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Evidence from the energy-technology-growth nexus: A new study based on technology-minerals based complexity index

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ABSTRACT

The increasing trend in sustainable economic growth over the last few decades has elevated the energy demand, technological innovation, and access to minerals resources are contributing well to economic development. This article investigates the nexus among minerals resource complexity, energy consumption, technology, and economic growth by employing autoregressive distributed lag and vector error correction techniques for Pakistan from 1995 to 2021. Following thorough research, the long-term results show that an important 9.73 points of economic growth result from every 1 % increase in the complexity of natural resources. On the other hand, technology and energy use negatively affect economic growth, causing drops of −0.03 and −12.9 points, respectively. One-way causality was noted between mineral resources' complexity and economic growth. Moreover, a one-sided causality effect was also confirmed between energy use, technology, and economic growth. Additionally, it was predicted that there is a neutral causality between mineral resources and technology. Corresponding to this, technology and energy consumption have a bidirectional causal relationship. These results imply that energy consumption, technological advancements, and mineral resources contribute as major economic growth drivers and can improve environmental quality.

1. Introduction

Emerging economies face complex challenges, such as prolonged disputed trade, ambiguous policies, sustainable economic growth, rising poverty rates, and climate issues in numerous emerging countries over the last several decades. In particular, emerging economies like Pakistan face these issues because of the lack of technology and sufficient energy production. As global entered a new era, the World Economic Situation and Prospects 2020 [1] cautioned that economic jeopardize persists strongly due to the energy crisis,

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Nomenclature

CO_2	Carbon dioxide
PCI	Product Complexity Index
ARDL	Autoregressive distributed lag
VECM	Vector error correction model
GDP	Gross Domestic Products
MCI	Minerals Complexity Index
M_t	Mineral resources complexity
E_t	Energy consumption
L_t	Total labor force
PP	Phillips-Perron
AIC	Akaike Information criteria
ECT	Error correction term
IPCC	Intergovernmental Panel Climate Change
FMOLS	Fully-modified ordinary least squares
DOLS	Dynamic ordinary least squares
ASEAN	Association of Southeast Asian Nations
ELA	Energy Information Administration
Y_t	Economic growth
T_t	Technological innovation
K_t	Gross Capital Formation
ADF	Augmented Dickey-fuller
KPSS	Kwiatkowski-Phillips-Schmidt-Shin
VAR	Vector autoregressive

technological advancement, and access to critical minerals in developing nations. Global gross product growth shrank by 2.3% in 2019, the lowest change since the 2008 global financial crisis.

Technology is crucial in the face of urgent global concerns about environmental betterment and economic development. Adoption of renewable energy is important, but technology also resolves these problems. As shown in electric cars, batteries, solar panels, and wind turbines, clean energy and technological innovation are essential for decarbonization and long-term economic prosperity. Integrating essential minerals and technology is essential for the promise of clean energy. The work of Sinha et al. emphasizes how technology and sustainable development are related [2]. Minerals resources, macro, and trace minerals play a vital role in economic development and technological advancement. Metals and critical minerals are inimitable components of advanced technology- (i) copper is used for countless everyday products, electronic instruments, hunting tools, computer and smartphone displays, car parts, and weapons; (ii) nickel, a silver chemical element that is used in coins since 19th century but since industrialization, the used of nickel extended to batteries cells, jet engines, microphones capsules; (iii) lithium is most gained praise element since discovered and considered an essential component of Li-Ion batteries, electric vehicles, telecommunication devices, and subsea electrification. Because of the mineral's importance, widespread and uncommon minerals used increased in the new and innovative technologies and became critical and significant.

Previous research has mostly concentrated on investigating the connection between economic growth and rental or total mineral resource development. However, a novel approach—incorporating the Minerals and Technology Complexity Index—remains poorly investigated. This index, unlike its predecessors, takes into account the complicated interactions between mineral resources and modern technology. Considering how technology affects the use and extraction of mineral resources, the current research aims to present a novel viewpoint on the relationship between mineral resources and economic development. This research intends to contribute a more thorough knowledge of economic development and resource management factors by focusing on previously neglected areas.

The forthcoming study seeks to advance earlier work in several crucial areas. Notably, to the author's knowledge, previous research has not sufficiently examined the impact of mineral complexity on important variables like energy consumption, technological innovation, and economic advancement. By examining the complex interplay between mineral complexity and these crucial factors, this study aims to close this knowledge gap and add a thorough perspective to the field of inquiry. This study adopts the Product Complexity Index (PCI) [3,4] to quantify mineral resource's complexity, reflecting knowledge in research and development, economic situation, resources and costs, transportation, manufacturing ability, and other important factors [3]. The study also encompasses technological innovation, contributing to sustainable economic growth. Thirdly, energy use is crucial for climate change and advanced and emerging economies. Unlike mainstream literature, the technology variable is represented by innovations registered as patents and trademarks. The proxy of these variables enables the study to understand better and make suitable policies in the framework of sustainable economic development and environmental quality. Fourth, the study employed the long and short-run regression model, the ARDL approach, which will examine the nexus between variables. Finally, the VECM was employed to capture the causality direction between variables.

After a detailed introduction, the rest of the study will proceed: the literature reviews are concluded in section 2 of the considered variables. Section 3 will include a detailed analysis of the data series and employed econometric models. Section 4 will conclude the outcomes and discussion of the study. Finally, the conclusion and implications are portrayed in section 5 for future policy-making perspectives.

2. Literature review

The literature review section comprises three main segments: (i) the nexus between technological advancement and economic growth, (ii) critical minerals complexity and economic growth, and (iii) the association between energy consumption and economic growth. As mentioned in every subcategory, literature outcomes on specific topics are inconsistent.

2.1. Technological innovation-economic growth nexus

There is widespread acceptance of the complex link between technology advancements and economic expansion [2]. The divergent economic progress of countries is primarily caused by technology [5,6], most ground-breaking discoveries coming from developed nations [7]. The distribution of income worldwide is considerably altered by this discrepancy, which also exacerbates climate-related problems, particularly in developing nations like Pakistan. Through increased productivity, efficiency, and creativity, technological revolutions encourage economic growth and promote affluence in countries at the forefront of the field. The importance of technology development in promoting sustainable growth and societal development is well recognized [8,9]. Additionally, technical advancements are crucial in reducing carbon emissions, a severe issue for the entire world [10,11]. By utilizing innovation and technology capabilities, nations may successfully address climate mitigation and promote sustainable growth [12].

While some scholars have emphasized the potential for ongoing technology innovation to reduce climate change, support sustainable economic growth, and realize societal ambitions [13,14], it's essential to think about the trade-offs. Rapid equipment replacement and importation might be a quick way to achieve targeted, sustainable growth, but doing so comes at a high cost and could hurt a nation's R&D efforts. Considering these observations, it becomes clear that technological innovation is essential for balancing societal well-being, environmental sustainability, and economic success. The adoption and replacement plan for technology must be carefully considered if a country is to accomplish its long-term research and development efforts while preserving its short-term growth aspirations.

