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Energy Consumption, Carbon Emissions, and Economic Growth in Pakistan: A Comprehensive Analysis of Long-Term Relations and Short-Term Dynamics

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Abstract: *In the current study, researchers have examined the association among consumption of energy, emission of carbon, and economic growth and investigated along with indicators such as urban population growth and rural population growth, whose data exist from the period 1981-2022. used (ADF) unite root test, ARDL, and bound test. The results based on ARDL models show that a unidirectional long-term relation exists between the variables being examined. In the short term, there is a strong and significant relationship between energy consumption (EC) and carbon emissions with economic gcorowth (GDP). The findings suggest that in Pakistan, energy is a factor for both short and long-term economic growth. Energy consumption, carbon emissions, and rural population growth, while the urban population also influences economic growth. The outcome of these empirical findings suggests that the country should aim at increasing energy consumption with minimum impacts of pollution and achieve energy security. Priority should be given to energy management that combines demand and supply factors. Efforts should be made to promote an adequate energy mix that includes clean, renewable energy and improve energy efficiency in a holistic framework. Environmental degradation, energy consumption, and urbanization policies must be adapted to achieve energy self-sufficiency together with minimum CO_2 emissions.*

Key Words: Energy Consumption, Economic Growth, Urbanization, CO_2 Emission, ARDL

Introduction

Energy could play an important role in the socio-economic development of a country. Improves the output of production factors (for example, capital and labour). Research from empirical studies, environmental economics, and energy consumption have been interconnected with economic growth. (Acheampong, 2018). energy consumption, environmental damage, and economic growth are interdependent (Destek and Sarkodie, 2019). There is an investigation of the association between energy consumption and economic growth, with output estimations indicating a substantial influence on economic growth. (Waheed R. et al., 2018) The outcome of the study shows that the correlation between energy consumption and economic growth has been investigated, and the result verified that the linkage between these variables is unidirectional (Shahbaz M et al. 2017). From the statistical calculation between economic growth and environmental degradation, the study between economic growth and consumption of energy (Yang and Zhao 2014). We now generally consider economic growth and energy use as interdependent. (Burney, N.A, 1995; Cheng 1997b; Cheng 1997a, Behram, Couture, Millunzi, *et al.* 1983). Energy is the basic component of physical infrastructure – holds the key to the success of a country's development endeavours. Socioeconomic upliftment requires efforts directed at education, health, communication, agriculture, and industry—all of which demand greater use of energy. The conclusion of this study is that there is a unidirectional causal relation between Gross national product and the consumption of energy (Sims 1972). No causality between energy consumption and GNP was identified through the use of various methods, Yu and Choi (1985). In fact, the prospects for the development of a nation in a linear relationship are based on its achievements in the field of energy. Energy is of equal importance to the economic prospects of

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developing countries. However, until recently, energy planning and energy issues were treated on an ad hoc basis in most developing countries, including Pakistan (DeLucia and Jacoby 1982; Smil and Knowland 1980; Munasinghe and Saunders 1989). Pakistan is experiencing a sustainably high growth rate in energy demand, which is a necessary prerequisite for rapid economic development. Commercial energy consumption increased during the period under consideration from 2.5 MTOE (million tons of oil equivalents) to 30.4 MTOE at an annual average growth rate of 7.5 per cent. real GNP (gross national product) showed performance over the same time) (Iqbal 1999; Ahmad 1998). Historically, the country has depended mainly on imported oil, thereby experiencing an annual growth rate of around seven per cent. Therefore, in both the present and the near future, Pakistan faces the crucial task of reducing energy demand elasticity or enhancing energy efficiency. It's worth noting that Pakistan's per capita commercial energy consumption is significantly lower, almost half that of the average consumption in developing countries. (Burney and Akhtar 1990). More significantly, the affordability of commercial energy is also quite low. This presents a challenge to the policy-makers to ensure the supply of energy at affordable prices to stimulate growth and, in turn, increase the affordability for visualized economic output (Ahmad 1998; Khan 1989).

