Nuclear Engineering and Technology 56 (2024) 2480–2488

Contents lists available at ScienceDirect

Nuclear Engineering and Technology

journal homepage: www.elsevier.com/locate/net

Original Article

Nuclear energy, economic growth and CO_2 emissions in Pakistan: Evidence from extended STRIPAT model

Muhammad Yousaf Raza, Songlin Tang *

School of Economics, Shandong Technology and Business University, Yantai, 255000, China

A R T I C L E I N F O

Keywords:
Nuclear energy
CO_2 emissions
STRIPAT model
Ridge regression
Pakistan

A B S T R A C T

Pakistan is a developing country whose maximum amount of mixed energy is provided by electricity, oil, coal, and gas. The study objective is to analyze the six major social factors to describe the significance of nuclear energy and CO_2 emissions at the decisive point coming from income, trade, energy, and urbanization. This study has tried to analyze the impact of different factors (i.e., fossil energy, GDP per capita, overall population, urban population, and merchandise trade) on Pakistan's CO_2 emissions using the extended STRIPAT model from 1986 to 2021. Ridge regression has been applied to analyze the parameters due to the multicollinearity problem in the data. The results show that (i) all the factors show significant results on carbon emissions; (ii) population and energy factors are the huge contributors to raising CO_2 emissions by 0.15% and 0.16%; however, merchandise and GDP per capita are the least contributing factors by 0.12% and 0.13% due to import/export and income level in Pakistan, and (iii) nuclear energy and substitute overall show a prominent and growing impact on CO_2 emissions by 0.16% and 0.15% in Pakistan. Finally, empirical results have wider applications for energy-saving, energy substitution, capital investment, and CO_2 emissions mitigation policies in developing countries. Moreover, by investigating renewable energy technologies and renewable energy sources, insights are provided on future CO_2 emissions reduction.

1. Introduction

Growing pollution has led to negative development (i.e., global warming and climate change), and certain advanced economies have highlighted decarbonization measures in their economic recovery (International Energy Agency (IEA [1]). For this reason, ecological excellence has become one of the imperative features for societies and countries, whereas economic problems have also reserved their significance. CO_2 emissions from human doings are the major reason for global warming, and Pakistan releases additional CO_2 emissions annually in South Asia than the other countries after India. In 2021, the major economies in South Asia that added the maximum CO_2 emissions followed the order of India, Pakistan, Bangladesh, and overall, Asia Pacific (see Table 1). In accordance with the growth, the present literature on environmental quality has currently extended in search of paths to lessen greenhouse gas (GHG) emissions [2]. Most of the current studies utilize CO_2 discharges as a substitute for environmental quality and as an outcome variable in environmental studies [3].

As an emerging economy in South Asia, Pakistan has played an increasing part in CO_2 emissions and global warming. Broadly analyzed CO_2 emissions mainly cause global warming, which applies to the phenomenon that the temperature is gradually increasing, such as when the earth's surface temperature in 2022 was 0.86 °C warmer than the 20th century [4]. A deep reduction in GHG discharges seems likely in the future decades; global warming of 1.5 °C and 2 °C above pre-industrial levels will be surpassed during the 21st century [5]. With such a situation is perhaps to have a gradually more common happening of excessive weather situations, which is not only a threat to the environment but also to economic growth.

Being an underdeveloped country, Pakistan always follows and is responsible for issues caused by CO_2 emissions in the world. During the past decade, Pakistan has experienced fast economic growth and wide-ranging energy consumption due to industrialization and associated market reforms [6]. This has increased production and caused a gradual increase in domestic demand. In 2021, Pakistan emitted 226.4 $MtCO_2$, with GDP per capita arriving at US$1505.01 and a national population of over 231.40 million. Moreover, the economic growth of Pakistan is greatly reliant on fossil fuel energy, in which 76.1% of overall CO_2

* Corresponding author.
E-mail addresses: yousaf.raza@ymail.com, yousaf.raza@sdtbu.edu.cn (M.Y. Raza), tangsonglin@sdtbu.edu.cn (S. Tang).

https://doi.org/10.1016/j.net.2024.02.006
Received 31 October 2023; Received in revised form 16 January 2024; Accepted 3 February 2024
Available online 5 February 2024
1738-5733/© 2024 Korean Nuclear Society. Published by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

Table 1
Top South Asian countries by CO_2 emissions in 2021.

Regions	CO_2 emission in 2021 (Mt)	Share 2021 (%)	Per annum growth rate (%)
World	33884.1	100	0.6
Asia Pacific	17734.6	52.3	1.8
India	2552.8	7.5	4.0
Pakistan	226.4	0.7	4.5
Bangladesh	100.9	0.3	6

Source: World Bank

emissions come through the energy sector [7].

Thus, to check the main leading factors of rising CO_2 emissions in Pakistan and give recommendations for lessening CO_2 emissions growth, we analyze the prospective indicators.[1] Since the late 1980s, there has always been a discussion between policymakers and research scholars about CO_2 emissions and economic growth impacting the environment, and natural resources; however, technological progress could benefit the rise of CO_2 emissions [8]. To investigate and prove this argument, the IPAT identity will be applied as a model that permits the major impacting influences of environmental excellence; for instance, affluence [A], population [P] and technology [T] are the main basic elements of the IPAT method. In addition, the STRIPAT method analyzes the stochastic influences of IPAT methods, which provides a useful construction to investigate the contribution of individual factors [9].

In preference, the demand for nuclear energy and cleaner energy sources has become a requisite to combat pollution, climate change and environmental variation, as there is consensus that they could improve personal well-being and level of life [10]. While the reduced form methods related to environmental issues are vulnerable to description errors, omitted variable bias, the selected valuation strategy, obtained results, used data for analysis, and econometric technique. Though, some scholars have examined how various econometric problems might abridge the absence of robust results? However, they confirmed that limited stress is given to the STRIPAT and ridge regression models.

Considering the literature gap, the position of Pakistan as one of the major nuclear-utilizing energy countries (annual growth by 14.3%), and the potential contribution to ecological quality, the present research analyzes the impacts of nuclear energy consumption on environmental quality (i.e., CO_2 emissions, fossil energy, GDP per capita, overall population, urban population, and merchandise trade). The objective of the study is to (a) develop the STRIPAT model; (b) test both the regression and ridge regression to make significant results; (c) analyze the effect of CO_2 emanations with nuclear energy and related social factors; (d) standardized ridge regression results to the significant outcomes, and (e) describe the decisive point to arouse the significant influence of income, trade, energy, and urbanization. The empirical outcomes will confirm and identify the standardized estimations by using the STRIPAT model, which will help policymakers and researchers take initiatives to attain economic growth and mitigate CO_2 emissions at the same time.