Using advanced bootstrap auto-regressive distributed lag (ARDL) methodologies in the context of Singapore for the period covering 1990 to 2018, a notable and positive relationship between green technology and economic growth has been discovered [15]. A considerable impact on Malaysia's economic growth is shown by using time series methods to analyze patent applications, which are used as a proxy for technological innovation [16]. Furthermore, the VECM econometrics model shows a strong, long-term association between technical innovation and economic growth across European countries from 2001 to 2016 [17]. This shows that several European nations have created roadmaps for technological innovation and implemented extensive strategies to encourage and stimulate economic growth. The ramifications of these discoveries are especially remarkable in the case of China, where unitary innovation has had a significant impact on the mining and exploitation of minerals as well as the industry of electricity production and supply [18]. The aggressive assistance given to these sectors by the Chinese government, which includes sponsoring scientific research and promoting the hiring of technical people, emphasizes how crucial technology is to advancing the nation's economy. These illustrations highlight the vital role that technical improvements play in supporting economic growth and development worldwide.

2.2. Minerals resources-economic growth nexus

Emerging nations have tapped into plentiful resources that could help them achieve sustainable growth and maintain a healthy economy [19]. These developing countries, such as Russia, Turkmenistan, Kazakhstan, and Azerbaijan, depend heavily on their mineral resources for economic growth [20]. However, a notable obstacle still exists: in pursuing sustainable growth, many concerns still lean more toward resource dependence than efficient, sustainable strategies for resource allocation [21]. Consequently, mature countries have a strategic edge over emerging economies due to their skilled resource management and well-organized policies for sustainable growth. Growing nations must practice effective resource management to harness energy and natural resources efficiently. It allows them to promote targeted, sustainable growth while avoiding the problems that frequently afflict developing countries [22].

According to empirical research, mineral resources have a positive effect on economic growth in both developed and developing economies. Mineral resources positively affect the economies of the BRICS countries [23]. Russia, a nation with abundant deposits of uranium, coal, gas, and petroleum, best shows this phenomenon. Similarly, China is a big supplier of minerals and energy in the area, supporting its economic development. Additionally, the economies of South African countries, Singapore, the Philippines, and Mexico benefit from energy-based mineral resources [24].

In contrast, several studies have found a link between the depletion of natural resources and economic growth [25,26]. Resource-rich nations frequently struggle with economic development issues due to an excessive reliance on natural resources, which is a sign of incomplete policies and poor management in harnessing mineral resources to spur economic growth. Contrarily, although not statistically significant, there is evidence that China's natural resource industry and economic growth are positively correlated [23]. It emphasizes the complex link between the exploitation of mineral resources and economic growth. This nuanced viewpoint emphasizes the many contributions of natural resources to economic growth and emphasizes the significance of resource management, comprehensive policies, and sustainable strategies for attaining long-term economic development.

2.3. Energy and economic growth nexus

The complex interplay between economic expansion and energy consumption has been thoroughly investigated in the body of literature already in existence, with a range of results. These results can be divided into four different scenarios: a) First, the "growth hypothesis" proposes a one-way causal relationship, contending that energy use is a critical factor in advancing economic development [27]. In essence, changes in energy consumption are thought to stimulate economic growth. b) Contrarily, the "conservation hypothesis" proposes a one-way causal relationship but in the reverse direction, where economic growth promotes increasing energy consumption, particularly in terms of increases in energy usage linked to economic growth [28]. c) The "bidirectional hypothesis," also known as the "feedback hypothesis," asserts that there is a dynamic, two-way relationship between economic growth and energy use, suggesting that both factors are mutually interconnected and exert an impact on one another [29]. d) Finally, the "neutral hypothesis" suggests that there is no observable relationship between economic growth and energy use, indicating that these variables are not significantly related to one another [30].

Studies examining the relationship between economic and energy indicators have yielded various conclusions, but several patterns stand out [31–33]. The growth hypothesis, for instance, has been observed in the context of both renewable and fossil fuel energy sources, demonstrating its adaptability to various energy sources. This study employed fully modified (FM) and dynamic ordinary least squares (DOLS) for 38 economies [34]. Another study discovered evidence favouring the growth hypothesis regarding renewable energy use and economic growth in non-OECD and emerging countries, especially if these countries surpass a specified level of development [35]. Additionally, the Granger causality approaches used to investigate the feedback hypothesis in several places, like Ghana and the Philippines, revealed a bidirectional causal relationship between economic growth and energy use [36]. Bidirectional causality was noted for energy use and economic growth using multivariate Granger causality from 1960 to 2015. Considering the literature, it is clear that different methodologies, such as the combination or segregation of energy analysis and economic advancement, are likely responsible for the inconsistent findings in earlier studies. By thoroughly analyzing the relationship between energy and economic growth in the context of Pakistan, this research project intends to close these gaps. We will better understand energy's role in sustainable economic development if we undertake this endeavor.

After analyzing the literature mentioned above, our studies' considered variables (energy use, natural resources, and technology) are continuously examined in their econometric applications to explore the effect of said variables on economic progress. But, to the best of the authors' information, minerals resources complexity has not been considered to observe the relationship between energy usage, technology innovation, economic growth, and minerals resources complexity. Therefore, notwithstanding examining the dynamic link between economic factors, this study will analyze the empirical impact on economic growth for emerging economies like Pakistan.

3. Research methodology and data

3.1. Theoretical framework

The dynamic interplay between the Minerals-Technology Complexity Index, energy consumption, and economic growth is supported by a theoretical framework focusing on the relationship between resource use, technical development, and socioeconomic development. The Minerals-Technology Complexity Index recognizes the complex relationship between technological advancement and mineral resource availability and how technological innovation influences resource extraction and exploitation efficiency. Because complicated technologies frequently require high energy inputs, energy consumption is a trigger. This interaction determines economic growth by affecting productivity, industrial diversification, and innovation potential. According to the concept, as the Minerals-Technology Complexity Index rises, economic growth is fueled by energy-intensive processes, technological advances, and increased resource extraction efficiency. However, because energy-consuming activities could potentially negatively affect the environment, this symbiotic relationship needs to be considered from the sustainability perspective. Therefore, a balanced strategy is essential to ensuring that technological advancement, energy efficiency, and management of mineral resources all work together to promote sustainable and inclusive economic development.

3.2. Research methodology

This research applied the ARDL technique to examine long- and short-term empirical nexus amongst the comprised variables, economic growth (Yt), minerals resources complexity (Mt), technological innovation (Tt), energy consumption (Et), capital (Kt), and labor (Lt). This approach was developed by ref. for co-integration assessment among the variables. Various studies have used different techniques for dynamic relationships between the variables. But, this study incorporates the ARDL approach, which has numerous advantages, e.g., it supports stationary variables characteristics either stationary at I(0), the 1st difference I(1), or a combination of both. (ii) Estimating endogeneity and sample size issues is also helpful. (iii) Further, the dynamic free error correction model under linear transformation framework. (iv) This is the best lag order selection technique to give more vigorous results. (v) More importantly, this empirical model addresses the serial correlation issues in the time series data.

