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Economic Growth and Decarbonization in Pakistan: A Time-Series Analysis of Carbon Intensity Drivers (1990–2023)

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Abstract

This research explores the prominent macroeconomic and energy-associated factors of the carbon intensity of the GDP in Pakistan between 1990 and 2023. The critical indicator of the ability to gauge the environmental efficiency of economic growth is carbon intensity which is expressed as the kg of CO 2 equivalent/per PPP-adjusted GDP dollar. The analysis is the data on the carbon intensity (CI), trade openness (TO), and the use of renewable energy (REN), GDP per capita (GDPPC), and the intensity of energy use (EU), all measured in terms of annual rates instead of the past years, employing a time-series econometric model. The first order I(1) integration of variables is supported by a set of diagnostic tests and a consistent relationship at the long-run level between the two variables is determined by the graph presenting the Johansen cointegration test. The estimated long-run coefficients indicate that consumption of renewable energy and GDP per capita have considerable negative impacts on carbon intensity meaning that they have contributed to decoupling of emissions and the production of the economy. On the other hand, intensity demonstrates a positive, but less significant relationship with trade openness. A Vector Error Correction Model (VECM) reflects the short-run dynamics and the renewable energy changes are noted as a powerful short-term force. The model has been tested to ensure that the tests of serial correlation, normality and heteroskedasticity are sound, but the CUSUM of squares test raises a warning of possible parameter instability, which could be associated with significant changes in policy. The results suggest that further development of Pakistan should be pegged on the aggressively increasing the infrastructure of renewable energy, promoting cost-effective economies, and planning their trade policies in such a way that their impact on the environment will be limited. The research gives policy makers empirically based knowledge on how to align the economy of Pakistan with the commitments of climate change.

Keywords: Carbon Intensity, Decoupling, Renewable Energy, Trade openness, VECM, Cointegration, Pakistan, Sustainable development.

1. Introduction

The necessity of curbing climate change around the world has further fuelled academic and policy discussions on the issue of the interdependence between economic development and environmental degradation. One of the key ideas that come out of such a discussion is decoupling, which implies the capability of the economies to maintain economic growth and at the same time decrease the use of natural resources and environmental pollution (UNEP, 2011). Decoupling is becoming one of the pillars of sustainable development, since this is the way to balance the economic goals and environmental limitations in the carbon-bound world.

This is especially acute with developing economies like Pakistan where the high pace of economic growth is needed to reduce poverty and create jobs, but at the same time environmental vulnerability is growing. Pakistan ranks as one of the nations that are most vulnerable to the effects of climate as well as heat stress, extreme flooding, and water shortages due to its high macroeconomic and social costs (Kreft, Eckstein, and Melchior, 2016). Regardless of this weakness, the country is still largely dependent on fossil fuels, particularly in the energy production and industrial industry, with the result being the worsening of air quality and increased emission of greenhouse gases (World Bank, 2023). Such structural features are important to note that the economic growth trend of Pakistan is increasingly or increasingly turning into a more carbon-efficient mode of development as time progresses.

The most popular measure of this relationship is the carbon intensity of GDP (CI), which is carbon dioxide emissions per unit of economic activity. Carbon intensity is used to indicate the effects of energy structure, production efficiency, technological advancement, and economic structure. A falling carbon intensity shows relative decoupling, in which the economic growth occurs with a proportionally lower growth, whereas an increasing trend shows the higher pressure of environment per unit of output. It is thus important to understand what determines carbon intensity to develop efficient plans to reduce carbon development.

The researches into the subject of carbon intensity have been conducted so far, revealing that the main trends in carbon intensity are the patterns of energy consumption, the level of technological development, the industry structure, and the process of international trade (Grossman and Krueger, 1991; Soytas et al., 2007; Shahbaz et al., 2013). The ambiguous effects, which trade openness may have, could allow scale, composition, and technique channels, whereas the adoption of renewable energy and the improvement of energy efficiency are likely to reduce the level of emissions. Nevertheless, it is an empirical question how these mechanisms work in Pakistan and to what degree.

Research Gap

Although there has been ever-increasing literature on the topic of carbon intensity and environmental efficiency internationally, empirical evidence on the same in the context of Pakistan is still little and diffused. The majority of the available research approaches focus on carbon emissions on a aggregate basis or include carbon intensity as a second-order variable in more comprehensive Environmental Kuznets Curve (EKC) models. These strategies usually mask the unique structural forces of carbon intensity and construe knowledge about the decoupling process itself.

Additionally, evidence on the previous studies of Pakistan normally uses a comparatively brief period of samples or constant modeling techniques that do not allow them to differentiate between the long-run equilibrium relations and short-run adjustment processes. This is especially troublesome when dealing with energy and environmental variables that are typified by the persistence, structural change and slow reactions to policy interventions. Consequently, a lack of evidence exists regarding the nature of the interaction between trade openness and the consumption of renewable energy and economic development and energy efficiency to determine the carbon intensity trend of Pakistan.