The current study makes numerous contributions to the recent literature. (i) This research emphasizes Pakistan as an emerging nuclear energy-consuming nation. However, there are few studies on Pakistan; for instance, Mahmood et al. [11] and Majeed et al. [12] analyzed nuclear and environmental analysis under limited and similar factors (i.e., GDP, CO_2 emissions and nuclear energy) from 1974 to 2019. These studies do not address the CO_2 emissions, fossil energy, GDP per capita, overall population, urban population, and merchandise trade by applying the STRIPAT framework and ridge regression. The extended STRIPAT methods includes the policy tools that describe environmental technologies, factors' contributions, and institutional quality to create the STRIPAT model and to analyze how these mechanisms add to mitigating CO_2 emissions. The IPAT model gives an advanced theory to regulate the driver of ecological grounds [13]. Thus, the primary strength of the IPAT falls in its foundation in environmental principles coupled with its ability to show variations in major factors are expected to alter effects. It is worth seeing the multicollinearity issues in the data; we will apply ridge regression to standardize the coefficient values in the model. (ii) The study includes annual data from 1986 to 2021, which is the connection of all the inputs. Thus, it is believed that current research makes a significant contribution to the existing literature by concentrating widely on the Pakistan example. To the best of our knowledge, no previous study has investigated nuclear energy with leading social factors, including population, affluence and technology on the carbon emissions, particularly in Pakistan. Finally, this research is predicted to be one of the ground-breaking works that gives a detailed analysis of the energy-economy and environmental tendencies and suggests mitigating future CO_2 emissions. Dealing with these problems, the current research can support the administration, environmentalists and policymakers in developing effective measures and quick doings that can improve the country's investment in nuclear energy to sustain economic growth.

The next part of the study is provided as: Section 2 presents a literature review. Section 3 presents the methodology and Section 4 presents empirical outcomes and discussion. The conclusion and proposed implications are given in Section 5.

2. Literature review

Energy, economics and environmental issues have been extensively discussed, including aggregate and disaggregate energy (i.e., fossil fuels and renewable energy sources). Environmental and economic factors in various countries, regions and sectors have provided mixed results (for example, Sarkodie and Strezov [14] for developing countries; Adekoya et al. [15] for BRI countries; Napolitano et al. [16] for 127 countries; Lin and Raza [17] for Pakistan). To attain sustainable development goals, clean energy plays a significant role in pollution mitigation, which has created immense attention among scholars. For this, few scholars have claimed that renewable energy resources help to reduce CO_2 emissions (e.g., Raza et al. [18]; Raza and Lin [19]; Guang et al. [20]). A theory of sustainable growth highlights the need to utilize capital in a manner that guarantees the capability of resources for upcoming generations to satisfy their demands [21]. On this basis, the literature found relevant but limited information in three ways: energy-economics using the Environmental Kuznets Curve (EKC), decomposition, technological perspectives, mixed modeling, and the nuclear energy nexus.

On the EKC hypothesis, several researchers found the nexus between energy, economy and environment; for example, Pata and Kartal [3] analyzed the influence of nuclear and renewable energy sources on ecological quality in South Korea using the ARDL method. They found that nuclear energy has an improving impact on environmental quality, which has confirmed the validity of the EKC hypothesis and confirms an optimistic input of nuclear energy into green development strategies. Dogan and Inglesi-Lotz [22] investigated the EKC hypothesis for European nations and found that total GDP is the factor with which CO_2 emissions show an inverted U-shaped relationship. Pata [23] analyzed renewable energy, carbon emissions, urbanization and GDP for Turkey using the ARDL bounds test and found that GDP caused CO_2 emissions, followed by urbanization and financial development, which also supports the U-shaped relationship. Gu et al. [24] investigated green finance and green growth for G7 countries and found that the region's leading factors of CO_2 emissions are natural resources, involving natural gas and minerals. Based on the above literature on EKC, it can be seen that past research gives different results relying on the situations of these countries; however, the regional, developed or underdeveloped countries proved the EKC outcomes with limited variables. These republics, with the latest technology, expert labor, and huge financial resources, can stabilize their country and have the maximum proportion of nuclear energy in the mixed energy. Yet, the empirical literature absences proof

[1] Used indicators are nuclear energy, fossil fuel energy, GDP per capita, overall population, urban population, and merchandise trade of GDP.

about emerging nations like Pakistan.

Respecting the various factors' decomposition, many scholars have analyzed energy-economy and environmental factors to identify demand-consumption, social impacts, and individual output. For example, Chang et al. [25] used energy intensity, economic level, emissions coefficient, and economic development factors for Japan and China using the logarithmic mean Divisia index (LMDI). They found that the energy intensity reduction in China significantly added to carbon emission mitigation besides the emission coefficient, while Japan has a similar condition. Raza and Lin [26] used the energy intensity, economic activity, labor productivity, and employed labor for Pakistan using decomposition analysis and investigated that each factor's ratio grew while labor and economic activity presented the maximum input, excluding the COVID-19 period. Raza and Lin [27] used sectorial natural gas share, energy intensity, economic structure share, per capita GDP, and population factors employing the LMDI method for Bangladesh. They analyzed that the economic structure effect is the major driving factor in growing gas consumption, while the energy-saving technology gap was found in the power, industry, fertilizers, tea estate, and CNG sectors. Yang et al. [28] used the economic activity, CO_2 emissions, industrial structure, energy import-export trade, and renewable energy efficiency factors for China using the LMDI method. They estimated that imported electricity is the best strategy to mitigate CO_2 emissions. Moutinho et al. [29] used the carbon trade intensity, fossil fuel trade, fossil intensity, renewable source output, electricity financial power, and financial growth effects for the top 23 countries on a group of renewable energies using the decomposition and decoupling approach. They analyzed that the efficiency of cleaner sources and the financial growth impact of renewable energy generation per GDP are the major factors for overall and negative variations of CO_2 emanations; however, a rise in CO_2 emissions was seen because of the fossil fuel energy use effect. Based on the above present and past studies on developed and underdeveloped countries, we observed that (i) factors used in these studies are not properly employed as per our objectives; however, (ii) as per their findings, economic growth, energy structure, population, and technological progress can positively or negatively impact the amount of CO_2 emissions.

Finally, mixed modeling has been employed in various studies. For example, Chang et al. [25] employed the mixed-frequency vector autoregressive model to analyze the causality between GDP and CO_2 emissions in Taiwan. They analyzed that there is a causal association between primary energy and economic progress, which needs energy framework policies for the country. Su and Ang [30] used the structural decomposition and input-output analysis using several factors, i.e., energy intensity for China, and found that energy demand is more concerned with economic development. Lin and Raza [31] employed LMDI and input-output analysis for Pakistan's coal and economic development using industrial structure, energy mix, and energy intensity factors effects. They found that economic scale is the only factor that is increasing coal consumption. Also, few studies used nuclear energy utilization as an environmental factor; for instance, Wang et al. [32] analyzed the association between nuclear energy, economic development and CO_2 emissions for a group of twenty-four countries. They originated from the idea that there is an optimistic increased connection between nuclear energy, renewable energy and economic growth. Price et al. [33] used the cost-optimizing power system method to analyze the techno-economic instance for investment in new nuclear capacity in the United Kingdom's net-zero emissions energy system and found that nuclear capacity is cost-effective if determined costs and construction times are taken. Ozgur et al. [34] used the ARDL method to analyze the association between nuclear energy and CO_2 releases in India and found a negative coefficient of nuclear energy consumption, which indicates the expansion of nuclear to attain clean and sustainable growth. Saidi and Omri [35] used a fully modified OLS technique for 15 OECD countries and found that in many countries, investment in nuclear energy reduces CO_2 emanations. Dong et al. [36] employed the EKC for China and found that nuclear and renewable energy play significant roles in lessening CO_2 emissions in the short and long-run.

