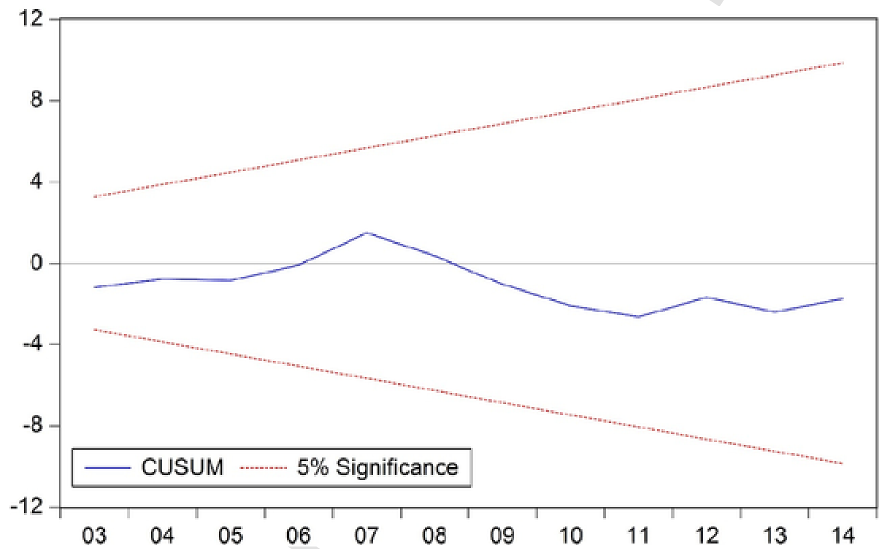

Fig. 3. Cumulative sum test.

Table 5
Nonlinearity BDS test.

Variables	m = 2	m = 3	m = 4	m = 5	m = 6
EFt	0.1943***	0.3296***	0.4257***	0.4896***	0.5361***
GDP_t	0.1609***	0.2628***	0.3405***	0.3893***	0.4273***
EC_t	0.2027***	0.3412***	0.4373***	0.5052***	0.5528***
CAPt	0.1269***	0.2775***	0.3597***	0.4252***	0.4725***

Note: Results reveal the presence of nonlinearity for all variables based on residual values determined through the BDS test within VAR with m dimension. The significance level represents ***, **, and * for 1%, 5%, and 10%, respectively.

In the long run, positive change in economic growth has a negative significant impact on environment quality (coefficient −0.5293 at 5% significance), indicating that a 1% increase in economic growth increases environmental pollution. We also found that negative shocks to economic growth have a positive effect on environmental quality (with 3.9271 at 1% significance). This positive sign indicates that negative changes in economic growth increase environmental quality (decrease environmental pollution). Zafar et al. (2019) also found that economic growth has a long-run impact on environmental quality. Some contradictory results have found that economic growth has a positive impact on EF (environmental quality) (York et al., 2003; Bagliani et al., 2008; Moran et al., 2008). These findings suggest that increasing various economic activities accelerates energy use and in response degrades environmental quality. In the short-run, positive shocks in economic growth have a negative impact on environmental quality (from lag 0 to lag 3), and these negative coefficients reveal that any positive change in economic growth hampers climate change and increases global warming. By contrast, a negative change in economic growth promotes environmental quality (coefficient 1.5886 at lag 0); however, economic growth (negative shock) decreases environmental quality (at lag 1 and 2 with coefficients −3.2190 and −1.7455, respectively). Likewise, growth in an economy leads to degradation of the environmental quality level, and a decrease in economic growth increases the EF. These findings are evidence that massive growth in economic activities would increase Pakistan's environmental performance index.

Finally, a long-run positive shock to capital has a positive significant effect on environmental quality (coefficient 0.4653), and this positive sign shows that long-run fiscal investments sustain and improve environmental quality. This finding demonstrates that any positive

Table 6
Nonlinear co-integration test.