Moreover, the literature already available has not sufficiently taken into consideration the post-1990 development of the energy and trade structure in Pakistan in a time-series format taking into consideration the recent years. As the country becomes more and more involved in the global markets, penetration of renewable energy capacity, and the development of energy intensity trends, a long-term analysis is required to make solid and policy implications.

Relevance of Contribution and Policy.

This research has a number of significant implications to the literature. To begin with, it offers a detailed time-series estimate of the carbon intensity of Pakistan covering the period between 1990 and 2023, thus, covering the major structural changes in the economy, energy sector, and the trade regime. Second, the study makes a direct prediction of decoupling processes by modelling CI as the dependent variable, as opposed to embedding carbon intensity on a broader EKC platform.

Third, the research concurrently examines four vital determinants such as the openness of trade (TO), use of renewable energy (REN), the gross domestic product (GDP) per capita (GDPPC), and the energy consumption per unit of gross domestic product (EU) in a single econometric model. The analysis, which uses the Johansen cointegration method and a Vector Error Correction Model (VECM), identifies long-run equilibrium relationships and short-run dynamics more deeply, which reveals aspects of structural and transitional effects.

Policy-wise, the research results of this paper are very pertinent to the climate and development program of Pakistan. Determining the long-run effect of renewable energy use and energy efficiency on the carbon intensity can be used to design specific energy transition policies. On the same note, the knowledge of whether trade openness enhances or reduces the carbon intensity offers evidence of how to optimize the trade policy in line with the environmental goals. This study can provide practical information to policymakers that may enable them to follow growth-based but climate friendly patterns of economic development within the framework of the international commitments of Pakistan in terms of climate change.

The rest of the paper is divided in the following manner: Section 2 creatively examines the pertinent theoretical and empirical literature. The data, variable formation, and methodology of construction of the econometric are detailed in section 3. The empirical findings of tests of unit root, cointegration, long-run and short-run estimates, and test of diagnoses are provided and interpreted in Section 4. In section 5, there is a critical discussion of the results, which examines implications, limitations, and contextual issues. Lastly, Section 6 then wraps up with a brief summary of main findings and policy conclusions that are targeted.

2. Literature Review

The interplay between economic action and environmental constraint is contextualized through a number of underlying ideas, which offer both competing and compliant explanations onto the path of carbon intensity (CI). According to the Environmental Kuznets Curve (EKC) hypothesis, the relationship between per capita income and pollution has the shape of inverted U therefore, in early industrialization, environmental degradation accelerates but at some turning point it reverses and decreases (Grossman and Krueger, 1991). Though originally used with local pollutants its reasoning applies to carbon intensity which is theorized to decline in subsequent developmental periods as a result of structural economic transformation and technological level (Stern, 2004). It is also strongly connected to the theory of decoupling, according to which CI tendencies are the signs of preventing the relative (CI falling and total emissions increasing) or absolute (CI falling and faster rate of growth) decoupling between the growth and the carbon emissions (Tapio, 2005).

To supplement the EKC, the STIRPAT (Stochastic Impacts by Regression on Population, Affluence, and Technology) model offers a versatile framework on which the environmental impact drivers are further disaggregated, in which technological factors- such as energy mix, efficiency- are paramount determinants of the environment and are flexible (York et al., 2003). This turns the analysis into the form of the particular structure of the production of economy and its technology. Along this line, economic complexity theories would have it that the country with more and sophisticated productive potentials farewell in the creation and uptake of new and advanced cleaner technologies, which may culminate in growth which is more ecologically slick (Hidalgo and Hausmann, 2009).

The international trade introduces an additional complexity in three main effects that include scale, composition, and technique effects. The scale effect is that with larger trade, there is a greater aggregate economic action and consequently pollution. The central idea that the Pollution Haven Hypothesis (PHH) puts forward is the composition effect in which high-environmental regulations in developed nations can cause the offshoring of carbon-intensive industries to jurisdictions with looser regulations, which raises the CI of the developing countries (Copeland and Taylor, 1994). On the other hand, the technique effect hypothesizes that cleaner technologies and management practices could be transferred at the cross-border level, using the techniques of trade and related foreign direct investment (FDI), and thus lead to the decreasing the pollution intensity of production (Antweiler et al., 2001). Business CI indirect effects on a country thus depends on its location in global value chains and institutional/policy structure which increase or diminish pollution haven effects (Cole, 2004).