As per the above discussion, it can be summarized that past research has had different outcomes based on different countries and models; however, there are still a few likenesses in the present study. Assuming that the relationship between energy and socio-economic factors is linear, many researchers used traditional linear techniques to investigate the relationship between energy and non-energy variables (i.e., fossil fuels, renewables, labor, population, CO_2 emissions, etc.). In fact, there is no STRIPAT relationship between CO_2 emissions, nuclear energy, fossil fuel energy, GDP per capita, overall population, urban population, and merchandise trade of GDP, particularly for Pakistan. The STRIPAT and ridge regression models are applied to check the variables, which confidentially identify the variables' output in a region, sector or country. In addition, most of the current studies used cross-sectional, time-series or panel data to estimate the relationship between different variables; however, these studies do not measure the current relationship under technical measures for Pakistan. Therefore, it is necessary to examine the current association between CO_2 emissions and economic-growth factors in a developing country like Pakistan.

3. The data

For evaluating the variables of nuclear energy consumption in Pakistan, time series data have been collected from 1986 to 2021. Concerning studies in the literature section, the objective of our study is to measure CO_2 emissions, fossil energy, GDP per capita, overall population, urban population, and merchandise trade in Pakistan. To see the empirical findings, we establish this study by specific time, developing nation, outcomes, and methodological description. The data relating to nuclear electricity and fossil fuel energy have been collected from the HDIP [7] and are estimated in million tons of oil equivalent (Mtoe). The CO_2 emissions-related data has been collected from the World Bank, which is considered as metric tons of CO_2 emissions ($MtCO_2$). All the data related to population, urban population, GDP per capita, and merchandise trade have been collected from the World Bank. The data related to population are taken in million US$, while GDP per capita and merchandise trade data are measured in current US$. For easy measurement, we transformed all variables into natural logarithms when investigating the assessed parameters. Table 2 and Fig. 1 summarize the statistics for each variable used in this analysis.

It can be seen in Fig. 1 that the plotted graphs of each variable present the correlation between them, thus suggesting the need to analyze the correlation between the variables. Also, it is obvious that GDPc, energy and population are presenting optimistic signs, as the data design for each variable presents a growing trend. Moreover, focusing on trade, it has been approved that the continued economy of Pakistan is extremely dependent on growing capital production and also on the share of investment [19]. In the current variation, all the variables in Pakistan over the measuring period show a rising trend during the studied period.

4. Methods

4.1. STRIPAT model

The primary framework employed for knowing environmental influence in the early 1970's with a hostile discussion about the relative significance of technology and population. Ehrlich and Holdren [39] apprehended that population was the main issue to deal with, however, Ridket [40] felt that technological variation after World War II was a major cause of concern. In understanding the environmental issues, a framework has been extensively applied, for instance, four variables are used and are acknowledged as the IPAT identity:

$$I = P.A.T \quad (1)$$

Table 2
Descriptive statistics.

Variables	Symbol	Unit	N	Mean	Std. Dev.	Minimum	Maximum	Sources
Nuclear energy	lnNe	Mtoe	36	1.4850	0.48703	0.4709	2.2466	[7]
Fossil fuel energy	lnFe	Mtoe	36	3.1882	0.4228	2.4169	3.8562	[7]
CO_2 emissions	$lnCO_2$	$MtCO_2$	36	4.6807	0.4549	3.7686	5.4222	[37]
Total population	lnP	Million	36	5.0894	0.2518	4.6113	5.4441	[38]
Urban population	lnUp	Million	36	3.9964	0.3203	3.3935	4.4617	[38]
Merchandise trade	lnMt	US$	36	10.3648	0.7391	9.0777	11.5209	[38]
GDP per capita	lnGDPc	US$	36	6.5103	0.5397	5.7589	7.3906	[38]

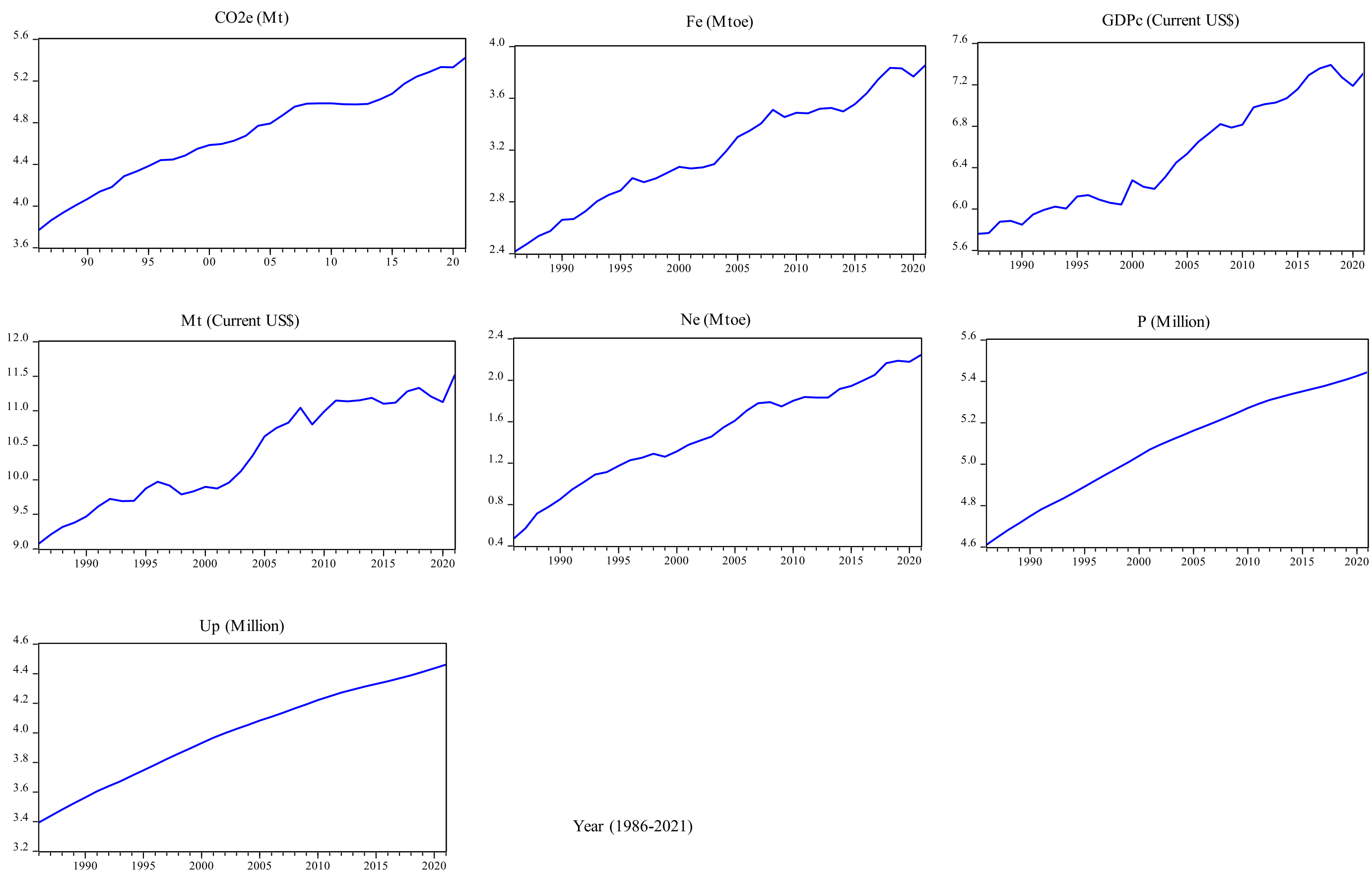

Fig. 1. Trend of variables 1986–2021.
Source: Author's evaluation based on analyzed data.

