Nexus Between Energy Income Emission in India: An ARDL Approach

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ABSTRACT

The study attempts to examine and test whether or not there is a long-run relationship between CO_2 emissions and GDP. Furthermore, the Environment Kuznets Curve hypothesis is being tested to see if there is any evidence of a non-linear relationship between the two. The current study employs a multivariate framework that includes CO_2 emissions (in kt), GDP (constant 2010 US dollar), GDP squared, and energy use (kg of oil equivalent per capita). The study employs annual data from World Bank Group's World Development Indicators database for the aforementioned variables from 1971 to 2014 for empirical analysis. We apply appropriate econometric techniques to our model, with CO_2 emission serving as regressand and GDP, GDP squared, and energy consumption serving as regressors. The study finds in India, both the long run and short run ARDL estimates of GDP and GDP squared point to an EKC. The short run GDP or income elasticity of CO_2 emission, on the other hand, is slightly lower than the long run income elasticity. The positive GDP coefficient and negative GDP squared coefficient show that India is following the inverted U-shaped EKC, in which environmental degradation increases with increased national income and then decreases with increased income effect and use of other renewable resources for consumption and production. However, the positive and significant coefficient of energy use or consumption shows that with increased demand for energy, CO_2 emissions will rise steadily in the future. Furthermore, after reaching a certain income level, the increased income effect may outweigh the increased energy consumption effect, and CO_2 emissions may begin to fall from a certain upper level.

JEL Classifications: C5; Q4: *Q5*

Keywords: *CO_2 emission; Gross domestic product; Energy use; Environmental Kuznets curve*

1. INTRODUCTION

Environment is a primitive concern in today's context. The global economy has been developing at an exponential rate over the last few decades, however the brunt of this development is being borne by the environment. Economic development and environmental degradation go hand in hand. This phenomenon is measured through the use of Environmental Kuznets Curve, EKC. The paper sheds light on India's economic development and its impact on the environment over the years ranging from 1971-2014. The technological advancements over the years have led to a trade-off between environment and growth. This is now deemed as necessarily true and unavoidable. The EKC translates into higher environmental depletion or higher environmental consumption upon attaining higher levels of growth or higher income. This simply points to the fact that more natural resources are exploited for a country to reach higher income and higher development. The EKC measures the relationship of income and environment depletion hence forming an inverted-U shape of the curve. The pioneer works in this area were [1], [2] and [3] who first explored the concept of EKC taking base of original Kuznets Curve [4].

Reference [1] in 1991 studied the relationship between economic growth and CO_2 emissions. The study was started in 1990s when the world had started being together after the Earth Summit in Rio, Brazil. The global issue of climatic change was highlighted, and this provided stimulus to further study. Since then, EKC attained high interest and attention from most economist and environmentalist consisting of [2, 3, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14]. We can summarize EKC as when the income increases for an economy, the level of environment depletion or natural resource consumption increases, and beyond a threshold the increase in the former is assisted with an increase in the latter as well. This gives an inverted U-shape to the curve known as Environment Kuznets Curve.

In short, with economic development as prime focus, environment quality will first be depleted for the worse and then will be improved for the better.

This hypothesis has been proven with empirical evidences. The reasons for the inverted U-shape are that firstly, there is income elasticity for environment quality demand. Humans tend to spend more on environment improvement when their income increases. This means that health is a luxury, which comes with higher level of income. The second reason is the economies of scale. When the economic growth is occurring, it exerts pressure on natural resources. These natural resources are consumed at a rate higher than their rate of renewal. Another aspect of the same is that higher level of production leads to higher level of pollution. The earth acts as a sink, but the capacity of the sink is limited. Beyond this, once the growth has started increasing, the economy tends to invest in sustainable technology which helps improve environment quality.

The third and final reason for the shape of the EKC is its linkage to international trade. The free trade leads to increase in pollution. Reference [15] in their study developed a model which showed the effects of free trade on environment depletion. The model was empirically proven to state that free trade is beneficial to the environment, however, another empirical analysis [16] using data from Chinese manufacturing industry proved that free trade is indeed harmful to the environment in the short run however, it turns out to be beneficial in the long run. Hence, forming a U-shaped EKC.

2. Review of Literature

When the economy is developing over the years, it is placed on the increasing side of EKC, that is as the income increases, the environment depletion increases as well. Following the increase, the economy reaches the peak where the level of depletion is highest, beyond this, the level of income increases and the depletion of environment starts decreasing. This translates to the fact that as the income increases and the country becomes developed, it invests back into environment protection. This scenario has been commonly observed in most developing and developed economies over decades. Some earlier studies (13, [17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29], have already established the existence of EKC. These studies include both developing and developed nations including OECD countries. Furthermore, [30] in their study of Asian countries focused on the period 1990-2011 for 14 countries. The results of the study were in line with empirical analysis and listed that the Asian countries were in on an inverted-U shape EKC.