In the energy economics perspective, the motivators of CI can be broken down further. An increase in the proportion of renewable energy (REN) in the primary energy ratios has a direct decrease in the content of carbon in energy offered, ceteris paribus, in CI (Bilgili et al., 2016). At the same time, the aggregate energy use intensity (EU) or the amount of energy needed per unit of GDP is one of the main indicators of general energy efficiency. CI is normally reduced in the EU, except when an offsetting movement towards fuels of higher carbon content occurs. This energy transformation process also largely depends on the specific policies of renewable energy and climate, including feed-in tariffs and price on carbon, which have become essential in decoupling growth and emissions in numerous settings (Polzin et al., 2015).

Heterogeneous trends are observed in the empirical evidence, especially on developing and emerging economies. Research on Pakistan in the South Asian context is an indication of this ambiguity. Shahbaz et al. (2013) discovered that an EKC of CO 2 emissions was supported, and energy consumption was one of its crucial factors. Javid and Sharif (2016) found that financial development promoted energy consumption and environmental quality was degraded whereas trade openness promoted quality of the environment- a fact which is consistent with the technique effect. On a more recent note, only a few researchers, among them Abbasi et al. (2021) determined that renewable energy also plays a significant role in minimizing the ecological footprint of Pakistan. But regional indications tend to highlight the continuing nature of pollution haven effect and the indefinitive character of an evident EKC turning point to carbon intensity in most developing nations, and where development still remains firmly linked with fossil fuel (Richmond and Kaufmann, 2006; Managi et al., 2009).

Regardless of this literature, a number of gaps are still observed in the special literature on Pakistan. Use of aggregate CO 2 emissions or ecological footprint as the dependent variable is common in many studies where both the scale and efficiency effects are confounded. The fact that fewer studies explicitly separate carbon intensity as the most important measure of economic-environmental comprehension. Moreover, the specific and potentially complementary functions of energy mix (ree renewable share) and aggregate energy efficiency (EU) are rarely separated into a single longitudinal system. The proposed study, hence, is an extension of the already existing literature with CI as the dependent variable of interest. It makes use of a solid time-series econometric model in order to isolate each of the effects of the penetration of renewable energy, total energy efficiency, and openness to trade and determine causal directions and long-run equilibrium relationship between these variables in the Pakistani economy in 34 years.

3. Methodology and Data

3.1. Theoretical Model and Variable Specification:

Carbon intensity is a factor modeled using the contraction of population, wealth, and technology (STIRPAT), which operates on the economic scale, technology, and structure (Dietz and Rosa, 1997). The long-run model is estimable as follows:

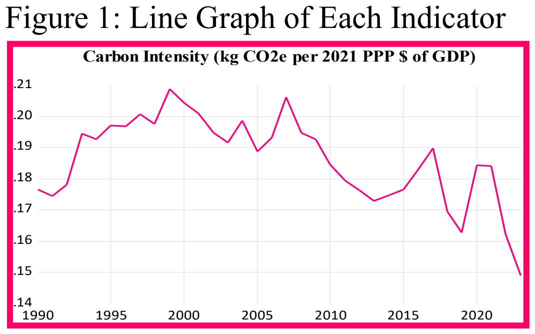
$$\mathbf{Ln(CI)_t = \beta_0 + \beta_1 Ln(TO)_t + \beta_2 Ln(REN)_t + \beta_3 Ln(GDPPC)_t + \beta_4 Ln(EU)_t + \epsilon_t}$$

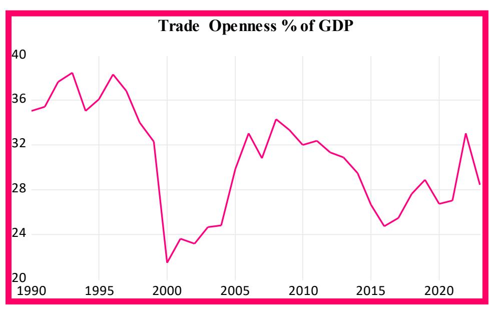
where:

$\mathbf{Ln(CI)_t}$ Natural log of Carbon Intensity of GDP (kg CO_2e per 2021 PPP \$ GDP).
$\mathbf{Ln(TO)_t}$ Natural log of Trade Openness (% of GDP).
$\mathbf{Ln(REN)_t}$ Natural log of Renewable Energy Consumption (% of total final consumption).
$\mathbf{Ln(GDPPC)_t}$ Natural log of GDP per capita (constant 2015 US\$).
$\mathbf{Ln(EU)_t}$ Natural log of Energy Use per unit of GDP (kg oil equivalent per 1000 PPP US\$).
$\boldsymbol{\epsilon_t}$ The error term.

All variables are transformed into natural logarithms, allowing the estimated coefficients to be interpreted as elasticities.