Eq. (1) shows that the environmental effect is the multiple of population (P), affluence (A) and times technology (T). Since A is commonly given as GDP per capita. With the specification of an environmental impact (i.e., CO_2 in time t), the technology or term becomes the residual or the quantity of the stated impact per unit of GDP. For instance, in the current situation T would be CO_2 emission measured in metric tons (CO_2Mt) is divided by GDP also calculated for the time, specified for I. The IPAT has been verified as very helpful partly due to its ease of use, transparency and partly. This is due to its flexibility in giving a different ecological issue. The IPAT identity is mostly used in analyzing the aim of economic movement in carbon emissions at industrial and national levels [41,42]. As per Xu and Lin [43] and Khan et al. [9], IPAT identity is a mathematical formula that does not rightly examine how certain aspects impact the climate. However, Wang and Zhao [44] claimed that this identity accepts that these factors' elasticities are uniform. To discourse these limitations (based on IPAT), Dietz and Rosa [45] suggested the STRIPAT model, we employed in the study. The STRIPAT works in the nonlinear situation, measure heteroskedasticity issue, measure the impact of human activities on environmental situations [46], and measure the elastic coefficient of each variable. Mathematically, the present study model can be stated as in Eq. (2).

$$I = \alpha P_i^{a}.A_i^{b}.T_i^{c}\varepsilon_i \tag{2}$$

Taking the natural logarithm of all the variables in Eq. (2), the STRIPAT model can be described as:

$$I = \ln \alpha + a \ln P + b\ln A + c\ln T + \ln \varepsilon \tag{3}$$

Where I, P, A, and T are stated as IPAT identity. a, b and c show the elasticity of I, P, A, and T, while ε denotes the residual error and i denotes the year. After the decomposition and extension. Thus, the latest formula of the STRIPAT model in Eq. (3) can be provided as:

$$\ln CO_2e = \alpha_0 + \alpha_1 \ln Fe + \alpha_2 \ln GDP_c + \alpha_3 \ln M_t + \alpha_4 \ln N_e + \alpha_4 \ln P + \alpha_5 \ln Up \tag{4}$$

Where CO_2e factor shows overall carbon dioxide emissions, Fe shows the fossil energy, GDP_c presents the GDP per capita, M_t represents the merchandise trade of GDP, N_e shows the nuclear electricity, P shows the total population, and Up represents the total urban population.

4.2. Measurement processes

4.2.1. Multicollinearity measurement

Given the tendencies of different energy models and due to the boundary and squared terms of the input effects in Eq. (4), the possibility occurs of the structure continuing severe multicollinearity issues, such as a numerical phenomenon in which '2' or more predictor effects in a multiple regression model are significantly correlated. In this situation, the coefficient estimates may change randomly because of little changes in the number or model. Moreover, multicollinearity states the strong linear relationship between explanatory variables; thus, the highly significant the relationship between inputs, the more perhaps these factors are measured as significantly multicollinear. When there is a high relationship between variables, it is not so easy to decompose each variables' effect. Thus, using this method, we will apply the linear association between the main explanatory variables, as discussed in Eq. (2). Ordinary least squares (OLS) technique outcomes would be incorrect if there is a multicollinearity issue [47].

Using the multicollinearity testing in this study is to estimate the level of relationships among variables. A few ways are used to find this issue: (i) check the correlation between '2' or more variables. If the correlation (r^2) is at the maximum point, it can be concluded that the factors are significantly interrelated, which verifies that there is a presence of multicollinearity among the variables. As shown in Table 3, the correlation results provide a significant correlation between them, which presents that there is a severe multicollinearity issue in the model. Generally, several researchers have estimated this issue in various countries and industries, for instance, Lin and Atsagli [48] for Nigeria; Raza and Lin [19] for Pakistan, and Lin and Raza [49] for the agriculture sector of Pakistan. (ii) In addition, the severity of the multicollinearity issue can be estimated by employing the variance inflation factor (VIF) method, which is confirmed by analyzing to what degree a particular independent variable can be described by the remaining factors in the model. As per the rule of thumb, if the VIF value is greater than ten, the multicollinearity issue will be severe. If the VIF value is less than ten, the multicollinearity issue will be reduced, which means that it improves the estimated variance of the coefficient. (iii) In order to evade the impact of the multicollinearity problem, this research applies the ridge regression method, which was suggested by Hoerl and Kennard [50].

4.2.2. Ridge regression

Using the Hoerl and Kennard [50] technique, the results show that stationarity drives us to use the ridge regression for additional valuation. To achieve the ridge parameter, we calculate for $(X'X+KI)\widehat{\beta} = h$ provides $\widehat{\beta} = (X'X+KI)^{-1}h$ where $h = X'Y$, K is the ridge parameter in which $K \geq 0$ and 'I' is the identity matrix. For any issue, there is a perfect or optimum K value, which is needed for a series of acceptances of K values between [0.00–1.00]. Few techniques apply K in measuring ridge trace and in econometric literature; for instance, Lin and Fei [51], Wesseh and Lin [52] and Raza et al. [53]. This study uses the ridge trace for easy understanding in which K values can be examined between [0–1], as indicated in Fig. 2. The $\widehat{\beta}_i$ standards are plotted on the basis of K values and the substantial value is measured at the point where $\widehat{\beta}_i$ a coefficient appears stable.

5. Empirical results

5.1. OLS, VIF and ridge trace

This study uses the OLS model primarily to check the variables' effects using Eq. (4). The numerical measurement of the coefficients would become challenging, and the *t*-test, F-test, VIF, and standard error may become biased. The maximum value of R^2 provides the maximum linear relationship between the contributing variables. In the current study, the coefficient of determination (R^2) estimates the degree of the association among each model with Fe, GDP_c, M_t, N_e, P, and Up as output variables is 0.999 for each, whereas the least correlation is 0.971 and the maximum correlation is 0.999, respectively, as shown in Table 3. The VIF of the used model is also large, which is more than ten. The VIFs of the individual variables given above in ascending order are 150.83, 52.67, 62.63, 164.54, 9225.79, and 10571.52, which proves that the model provided in Eq. (4) gives inconsistent results using the OLS method. In addition, it is obvious in Table 4 that half of the regression coefficients are negative, which opposes economic reality. This presents that all the factors, excluding population, nuclear electricity and fossil energy, are not presenting a growing trend. These results are signs of huge multicollinearity that have severely influenced the parameters. As per Kmenta [54], the OLS model outcomes have validated the severity of the multicollinearity issue.

In order to evade the multicollinearity problem, a ridge trace is first employed whose, objective is to check the consistent point at a specific value of K. As shown in Fig. 2, due to the changeability in R^2 and beta coefficients, the ridge trace of the factors of the STRIPAT model is provided. The K-value is seen at the significant level of $K = 0.65$, which describes the high significance of the influences shown in Table 5. We employed Eviews and Stata software to get the model outcomes. As presented in Fig. 2, the beta coefficients of ridge regressions and R^2 values become sound when the K-value reaches 0.65 to onward. Besides, beta coefficient values of lnNe, lnFe, lnGDPc, lnP, lnUp, and lnMt are unstable, varying with the maximum value of VIF and K-values.