Moreover, [31] and [18] took a case study of France, [32] used data from Canada, [21] analyzed Spain and [27] took OECD countries under the scanner to verify the existence of EKC and found strong support for the same. The phenomenon of EKC was examined and found true for countries like Turkey in [33] and Tunisia in [34] as well.

However, there is enough literature which do not support the existence of EKC at all. These includes [35, 36, 37, 38, 39, 40], and the studies mostly include developed American and European economies. Many of the studies like [14, 34, 41, 42, 43, 44, 45, 46, 47, 48], provides mixed results for EKC depending on the function, type of pollutant, pool of countries and time considered which creates variability in results. Further, [49] in their study of Vietnam found that the EKC was applicable only in the long run but not in the short run. This left us with a question of applicability and viability of EKC. So, this paper tries to test the applicability and viability of EKC for India in the long run and short run as well.

As far as India is concerned, the economy has reached to 3.17 trillion Dollar in 2021 from just 321 billion Dollar in 1990 [50]. The growth trajectory has been tremendous over the years and economy grows at 6.9 percent over the previous year with some shocks in the years 2000 and 2008, when the growth has just dropped to 3.0 percent. The per capita GDP has risen from 367 US dollar in 1990 to 2277 US Dollar in 2021. The value for CO_2 emissions (kt) in India was 2,238,377 (1.7 metric tons per capita) as of 2014 which was just a value of 6,19,154 (0.71 metric tons per capita) in 1990. India is positioned 3rd after China (10,291,926 kt) and United States of America (5,254,279 kt) in CO_2 emissions world-wide. Moreover, the value for energy use (kg of oil equivalent per capita) or consumption in India was just at 1662 as of 1990 which risen to 1922 in 2014. India has been a developing economy for the last couple of decades, the environmental degradation in India has been rising as speedily as the rate of growth (see Appendix). The concern of environmental degradation is not new to India. It is the first nation to actively include a constitutional amendment that enables the State to protect and enhance the environment for the preservation of public health, forests, and wildlife [11]. In this context, there are concerns over energy efficiency front at the outset of global warming and achieving high economic growth with sustainable development is the need of time [51].

Here, [11] used the analysis of states-level industrial data from 1991 to 2003 to successfully demonstrate the EKC relationship between environmental productivity of three pollutants, such as SO_2, nitrogen dioxide (NO_2), and suspended particulate matter, and income. Similar research on the association between household income and indoor air pollution has been done by [52] using data from the National Sample Survey (NSS) from 1983 to 2000. The findings confirmed that the EKC hypothesis was a valid way to investigate the observations in rural families. Reference [53] used a pooled cross-country time series data to incorporate the effect of goods trade and trade policy orientation of EKC hypothesis. The study found that the reason for upward sloping portion of EKC is the export of manufacturing goods by industrialized countries and the downward sloping portion is contributed to import of manufacturing goods by industrialized countries.

Reference [54] analyzed sectoral contributions of CO_2 emissions in India using Input Output model and found power sector to be the highest contributor of emissions followed by manufacturing, steel and road transportation. Reference [55] examined the causal relationship of energy consumption, output and carbon emission for energy dependent Brazil, Russia, India and China (BRIC) countries and uses panel data for the period of 1971-2005. The study supported EKC hypothesis but does not find any evidence of causality running from output to emissions, however, energy consumption is being the strong contributor of emission. Reference [56] showed a positive picture and opined that detailed MARKAL simulations projects that with energy consumption and aggressive use of renewable energy systems in India, carbon emissions decrease steeply after the year 2040 which solidify the efforts made towards sustainable development.

Reference [57] examined the case of India using a dynamic modelling approach and found strong bidirectional causality between energy and emission but no such causality is found between energy – income and emission – income. Reference [24] analyzed the time series data for India from 1971 to 2008 and confirmed the existence of EKC and long run relationship among energy, output and emissions. The study also found that CO_2 emission to be highly elastic with respect to per capita income and energy consumption which necessitates the apt environmental policy framework for India. Further, [58, 59] also supported the EKC for India. However, [60] made a departure from inverted U shape EKC and have developed an N shaped relationship between emission and economic growth for India and China for the period of 1971-2012.