Figure 1: Line Graph of Each Indicator





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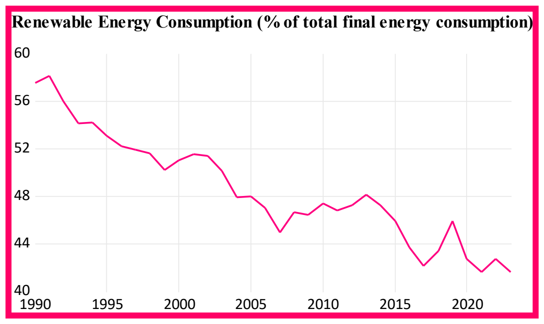
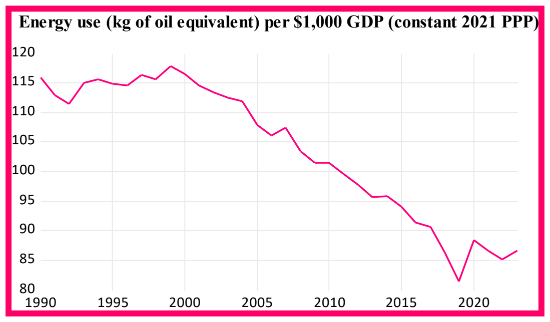
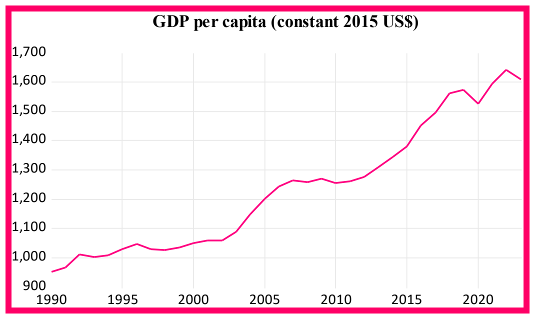






2. Figure 1 shows the longitudinal patterns of the fundamental variables. The trend of carbon intensity (CI) in Pakistan indicates that the country enjoyed some relative stability during the 1990s, but thereafter has been on the gradual downtrend since the year 2000, which reflects some phases of economic restructuring. Interestingly, this downward trend is accompanied by a considerable rise in GDP per capita (GDPPC) and a substantial rise in the share of renewable energy (REN) since the middle of the last decade, which is a first graphic sign of the hypothesized stimulating forces of decarbonization. This is further indicated in parallel reduction in energy use intensity (EU) implying gains made on aggregate energy efficiency within the period.
3. ***3.2. Data Sources:***
4. In the study, annual time-serious data are used (1990-2023 (34 observations). The information in all the data is obtained through the World Bank-World Development Indicators (WDI) which is a standard and reliable source of data on macroeconomic and environmental data (World Bank, 2024). Table 1 presents the summary of the description of the variables.
5. Table 1: Variable Description and Data Source

Symbol	*Variable and Measurement*	*Source*	*Description of the Variables*
CI	Carbon intensity of GDP (kg CO2e per 2021 PPP $ of GDP)	WDI	Measures the quantity of emissions of CO_2 per unit of economic output..
TO	Trade Openness (% of GDP)	WDI	Ratio of the sum of exports and imports to GDP, indicating how open an economy is to international trade
EU	Energy use (kg of oil equivalent per 1,000 constant 2021 PPP US dollars)	WDI	Total energy consumption per capita, typically measured in kg of oil equivalent.
GDPPC	GDP per capita (constant 2015 US$)	WDI	Economic output per person, usually expressed in constant or PPP-adjusted dollars.
REN	Renewable energy consumption (% of total final energy consumption)	WDI	Percentage of total electricity generated from renewable energy sources.

Source: Author's formulation using data of WDI

3.3. Econometric Strategy:

The systematic time-series econometrics analysis is performed:

Descriptive Statistics and Correlation Analysis: Preliminary investigation of the data properties and bivariate-relationship.

Unit Root Testing: Augmented Dickey-Fuller test (ADF) and Phillips-Perron test (PP) are methods to test for stationarity, which involves testing the intercept and intercept and trend variants.

Cointegration Analysis When the variables are integrated of order one I(1) then to test whether there is a long-run cointegrating relationship we use the Johansen (1991) test (both Trace and Maximum Eigenvalue areas).

Estimation at Long Run Model: When cointegration is discovered, the normalized cointegrating vector is assumed to be the long-run equilibrium equation.

Short-Run Dynamics (VECM): A Vector Error Correction Model: It is estimated by means of a short-run movement towards the long-run equilibrium. The general form is:

$$\Delta Y_t = \alpha + \lambda ECT_{t-1} + \sum_{i=1}^{p-1} \beta i \, \Delta Y_{t-i} + \epsilon_t$$

where

ECT_{t-1} is the lagged error correction term, and λ measures the speed of adjustment.