5.2. Ridge regression with standardized ridge

As discussed above, lowering the ridge trace value presents a quick decrease in VIF values, which makes it obvious that the K-value is suitable for ridge regression. As shown in Table 5, we estimate the standard ridge based on raw ridge coefficients. According to the outcomes, the standard ridge, F-value, *t*-test, and P-value show significant results, which are consistent with the economic theory. In addition, the VIF values of all the variables are less than ten. The statistical measures, for example, R^2 and VIFs, show that the model is acceptable, which is in line with Lin et al. [55]. However, it must be noted that we have significantly lessened the multicollinearity problem in the model. With the least VIFs, the coefficients of the input variables are positive; therefore, the positive and consistent coefficients present that all the inputs are growing in return to scale. Table 5 calculates the STRIPAT

Table 3
Correlation results.

	lnNe	$lnCO_2e$	lnFe	lnGDPc	lnP	lnUp	lnMt
lnNe	1.0000						
$lnCO_2e$	0.9910	1.0000					
lnFe	0.9915	0.9879	1.0000				
lnGDPc	0.9864	0.9794	0.9892	1.0000			
lnP	0.9979	0.9925	0.9933	0.9864	1.0000		
lnUp	0.9979	0.9925	0.9933	0.9864	0.9999	1.0000	
lnMt	0.9719	0.9568	0.9712	0.9784	0.9699	0.9699	1.0000

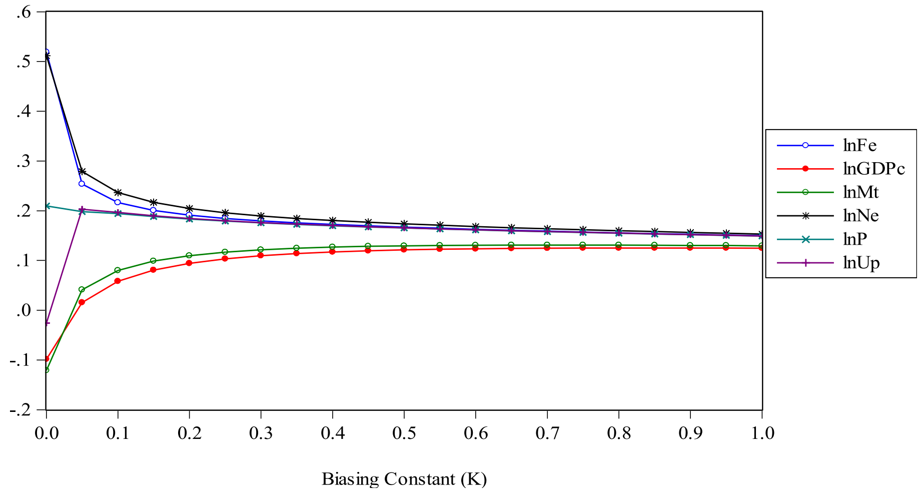

Fig. 2. Ridge trace [0–1].

Table 4
OLS regression results.

Variables	Coefficients	Std. Error	T-statistics	P-value	VIF
lnFe	0.55836	0.10943	5.10250	0.0000	150.8354
lnGDPc	−0.08305	0.05042	−1.64729	0.1103	52.16709
lnMt	−0.07444	0.04034	−1.84516	0.0752	62.63364
lnNe	0.47781	0.09924	4.81464	0.0000	164.5459
lnP	0.37870	1.43718	0.26351	0.7940	9225.792
lnUp	−0.03672	1.20935	−0.03036	0.9760	10571.52
R-square	0.99801				
F-value	2425.112				0.00000

Table 5
Ridge regression estimates for the STRIPAT model.

Variables	Std. Ridge	Std. Error	T-statistics	P-value	VIF
lnFe	0.16070	0.02179	7.37463	0.00036	0.04039
lnGDPc	0.12420	0.02479	5.01070	0.00234	0.09940
lnMt	0.13100	0.02414	5.42779	0.00144	0.07690
lnNe	0.16590	0.02145	7.73546	0.00029	0.04600
lnP	0.15950	0.02187	7.29218	0.00038	0.04960
lnUp	0.15980	0.02185	7.31276	0.00038	0.04620
Model diagnostics					
Ridge parameter K	0.65000				
R-square	0.97680				
F-value	166.77700				0.00000

model using ridge regression and measures that all the major variables, such as lnNe, lnFe, lnGDPc, lnP, lnUp, and lnMt are significantly correlated with the actual development of the economy of Pakistan. Thus, these results are useful to the set of studies that point to a sign of one-way causality from energy to the economy, as reflected in the literature review. The calculated outcomes are acceptable and can be used for further analysis and policy perspectives.

6. Discussion summary

The results discussed in the current study have significant impacts on economic growth, renewable energy technologies (RETs), green production, and CO_2 emissions mitigation in Pakistan and related developing countries with similar characteristics. The current study has empirically proven and presented that, among other inputs, while nuclear electricity looks to be an imperative factor in the country's economy, there remains slight productivity for nuclear electricity to check economic growth and social factors' impact in Pakistan. In addition, due to the growing trend of technical evolution in the progression of RETs, particularly in the case of the China-Pakistan Economic Corridor (CEPC), and the country's renewable energy visions (i.e., Vision 2025, 2035 [56,57]), the current results of the study have also shown substantial implications. In the end, CO_2 emissions reduction and environmental protection could come with merits; for instance, different energy transition technologies might have different cost designs. The major findings will discuss the outcomes as.

First, a robustness analysis of the ridge regression was used when K = 0.65 for carrying-out ridge regression coefficients in our statistics (see Fig. 2 and Table 5). Based on the particular parametric value, we found significant variations in all the variables. The fitting line was satisfied. The proper equation for ridge regression is shown in Eq. (5).

$$\ln CO_2e = 0.160\ln Fe + 0.124\ln GDP_c + 0.131\ln M_t + 0.165\ln N_e + 0.159\ln P + 0.160\ln Up \quad (5)$$

Second, as per the coefficients of the standardized ridge taken from Eq. (5), the leading forces of Pakistan's CO_2 emissions are shown in Fig. 1. The importance of these influences can be ordered as per their absolute value elastic coefficients in varying order: nuclear energy, fossil energy, GDP per capita, merchandise trade, the whole population, and urban-population. Fossil fuel energy and population (as a whole), and urban population turned-out to be the highest drivers of leading CO_2 emissions in Pakistan. This shows that when GDP per capita rises by 1%, there is a rise of 0.16%, 0.159% and 0.160% in CO_2 emissions. These results are reliable with the latest research [34]. Moreover, the significant rise in the merchandise trade level has also had an imperative impact on the growth of CO_2 emissions, with an elastic coefficient of 0.131. It can be noted that merchandise trade is the summation of imports and exports in Pakistan; however, on the other side, Pakistan is possibly going to further encourage merchandise trade because of globalization and industrial framework growth. For example, many exported products (i.e., food groups, textile manufacture, petroleum, and other manufactures) suggested that all groups provided impressive growth in Pakistan [58]. Also, the use of energy is partly initiated by consecutive growth in merchandise trade and long-route transportation [47,59].

Third, nuclear and substitutive energy overall significantly impact CO_2 emissions in Pakistan, though they present a greater contribution to CO_2 emissions than other merchandise trade or fossil fuels, with an elastic coefficient of 0.165. We found '2' sources relating to nuclear energy: (i) nuclear coincidence and (ii) storage of dangerous waste. In the United States, electricity produced by nuclear energy needs radioactive materials. As they are free into the environment and interact with humans, they may cause diseases (i.e., cancer, birth, death, etc.). The biggest danger of using nuclear energy is the possible rate of nuclear coincidences and the removal of nuclear wastes [60]. For instance, Pakistan is making nuclear energy from nuclear technology, whose impact is growing slowly. In 2021, the gross capacity of plants was 2530 MW, which provided around 7076 million units of electricity to the national grid [7]. Overall, the capacity of nuclear power plants has grown by 39% and it stands at 3530 MW.