For estimations of statistical analysis, the impact of minerals resources complexity, technology innovation, energy use, capital, and labor on economic development, the equation are revealed below Eq. (1):

$$Y_t = f(M_t, T_t, E_t, K_t, L_t) \tag{1}$$

Whereas Y_t is economic growth, M_t is minerals resources complexity, T_t is a technological innovation, E_t is energy consumption, K_t gross capital formation, and L_t Labor force. All comprised variables are converted into logarithm form to minimize scattering in the series and reduce heteroscedasticity and multi-collinearity issues in the equation. Further, log-linear converted series also generate more consistent and efficient outcomes than an ordinary form of linear [37,38]. The log-linear form is shown below in Eq. (2):

$$lnY_t = \alpha_0 + \alpha_1 \ ln \ M_t + \alpha_2 \ ln \ T_t + \alpha_3 \ ln \ E_t + \alpha_4 \ ln \ K_t + \alpha_5 \ ln \ L_t + \varepsilon_t \tag{2}$$

Here α_t the coefficient of constant, minerals resources complexity, technology innovation, energy consumption, gross capital formation, and Labor force. Where the error term is shown as ε_t, and the time operator is represented by t. The long-run, short-run, and error-term regression analysis is based on the ARDL approach in Eq. (3).

$$\begin{aligned}\Delta ln \ Y_t = {} & c_0 + \alpha_1 lnY_{t-1} + \alpha_2 lnM_{t-1} + \alpha_3 lnT_{t-1} + \alpha_4 lnE_{t-1} + \alpha_5 lnK_{t-1} + \alpha_6 lnL_{t-1} \sum_{i=1}^{p} \beta_1 \Delta Y_{t-r} + \sum_{i=0}^{q} \beta_2 \ ln\Delta M_{t-r} + \sum_{i=0}^{q} \beta_3 \Delta ln \ T_{t-r} \\ & + \sum_{i=0}^{q} \beta_4 \Delta ln \ E_{t-r} + \sum_{i=0}^{q} \beta_5 \Delta ln \ K_{t-r} + \sum_{i=0}^{q} \beta_6 \Delta ln \ L_{t-r} + \varepsilon_t\end{aligned} \tag{3}$$

After taking the first difference, the lag interval operator is denoted by q and p, while β and α are the short and long-run coefficients. Co-integration does not exist under the null hypothesis. $H_0 : \alpha_1 = \alpha_2 = \alpha_3 = \alpha_4 = \alpha_5 = \alpha_6 = 0$.

Before proceeding with the ARDL, knowing that the data series is stationary at I(0) or I(1) is compulsory. None of them is stationary at 2nd difference; otherwise, model results will not be reliable. For this purpose, we employed several stationary tests, ADF [39], Phillips-Perron (PP) [40], KPSS [41], and Dickey-Fuller (DF-GLS), for stationary examination of the data.

After analyzing the integration order in the data, we applied the lag length criterion test, Akaike Information criteria (AIC), for optimal selection lags. Further, bound test techniques confirmed the long-term co-integration between the comprised variables. This article also used the Johansen test to estimate the co-integration, essential to decide whether the VAR or VECM is suitable for the data. After confirming co-integration, VECM is the best option to capture the Granger causality nexus between the variables, which shows the direction of the causality. This statistical model assesses the short-term causality and long-term results between included variables. Short-run causality is calculated via the Wald test, while long-run causality is estimated through the error correction term (ECT). The VECM causality is statistically shown in the below form, Eq. 4.

$$\begin{bmatrix} \Delta ln \ Y_t \\ \Delta ln \ M_t \\ \Delta ln \ T_t \\ \Delta ln \ E_t \\ \Delta ln \ K_t \\ \Delta ln \ L_t \end{bmatrix} = \begin{bmatrix} \gamma_1 \\ \gamma_2 \\ \gamma_3 \\ \gamma_4 \\ \gamma_5 \\ \gamma_6 \end{bmatrix} + \sum_{p-1}^{q} \begin{bmatrix} \vartheta_{11p} & \vartheta_{12p} & \vartheta_{13p} & \vartheta_{14p} & \vartheta_{15p} & \vartheta_{16p} \\ \vartheta_{21p} & \vartheta_{22p} & \vartheta_{23p} & \vartheta_{24p} & \vartheta_{25p} & \vartheta_{26p} \\ \vartheta_{31p} & \vartheta_{32p} & \vartheta_{33p} & \vartheta_{34p} & \vartheta_{35p} & \vartheta_{36p} \\ \vartheta_{41p} & \vartheta_{42p} & \vartheta_{43p} & \vartheta_{44p} & \vartheta_{45p} & \vartheta_{46p} \\ \vartheta_{51p} & \vartheta_{52p} & \vartheta_{53p} & \vartheta_{54p} & \vartheta_{55p} & \vartheta_{56p} \\ \vartheta_{61p} & \vartheta_{62p} & \vartheta_{63p} & \vartheta_{64p} & \vartheta_{65p} & \vartheta_{66p} \end{bmatrix} \times \begin{bmatrix} \Delta ln \ Y_{t-p} \\ \Delta ln \ M_{t-p} \\ \Delta ln \ T_{t-p} \\ \Delta ln \ E_{t-p} \\ \Delta ln \ K_{t-p} \\ \Delta ln \ L_{t-p} \end{bmatrix} + \begin{bmatrix} \sigma_1 \\ \sigma_2 \\ \sigma_3 \\ \sigma_4 \\ \sigma_5 \\ \sigma_6 \end{bmatrix} ECT_{it-1} + \begin{bmatrix} \mu_{1t} \\ \mu_{2t} \\ \mu_{3t} \\ \mu_{4t} \\ \mu_{5t} \\ \mu_{6t} \end{bmatrix} \tag{4}$$

Where Δ represents the difference operator, p represents the lag length, and the error term is μ_t.

3.3. Data presentation

This research comprises variables, the complexity of minerals resources, energy consumption, technology innovation, and economic growth, while additional production factors, capital, and labor are also included in the study Table 1. A time-series data of Pakistan span 1995–2021 to evaluate the effect of exogenous variables on the endogenous variable, economic growth. The real gross domestic product (GDP), gross capital formation, labor force, and technology innovation (patent applications registered by residents and non-residents) are collected from World Bank Indicators. Energy use (renewable and non-renewable energy use in quad Btu units) is derived from the United States EIA. Please see Fig. 1.

Further, the most important factor is mineral resource complexity; copper, graphite, nickel, and manganese are collected from the Atlas of Economic Complexity. This variable is derived from the average of comprised minerals. Literature shows that mineral

Table 1
Comprised variables.