Diagnostic and Stability Tests: The model will undergo LM tests to test serial correlation, Jarque-Bra at least tests on the normality of residuals, ARCH tests on the heteroskedasticity and CUSUM / CUSUM squares test of stability of a parameter.

Analysis software employed is EViews 12 and Stata 17.

4. Results and Interpretation

The Section contains the empirical results of the time-series analysis, beginning with the diagnostics before making the fundamental estimates of the long-run and short-run. The outcomes of unit root tests, cointegration, Vector Error Correction Model (VECM) and related diagnostic tests are tabulated and explained accordingly.

4.1: Descriptive Statistics and Correlation:

Table 2: Results of Descriptive Statistics

Variable	*Mean*	*Median*	*Std. Dev.*	*Min*	*Max*	*Skewness*	*Kurtosis*	*JB Prob.*
CI	0.186	0.189	0.014	0.149	0.209	−0.619	3.016	0.339
TO	30.678	31.105	4.730	21.460	38.499	−0.140	1.991	0.460
REN	48.529	47.650	4.526	41.600	58.100	0.320	2.322	0.540
GDPPC	1236.25	1250.318	215.993	950.885	1642.281	0.466	1.926	0.239
EU	103.719	106.704	11.576	81.480	117.861	−0.426	1.728	0.190

Source: Author's formulation based on empirical estimates

Notes: CI = Carbon intensity of GDP; TO = Trade openness (%) = REN = Renewable energy consumption (%) = GDPPC = GDP per capita (constant US) = EU = Energy use per unit of GDP. JB Prob. refers to Jarque-Bera probability of normal.

Table 3: Correlation Matrix

Variables	*lnCI*	*lnTO*	*lnREN*	*lnGDPPC*	*lnEU*
lnCI	1				
lnTO	−0.017	1			
lnREN	0.355	0.435	1		
lnGDPPC	−0.597	−0.350	−0.944	1	
lnEU	0.723	0.278	0.844	−0.969	1

Source: Author's formulation based on empirical estimates

The descriptive statistics also show that the carbon intensity of GDP (CI) in Pakistan had a mean of 0.186 kg of CO 2 equivalent/ PPP-adjusted dollar and a standard deviation of 0.014 indicating that there was a moderate variation around the mean. All Jarque-Braun tests have probabilities greater than the traditional significance levels and the null hypothesis of normal distribution is not rejected; and this is backed by skew values close to zero and kurtosis values close to 3 with many of the series. The correlation analysis shows preliminary results of the relationship between variables: carbon intensity (LnCI) has high positive correlation with energy use intensity (LnEU, 0.723) and moderate positive correlation with renewable energy share (LnREN, 0.355), whereas it has high negative correlation with the GDP per capita (LnGDPPC, -0.597). It is important to note that there is a close-to-perfect negative relationship between LnGDPPC and LnEU (-0.969) which shows that there is a high level of multicollinearity thus are used by estimating a one system based on Vector Error Correction Model (VECM).

4.2: Unit root Test

Table 4: Results of Unit root Test

Variables	*Intercept*		*Intercept & Trend*	
	Level	**1st Diff.**	**Level**	**1st Diff.**
Augmented Dickey Fuller (ADF)				
LnCI	-0.971	-5.444***	-2.234	-6.205***
LnTO	-2.080	-5.790***	-2.186	-5.703***
LnEU	-0.096	-6.436***	-2.185	-5.684***
LnREN	-1.167	-5.778***	-3.234*	-5.686***
LnGDPPC	0.053	-4.144***	-3.154	-4.054***
Phillips and Peron (PP)				
LnCI	-0.886	-4.900***	-1.140	-9.214***
LnTO	-2.137	-5.790***	-2.299	-5.703***
LnEU	0.097	-6.469***	-2.049	-6.716***
LnREN	-1.010	-7.041***	-3.133	-7.411***

LnGDPPC	-0.022	-4.169***	-2.097	-4.054***

Source: Author's formulation based on empirical estimates

The ADF and Phillips Perron tests (ADF and PP) were used to determine the levels of stationarity of the time series, and a combination of intercept and trend was taken as a specification. The findings of both tests are consistent as explained in Table 4; at all the variables in their natural logarithmic domain (LnCI, LnTO, LnREN, LnGDPPC, and LnEU), the null hypothesis of not having a unit root cannot be rejected at the level. Nonetheless, this hypothesis is highly rejected (at 1% level of significance) of the first differences of both series. This ascertains that all the variables are integrated of one, I(1). To carry out cointegration analysis to examine the possible relationships between the long-run equilibrium by establishing that the series share the same order of integration meets the basic precondition of proceeding with the analysis.