Variables	Coefficient	*t* Statistic	Probability
Constant	40.1472***	6.1750	0.0000
EF_{t-1}	−2.2141***	−6.1153	0.0001
$EC_{t-1}{}^{+}$	5.9336***	6.2752	0.0000
$EC_{t-1}{}^{-}$	4.4890***	5.9412	0.0001
$GDP_{t-1}{}^{+}$	−0.5293**	−2.3320	0.0379
$GDP_{t-1}{}^{-}$	3.9271***	5.9149	0.0001
$CAP_{t-1}{}^{+}$	0.4653**	2.4273	0.0319
$CAP_{t-1}{}^{-}$	−1.1309***	−5.5673	0.0001
D_{1984}	−0.1806***	−3.2424	0.0071
ΔEF_{t-1}	1.1628***	4.5943	0.0006
ΔEF_{t-2}	0.3576**	2.1913	0.0489
ΔEF_{t-3}	−0.1994	−1.3285	0.2087
$\Delta EC_{t}{}^{+}$	1.8560***	4.0586	0.0016
$\Delta EC_{t-1}{}^{+}$	−2.9149***	−4.7992	0.0004
$\Delta EC_{t-2}{}^{+}$	−1.9979***	−4.414	0.0008
$\Delta EC_{t-1}{}^{-}$	−4.4932***	−4.6516	0.0006
$\Delta EC_{t-3}{}^{-}$	−4.7936***	−5.2595	0.0002
$\Delta GDP_{t}{}^{+}$	−0.6994***	−4.0402	0.0016
$\Delta GDP_{t-1}{}^{+}$	−0.3588**	−2.2878	0.0411
$\Delta GDP_{t-2}{}^{+}$	−0.9195***	−5.4870	0.0001
$\Delta GDP_{t-3}{}^{+}$	−0.4437***	−3.3444	0.0058
$\Delta GDP_{t}{}^{-}$	1.5886***	4.6528	0.0006
$\Delta GDP_{t-1}{}^{-}$	−3.2190***	−3.6464	0.0033
$\Delta GDP_{t-2}{}^{-}$	−1.7455***	−5.6498	0.0001
$\Delta CAP_{t}{}^{+}$	0.4859***	2.8105	0.0157
$\Delta CAP_{t-1}{}^{+}$	0.2267**	2.1562	0.0521
$\Delta CAP_{t-1}{}^{-}$	0.8623***	3.0090	0.0109
$\Delta CAP_{t-2}{}^{-}$	1.6709***	5.7695	0.0001

Notes: Positive and negative variation are denoted by "+" and "–", respectively. The structural break, dummy variable, is equal to 1 for the year 1984 and calculated through Kim and Perron (2009). The significance level represents ***, **, and * for 1%, 5%, and 10%, respectively.

shock to capital sanction long-run capital investments in technological development, and by that, increase environmental quality for the long term. In the future, governments and policymakers in developing countries, such as Pakistan, should uninterruptedly monitor productive capital investment when implementing public policies that aim to accomplish sustainable environmental growth. A negative shock to capital has a negatively significant effect on the environment (with coefficient –1.1309 at 1% level of significance). This negative sign is a warning that a 1% decrease in capital will hamper environmental quality. This may occur because of the decreasing investment in environmentally friendly technologies in Pakistan, which can affect the EF. From a policy point view, policymakers in developing countries, such as Pakistan, should make capital investments in the agriculture sector to achieve long-run sustainable economic growth and contribute to reducing global warming. In the short run, we find capital (both negative and positive shocks) has a positive significant effect on environmental quality (in lags 0 to 2). These findings suggest that a slight increase or decrease in capital will improve the environment and protect the environment from global warming.

Finally, we derived multiplier dynamic adjustments. The cumulative multipliers for energy consumption are shown in Fig. 4, and they confirm the existence of a positive nexus between energy consumption and environmental quality. The positive shock in energy consumption was more dominant than negative shock initially. Although in Fig. 5, the negative shock in economic growth has a positive association with environmental quality. Moreover, the negative shock in economic growth has dominant its negative shock. Finally, Fig. 6 indicates a positive relationship between capital and environmental quality. Similarly, the negative shock in capital also dominant its positive shock.

3.4. Symmetric and asymmetric causalities

Table 7 shows the symmetric and asymmetric (Hatemi-j, 2012) bootstrap causality nexus among the variables. No causality runs from the EF to GDP in both cases, asymmetric and symmetric. Table 7 also shows no causal link runs from GDP to the EF with regard to asymmetric causality. Accordingly, the null hypothesis that there is no causal nexus between the EF and GDP can be accepted, and an alternative hypothesis is rejected. Similarly, Kasman and Duman (2015) and Wang et al. (2016) have also concluded that there is no causality between the environment and economic growth. However, some findings contradict the results of Alola et al. (2019a). Akram et al. (2020) and Ozcan et al. (2020) have also demonstrated that economic growth affects the EF of developing countries. Nevertheless, increases in economic growth decrease the EF, and decreases in economic growth increase EF. These findings show that environmental quality can improve without economic growth in Pakistan. Implementation of environmental policies that sustain economic growth will not degrade environment in Pakistan.