	Variables	Units	Sources
Y_t	Real gross domestic products	Per capita in constant 2010 US$	World Bank Indicators
K_t	Gross capital formation	US dollars in constant 2010	World Bank Indicators
L_t	Labor force	Total available labor force	World Bank Indicators
T_t	Technological innovation	Registered Patent (residents and non-residents)	World Bank Indicators
E_t	Energy consumption	Quad Btu units	Energy Information Administration
M_t	Mineral resources complexity (copper, graphite, nickel, and manganese)	Based on the Product complexity index	Atlas of Economic Complexity

Note. Economic growth, mineral resources, technological innovation, energy consumption, capital, and labor are represented by Y_t, M_t, T_t, E_t, K_t, *and* L_t, respectively.

resources have been a hot topic regarding economy and development. However, to the finest of the author's information, past research has not investigated the mineral's complexity. We included this factor because of its importance in development, especially technological innovation. These mineral use has been recorded intensively in different sectors, such as power generation and manufacturing of electronic products, building construction, industrial production, transportation, and transmission. Specifically, listed minerals have essential characteristics, e.g., wiring, electric motors, connectors, bearings, brakes, radiators, electric vehicles, and batteries. Under our calculation, nickel is the most complex mineral (MCI>1), graphite and copper are among the average complex (1 > MCI>0), while manganese is the least complex mineral among others. For reference Fig. 2, nickel complexity values fall from 0.64 to 2.0; graphite complexity indexes are 0.39–1.51, copper values are 0.16–1.23, while manganese complexity index values are −1.25 to 0.67.

4. Empirical result and discussion

The statistical details of the variables are presented in Table 2, which reveals remarkable consistency in both mean and median values. Notably, compared to minerals, energy consumption, and labor, which seem more stable, economic growth, technology, and capital have higher standard deviations, indicating greater fluctuation. Positive kurtosis signs and nearly normal distributions are implied by all variables' close-to-zero positive skewness and near-zero positive kurtosis. The overall data distribution quality and absence of notable outliers are both confirmed by the Jarque-Bera test. Table 3 shows a negative link between technology and labor, minerals, energy use, and GDP growth. In contrast, positive correlations are seen amongst the other variables, helping us understand the unique aspects of the dataset. The minerals complexity index fell from −1.5 to 2.0; the more positive the value, the more complex the products are (Fig. 3).

Before applying the regression model, confirming whether the comprised variables are stationary at I(0) or I(1) is necessary. For this purpose, we applied Phillips-Perron (PP), ADF, DF-GLS, and KPSS. The stationary test outcomes show that all variables have stationary characteristics at I(0) or 1st difference and none at 2nd (Table 4). The results suggest that the null hypothesis of no stationarity was rejected, and the alternative hypothesis was accepted, implying that series are stationary. Thus, the mixed result of the integrated order consents authors to use the ARDL bound test method.

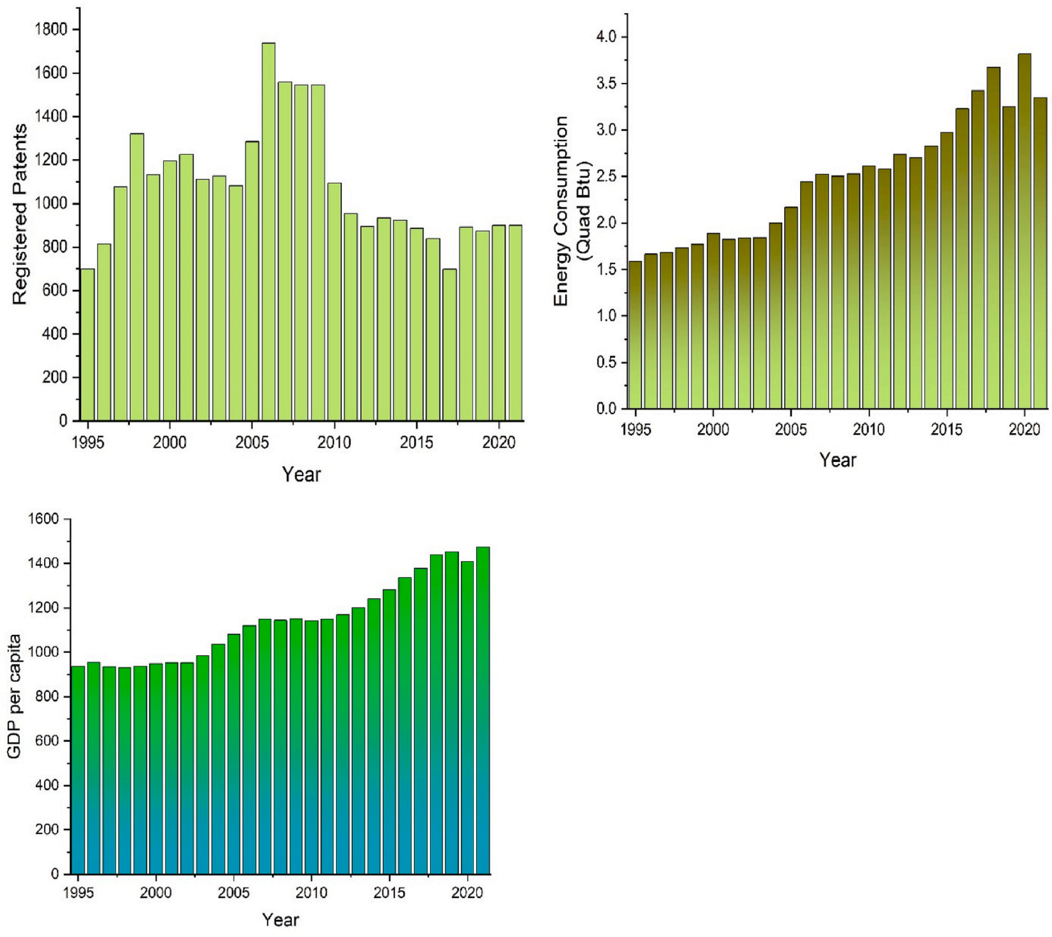

Fig. 1. Graphical presentation of Energy use, registered patents, and GDP per capita.

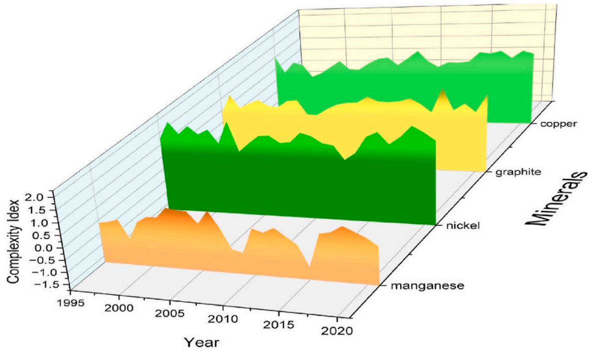

Fig. 2. Complexity index of manganese, nickel, graphite, and copper.

Table 2
Descriptive statistics.