Literature Review

Over the past decades, new methodologies have emerged to measure the relationships between energy consumption, economic growth, and carbon emissions. Earlier research primarily focused on analyzing data from individual countries, and many of these countries are prominently featured in the most recent literature review on this subject. Find a uni-directional causal relation between nuclear power use and economic growth (J.-Y. Heo, S.-H. Yoo 2011). Investigation shows the carbon emission association with economic growth and consumption of energy is a bidirectional causality (Magazzino. C, 2016); Mahadevan and Asafu - Adaye 2007). From the empirical investigation, the causal association between energy use, energy prices, and economic development. The paper's empirical study reveals that in India and Indonesia, there is a unidirectional causal relationship between the two countries. Thus, there is a causal bidirectional correlation between energy consumption and income (Asafu-Adjay 2000). In this analysis, a bi-directional causal relationship exists in Argentina, a unidirectional causal relationship between GDP and energy consumption in Turkey, and a unidirectional causal correlation between energy consumption and GDP (Sari, R., & Soytas, U. 2004). Have investigated the bidirectional causal association of electricity consumption with economic growth, but a unidirectional causal relation GDP power consumption (Jombe 2004) studied Sir Lanka and Shanghai has found that there is a unidirectional causal association of energy consumption with GDP and other studies have conflicting findings, (Morimoto, R., & Hope, C. 2004). Indicated the study that in Korea, a bidirectional causal relationship with GDP in the long term and a unidirectional causal relation between energy consumption and GDP in the short term (Oh, W., & Lee, K. 2004). This study investigated the unidirectional relation between energy consumption and GDP in African countries (Wolde Rafael 2005). There is a link between emissions and energy usage explored in this study, and there is also a long-term and short-term causality in Malaysia (Ang, J. B. 2008). the outcome of the study shows there exists a long-term relationship between variables, and in the short run, bidirectional causality exists between the two series and a unidirectional causality in the short term from the energy to GDP (Bellouni 2009). Investigated from the study, there exists a unidirectional causality in the long run between GDP and energy consumption and a unidirectional causality of energy consumption with carbon emissions in the long run, but neither carbon emissions nor energy consumption leads to economic growth (Zhang, X. P., & Cheng, X. M 2009)

Data Sources and Econometric Methods

The primary focus of this section is to explore and analyze the connections between three key factors: energy consumption, environmental degradation, and economic growth. The aim is to understand how these variables are interrelated and what impact they have on each other. We built the econometric model, like:

Yt =f (ECt, COt, UPGt, RPGt) …….(1)

Where subscripts *T* stands for indexes the time. *Yit* has used economic growth. *COt, ECt, RUPGt* and *RPGt* are Carbon emissions per capita, consumption of energy, Urban population growth, and rural population growth, t for time, respectively. Hence, the long-term equilibrium for the following logarithmic form can be written as:

$lnYt = \beta1(lnECt) + \beta2(lnCOt) + \beta3(lnUPGt) + \beta4(lnRPGt) + \varepsilon t$.........(2)

World Development Indicator (WDI) is the principal source of data. The time series was used from 1981 until 2022. Annual data has been collected for per capita carbon emissions (metric tons per capita), energy consumption (EC) (kg of oil equivalent per capita), urban population growth, and rural population growth. The study's procedure consists of:

Results and Discussion

ADF test was applied to verify the data stationarity standard. The ADF test results showed us that all indicators are stationery(integrated) on the first difference I (1). Thus, the results of the ADF test demonstrate that all variables are stationary at the first difference, and the degree of integration of variables tells us which statistical model we can use. The author has utilized autoregressive distributed lag (ARDL) and bound tests to check the long-term association among variables. In the table, The unit-roots test (ADF) was used to assess the stationary level of the indicators. Often, the action of information in the time series is not stationary. Dickey and Fuller (1979) developed the ADF test. We used ADF testing to check the indicator stationarity level. Since many macroeconomic variables are non-stationary, ADF tests are useful for order determination of the order of integration of the variables and, therefore, to provide the time-series properties of data, the ADF test has been employed.