In Table 6, we observe a symmetric nexus between the EF and energy consumption that runs from the EF to energy consumption. The asymmetric causal nexus between positive shocks in EF and energy consumption is significant (Wald test 8.192 at 5%). Furthermore, the

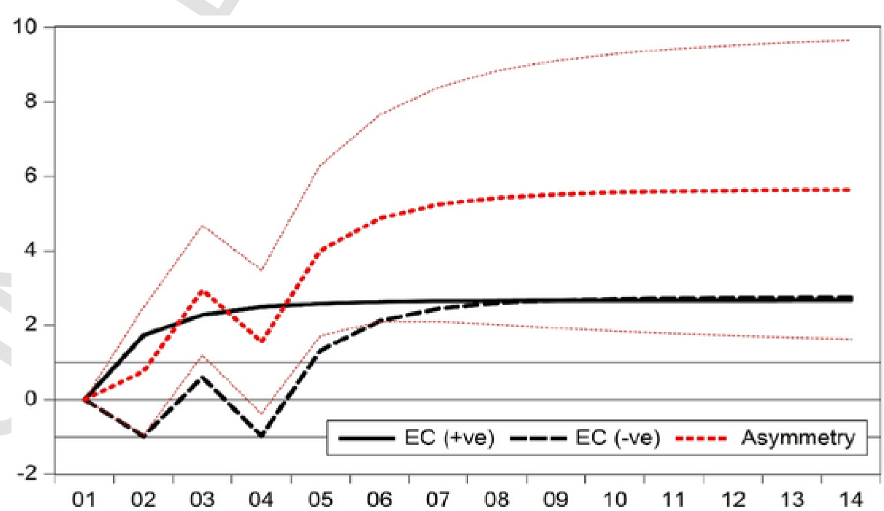

Fig. 4. Multiplier dynamic adjustments of EC on EF.

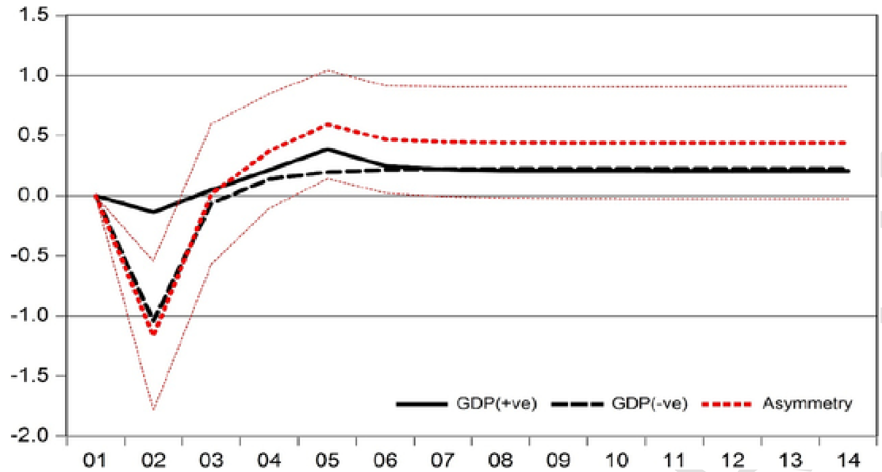

Fig. 5. Multiplier dynamic adjustments of GDP on EF.

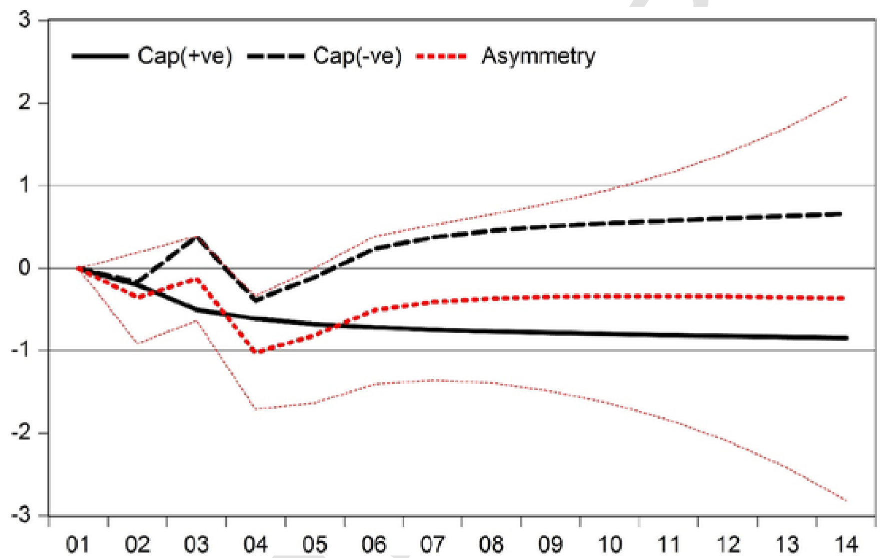

Fig. 6. Multiplier dynamic adjustments of Capital on EF.