In this context, we found mixed results on EKC for India. Previous studies in literature have either used sectoral analysis or pool of countries for estimation of EKC and very few of them has seen the scenario on national level data taking big time series to capture the whole essence of EKC. Many of them are very old and few of them which are new, took too many variables in a small time series which may results into specification bias. It is thus very important to revisit the issue with maximum available years' time series to understand the energy, output, emission relationship to draw appropriate economic policies using advanced econometric analysis.

3. Research Methodology

Data: The present study uses multivariate framework that includes CO_2 emissions (in kt), gross domestic product (constant 2010 US dollar), square of gross domestic product and energy use (kg of oil equivalent per capita). For empirical analysis the study uses annual data for the aforementioned variables from 1971 to 2014. The data has been collected from World Development Indicators (WDI) database of World Bank Group.

Model specification: The study attempts to analyse and test, whether there exists a long run relationship between CO_2 emission and GDP or not. In addition, Environment Kuznets Curve (EKC) hypothesis is being tested to find any evidence of non-linear relationship between the two. In this context "(1)" has been used to test the model and multivariate model with CO_2 emission as the regressand (dependent variable) is being set up as:

$$\boldsymbol{CO_{2t} = f(GDP_t, SQGDP_t, EU_t)} \qquad (1)$$

Where CO_2, GDP, SQGDP and EU stands for CO_2 emissions (in kt), gross domestic product, square of gross domestic product and energy use (kg of oil equivalent per capita). The aforementioned equation has been used after we predicted quadratic fit ranging from time period 1 to 60 where 1 corresponds to 1971 and 60 corresponds to 2030 (see appendix).

Furthermore, the regressand and regressors are converted to logarithmic form so that the coefficients in "(2)" can be interpreted as the regressand's elasticity with respect to the respective regressor. The expected signs of the regressors are indeterminate, so we test the hypothesis using the coefficients' signs and statistical significance of estimators β_{it} to see the effect of respective regressor on CO_2 emission. According to literature and theory, the coefficient β_1 is expected to be positive and β_2 (square of GDP) to be negative. If the null hypothesis can be rejected ($\beta_{it} \neq 0$) study concludes that GDP has positive or negative effect on CO_2 emission. The sing of β_3

(energy use) is expected to be positive which indicates that more energy use or consumption leads to more carbon emission.

$$\boldsymbol{ln}\ (\boldsymbol{CO_2})_t = \boldsymbol{\beta_0} + \boldsymbol{\beta_1 ln}(\boldsymbol{GDP_t}) + \boldsymbol{\beta_2 ln}(\boldsymbol{SQGDP_t}) + \boldsymbol{\beta_3 ln}(\boldsymbol{EU_t}) + \mu_t \quad (2)$$

In simple words what the study hypotheses is that to prove an EKC in the context of India, the expected sign of GDP should be statistically significant and positive ($\beta_{it} > 0$), the expected sign of square of GDP is significantly negative ($\beta_{it} < 0$) and the sign of EU should be significantly positive ($\beta_{it} > 0$). The said hypotheses with positive coefficient of GDP and negative coefficient of square of GDP suggests that as income or GDP increases, CO_2 emission, first increase and then decrease. It also proposes that in the early stages of development with increased rates of utilisation of factors of production (especially natural resources) or undergoing industrialisation, carbon emissions increase very rapidly. However, with increased income or GDP, the composition of economy changes very rapidly and share of services increases in national income. The increased use of renewable resources, green technology, increased income effect makes it possible to reduce the level of carbon emission in economy.

To start the testing procedure, first, the study employs the augmented Dickey-Fuller test and the Phillips-Perron test to determine the presence of unit roots. The result gets validation and order of integration of series is certain if both the tests give similar results. The investigation continues to look for cointegration among the variables.

ARDL bounds test for cointegration: The ARDL bounds testing approach was developed by [61] and this study uses the same. While testing the co-integration among variables, the ARDL bounds test uses unrestricted error correction model (ECM) using F statistics to validate the significance of estimations. The Wald test is applied to determine the long run relationship among variables. Here the bounds test is performed on “(3)”.

$$\Delta \boldsymbol{ln}(\boldsymbol{CO_2})_t = \boldsymbol{\lambda_0} + \sum_{i=1}^{p} \boldsymbol{\theta_i} \Delta \boldsymbol{ln}(\boldsymbol{CO_2})_{t-i} + \sum_{j=0}^{q} \boldsymbol{\phi_j} \Delta \boldsymbol{lnGDP}_{t-j} + \sum_{k=0}^{m} \boldsymbol{\varphi_k} \Delta \boldsymbol{lnSQGDP}_{t-k} + \sum_{l=0}^{n} \boldsymbol{\gamma_l} \Delta \boldsymbol{lnEU}_{t-l} + \boldsymbol{\lambda_1 ln}(\boldsymbol{CO_2})_{t-1} + \boldsymbol{\lambda_2 lnGDP}_{t-1} + \boldsymbol{\lambda_3 lnSQGDP}_{t-1} + \boldsymbol{\lambda_4 lnEU}_{t-1} + \mu_t \quad (3)$$