Fourth, population plays an important role in the growth of CO_2 emissions in Pakistan [17]. Evidently, if the population rises by 1%, the level of CO_2 emissions increases by 0.159%, while 0.160% is obtained when the urban population rate rises by 1%. As we know and as is obvious in Fig. 1, the population of Pakistan has an optimistic degree of contribution to CO_2 emissions as contrasted with other factors. As per the Pakistan Economic Survey [58], the rising population, unplanned urban development, and delicate reliance on natural resources put a huge burden on the environment, activating weather transformation. Also, the Pakistan Bureau of Statistics [61] proposed that the urban population would increase by 76.1%–77.3% in 2022. The population growth size will certainly impact the environmental quality. As the population volume rises, there will be huge demands for each type of resource involving energy, which will directly cause CO_2 emissions.

Fifth, the GDP per capita (lnGDPc) also turned-out to be a positive contributor to CO_2 emanations in Pakistan, with an elastic ridge coefficient of 0.124, showing that when lnGDPc rises by 1%, there is a rise of 0.124 in CO_2 emissions. The results are in line with the study of Khan et al. [9]. Due to the economic recession in 2008, the country has faced economic issues and is trying to recover at its best level, as economic growth is the fundamental factor adding to the rise of Pakistan's CO2 emissions. Even though, CO_2 emissions impacted every sector, such as agriculture, industry, transport, power, etc. [62], they further impact global trade. The CO_2 emissions can be further declined by the RETs and various energy-economy projects under CPEC, which will sustain economic growth and reduce pollution.

Finally, the use of fossil fuels has an optimistic and significant influence on CO_2 releases in Pakistan, which is in line with the previous studies stated above. The CO_2 emissions grow by 0.160% when the fossil fuel energy use increases by 1%. Obviously, all the fossil fuel energy use is concerned with carbon emissions; for instance, as fossil fuels are consumed, they create pollution in the atmosphere, which causes global warming [63]. For this, renewable energy (wind, solar, biogas, etc.) and RETs (low-carbon transition, machines, substitutive energy devices, etc.) can significantly mitigate CO_2 emissions if applied in the huge energy-consuming industries.

7. Conclusion and policy suggestion

7.1. Conclusion

The current study has endeavored to measure the impact of energy and non-energy factors on CO_2 emissions in Pakistan from 1986 to 2021. The ridge regression method based on '6' major indicators is employed to handle the multicollinearity issue; however, this study employed the STRIPAT model, including ridge regression, which provides robust results. We found a few interesting outcomes using the country's latest situation and energy-economic data.

1. The CO_2 emission trend in Pakistan has a rising trend. As per the findings of this research, the overall population (including urban), nuclear energy, GDP per capita, merchandise trade, and fossil fuel consumption have an optimistic impact on CO_2 emissions. Population and energy-related factors are the most significant factors impacting CO_2 emissions in Pakistan which increased by 0.15% and 0.16%. To enhance economic and environmental sustainability, RETs, renewable energy and domestic production should be given more attention.
2. Economic growth and merchandise played the least by 0.12% and 0.13% but an optimistic role in raising CO_2 emissions, as compared to other factors. For this, Pakistan should take advantage of the carbon pricing mechanism and provide subsidies to protect the environment.
3. Finally, CO_2 emissions are a major issue in developing countries like Pakistan. The issue with the energy option is that CO_2 emissions basically include an externality to the energy consumer, which has provided rising results in all cases while employing these factors. Moreover, we found an optimistic and significant relationship between each factor, which is obviously sustained by the degree of the factor's progress. These conclusions help develop the substitutability and sustainability of renewables and fossil energy.

7.2. Policy implications

On the basis of empirical findings and Pakistan's situation, current research gives significant measures, particularly within the framework of the Paris Agreement (COP-21), CPEC and renewable energy Visions 2025–2035. The major policy recommendation is:

First, Pakistan reached the maximum amount of CO_2 emissions without any declination due to numerous factors. Due to the Paris Agreement and its development, Pakistan is under huge pressure to set a driving example in reducing CO_2 emissions. For example, due to the enormous energy crisis, Pakistan is dedicated to China, in which China has invested $33.8 billion in the energy sector [64]. This project will initially comprise energy projects worth 7560 MW and cleaner energy projects worth 2790 MW, respectively. As per the HDIP [7], nuclear electricity has increased by 9.14% and renewable energy by 11.3% than the previous year. This is because the government of Pakistan has assured to mitigate CO_2 emissions and enhance renewables since 2015. For this, the energy sector, industries and consumers could benefit from efficient energy use, which will ultimately reduce pollution.

Second, due to the significant rise in population, the government should redesign the energy framework, reform the old structure, and create awareness among consumers and industrialists. For this, the government should provide specific units near each grid for consumer awareness, and provide subsidies on renewable energy, especially in rural areas.

Third, as all the coefficients are close to unity and are consistent with the economic theory, we have found optimistic results. With this concentration, this study makes a novel effort to analyze the major factors contributing to Pakistan's CO_2 emissions and establishes that the STRIPAT model can be employed for building a low-carbon society. Finally, the study has some limitations: (i) lack of provincial data, (ii) access to potential data at sector and provincial data which will impact on the quality and research value, (iii) current study is concerned to the country level and discussed the measures at policy perspective. Thus, further research can be measured at sectorial, regional and provincial levels, and (iv) further study can be made cost-effective based on more latest data, which will provide clear paths for policymakers, scholars and academics.

Data availability

Data will be made available on request.

Declaration of competing interest

We declare that there is no conflict of interest.

Acknowledgements

This paper is supported by the National Social Science Fund of China (Grant No. 21BJY113).

Nomenclature

IEA	international energy agency
GHG	greenhouse gas
BRI	belt and road initiatives
EKC	environmental Kuznets curve
ARDL	auto regressive distributive lag
LMDI	logarithmic mean Divisia index
OLS	ordinary least square
HDIP	hydro carbon development institute of Pakistan
VIF	variance inflation factor
CPEC	China-Pakistan economic corridor
COP	conference of parties
ε	residual error
Mt	metric tones
$\widehat{\beta}_i$	coefficient
RETs	renewable energy technologies
Mtoe	million tons of oil equivalent
CO_2e	carbon dioxide emission
N_e	nuclear electricity
GDP_c	GDP per capita
M_t	merchandise trade of GDP
P	population
Up	urban population
Fe	fossil energy

References

[1] IEA, International Energy Agency, 2021. Www.Iea.Org/Reports/Global-Energy-Review-Co2-Emissions-in-2021-2.

[2] M.Y. Raza, B. Lin, Analysis of Pakistan's electricity generation and CO2 emissions: based on decomposition and decoupling approach, J. Clean. Prod. 359 (2022) 132074, https://doi.org/10.1016/j.jclepro.2022.132074.

[3] U.K. Pata, M.T. Kartal, Impact of nuclear and renewable energy sources on environment quality: testing the EKC and LCC hypotheses for South Korea, Nucl. Eng. Technol. 55 (2023) 587–594, https://doi.org/10.1016/j.net.2022.10.027.

[4] Rebecca Lindsey, Luann Dahlman, Global Climate Change, 2022. Www.Climate.Gov/News-Features/Understanding-Climate/Climate-Change-Global-Temperature.

[5] IPCC, Working Group I, Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, 2021.