Statistics	Y_t	M_t	T_t	E_t	K_t	L_t
Mean	948.79	0.742	1106.958	2.365	157.922	52.474
Median	978.52	0.718	1087.500	2.473	156.032	51.189
Maximum	1197.91	1.109	1738.000	3.675	199.205	72.035
Minimum	801.15	0.492	698.000	1.586	132.136	34.623
Std. Dev.	121.24	0.163	280.168	0.595	17.860	11.613
Skewness	0.319	0.589	0.612	0.488	0.520	0.166
Kurtosis	2.056	2.556	2.608	2.306	2.352	1.821
Jarque-Bera	1.299	1.587	1.652	1.433	1.500	1.500
Probability	0.522	0.452	0.437	0.488	0.472	0.472

Note. Economic growth, mineral resources, technological innovation, energy consumption, capital, and labor are represented by Y_t, M_t, T_t, E_t, K_t, *and* L_t, respectively.

Table 3
Correlation matrix.

	Y_t	M_t	T_t	E_t	K_t	L_t
Y_t	1.000					
M_t	0.148	1.000				
T_t	−0.202	−0.122	1.000			
E_t	0.991	0.200	−0.218	1.000		
K_t	0.577	0.202	0.146	0.560	1.000	
L_t	0.971	0.111	−0.262	0.972	0.379	1.000

Note. Economic growth, mineral resources, technological innovation, energy consumption, capital, and labor are represented by Y_t, M_t, T_t, E_t, K_t, *and* L_t, respectively.

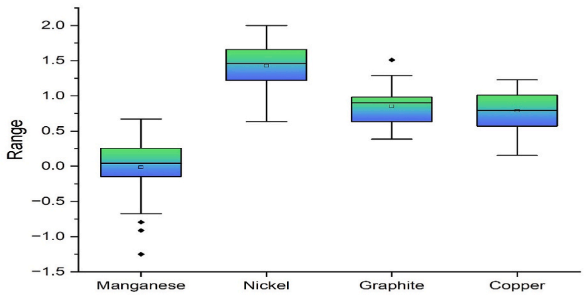

Fig. 3. Box plot of minerals complexity index.

Short- and long-term dynamics results are estimated after confirming the co-integration in the economic growth Table 5. In the long run, a positive nexus was found between minerals and economic development. The empirical outcomes show that a 1% change in the minerals increases economic growth by 9.73 points. In the results of the short-run dynamic, the coefficient of minerals (−39.30) has a

Table 4
Stationary results.

—	ADF		PP		KPSS		DF-GLS	
	Level	1st diff.	Level	1st diff.	Level	1st diff.	Level	1st diff.
Y_t	-3.34^c	-2.41	-1.85	-2.54	0.71^b	0.124	-3.43^b	-2.50
M_t	-3.82^a	-7.73^a	-3.41^c	-12.9^a	0.084	0.50^b	-3.77^a	-5.78^a
T_t	-3.56^c	-3.59^b	-2.56	-3.45^c	0.16^b	0.08	-1.64^c	-3.35^a
E_t	-3.85^a	-3.46^b	-1.99	-3.82^b	0.71^b	0.116	-3.85^a	-3.46^a
K_t	-3.72^b	-2.98^b	-1.66	-3.27^c	0.63^b	0.156	-4.88^a	-3.31^b
L_t	-2.115	-4.39^a	-3.28^b	-3.53^b	0.71^b	0.56^b	-1.92	-4.55^a

Note. Letters a, b, and c are denoted for significance at 1 %, 5 %, and 10 % levels. Included in test equation trend and intercept.

significantly positive effect on GDP per capita income. This finding emphasizes how essential minerals are to promoting economic growth, particularly in the context of clean energy and technological breakthroughs. Notably, this study added a fresh viewpoint by taking into account an aspect of minerals complexity index analysis that had not previously been examined in previous studies. We noticed some similarities between our findings and the proxy for mineral resources. Notably, our results largely corroborate those of a previous study ref. [42], which stressed the close relationship between natural resources and economic growth in the Chinese economy. While using these resources has helped China's economy flourish, administrators must now concentrate on creating a successful plan for their sustainable extraction and consumption [43,44]. By contrast, natural resources impede the economy in India [45] was mentioned that resources impede the Indian economy, suggesting the natural resources sector needs capitalization and conversion.

Our research, however, found an unexpected finding regarding technology innovation, showing a negative correlation with economic growth. Our results indicate that a 1 % increase in technology is associated with a 2.9 % decline in economic growth. Especially in light of our prior discussion of the value of green technology in enhancing environmental quality, this unexpected result raises concerns about the role of technology in fostering economic development and its implications for clean energy. These findings seem at odds with those of a previous study ref. [46], which found a strong positive correlation between information technology and economic growth, especially in developed economies. In that research, technology was seen as a driving force behind economic growth, encouraging innovation, and promoting wealth overall [47]. This discrepancy in findings emphasizes how complicated the relationship between technology and economic growth is, and how it can differ based on elements like the degree of technological sophistication and the economic environment. Despite contradictory findings, policymakers should adopt a balanced approach to technology innovation strategies.

The study examined a negative and significant link between energy use and GDP per capita growth in the long-run; a 1% change in energy usage decreased economic growth by 12.29 points. This finding indicates that most sectors are not working on the full pledge in Pakistan, which indicates that the industry sector is not well developed in the industrialized world. The assessed coefficient of energy use (−45.00) in the short-term is significantly greater than in the long-term, suggesting that energy consumption knocks Pakistan's economy. Current noteworthy results are contradict to the recent study of ref. [34], who captured a long-run association between energy and economic progress for cross-section panel 38 nations data. Similarly, a negative impact of energy use on economic development was noted in developing countries [35]; if the energy use is below the threshold level, a positive relationship was noted between GDP per capita and energy use for developed economies. Based on these findings, developing countries like Pakistan should revisit energy-related policies, and much better to adopt a conversion policy from non-renewable to clean energy.

The two control variables, capital and labor, are used in our model, which is the core of the production function. The results show

Table 5
Long- and short-run regression (ARDL).

Variables	Coefficients	t-Statistic	Probabilities
Constant	311.89^c	8.925	0.000
lnY_{t-1}	0.222^a	2.363	0.027
lnM_{t-1}	9.735^c	2.619	0.015
lnT_{t-1}	-0.029^b	−1.791	0.086
lnE_{t-1}	−12.29	−2.002	0.057
lnK_{t-1}	0.004^b	2.468	0.000
lnL_{t-1}	0.002^a	6.048	0.000
ΔlnM_{t-1}	39.30^a	7.445	0.017
ΔlnT_t	0.198	6.569	0.022
ΔlnE_t	-45.005^a	−4.397	0.048
ΔlnK_t	$0.0005e^c$	12.164	0.006
ΔlnK_{t-1}	0.005^a	0.355	0.755
ΔlnL_t	-0.005^b	−4.802	0.040
$CointEq_{t-1}$	-1.838^a	−8.412	0.013

Note. Letters a, b, and c represent 1 %, 5 %, and 10 % significance levels. Ln is used for natural logarithms and Δ short-run outcomes.

that capital significantly and positively impacts the economy, such that a 1 % rise in capital boosts the economy by 0.4 % in Pakistan. In contrast, the capital findings of the short-run coefficient are lower than the long-run, indicating that capital is a vital factor for sustainable economic growth. Another control variable in the model is labor, a significant economic factor. The labor coefficient is positively linked to economic growth, suggesting that a 1 % induction of labor contribution enhances the economy by 0.2 % in Pakistan. The assessed figure for labor is significantly larger than the capital's figure, suggesting that labor is one of the major requirements for economic development, perhaps because less advanced technology is used in the country. Similar results showed that capital and labor positively link with economic growth in cross-section panel data for 38 countries [34].