Where $ln(CO_2)_t$ is a vector, λ_0 is constant; p, q, m, n are optimal lag orders; μ_t is a vector of error term (unobservable zero mean white noise vector process; serially uncorrelated or independent).

The ARDL model is such that the regressand is a function of its lagged values, the current and lagged values of regressors (or exogenous variables) in the model. Before applying ARDL bounds test it is necessary to check the appropriate lag order for the model and from different lag order criteria like AIC, SBIC, HQIC etc. the study uses the rule of majority to choose the optimal lag order for the abovementioned model. Here, the lag orders (e.g., p, q, m, n) may not necessarily be the same and p lag is used for the regressand.

In bounds test, the calculated F statistics is compared with critical values of F at different significance level. These critical (or tabulated) values are in pair of lower and upper bounds for each level of significance. The null hypothesis of no co-integration is rejected if F-calculated is greater than the upper bound critical value of F at a particular level of significance. The null hypothesis is accepted if F-calculated is lower than the lower bound critical value of F and the result is inconclusive if F-calculated lies between the lower and upper bound critical values of F at a particular level of significance.

Johansen’s co-integration test: The study employs the Johansen cointegration test to support the ARDL bounds testing results. This entails building the Vector autoregressive (VAR) model at the levels of variables. The VAR model is described as follows:

$$\boldsymbol{X_t} = \mu + \sum_{i-1}^{p} \boldsymbol{\beta_i X_{t-i}} + \boldsymbol{\varepsilon_t} \quad (4)$$

Where X_t is a vector of variables (ln (CO_2), ln (GDP), ln (SQGDP) and ln (EU)), μ is a vector of constant terms, ε is the vector of error terms, and β_i is a matrix of VAR parameters for lag i. The Maximum Eigenvalue test and the Trace test, two probability tests, are taken into account by the Johansen cointegration test to establish the quantity of cointegrating equations. Both tests compare the alternative hypothesis of n cointegrating equations, where n is the total number of variables in the system, against the null hypothesis of r cointegrating equations.

Further, to estimate the long and short run elasticity and relationship among regressand and regressors, the study employs the following “(5)” to estimate the short run estimation;

$$\Delta \boldsymbol{ln}(\boldsymbol{CO_2})_t = \boldsymbol{\beta_1} + \sum_{i=1}^{p} \boldsymbol{\beta_{1i}} \Delta \boldsymbol{ln}(\boldsymbol{CO_2})_{t-i} + \sum_{j=0}^{q} \boldsymbol{\beta_{2j}} \Delta \boldsymbol{lnGDP}_{t-j} + \sum_{k=0}^{m} \boldsymbol{\beta_{3k}} \Delta \boldsymbol{lnSQGDP}_{t-k} + \sum_{l=0}^{n} \boldsymbol{\beta_{4l}} \Delta \boldsymbol{lnEU}_{t-l} + \boldsymbol{\alpha ECT}_{t-1} + \boldsymbol{\varepsilon_t} \quad (5)$$

The estimates of long run elasticity or relationship depends on the first two steps where the study finds any evidence of co-integration among variables using a defined ARDL model and coefficient of short run elasticity are estimated using differenced series. To capture the joint significance of the short run towards long run, the Wald test is used where α (in "(5)") denotes the error correction term (ECT). ECT should be negative, statistically significant and the value of ECT should be between 0 and 1 which shows the speed of convergence for any short run shock towards long run equilibrium.

The study performs various diagnostic tests to confirm the reliability, validity and stability of the estimations of ARDL model. The tests are performed to check for any autocorrelation, serial correlation, heteroskedasticity and non-normality in abovementioned model. To check the stability in the model cumulative sum (CUSUM) and cumulative sum squared (CUSUMsq) tests are applied proposed by [62].

Granger causality test: Here, the final step is to know the direction of causality among variables of interest. The traditional or ordinary causality test was proposed by [63] which represents that if a variable X is influenced by the lagged values of variable Y and lagged values of X itself then Y Granger causes X and vice versa. This relationship may be unidirectional or bidirectional or both. The test has null hypothesis of no Granger cause or the variables are independent of each other. However, ordinary Granger causality test has some limitations like specification bias and problem of spurious regression [64].