[6] M. Yousaf Raza, B. Lin, Development trend of Pakistan's natural gas consumption: a sectorial decomposition analysis, Energy 278 (2023) 127872, https://doi.org/10.1016/j.energy.2023.127872.

[7] HDIP, Hydrocarbon Development Institute of Pakistan), Pakistan energy yearbook. Ministry of energy (Petroleum Division) Hydrocarbon development institute of Pakistan. https://hdip.com.pk/contents.php?cid=32, 2021.

[8] B. Jiang, M.Y. Raza, Research on China's renewable energy policies under the dual carbon goals: a political discourse analysis, Energy Strategy Rev. 48 (2023) 101118, https://doi.org/10.1016/j.esr.2023.101118.

[9] A.N. Khan, X. En, M.Y. Raza, N.A. Khan, A. Ali, Sectorial study of technological progress and CO2 emission: insights from a developing economy, Technol. Forecast. Soc. Change 151 (2020) 119862, https://doi.org/10.1016/j.techfore.2019.119862.

[10] A. Maxim, Sustainability assessment of electricity generation technologies using weighted multi-criteria decision analysis, Energy Pol. 65 (2014) 284–297, https://doi.org/10.1016/j.enpol.2013.09.059.

[11] N. Mahmood, Danish, Z. Wang, B. Zhang, The role of nuclear energy in the correction of environmental pollution: evidence from Pakistan, Nucl. Eng. Technol. 52 (2020) 1327–1333, https://doi.org/10.1016/j.net.2019.11.027.

[12] M.T. Majeed, I. Ozturk, I. Samreen, T. Luni, Evaluating the asymmetric effects of nuclear energy on carbon emissions in Pakistan, Nucl. Eng. Technol. 54 (2022) 1664–1673, https://doi.org/10.1016/j.net.2021.11.021.

[13] R.E.A. T, Y.R. Dietz, Driving the human ecological footprint, Front. Ecol. Environ. 5 (2007) 13–18.

[14] S.A. Sarkodie, V. Strezov, Effect of foreign direct investments, economic development and energy consumption on greenhouse gas emissions in developing countries, Sci. Total Environ. 646 (2019) 862–871, https://doi.org/10.1016/j.scitotenv.2018.07.365.

[15] O.B. Adekoya, J.A. Oliyide, O.T. Kenku, O.F. Ajayi, China's technological spillover effect on the energy efficiency of the BRI countries, Energy Pol. 182 (2023) 113740, https://doi.org/10.1016/j.enpol.2023.113740.

[16] O. Napolitano, P. Foresti, K. Kounetas, N. Spagnolo, The impact of energy, renewable and CO_2 emissions efficiency on countries' productivity, Energy Econ. 125 (2023) 106795, https://doi.org/10.1016/j.eneco.2023.106795.

[17] B. Lin, M.Y. Raza, Analysis of energy related CO2 emissions in Pakistan, J. Clean. Prod. 219 (2019) 981–993, https://doi.org/10.1016/j.jclepro.2019.02.112.

[18] M.Y. Raza, M. Wasim, M.S. Sarwar, Development of renewable energy technologies in rural areas of Pakistan, energy sources, Part A: recovery, utilization, Environ. Eff. 42 (2020) 740–760, https://doi.org/10.1080/15567036.2019.1588428.

[19] M.Y. Raza, B. Lin, Renewable energy substitution and energy technology impact in a transitional economy: a perspective from Pakistan, J. Clean. Prod. 360 (2022) 132163, https://doi.org/10.1016/j.jclepro.2022.132163.

[20] F. Guang, Y. Deng, L. Wen, B. Sharp, S. Hong, Impact of regional energy allocation distortion on carbon emission efficiency: evidence from China, J. Environ. Manag. 342 (2023) 118241, https://doi.org/10.1016/j.jenvman.2023.118241.

[21] Yu Ma, A Study on the Estimation of the Desirable Range of Cross-Border Capital Flows in Emerging Economies[M], China Social Sciences Press, Beijing, 2023.

[22] E. Dogan, R. Inglesi-Lotz, The impact of economic structure to the environmental Kuznets curve (EKC) hypothesis: evidence from European countries, Environ. Sci. Pollut. Control Ser. 27 (2020) 12717–12724, https://doi.org/10.1007/s11356-020-07878-2.

[23] U.K. Pata, Renewable energy consumption, urbanization, financial development, income and CO2 emissions in Turkey: testing EKC hypothesis with structural breaks, J. Clean. Prod. 187 (2018) 770–779, https://doi.org/10.1016/j.jclepro.2018.03.236.

[24] X. Gu, X. Shen, X. Zhong, T. Wu, S. Rahim, Natural resources and undesired productions of environmental outputs as green growth: EKC in the perspective of green finance and green growth in the G7 region, Resour. Pol. 82 (2023) 103552, https://doi.org/10.1016/j.resourpol.2023.103552.

[25] T. Chang, C.-M. Hsu, S.-T. Chen, M.-C. Wang, C.-F. Wu, Revisiting economic growth and CO2 emissions nexus in Taiwan using a mixed-frequency VAR model, Econ. Anal. Pol. 79 (2023) 319–342, https://doi.org/10.1016/j.eap.2023.05.022.

[26] M.Y. Raza, B. Lin, Energy efficiency and factor productivity in Pakistan: policy perspectives, Energy 247 (2022) 123461, https://doi.org/10.1016/j.energy.2022.123461.

[27] M.Y. Raza, B. Lin, Future outlook and influencing factors analysis of natural gas consumption in Bangladesh: an economic and policy perspectives, Energy Pol. 173 (2023) 113379, https://doi.org/10.1016/j.enpol.2022.113379.

[28] J. Yang, W. Cai, M. Ma, L. Li, C. Liu, X. Ma, L. Li, X. Chen, Driving forces of China's CO2 emissions from energy consumption based on Kaya-LMDI methods, Sci. Total Environ. 711 (2020) 134569, https://doi.org/10.1016/j.scitotenv.2019.134569.