asymmetric causality also noted between the positive shocks in energy consumption and the EF is significant (Wald test 5.534 at 5%). These findings reveal the feedback effect between positive shocks to the EF and energy consumption. Olanipekun et al. (2019), Zafar et al. (2019) and Ozcan et al. (2020) have demonstrated bidirectional causality between energy consumption and economic growth. Thus, both variables affect each other in the case of increases in energy consumption and will affect environmental quality. Similarly, an increase in the EF also requires energy supply in Pakistan. Notably, negative shocks to both the EF and energy consumption have no significant impact and run from the EF to energy consumption. The same results are also noted for negative changes in energy consumption and the EF, and they run from energy consumption to the EF.

Various factors have greatly counteracted the contribution of environmental quality. Energy sources, especially fossil fuels, have been a significant driver for developed and developing economies. Additionally, technological development has increased the energy efficiency of economies, but its role should be minimized because of concerns for environmental quality. Notably, the energy mix of economic countries has included vigorous development of nuclear energy and renewable energy in recent years, but fossil fuel resources remain essential because most developing countries rely on non-renewable energy. In this case, any policies related to decreases in energy consumption would not hamper environmental quality; however, for the sake of sustainable economic growth, these policies should reduce fossil fuel consumption, which is a huge trade deficit in Pakistan's economy.

Finally, we observe a neutral effect for the symmetric and asymmetric causalities between the EF and capital. The same results were found by Zafar et al. (2019) for the EF and human capital in the case of the United States, whole (Bano et al., 2018) from Pakistan. According to the results, the null hypothesis of no nexus between the EF and capital is accepted, which means that both variables have no relationship with each other. These findings confirm that capital makes no substantial contribution to the improvement of environmental quality. There were gainsay results that capital has a negative impact on the EF (Chen et al., 2019). Wang (2019) also demonstrated the bidirectional causality between EF and capital. These findings suggest that Pakistan's policymakers will pay less attention to capital when attempting to improve environmental quality. Moreover, it will help decrease spending on environmental degradation.

4. Conclusion and policy implications

Energy consumption along and economic growth are the main causes environment problems worldwide. We applied a neoclassical production function to investigate the associations among environmental quality, energy consumption, economic growth, and capital for the

Table 7
Symmetric and asymmetric causality.

Causalities	Wald test	CV at 10%	CV at 5%	CV at 1%
$EF_t \nRightarrow GDP_t$	0.440	3.445	4.901	8.775
$EF_t^{+} \nRightarrow GDP_t^{+}$	0.586	2.578	4.249	13.851
$EF_t^{-} \nRightarrow GDP_t^{-}$	2.594	3.605	5.560	12.638
$GDP_t \nRightarrow EF_t$	2.767	7.149	9.290	14.720
$GDP_t^{+} \nRightarrow EF_t^{+}$	0.583	5.140	7.036	11.414
$GDP_t^{-} \nRightarrow EF_t^{-}$	0.442	2.768	4.083	8.946
$EF_t \Rightarrow EC_t$	6.915*	6.082	8.086	13.583
$EF_t^{+} \Rightarrow EC_t^{+}$	8.192**	2.224	4.287	138.868
$EF_t^{-} \nRightarrow EC_t^{-}$	2.594	3.605	5.560	12.638
$EC_t \nRightarrow EF_t$	0.001	3.377	4.807	8.7830
$EC_t^{+} \Rightarrow EF_t^{+}$	5.534**	2.394	4.543	59.091
$EC_t^{-} \nRightarrow EF_t^{-}$	0.698	4.947	6.798	13.195
$EF_t \nRightarrow CAP_t$	0.997	3.273	4.663	8.1980
$EF_t^{+} \nRightarrow CAP_t^{+}$	0.076	2.916	4.986	16.776
$EF_t^{-} \nRightarrow CAP_t^{-}$	2.491	5.654	7.668	14.940
$CAP_t \nRightarrow EF_t$	2.639	6.163	8.137	13.113
$CAP_t^{+} \nRightarrow EF_t^{+}$	0.115	4.327	6.642	16.377
$CAP_t^{-} \nRightarrow EF_t^{-}$	1.099	2.670	4.026	9.4350