Table 1

Results of Unite root test

Variables	Level		First Difference	
	I	T&I	I	T&I
	T-Statistics	T-Statistics	T-Statistics	T-Statistics
Ln GDP	3.664279	0.713952	-5.486100***	--
Ln CO_2	-0.235326	-1.537569	-6.474847***	--
Ln EC	-0.705907	-1.470198	-5.572791***	--
Ln RP	-0.955487	-1.834730	-3.241526**	--
Ln UP	-0.529039	-2.037072	-4.963382***	--

*Note: significant 0.0000*** and 0.0227** show significant level of variables*

Once the ADF test has strongly rejected unit roots, the methodology considers the following specification: we can apply the ARDL estimator for estimation because the cointegration test shows the relation between variables that exist in the long run. For this purpose, we have utilized Auto-Regressive Distributed Lag Models (ARDL). The results are summarized in the tables.

Short-run Results

Table 2 shows the outcomes of the concerned variables, showing that energy consumption has a positive and significant effect on economic growth in the short run. The value of this indicator shows if there is a 1% increase in energy use, this will be a 0.0479-unit increase. From the theoretical causes of energy use in the industrial production process, it is the main source of industrial development that will affect our economic growth positively. Another indicator in the table below in row 2 is carbon emission per capita, which has a significant and positive association with economic growth. If carbon emission per capita increases by 1%, that will positively affect economic growth 1.242966. Because the carbon emission is high in the environment, it means industries are working, and they produce larger production, which will affect economic growth. Another concerned indicator is rural population growth. Rural population growth has a significant and negative association with economic growth. If one per cent increases rural population growth, it will affect -10.31938 unite economic growth because the rural area people just work in agriculture side, and there are many disguised employments for this reason, this indicator affects economic growth negatively in the short run. Urban population is another indicator, so if the urban population increases by one per cent, it affects economic growth by 0.573625 units, so it affects economic growth positively because the association between urbanization and economic growth is positive and significant.

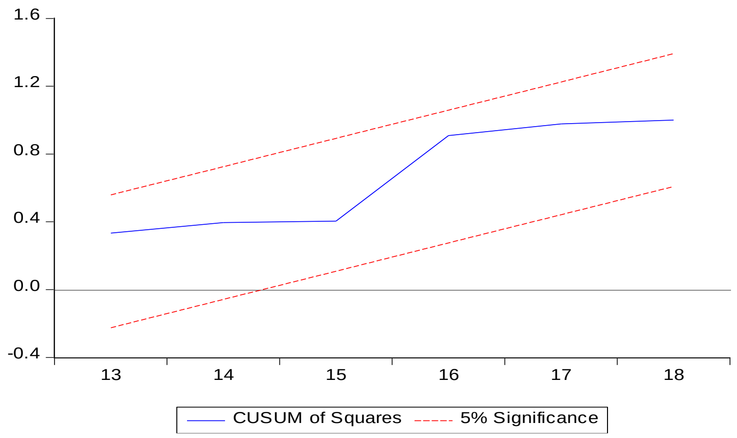
Table 2

Dependent variables lnY: Short-run result

Variables	Coefficient	Std-Error	T-Stat	prob***
LnC	0.741	0.348	2.131	0.047
LnE	1.242	0.313	3.964	0.001
LnUP	-10.319	4.839	-2.132	0.047
lnRP	0.573	0.167	3.423	0.003
C	-4.125	2.355	-1.751	0.047
EC	-0737	0.311	-2.370	0.030

Table 2 shows the outcome of the short-run relationship where s ECM is highly significant, containing a negative sign, which shows there is a long-run relationship in the model. The error correction test was used to verify the statistical significance of ARDL, using the cumulative sum of recursive residuals (CUSUM) and cumulative sum of squares of recursive residuals (CUSUMSQ) stability testing technique presented by Brown et al. (1975).

Graph 1



CUSUM and CUSUMSQ) respectively. Since in both plots, the statistical significance level was set at 0.05 per cent, the figure illustrates the basic model is stable.

Table 3

The outcome of a bound test

Model	f-stat	Significant	Critical values	
			I (0)	I (1)
LnY= lnC, lnE, lnUP, lnRP	6.242073	10%	2.45	3.52
		5%	2.86	4.01
		2.4%	3.25	4.49
		1%	3.74	5.06

Table 3. Describing the bound test results, we used bound testing to determine whether or not co-integration occurs if the F-statistical estimated value reaches the upper limit. We can assume whether there is a co-integration or a long-term relationship so that we switch from short-term ARDL to long-term ARDL. In Table CI (iii) Case III, the lower and upper bound values (42.45 and 3.52) show: for F-statistics are taken: No trend is seen and an unrestricted intercept According to Pesaran et al. The best lag duration for the indicators included in the ARDL model was determined using the Schwarz Bayesian Criterion (SBC). Table 4 presents the outcome of the long-term relationship by the selected ARDL model (1, 1, 0, 0) using SBC.