Diagnostic findings are shown in Table 6; the F-statistic (20.687) and t-statistic (−5.140) values are significant at 1 %, confirming that all variables are co-integrated and have a long-run relationship. We also note that the R-squared value of 99.4 % and the error term of 0.6 % explain the variation in the equation. The diagnostic results also confirmed the model's absence of Heteroskedasticity and serial correlation LM. The functional form (Ramsay test) shows that the model is well-designed, and the Jarque-Bera test detected a normality issue. These results show the reliability and stability of the model. This research also executes the cumulative-sum (CUSUM) and cumulative-sum of square (CUSUMQ) stability tests to probe constancy and reliability. As shown in Fig. 4, the stability results indicate that the equation performed well, and the residual values fall between upper and lower boundaries at a 5 % significant level.

After examining the existence of co-integration among the variables under the specific lag selection criterion, we used the Johansen approach to capture the long-term link between the comprised variables. This model is based on vector autoregressive (VAR), which provides sufficient co-integration evidence. The statistics show co-integration in three at a 5 % significant level at none, at most one, and two equations Table 7. Several methods are used for lag selection, i.e., AIC, SC, HQ (full form are written in nomenclature table), which is worked under the VAR statistical framework; in this research, authors use the AIC technique. Co-integration between comprised variables leads authors to employ VECM.

The outcomes of VECM causality, short and long-term, are revealed in Table 8. These results are inferred from the nexus between economic development, energy use, technological innovation, mineral complexity, capital, and labor. A one-way causality occurs between mineral resource's complexity and GDP per capita. These findings suggest that an increase in mineral resources boosts economic growth. By contrast, another study [48] noted a neutral effect between natural resources and GDP per capita using nonlinear techniques in minerals-rich countries. Moreover, similar results were found between natural resources and economic development for Asian economies except for India [49]. Based on current findings, policymakers must implement new mineral resource use policies that will help boost economic performance.

Similarly, a one-way causal nexus between GDP growth and energy usage is found, suggesting that an energy supply escalation would enhance sustainable economic growth. The ref. [50] showed the same results for Pakistan, feedback causality, between GDP and energy use employing asymmetric causal test. While unidirectional casualty was investigated for Pakistan [51], running total energy use to economic growth using the nonlinear method. Prospectively, energy requirements can be fulfilled by installing modern technologies, especially clean-energy equipment, without undermining climate intactness.

Moreover, a neutral causal link between mineral resource's complexity and energy consumption is found. To this end, energy use affects Ghana's natural resource extraction and exploitation [52]. Another scholar [53] found that natural resources affect energy use for the panel data set of top Asian economies. Suggests that mineral resources are essential in energy, especially energy generation and storage. The mentioned minerals (copper, nickel, graphite, and manganese) are used to generate and transmit power, manufacture electronic products, industrial machinery manufacturing, transportation, communication, and home appliances.

Further, one-way causality is noted from technology and capital to energy usage, indicating that both variables play a critical role in energy. Comparably, another scholar [54] found that technological innovation enhances energy efficiency, effectively reducing energy use. In contrast, in the case of non-commercial electricity consumption in California [55], efficient technology is a better choice for energy saving. It is difficult to fulfil energy demand and supply in the country without technological advancement.

5. Conclusion and implication

The foremost objective of the current study is to quantify the nexus between mineral resource complexity, energy use, technology, and economic development in Pakistan. This article employed the autoregressive distributed lag technique for long and short-term assessment. At the same time, vector error correction models capture the causal nexus between the variables for the time series from 1995 to 2021. The findings have clear implications for implementing future policies that encourage economic growth with macroeconomic strategies in emerging economies like Pakistan.

The regression model showed that a 1 % change in exogenous variables, energy consumption, technology innovation, and minerals resources complexity enhances economic growth in the long run by 12.9 %, 2.9 %, and 9.73 %, respectively. The phenomenon persists in Pakistan's economy as the energy sector is comparatively less advanced and does not influence economic growth. Further, the study captured the feedback causality between GDP per capita and energy usage. Similarly, a one-side causal nexus is found between technology and energy consumption, running technology to energy use. Energy has been one of the major issues in Pakistan over the last several decades because of improper policies and mismanagement. Additionally, a one-way effect is noted between minerals resources complexity and economic growth, unidirectional causality between minerals resources complexity, and technology innovation running from minerals to technological innovation. These outcomes suggest mineral resources, technological innovation, and energy are important economic drivers. So, for sustainable economic growth, the government of Pakistan and its policymakers should revisit the energy, research and development policies and the minerals extraction and exploitation industry.

These results underscore significant policy ramifications for promoting long-term economic growth. Policymakers should actively encourage local and foreign investors to direct funds toward research and development projects given the crucial role technology plays

Table 6
Diagnostic statistics.

Diagnostic tests	Values	Probability
Heteroskedasticity	0.789	0.587
Serial correlation LM	0.924	0.411
Ramsay Reset	0.497	0.624
Jarque-Bera	1.121	0.571
F-Bounds	20.687[a]	0.000
T-Bounds	−5.140[a]	0.000
R-square	0.994	
Adj-R-square	0.993	

Note. Letters, a, b, and c represent 1 %, 5 %, and 10 % significant level.

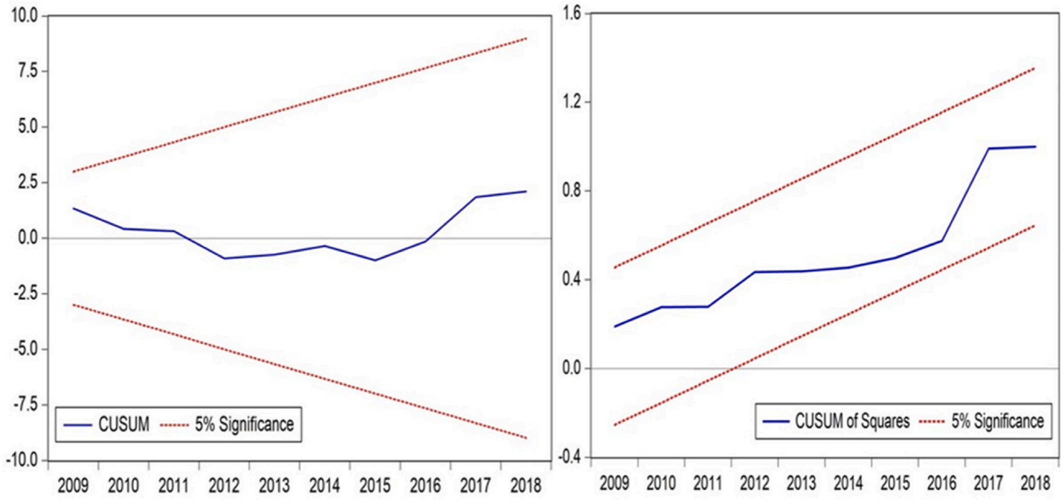

Fig. 4. Stability check of CUCUM and CUSUM of squares.