4.3: Lag Selection and Johansen Cointegration Test

Table 5: Results of Lag Order Selection Criteria

Lag	***LL***	***LR***	***FPE***	***AIC***	***SC***	***HQ***
0	193.632	-	8.37e-11	-11.852	-11.668	-11.791
1	293.508	**168.541***	**4.47e-13***	**-17.094***	**-16.178***	**-16.790***
2	309.256	22.638	4.79e-13	-17.078	-15.429	-16.531

Source: Author's formulation based on empirical estimates

Note: LR: sequential modified LR test statistic (at each level of 5 percent); FPE: Final prediction error; AIC: Akaike information criterion; SC: Schwarz information criterion; HQ: Hannan-Quinn information criterion. * Lag order chosen by the criterion at 5% level of significance.

Table 6: Results of Johansen Co-integration Rank Test

Hypothesized CE(s)	***Trace Statistic***	***5% Critical Value***	***Max-Eigen Statistic***	***5% Critical Value***
*None**	78.019	69.819	42.602	33.876
At most 1	35.416	47.856	18.291	27.284

Source: Author's formulation based on empirical estimates

Note: * indicates rejection of the null hypothesis at the 5% significance level. Trace and Max-Eigen tests indicate one cointegrating equation. Critical values from MacKinnon-Haug-Michelis (1999).

The lag order selection criteria were used to select the optimal specification that would be used in further analysis of the system of vector autoregressive (VAR). Table 5 indicates that many information criteria such as the sequential LR test, Final Prediction Error (FPE), Akaike Information Criterion (AIC), Schwarz Criterion (SC), and Hannan-Quinn (HQ) all indicated, with unanimous agreement, the optimum lag length to be one. This guided the specification of testing of long-run relationships.

Using this lag structure, the procedure of cointegration by Johansen was performed. The findings, which are located in Table 6 indicate the statistically significant long-run correlation between the variables. The Trace test value of (78.019) and Maximum Eigenvalue of (42.602) are both above the 5 percent critical values of (69.819 and 33.876) which makes it possible to reject the null-no cointegration hypothesis. The tests prove that there is one cointegrating equation at the level of 5%. This observation offers sound empirical support of a long run equilibrium between carbon intensity and the macroeconomic and energy determinants of the basis of such equilibrium in the context of the research in Pakistan during the period under consideration.

4.4. Long-Run Coefficients

Table 7: Long Run Normalized Co-integration Coefficients

LnCI	***LnTO***	***LnREN***	***LnGDPPC***	***LnEU***
1.000000	0.436237	-23.26617	-25.52274	-21.21212
	(0.23499)	(2.92256)	(3.30319)	(2.85059)

$$\boldsymbol{LnCI_t = -0.436237 LnTO_t + 23.26617 LnREN_t + 25.52274 LnGDPPC_t + 21.21212 LnEU_t}$$

Dependent Variable = LnCI

Independent Variables	**Co-efficients**	**St.error**	**t-statistics**	**Significance**
LnTO	0.436237	0.23499	1.8564	* (10%)
LnREN	-23.26617	2.92256	-7.9608	*** (1%)
LnGDPPC	-25.52274	3.30319	-7.7267	*** (1%)
LnEU	-21.21212	2.85059	-7.4413	*** (1%)

Source: Author's formulation based on empirical estimates

Note: *, **, *** denote significance at 10%, 5%, 1% levels, respectively.

Trade Openness (TO): The coefficient is, -0.436 and significant at the 10 percentage mark. It implies that a 1 percent improvement in the level of trade openness is correlated with the reduction of 0.44 percent in the carbon intensity in the long run. This favors the overwhelming nature of a technique effect on the part of Pakistan, in which trade can work to open up cleaner technologies, inputs, and standards of efficiency.

Renewable Energy (REN): This coefficient is -23.266 and it is very large (1%). The implication of such a high elasticity is that an increase in the proportion of renewables in the energy mix is a strong motivator in decarbonizing energy. A 1 percent increment on the renewable share is linked to the decline in CI by 23.27 percent.

GDP per capita (GDPPC): The coefficient is -25.522 and it is very significant (1%). This means that with the expansion of the Pakistani economy and increase in income, the carbon intensity of its output does decrease drastically. This is consistent with the subsequent months of the EKC story and is an indication of a continuous process of structural change to less emission-intensive services and industries.

Energy Use Intensity (EU): The coefficient = -21.212 and it is very significant (1%). This counterintuitive negative symbolism has to be construed in the system. It implies that, other variables being equal in the long-run equilibrium, an increase in the energy consumption per GDP would be associated with a reduction in CI. This may indicate experiences where enhanced quantities of energy consumption are linked to transitioning to less carbon-containing energy carriers in the fossil fuel blend (e.g. coal to gas) or investment in technologies that consume energy and minimize efficiency (e.g. by indexing). Nonetheless, its negative correlation with GDPPC is very strong, and thus, there should be caution when isolating the effect.