Note:$\Rightarrow$/$\nRightarrow$ indicates unidirectional causality/no causality, respectively. The critical values are represented by CV for significance level *, **, and *** represents 10%, 5%, and 1%, respectively. The HJC criterion is used for lag selection, and the VAR model is used for unit root effect, as proposed by Toda and Yamamoto (1995).

period of 1971 to 2014, and annual frequency in the case of Pakistan. In this study, the asymmetric nexus was examined among the variables through an asymmetric and nonlinear ARDL co-integration technique developed by Shin et al. (2014), and the asymmetric causal link was investigated between the variables proposed by Hatemi-j (2012). The empirical evidence confirms the presence of an asymmetric connection among the variables.

In the symmetric and asymmetric causality analyses, the only feedback effect we observed was between positive shocks to environmental quality and energy consumption, and a unidirectional symmetric causality was observed running from environmental quality to energy consumption. The NARDL long-run equilibrium also validated that energy consumption has positive significant impact on environmental quality. These findings suggest that a one point increase in energy consumption impedes environmental quality and vice versa. By contrast, negative shocks to environmental quality do not affect energy consumption. This relationship validates that the increase in energy consumption plays a vital role in improving environmental quality. Notably, we observed a symmetric and asymmetric neutral effect between economic growth and the EF.

We captured the same results for positive and negative shocks to the EF and capital. Hence, policymakers should concentrate on the renewable energy supply to consumers and sustain the environment to attain sustainable economic growth. The government authorities should also install modern, free pollution technologies such as nuclear; develop a renewable energy portfolio; and more efficiently shift from fossil fuel consumption to renewable energy to enhance environmental quality. Moreover, fossil fuels are largely used in Pakistan because of the nation's trade deficit. In addition, the substantial increases in population are affecting arable land per capita. Further, to achieve sustainable growth and enhance the environment, the Pakistani government should attract more foreign investment to the country, especially in renewable energy generation and the agriculture sector, which will vast cultivation land size. Most importantly, the Government of Pakistan should prioritize improvements to water restoration and the quality of drinking water, because the water footprint represents one of the basic needs of human life. Further research could improve on our research by incorporating non-renewable energy, the EF, and bio-capacity within nonlinear and asymmetric approaches.

CRediT authorship contribution statement

Khan Baz: Conceptualization, Methodology.**Deyi Xu:**Conceptualization.**Hashmat Ali:**Writing - original draft.**Imad Ali:**Writing - review & editing.**Imran Khan:**Writing - review & editing.**Muhammad Muddassar Khan:**Writing - review & editing.**Jinhua Cheng:**Writing - original draft.

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.

Acknowledgments

This work was supported by the National Natural Science Foundation of China (grant number 71991482).

Appendix A. Data units and description

Variables	Abbreviation	Proxy unit	Source
Ecological footprint	EF	Global hectare of land	GFP
Energy consumption	EC	Oil equivalent per capita	WDI
Gross domestic product	GDP	Constant 2010 (local currency)	WDI
Gross fixed capital	CAP	Constant 2010 (local currency)	WDI

Note. GFP represents global footprint network (https://www.footprintnetwork.org/) while WDI denotes world development indicator (https://data.worldbank.org).

Appendix B. Nomenclature

EC_t	Energy consumption	EC_{t-1}^{+}	Positive shocks (energy consumption)
EF_t	Ecological footprint	EC_{t-1}^{-}	Negative shocks (energy consumption)
GDP_t	Gross domestic product	GDP_{t-1}^{+}	Positive shocks (economic growth)
CAP_t	Gross fixed capital	GDP_{t-1}^{-}	Negative shocks (economic growth)
D_{1984}	Break date	CAP_{t-1}^{+}	Positive shocks (capital)
Δ	Change in time	CAP_{t-1}^{-}	Negative shocks (capital)
T	Time	EF_t^{+}	Positive shocks (ecological footprint)
α_i	Short run coefficient	EF_t^{-}	Positive shocks (ecological footprint)
γ_i	Long run coefficient	VAR	Vector autoregressive model
ϵ_t	Error term	NARDL	Non-linear autoregressive distributed lag
Ln	Natural log	HJC	Hatemi-J lag selection criterion
Q	Lag order	CO_2	Carbon dioxide
Hga	global hectares	Quantity	kg of oil equivalent

References

Akram, R., Chen, F., Khalid, F., Ye, Z., Majeed, M.T., 2020. Heterogeneous effects of energy efficiency and renewable energy on carbon emissions: evidence from developing countries. J. Clean. Prod. 247, 119122.