Table 7
Co-integration and lag selection.

Hypothesized co-integration equations	Unrestricted Co-integration Rank Test		
	Eigenvalue	Trace Statistic	Probabilities
None	0.894	189.115	0.000
At most 1	0.793	121.818	0.000
At most 2	0.652	74.541	0.000
At most 3	0.628	42.912	0.000
At most 4	0.345	13.223	0.107
At most 5	0.016	0.492	0.483
VAR criteria of lag order assortment			
Lags	AIC	SC	HQ
1	99.20	100.89*	99.745
2	99.700	103.063	100.775
3	97.837*	102.882	99.451*

Note. A, b, and c denoted 1 %, 5 %, and 10 % significance levels correspondingly. And *is used for the lag selection criterion.

in fostering such growth. In addition to achieving their economic growth goals, nations can improve environmental quality by using advanced green technologies and energy production and transmission networks by integrating advanced technologies and stepping up their research and development efforts. Maintaining a consistent supply of vital minerals from resource-rich countries is crucial for manufacturing sector growth to continue in emerging economies. Governments can also encourage investor interest by lowering taxes on mining extraction and exploitation, encouraging investment in natural resources.

Several intriguing directions for future research can be considered in light of this study's findings and the limitations noted. Future studies could examine nonlinear modelling techniques, take into account technical complexity, disaggregate energy sources for deeper insights, and use a panel study design with different economies. By improving our knowledge of the connections between mineral resources, energy use, technology, and economic development, these methods can help us create policies and growth-oriented

Table 8
Nexus of granger-causality (VECM).

Endogenous variable		Sources of causation					Long run
	Y_t	M_t	T_t	E_t	K_t	L_t	ECT
Y_t	–	−0.022[c]	−0.068[a]	0.077[a]	−0.149	−0.920[b]	−0.432[c]
M_t	2.427		0.199	−0.451	0.696	6.641	−5.472
T_t	−2.210	−0.145	–	0.442[c]	0.792	−1.579	4.993[b]
E_t	−1.776	0.065	−0.462[c]	–	1.467[c]	−6.783[b]	4.477[b]
K_t	−0.617	2.07	−0.257[a]	0.310[a]	–	−2.909[b]	2.784[a]
L_t	−0.17	−0.007	0.023	0.048[b]	−0.650	–	0.111

Note. A, b, and c correspondingly denoted 1 %, 5 %, and 10 % significance levels.

initiatives that are more effective.

Data availability

Data will be made available upon request.

CRediT authorship contribution statement

Imad Ali: Conceptualization, Formal analysis. **Renpu Li:** Supervision, Writing – review & editing. **Khan Baz:** Methodology, Writing – original draft. **Hashmat Ali:** Investigation, Supervision. **Shehryar Khan:** Validation, Visualization. **Sun Huping:** Writing – review & editing. **Qamar Abbas:** Investigation. **Adham E. Ragab:** Visualization.

Declaration of competing interest

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

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References

[1] U. Nations, World economic situation and prospects 2020, in: United Nations, 2020, p. 2020. New York.
[2] J.J. Ferreira, C.I. Fernandes, F.A. Ferreira, Technology transfer, climate change mitigation, and environmental patent impact on sustainability and economic growth: a comparison of European countries, Technol. Forecast. Soc. Change 150 (2020), 119770.
[3] K. Baz, et al., Effect of mineral resource complexity and fossil fuel consumption on economic growth: a new study based on the product complexity index from emerging Asian economies, Energy 261 (2022), 125179.
[4] K. Baz, et al., Nexus of minerals-technology complexity and fossil fuels with carbon dioxide emission: emerging Asian economies based on product complexity index, J. Clean. Prod. 373 (2022), 133703.
[5] E.B. Bayarcelik, F. Taşel, Research and development: source of economic growth, Procedia-Social and Behavioral Sciences 58 (2012) 744–753.
[6] A.M. Pece, O.E.O. Simona, F. Salisteanu, Innovation and economic growth: an empirical analysis for CEE countries, Procedia Econ. Finance 26 (2015) 461–467.
[7] W. Keller, International trade, foreign direct investment, and technology spillovers, in: Handbook of the Economics of Innovation, Elsevier, 2010, pp. 793–829.
[8] F. Boons, et al., Sustainable innovation, business models and economic performance: an overview, J. Clean. Prod. 45 (2013) 1–8.
[9] S. Matos, B.S. Silvestre, Managing stakeholder relations when developing sustainable business models: the case of the Brazilian energy sector, J. Clean. Prod. 45 (2013) 61–73.
[10] R. Wennersten, Q. Sun, H. Li, The future potential for Carbon Capture and Storage in climate change mitigation–an overview from perspectives of technology, economy and risk, J. Clean. Prod. 103 (2015) 724–736.
[11] R. Bagatin, et al., Conservation and improvements in water resource management: a global challenge, J. Clean. Prod. 77 (2014) 1–9.
[12] A. Lema, R. Lema, Low-carbon innovation and technology transfer in latecomer countries: insights from solar PV in the clean development mechanism, Technol. Forecast. Soc. Change 104 (2016) 223–236.
[13] C. Voegtlin, A.G. Scherer, Responsible innovation and the innovation of responsibility: governing sustainable development in a globalized world, J. Bus. Ethics 143 (2) (2017) 227–243.
[14] G. Cainelli, V. De Marchi, R. Grandinetti, Does the development of environmental innovation require different resources? Evidence from Spanish manufacturing firms, J. Clean. Prod. 94 (2015) 211–220.
[15] T. Meirun, et al., The dynamics effect of green technology innovation on economic growth and CO 2 emission in Singapore: New evidence from bootstrap ARDL approach, Environ. Sci. Pollut. Control Ser. 28 (4) (2021) 4184–4194.
[16] S.H. Law, T. Sarmidi, L.T. Goh, Impact of innovation on economic growth: evidence from Malaysia, Malays. J. Econ. Stud. 57 (1) (2020) 113–132.
[17] R.P. Pradhan, et al., The dynamics among entrepreneurship, innovation, and economic growth in the Eurozone countries, J. Pol. Model. 42 (5) (2020) 1106–1122.
[18] S. Fan, J. Yan, J. Sha, Innovation and economic growth in the mining industry: evidence from China's listed companies, Resour. Pol. 54 (2017) 25–42.