4.5. Short-Run Dynamics (VECM) and Error Correction

Table 8: Result of ECM for Short Run Dynamics

Dependent Variable ΔLnCI

Variables	**Co-efficient**	**Std. error**	**t-statistics**	**p-value**
C	-0.0081	0.0086	-1.0166	0.3183
D(LnREN)	-1.1512	0.4153	-2.7713	0.0100
D(LnTO)	-0.0171	0.0616	-0.2782	0.7830
D(LnEU)	0.4147	0.5654	0.7336	0.4695
D(LnGDPPC)	-0.1907	0.5068	-0.3762	0.7097
ECT(-1)	-0.2172	0.2659	-0.8162	0.4211

Source: Author's formulation based on empirical estimates

The approximate VECM findings indicate that the change in the consumption of renewable energy ([D(LnREN)]) is the only statistically significant variable (with 5 in the significance level) that influences the change in the carbon intensity ([D(LnCI)]) in the short run. An increase of renewable share by one percent in the short term would cut the increase in CI by approximately 1.15 percent. Change coefficients of TO, EU and GDPPC are not significant. The error correction term (ECT) coefficient is -0.217 which is statistically insignificant (p=0.421). It means that the recovery to the long-run equilibrium after a shock is slow and statistically equal to zero in this sample, which could be explained by institutional and technological rigidities.

4.6. Diagnostic Tests

The model passes key diagnostic checks, affirming its reliability:

Table 9: Breusch-Godfrey Serial Correlation LM test

Test	***Statistic***	***p-value***	***Conclusion***
LM (F-statistic)	2.225006	0.1275	No serial correlation
LM (Chi-square)	4.669328	0.0968	No serial correlation

The outcomes of the LM test show that the null hypothesis that the two series are not correlating serially is not rejected at 5% level and therefore verify that there is no correlation in residual. Even though the Chi-square value is slightly significant at the 10 per cent level, the general evidence indicates that there is no severe issue of autocorrelation.

Table 10: Jarque-Bera Normality Test

Variable	***JB Statistic***	***p-value***	***Conclusion***
ΔLnCI	4.0508	0.1319>0.05	Residuals approximately normal
ΔLnTO	1.833404	0.3998>0.05	Residuals approximately normal
ΔLnREN	1.02428	0.59920>0.05	Residuals approximately normal
ΔLnGDPPC	2.60924	0.2712>0.05	Residuals approximately normal
ΔLnEU	3.38894	0.18369>0.05	Residuals approximately normal

Source: Author's formulation based on empirical estimates

According to Jarque-Bra test results, the residuals of all equations employed in the VECM are normally distributed as all the p-values are greater than 0.05. This establishes the assumptions of the model about the normality of the residual, as valid.

Table 11: Heteroscedasticity ARCH Test Results

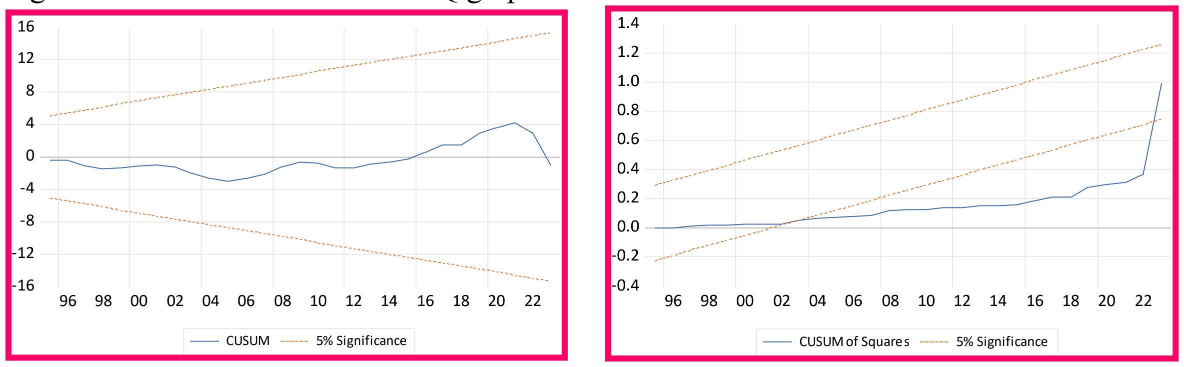
Test	***Statistic***	***p-value***	***Decision***
(F-stat)	0.0288	0.8664	Residuals homoskedastic
*(Obs*R²)*	0.0306	0.8512	Residuals homoskedastic

Source: Author's formulation based on empirical estimates

The ARCH test of heteroskedasticity shows that both the F-test and ObsR 2 test are not significantly different ($p > 0.05$), which implies that the VECM residuals are homoskedastic. This establishes the trustworthiness of the estimates of the standard errors.***Stability Test:***