Table 4

Dependent variable lnY: Results for long-run relationship

Variables	Coefficient	std-error	t-stat	prob***
lnC	0.771	0.289	2.666	0.016
lnE	1.513	0.322	4.691	0.000
lineup	1.721	0.562	3.058	0.007
lnRP	2.997	1.264	2.369	0.029
Constant	-23.997	3.523	-6.811	0.000

Table 4 reveals that Ln carbon emission per capita is a significant indicator and is vital to economic growth. The significant level of *In carbon emission per capita* is 0.016 per cent, and the effect of *carbon emission per capita* on *economic growth*, as expected, is positive. The coefficient value (0.771630) of $lnCO_2$ shows that a one per cent increase in per capita carbon emission will lead to economic growth of 0.771630 units in the long term. *Ln energy consumption* is another important variable of economic growth in Pakistan. The effect of *energy consumption* on *economic growth* is a one per cent level of significance. The coefficient value of energy use is (1.513), ln (*energy use*) outcome shows that if one per cent increase in *In energy use* that will lead to 1.513 unite increase in economic growth in the long-term The coefficient value (2.997806) Ln(RPG) show that if one per cent increase rural population growth so it will affect economic growth (2.997806) unite positively in the long run. Another concerned explanatory variable is the significant and positive association with economic growth. If there is a one per cent increase in the urban population, it will affect 1.721267 units of economic growth, and the outcome of the presented study in this paper signifies the importance of energy use and environmental degradation on economic growth. The above results show that concerned policymakers should devise and adopt strategies that the government wants to invest in the energy sector because it plays a supportive role in the maintenance of economic growth.

Conclusions and Policy Suggestions

In the present paper, we have investigated the association of energy consumption and CO_2 emissions with Pakistan's economic growth and other macroeconomic indicators, such as rural population growth and urban population growth. We have employed time series methods to study the long-term relationship among these variables and also reviewed the economic growth situation in Pakistan. Based on our empirical analysis, the following conclusions and policy suggestions may be made:

1. Empirical analysis of Pakistan's energy sector reveals that the energy sector has been growing in terms of production and consumption at the aggregate level. The gap between energy consumption and output has, however, widened and made Pakistan dependent on energy imports. However, energy efficiency has increased, and energy insecurity has increased marginally.
2. Johansen's co-integration test outcome rejected the null hypothesis and showed there is no cointegration among variables included in the model and thus supports the long-run neutrality hypothesis. The findings reveal that there is a bilateral long-run causal relation between the examined variables. Thus, the feedback hypothesis between energy consumption, carbon emission, and economic growth has been proved for Pakistan.

Policy Suggestions

1. Achieving security of energy consumption and sustainability requires an all-inclusive method that needs to be integrated with development needs and environmental implications. To frame policies to achieve and sustain energy security in Pakistan, the links between energy consumption, environmental degradation, and economic growth are significant.
2. Critical for achieving energy protection is rising energy efficiency. Pakistan must battle for competitive chances of advancing energy production and rising concentration of oil. A free market between the state (governmental), private, and state (PPP) is the most efficient way of achieving sufficiency in energy.
3. There are several suggestions regarding the bidirectional causal association of energy consumption with GDP. To sustain its economic growth, Pakistan should increase its energy consumption. At the

same moment, Adequate policies on energy management are required, which do not impede the achieved economic growth. In this phase, you should reduce problems related to carbon with the right energy mix and reduce your dependency on it.

4. Pakistan needs to reduce its dependence on hydropower and develop alternative sources of energy. The country needs cheaper energy to support its growing industry and infrastructure.

Pakistan should boost energy production in favour of clean, renewable resources such as solar energy, wind energy, tidal, hydro, vehicle plug, and bi-fuel engines (hydrogen plus diesel, hydrogen plus natural gas) in the long term. Pakistan should need to implement the same policy in urban areas and rural areas.

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