[19] M. Shahbaz, et al., An empirical note on comparison between resource abundance and resource dependence in resource abundant countries, Resour. Pol. 60 (2019) 47–55.
[20] M.E. Bildirici, F. Kayıkçı, Effects of oil production on economic growth in Eurasian countries: panel ARDL approach, Energy 49 (2013) 156–161.
[21] Z. Khan, et al., Natural resource abundance, technological innovation, and human capital nexus with financial development: a case study of China, Resour. Pol. 65 (2020), 101585.
[22] J. Guan, et al., Natural resources rents nexus with financial development in the presence of globalization: is the “resource curse” exist or myth? Resour. Pol. 66 (2020), 101641.
[23] S. Wu, L. Li, S. Li, Natural resource abundance, natural resource-oriented industry dependence, and economic growth: evidence from the provincial level in China, Resour. Conserv. Recycl. 139 (2018) 163–171.
[24] M.A. Baloch, N. Mahmood, J.W. Zhang, Effect of natural resources, renewable energy and economic development on CO2 emissions in BRICS countries, Sci. Total Environ. 678 (2019) 632–638.
[25] T. Gylfason, Natural resources, education, and economic development, Eur. Econ. Rev. 45 (4–6) (2001) 847–859.
[26] C.N. Brunnschweiler, E.H. Bulte, The resource curse revisited and revised: a tale of paradoxes and red herrings, J. Environ. Econ. Manag. 55 (3) (2008) 248–264.
[27] Q. Munir, H.H. Lean, R. Smyth, CO2 emissions, energy consumption and economic growth in the ASEAN-5 countries: a cross-sectional dependence approach, Energy Econ. 85 (2020), 104571.
[28] U. Umurzakov, et al., Energy consumption and economic growth: evidence from post-communist countries, Int. J. Energy Econ. Pol. 10 (6) (2020) 59.
[29] A.N. Ajmi, R. Inglesi-Lotz, Biomass energy consumption and economic growth nexus in OECD countries: a panel analysis, Renew. Energy 162 (2020) 1649–1654.
[30] E.I. Cevik, D.Ç. Yıldırım, S. Dibooglu, Renewable and non-renewable energy consumption and economic growth in the US: a Markov-Switching VAR analysis, Energy Environ. 32 (3) (2021) 519–541.
[31] I. Khan, et al., Environmental quality and the asymmetrical nonlinear consequences of energy consumption, trade openness and economic development: prospects for environmental management and carbon neutrality, Environ. Sci. Pollut. Control Ser. 29 (10) (2022) 14654–14664.
[32] I. Ali, et al., Asymmetric impact of coal and gas on carbon dioxide emission in six Asian countries: using asymmetric and non-linear approach, J. Clean. Prod. 367 (2022), 132934.
[33] K. Baz, et al., Asymmetric impact of energy consumption and economic growth on ecological footprint: using asymmetric and nonlinear approach, Sci. Total Environ. 718 (2020), 137364.
[34] M. Shahbaz, et al., The effect of renewable energy consumption on economic growth: evidence from the renewable energy country attractive index, Energy 207 (2020), 118162.
[35] C. Chen, M. Pinar, T. Stengos, Renewable energy consumption and economic growth nexus: evidence from a threshold model, Energy Pol. 139 (2020), 111295.
[36] M.O. Appiah, Investigating the multivariate Granger causality between energy consumption, economic growth and CO2 emissions in Ghana, Energy Pol. 112 (2018) 198–208.
[37] M.W. Zafar, et al., The impact of natural resources, human capital, and foreign direct investment on the ecological footprint: the case of the United States, Resour. Pol. 63 (2019), 101428.
[38] A. Sinha, M. Shahbaz, Estimation of environmental Kuznets curve for CO2 emission: role of renewable energy generation in India, Renew. Energy 119 (2018) 703–711.
[39] D.A. Dickey, W.A. Fuller, Distribution of the estimators for autoregressive time series with a unit root, J. Am. Stat. Assoc. 74 (366a) (1979) 427–431.
[40] P.C. Phillips, P. Perron, Testing for a unit root in time series regression, Biometrika 75 (2) (1988) 335–346.
[41] D. Kwiatkowski, et al., Testing the null hypothesis of stationarity against the alternative of a unit root: how sure are we that economic time series have a unit root? J. Econom. 54 (1–3) (1992) 159–178.
[42] Z. Li, et al., Structural transformation of manufacturing, natural resource dependence, and carbon emissions reduction: evidence of a threshold effect from China, J. Clean. Prod. 206 (2019) 920–927.
[43] J. Wang, et al., Identifying critical sectors and supply chain paths for the consumption of domestic resource extraction in China, J. Clean. Prod. 208 (2019) 1577–1586.
[44] Y. Hao, et al., Relationship between forest resources and economic growth: empirical evidence from China, J. Clean. Prod. 214 (2019) 848–859.
[45] I.H. Shah, L. Dong, H.-S. Park, Characterization of resource consumption and efficiency trends in Bangladesh, India and Pakistan: economy-wide biotic and abiotic material flow accounting from 1978 to 2017, J. Clean. Prod. 250 (2020), 119554.
[46] M. Pohjola, Information Technology and Economic Growth: A Cross-Country Analysis, 2000.
[47] R. Landau, N. Rosenberg, The Positive Sum Strategy. Harnessing Technology for Economic Growth, ERIC, 1986.
[48] G.K.M. Ampofo, et al., Total natural resource rents, trade openness and economic growth in the top mineral-rich countries: new evidence from nonlinear and asymmetric analysis, Resour. Pol. 68 (2020), 101710.
[49] M. Haseeb, et al., The natural resources curse-economic growth hypotheses: quantile–on–Quantile evidence from top Asian economies, J. Clean. Prod. 279 (2021), 123596.
[50] K. Baz, et al., Asymmetric impact of fossil fuel and renewable energy consumption on economic growth: a nonlinear technique, Energy 226 (2021), 120357.
[51] K. Baz, et al., Energy consumption and economic growth nexus: new evidence from Pakistan using asymmetric analysis, Energy 189 (2019), 116254.
[52] P.A. Kwakwa, H. Alhassan, G. Adu, Effect of Natural Resources Extraction on Energy Consumption and Carbon Dioxide Emission in Ghana, International Journal of Energy Sector Management, 2020.
[53] H.I. Hussain, et al., The causal connection of natural resources and globalization with energy consumption in top Asian countries: evidence from a nonparametric causality-in-quantile approach, Energies 13 (9) (2020) 2273.
[54] Y. Li, S. Solaymani, Energy Consumption, Technology Innovation and Economic Growth Nexuses in Malaysian, Energy, 2021, 121040.
[55] J. Li, R.E. Just, Modeling household energy consumption and adoption of energy efficient technology, Energy Econ. 72 (2018) 404–415.