Advance Journal of Econometrics and Finance
Vol-4, Issue-1, 2026

Figure 2: CUSUM and CUSUMSQ graphs



The parameter stability test which is CUSUM of squares test indicates that the parameter crosses the 5 percentage significant values meaning that the model coefficients are not completely stable throughout the sample time-period. This deviation indicates the potential happenings of the structural break- a major change in the inherent connection between carbon intensity and its determinants. This break can be explained by the major economic or policy shocks within the time period of the study, such as the economic liberalization periods in the middle of the 2000s, the severe energy crisis of the 2010s, or the increased renewable energy plans of 2020 under the Alternative and Renewable Energy Policy of Pakistan.

5. Discussion

The findings provide subtle information in the dynamics of the carbon intensity of Pakistan. It is the paramount nature of the enduring energy transformation of Pakistan that is amplified by the renewable energy (REN) impact that is strong and negative in the long run. Indicative Generation Capacity Expansion Plan (IGCEP) which aims at 60% renewables by the year 2030 is empirically justified. But the large elasticity means that the progress has been too little historically and more ambition and investment is essential.

The fact that GDP per capita (GDPPC) impact is significant points to the fact that even a properly managed economic growth can be decarbonized. This could portray a gradual immigration with the high-intensive farming and fledgling manufacturing towards services. This should not however be a cause of complacency because ultimate emissions can still increase provided that the scale effect over-rules the improvement in the intensity.

The result of trade openness (TO) in support of technique effect is promising to a globalizing economy such as that of Pakistan. It indicates that participation in global value activities has not rendered Pakistan a strong "pollution haven" perhaps environmental conditionalities in the export markets (e.g., EU) or technology transfer. Nonetheless, this conclusion should be optimistically approached with criticism and further observation particularly when it comes to trading with nations that have lower standards.

The short run dynamics reveal the leveraging nature of leveraging on renewable energy on short run basis. The trivial ECT term indicates a slow mechanism of adjustment, indicating the presence of inertia of structure in the energy system and the economy. This inertia supports policymaking requirements of long-term commitments of policies instead of short-term interventions.

The possible structural discontinuity that is established requires further investigation. Future researchers might use the techniques such as the Gregory-Hansen test to endogenously estimate the breakpoints and examine whether drivers of CI evolved following significant events such as the 18 th Constitutional Amendment (devolution of environmental governance) or the investments in the China-Pakistan Economic Corridor (CPEC).

Weakness of this study would be that the sample size is rather small (n=34) that limits the degrees of freedom and the power of tests. The aggregate national data is used to conceal relevant sectoral and regional heterogeneities. Additionally, the other possible causal factors, like financial development, urbanization, or certain climate policy, were not taken into account because of the data limitations and the parsimony of the model.

6. Conclusion and Policy Recommendations

This paper has been an empirical investment to determine the determinants of carbon intensity in Pakistan between the year 1990 and 2023. The findings validate the presence of a long-run association where the rate of consumption of renewable energy and GDP per capita are a significant negative term, and trade openness also aids in decreasing the intensity, although the strength is insignificant. The role of energy use intensity is a complex and system dependent role. The fluctuations in the renewable energy share are the main way of driving the short run changes.

The resultant policy recommendations are:

Transition to Renewable Energy faster: Build the growth of wind, solar, and hydro power as the national energy and climate policy. This includes the elimination of regulatory obstacles, encouraging the use of private funds to integrate and store grids, and decommissioning both the explicit and implicit subsidies of fossil fuels.

Upgrade Energy Efficiency as a Side Pillar: Introduce a policy of high energy efficiency in the industry, buildings, and appliances. Create an ESCO market and promote the widespread use of smart grid technologies to decrease the overall energy use intensity (EU).

Green Growth: Use leverage trade policy to include environmental requirements in the trade agreements and export promotion policies. Support industries to embrace international environmental management standards (e.g. ISO 14001) to amplify the beneficial manner effect of trade.

Promote Sustainable Structural Adjustment: Plan the policies, both industrial and agricultural, which clearly enhance the creation of the value addition in low carbon industries. Invest in green skills and green innovation in order to make a just transition of the workforce.

Enhance Monitoring and Adaptive Policy Frameworks: Have a high resolution data system to monitor carbon intensity both at sectoral and provincial levels. Review policies regularly to discern structural discontinuities and make changes in strategy, to ensure Pakistan progresses on achieving its NDCs and sustainable development ambitions.

To sum up, the process of decoupling of the carbon emission and economic growth in Pakistan is not easy but possible. It needs to lay the way ahead with an unswerving determination to change its energy system, increase its economic efficiency and use global trade to achieve sustainable goals. This research paper is the empirical basis through which such a radical agenda can be developed.

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