Ali, R., Kuriqi, A., Abubaker, S., Kisi, O., 2019. Hydrologic alteration at the upper and middle part of the Yangtze river, China: towards sustainable water resource management under increasing water exploitation. Sustainability 11 (19), 5176.

Alola, A.A., Bekun, F.V., Sarkodie, S.A., 2019. Dynamic impact of trade policy, economic growth, fertility rate, renewable and non-renewable energy consumption on ecological footprint in Europe. Sci. Total Environ. 685, 702–709.

Alola, A.A., Saint Akadiri, S., Akadiri, A.C., Alola, U.V., Fatigun, A.S., 2019. Cooling and heating degree days in the US: the role of macroeconomic variables and its impact on environmental sustainability. Sci. Total Environ. 695, 133832.

Aşıcı, A.A., Acar, S., 2018. How does environmental regulation affect production location of non-carbon ecological footprint? J. Clean. Prod. 178, 927–936.

Bagliani, M., Bravo, G., Dalmazzone, S., 2008. A consumption-based approach to environmental Kuznets curves using the ecological footprint indicator. Ecol. Econ. 65 (3), 650–661.

Balado-Naves, R., Baños-Pino, J.F., Mayor, M., 2018. Do countries influence neighbouring pollution? A spatial analysis of the EKC for CO_2 emissions. Energy Policy 123, 266–279.

Baloch, M.A., Zhang, J., Iqbal, K., Iqbal, Z., 2019. The effect of financial development on ecological footprint in BRI countries: evidence from panel data estimation. Environ. Sci. Pollut. Res. 26 (6), 6199–6208.

Banerjee, A., Dolado, J., Mestre, R., 1998. Error-correction mechanism tests for cointegration in a single-equation framework. J. Time Ser. Anal. 19 (3), 267–283.

Bano, S., Zhao, Y., Ahmad, A., Wang, S., Liu, Y., 2018. Identifying the impacts of human capital on carbon emissions in Pakistan. J. Clean. Prod. 183, 1082–1092.

Baz, K., Xu, D., Ampofo, G.M.K., Ali, I., Khan, I., Cheng, J., Ali, H., 2019. Energy consumption and economic growth nexus: new evidence from Pakistan using asymmetric analysis. Energy 116254.

Bejarano, M., Sordo-Ward, A., Gabriel-Martin, I., Garrote, L., 2019. Tradeoff between economic and environmental costs and benefits of hydropower production at run-of-river-diversion schemes under different environmental flows scenarios. J. Hydrol. 572, 790–804.

Bello, M.O., Solarin, S.A., Yen, Y.Y., 2018. The impact of electricity consumption on CO_2 emission, carbon footprint, water footprint and ecological footprint: the role of hydropower in an emerging economy. J. Environ. Manag. 219, 218.

Benkraiem, R., Lahiani, A., Miloudi, A., Shahbaz, M., 2019. The asymmetric role of shadow economy in the energy-growth nexus in Bolivia. Energy Policy 125, 405–417.

Broock, W.A., Scheinkman, J.A., Dechert, W.D., LeBaron, B., 1996. A test for independence based on the correlation dimension. Econ. Rev. 15 (3), 197–235.

Chang, C.C., 2010. A multivariate causality test of carbon dioxide emissions, energy consumption and economic growth in China. Appl. Energy 87 (11), 3533–3537.

Charfeddine, L., Mrabet, Z., 2017. The impact of economic development and social-political factors on ecological footprint: a panel data analysis for 15 MENA countries. Renew. Sust. Energ. Rev. 76, 138–154.

Chen, S., Saud, S., Saleem, N., Bari, M.W., 2019. Nexus between financial development, energy consumption, income level, and ecological footprint in CEE countries: do human capital and biocapacity matter? Environ. Sci. Pollut. Res. 26 (31), 31856–31872.

Destek, M.A., Sinha, A., 2020. Renewable, non-renewable energy consumption, economic growth, trade openness and ecological footprint: evidence from organisation for economic co-operation and development countries. J. Clean. Prod. 242, 118537.

Destek, M.A., Ulucak, R., Dogan, E., 2018. Analyzing the environmental Kuznets curve for the EU countries: the role of ecological footprint. Environ. Sci. Pollut. Res. 25 (29), 29387–29396.