[29] V. Moutinho, M. Madaleno, R. Inglesi-Lotz, E. Dogan, Factors affecting CO2 emissions in top countries on renewable energies: a LMDI decomposition application, Renew. Sustain. Energy Rev. 90 (2018) 605–622, https://doi.org/10.1016/j.rser.2018.02.009.
[30] B. Su, B.W. Ang, Structural decomposition analysis applied to energy and emissions: Frameworks for monthly data, Energy Econ. 126 (2023) 106977, https://doi.org/10.1016/j.eneco.2023.106977.
[31] B. Lin, M.Y. Raza, Coal and economic development in Pakistan: a necessity of energy source, Energy 207 (2020) 118244, https://doi.org/10.1016/j.energy.2020.118244.
[32] Q. Wang, J. Guo, R. Li, X. Jiang, Exploring the role of nuclear energy in the energy transition: a comparative perspective of the effects of coal, oil, natural gas, renewable energy, and nuclear power on economic growth and carbon emissions, Environ. Res. 221 (2023) 115290, https://doi.org/10.1016/j.envres.2023.115290.
[33] J. Price, I. Keppo, P.E. Dodds, The role of new nuclear power in the UK's net-zero emissions energy system, Energy 262 (2023) 125450, https://doi.org/10.1016/j.energy.2022.125450.
[34] O. Ozgur, V. Yilanci, M. Kongkuah, Nuclear energy consumption and CO2 emissions in India: evidence from Fourier ARDL bounds test approach, Nucl. Eng. Technol. 54 (2022) 1657–1663, https://doi.org/10.1016/j.net.2021.11.001.
[35] K. Saidi, A. Omri, Reducing CO2 emissions in OECD countries: do renewable and nuclear energy matter? Prog. Nucl. Energy 126 (2020) 103425 https://doi.org/10.1016/j.pnucene.2020.103425.
[36] K. Dong, R. Sun, H. Jiang, X. Zeng, CO2 emissions, economic growth, and the environmental Kuznets curve in China: what roles can nuclear energy and renewable energy play? J. Clean. Prod. 196 (2018) 51–63, https://doi.org/10.1016/j.jclepro.2018.05.271.
[37] Review of World Energy, BP Statistical Review of World Energy, 2023. Www.Bp.Com/En/Global/Corporate/Energy-Economics/Statistical-Review-of-World-Energy.Html.
[38] World Bank, World Development Indicators, 2022. Databank.Worldbank.Org/Reports.Aspx?Source=World-Development-Indicators.
[39] P.R. Ehrlich, J.P. Holdren, Impact of population growth, Science 171 (1971) 1212–1217, https://doi.org/10.1126/science.171.3977.1212 (1979).
[40] R.G. Ridker, Population, resources, and the environment, in: [Washington, Commission on Population Growth and the American Future; for Sale by the Supt. Of Docs., U.S. Govt. Print. Off.], 1972.
[41] C.A. Jenne, R.K. Cattell, Structural change and energy efficiency in industry, Energy Econ. 5 (1983) 114–123, https://doi.org/10.1016/0140-9883(83)90018-X.
[42] L. Wen, Z. Li, Driving forces of national and regional CO2 emissions in China combined IPAT-E and PLS-SEM model, Sci. Total Environ. 690 (2019) 237–247, https://doi.org/10.1016/j.scitotenv.2019.06.370.
[43] B. Xu, B. Lin, Regional differences in the CO2 emissions of China's iron and steel industry: regional heterogeneity, Energy Pol. 88 (2016) 422–434, https://doi.org/10.1016/j.enpol.2015.11.001.
[44] Y. Wang, T. Zhao, Impacts of energy-related CO2 emissions: evidence from under developed, developing and highly developed regions in China, Ecol. Indicat. 50 (2015) 186–195, https://doi.org/10.1016/j.ecolind.2014.11.010.
[45] T, R.E.A. Dietz, Rethinking the environmental impacts of population, affluence and technology, Hum. Ecol. Rev. 1 (1994) 277–300.
[46] M.Y. Raza, M.M. Hasan, Estimating the multiple impacts of technical progress on Bangladesh's manufacturing and industrial sector's CO2 emissions: a quantile regression approach, Energy Rep. 8 (2022) 2288–2301, https://doi.org/10.1016/j.egyr.2022.01.005.
[47] B. Lin, M.Y. Raza, Energy substitution effect on transport sector of Pakistan: a trans-log production function approach, J. Clean. Prod. 251 (2020) 119606, https://doi.org/10.1016/j.jclepro.2019.119606.
[48] B. Lin, P. Atsagli, Energy consumption, inter-fuel substitution and economic growth in Nigeria, Energy 120 (2017) 675–685, https://doi.org/10.1016/j.energy.2016.11.115.
[49] B. Lin, M.Y. Raza, Fuels substitution possibilities and the technical progress in Pakistan's agriculture sector, J. Clean. Prod. 314 (2021) 128021, https://doi.org/10.1016/j.jclepro.2021.128021.
[50] A.E. Hoerl, R.W. Kennard, Ridge regression: biased estimation for nonorthogonal problems, Technometrics 12 (1970) 55–67, https://doi.org/10.1080/00401706.1970.10488634.
[51] B. Lin, R. Fei, Analyzing inter-factor substitution and technical progress in the Chinese agricultural sector, Eur. J. Agron. 66 (2015) 54–61, https://doi.org/10.1016/j.eja.2015.02.005.
[52] P.K. Wesseh, B. Lin, Energy consumption, fuel substitution, technical change, and economic growth: implications for CO2 mitigation in Egypt, Energy Pol. 117 (2018) 340–347, https://doi.org/10.1016/j.enpol.2018.03.022.
[53] M.Y. Raza, B. Lin, X. Liu, Cleaner production of Pakistan's chemical industry: perspectives of energy conservation and emissions reduction, J. Clean. Prod. 278 (2021) 123888, https://doi.org/10.1016/j.jclepro.2020.123888.
[54] Kmenta Jan, Elements of Econometrics, second ed., Macmillan Publishing Company, New York, 1986. https://archive.org/details/elementsofeconom0003kmen. (Accessed 16 January 2024).
[55] B. Lin, R. Zhu, M.Y. Raza, Fuel substitution and environmental sustainability in India: perspectives of technical progress, Energy 261 (2022) 125309, https://doi.org/10.1016/j.energy.2022.125309.
[56] Vision 2025, Vision 2025, 2014. Pakistan 2025, One Nation-One Vision. Planning Commission, Ministry of Planning, Development & Reforms. Government of Pakistan, Islamabad, 2014 fics.seecs.edu.pk/Vision/Vision-2025/Pakistan-Vision-2025.pdf.
[57] Vision 2035, Vision 2035, 2014. Pakistan 2035, One Nation-One Vision. Planning Commission, Ministry of Planning, Development & Reforms. Government of Pakistan, Islamabad, 2014. https://www.sdpi.org/publications/files/Pakistan%20Energy%202035FINAL%2020th%20October%202014.pdf.
[58] Pakistan Economic Survey, Pakistan Economic Survey, 2021-2022, Ministry of Finance. Government of Pakistan, Islamabad, 2022. http://www.finance.gov.pk/survey/chapters_/Pakistan_ES_2021_2022_pdf.
[59] M.Y. Raza, B. Lin, Decoupling and mitigation potential analysis of CO2 emissions from Pakistan's transport sector, Sci. Total Environ. 730 (2020) 139000, https://doi.org/10.1016/j.scitotenv.2020.139000.
[60] B. Pan, Y. Zhang, Impact of affluence, nuclear and alternative energy on US carbon emissions from 1960 to 2014, Energy Strategy Rev. 32 (2020) 100581, https://doi.org/10.1016/j.esr.2020.100581.
[61] Ministry of Statistics, Pakistan Bureau of Statistics, 2022. Www.Pbs.Gov.Pk/Sites/Default/Files/Population_Census_2022_Results_0.Pdf.
[62] B. Lin, M.Y. Raza, Analysis of energy security indicators and CO2 emissions. A case from a developing economy, Energy 200 (2020) 117575, https://doi.org/10.1016/j.energy.2020.117575.
[63] T.P. Hughes, J.T. Kerry, A.H. Baird, S.R. Connolly, T.J. Chase, A. Dietzel, T. Hill, A. S. Hoey, M.O. Hoogenboom, M. Jacobson, A. Kerswell, J.S. Madin, A. Mieog, A. S. Paley, M.S. Pratchett, G. Torda, R.M. Woods, Global warming impairs stock–recruitment dynamics of corals, Nature 568 (2019) 387–390, https://doi.org/10.1038/s41586-019-1081-y.
[64] John McGarrity, Beth Walker, Chinese-Funded Energy Projects in Pakistan Likely to Damage Environment, 2015. Www.Eco-Business.Com/Opinion/Chinese-Funded-Energy-Projects-in-Pakistan-Likely-to-Damage-Environment/.