Dickey, D.A., Fuller, W.A., 1979. Distribution of the estimators for autoregressive time series with a unit root. J. Am. Stat. Assoc. 74 (366), 427–431.

Faruqee, R., Carey, K., 1995. Reforming the government's role in Pakistan's agriculture sector. Pakistan Development Review 34 (3), 225–262.

Galli, A., Kitzes, J., Niccolucci, V., Wackernagel, M., Wada, Y., Marchettini, N., 2012. Assessing the global environmental consequences of economic growth through the ecological footprint: a focus on China and India. Ecol. Indic. 17 (3), 99–107.

Granger, C.W., 1969. Investigating causal relations by econometric models and cross-spectral methods. Econometrica: Journal of the Econometric Society 424–438.

Grossman, G.M., Krueger, A.B., 1991. Environmental impacts of a North American free trade agreement. Social Science Electronic Publishing 8 (2), 223–250.

Grossman, G.M., Krueger, A.B., 1995. Economic growth and the environment. Nber Working Papers 110 (2), 353–377.

Hacker, S., Hatemi-J, A., 2012. A bootstrap test for causality with endogenous lag length choice: theory and application in finance. J. Econ. Stud. 39 (2), 144–160.

Hatemi-J, A., 2003. A new method to choose optimal lag order in stable and unstable VAR models. Appl. Econ. Lett. 10 (3), 135–137.

Hatemi-J, A., 2008. Forecasting properties of a new method to determine optimal lag order in stable and unstable VAR models. Appl. Econ. Lett. 15 (4), 239–243.

Hatemi-j, A., 2012. Asymmetric causality tests with an application. Empir. Econ. 43 (1), 447–456.

Imamoglu, H., 2018. Is the informal economic activity a determinant of environmental quality? Environ. Sci. Pollut. Res. 25 (29), 29078–29088.

Isik, C., Dogru, T., Turk, E.S., 2018. A nexus of linear and non-linear relationships between tourism demand, renewable energy consumption, and economic growth: theory and evidence. Int. J. Tour. Res. 20 (1), 38–49.

Kasman, A., Duman, Y.S., 2015. CO_2 emissions, economic growth, energy consumption, trade and urbanization in new EU member and candidate countries: a panel data analysis. Econ. Model. 44 (44), 97–103.

Kim, D., Perron, P., 2009. Unit root tests allowing for a break in the trend function at an unknown time under both the null and alternative hypotheses. J. Econ. 148 (1), 1–13.

Kuriqi, A., Pinheiro, A.N., Sordo-Ward, A., Garrote, L., 2019. Flow regime aspects in determining environmental flows and maximising energy production at run-of-river hydropower plants. Appl. Energy 256, 113980.

Kuriqi, A., Pinheiro, A.N., Sordo-Ward, A., Garrote, L., 2019. Influence of hydrologically based environmental flow methods on flow alteration and energy production in a run-of-river hydropower plant. J. Clean. Prod. 232, 1028–1042.

Lanouar, C., 2017. The impact of energy consumption and economic development on ecological footprint and CO_2 emissions: evidence from a Markov Switching Equilibrium Correction Model. Energy Econ. 65, S0140988317301524.

Lee, S.J., Yoo, S.H., 2016. Energy consumption, CO_2 emission, and economic growth: evidence from Mexico. Energy Sources Part B Economics Planning & Policy 11 (8), 711–717.

Menyah, K., Wolde-Rufael, Y., 2010. CO emissions, nuclear energy, renewable energy and economic growth in the US. Energy Policy 38 (6), 2911–2915.

Moran, D.D., Wackernagel, M., Kitzes, J.A., Goldfinger, S.H., Boutaud, A., 2008. Measuring sustainable development—nation by nation. Ecol. Econ. 64 (3), 470–474.

Mrabet, Z., AlSamara, M., Jarallah, S.H., 2017. The impact of economic development on environmental degradation in Qatar. Environ. Ecol. Stat. 24 (1), 7–38.

Nordin, S.K.B.S., Sek, S.K., 2018. Comparing the relationship among CO_2 emissions, energy consumption and economic growth in high and low income countries: Panel Granger causality and cointegration testing. In: AIP Conference Proceedings. AIP Publishing.

Olanipekun, I.O., Olasehinde-Williams, G.O., Alao, R.O., 2019. Agriculture and environmental degradation in Africa: the role of income. Sci. Total Environ. 692, 60–67.

Ozcan, B., Tzeremes, P.G., Tzeremes, N.G., 2020. Energy consumption, economic growth and environmental degradation in OECD countries. Econ. Model. 84, 203–213.

Ozturk, I., Al-Mulali, U., 2015. Investigating the validity of the environmental Kuznets curve hypothesis in Cambodia. Ecol. Indic. 76, 123–131.

Perron, P., 1989. The great crash, the oil price shock, and the unit root hypothesis. Econometrica: Journal of the Econometric Society 1361–1401.

Pesaran, M.H., Shin, Y., Smith, R.J., 2001. Bounds testing approaches to the analysis of level relationships. J. Appl. Econ. 16 (3), 289–326.

Phillips, P.C., Perron, P., 1988. Testing for a unit root in time series regression. Biometrika 75 (2), 335–346.

Saboori, B., Sulaiman, J., Mohd, S., 2012. Economic growth and CO_2 emissions in Malaysia: a cointegration analysis of the environmental Kuznets curve. Energy Policy 51 (4), 184–191.

Saint Akadiri, S., Bekun, F.V., Sarkodie, S.A., 2019. Contemporaneous interaction between energy consumption, economic growth and environmental sustainability in South Africa: what drives what? Sci. Total Environ. 686, 468–475.

Sarkodie, S.A., Strezov, V., 2018. Empirical study of the environmental Kuznets curve and environmental sustainability curve hypothesis for Australia, China, Ghana and USA. J. Clean. Prod. 201, 98–110.

Sarwar, S., Chen, W., Waheed, R., 2017. Electricity consumption, oil price and economic growth: global perspective. Renew. Sust. Energ. Rev. 76, 9–18.

Shahbaz, M., Hye, Q.M.A., Tiwari, A.K., Leitao, Carlos, N., 2013. Economic growth, energy consumption, financial development, international trade and CO_2 emissions in Indonesia. Renew. Sustain. Energy Rev. 25 (25), 109–121.

Shahbaz, M., Hoang, T.H.V., Mahalik, M.K., Roubaud, D., 2017. Energy consumption, financial development and economic growth in India: new evidence from a nonlinear and asymmetric analysis ☆. Energy Econ. 66, 199–212.

Shahbaz, M., Van Hoang, T.H., Mahalik, M.K., Roubaud, D., 2017. Energy consumption, financial development and economic growth in India: new evidence from a nonlinear and asymmetric analysis. Energy Econ. 63, 199–212.

Shin, Y., Yu, B., Greenwood-Nimmo, M., 2014. Modelling asymmetric cointegration and dynamic multipliers in an ARDL framework. In: Festschrift in Honor of Peter Schmidt. Springer Science and Business Media, New York.

Solomon, S., Manning, M., Marquis, M., Qin, D., 2007. Climate Change 2007-The Physical Science Basis: Working Group I Contribution to the Fourth Assessment Report of the IPCC. Cambridge university press.

Toda, H.Y., Yamamoto, T., 1995. Statistical inference in vector autoregressions with possibly integrated processes. J. Econ. 66 (1–2), 225–250.

Tugcu, C.T., Topcu, M., 2018. Total, renewable and non-renewable energy consumption and economic growth: revisiting the issue with an asymmetric point of view. Energy 152.

Ulucak, R., Bilgili, F., 2018. A reinvestigation of EKC model by ecological footprint measurement for high, middle and low income countries. J. Clean. Prod. 188, 144–157.

Wang, Z., 2019. Does biomass energy consumption help to control environmental pollution? Evidence from BRICS countries. Sci. Total Environ. 670, 1075–1083.

Wang, S., Li, Q., Fang, C., Zhou, C., 2016. The relationship between economic growth, energy consumption, and CO_2 emissions: empirical evidence from China. Sci. Total Environ. 542, 360–371. Pt A.

York, R., Rosa, E.A., Dietz, T., 2003. Footprints on the earth: the environmental consequences of modernity. Am. Sociol. Rev. 279–300.

Yousefisahzabi, A., Sasaki, K., Sugai, Y., Yousefi, H., 2011. CO_2 emission and economic growth of Iran. Mitigation & Adaptation Strategies for Global Change 16 (1), 63–82.

Zafar, M.W., Zaidi, S.A.H., Khan, N.R., Mirza, F.M., Hou, F., Kirmani, S.A.A., 2019. The impact of natural resources, human capital, and foreign direct investment on the ecological footprint: the case of the United States. Resources Policy 63, 101428.