An advancement to ordinary granger is proposed by [65] and [66] which uses augmented VAR procedure. It provides Wald statistics based on chi (χ^2) squared distribution and also known as modified Wald (MWald). This test may be used even if the series are not co-integrated. The test uses following VAR equation for testing Granger causality in the model.

$$\begin{bmatrix} ln(CO_2)_t \\ lnGDP_t \\ lnSQGDP_t \\ lnEU_t \end{bmatrix} = \begin{bmatrix} \alpha_1 \\ \alpha_2 \\ \alpha_3 \\ \alpha_4 \end{bmatrix} + \sum_{i=1}^{k} \begin{bmatrix} \beta_{11,i} & \beta_{12,i} & \beta_{13,i} & \beta_{14,i} \\ \beta_{21,i} & \beta_{22,i} & \beta_{23,i} & \beta_{24,i} \\ \beta_{31,i} & \beta_{32,i} & \beta_{33,i} & \beta_{34,i} \\ \beta_{41,i} & \beta_{42,i} & \beta_{43,i} & \beta_{44,i} \end{bmatrix} \begin{bmatrix} ln(CO_2)_{t-i} \\ lnGDP_{t-i} \\ lnSQGDP_{t-i} \\ lnEU_{t-i} \end{bmatrix} +$$

$$\sum_{j=1}^{d_{max}} \begin{bmatrix} \beta_{11,k+j} & \beta_{12,k+j} & \beta_{13,k+j} & \beta_{14,k+j} \\ \beta_{21,k+j} & \beta_{22,k+j} & \beta_{23,k+j} & \beta_{24,k+j} \\ \beta_{31,k+j} & \beta_{32,k+j} & \beta_{33,k+j} & \beta_{34,k+j} \\ \beta_{41,k+j} & \beta_{42,k+j} & \beta_{43,k+j} & \beta_{44,k+j} \end{bmatrix} \begin{bmatrix} ln(CO_2)_{t-k-j} \\ lnGDP_{t-k-j} \\ lnSQGDP_{t-k-j} \\ lnEU_{t-k-j} \end{bmatrix} + \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \varepsilon_3 \\ \varepsilon_4 \end{bmatrix} \quad (6)$$

Where the variables are same as defined earlier in previous equations, k is the number of lags, α is the vector of constant, β_s are parameter matrices, d_{max} is the highest order of integration for the variables in the model. The study uses VAR Granger/Block exogeneity Wald test to capture the relationship among variables and MWald test for Granger causality test.

4. Econometric analysis and discussion

To investigate for any co-integration among variables and analyse the relationship between regrassand and regressors, the study first tests for unit root properties of the variables using augmented Dickey-Fuller test [67, 68] and Phillips-Perron test [69] to natural logs of our variables of interest. The result of ADF test denotes that all the variables have unit root at levels but the 1st difference of all variables are stationary or did not have any unit roots. This indicates that all the variables are integrated at order 1 or called I (1).

Table 1: Unit Root Tests

Variables	**Augmented Dickey-Fuller Test (Lag 1)**		**Phillips-Perron Test (Lag 1)**		**Outcome**
	Levels	I-Difference	Levels	I-Difference	
ln (CO_2)	0.328	-4.276***	0.318	-6.333***	I (1)
ln (GDP)	3.059	-4.174***	3.530	-6.485***	I (1)
ln (SQGDP)	3.352	-3.918**	3.934	-6.139***	I (1)
ln (EU)	3.007	-2.819*	3.768	-4.739***	I (1)

Note: *, ** and *** denote 0.05, 0.01 and 0.001 level of significance, respectively.

The Phillips-Perron test supports the result reported by ADF and indicates that natural logs of CO_2 emissions (in kt), GDP, GDP^2 and energy use (kg of oil equivalent per capita) have unit roots at level but become stationary at first difference which suggests that all variables are integrated at order 1.

Further, to investigate any co-integration among variables the study employed ARDL bounds test and uses F statistic to come to a conclusion. Before calculating F statistic, the study chooses optimum lag length using AIC criteria because for every optimum lag length the F statistic changes its value. For choosing optimum lag length using AIC criteria we take minimum value of AIC.

From the ARDL testing we compare the calculated F statistic with the lower and upper critical bounds at 1 percent and 5 percent level of significance using [61] critical bounds. It can be seen from table 2 that calculated F statistics (5.915) is greater than the upper critical bounds at 1 percent and 5 percent levels which indicates the presence of co-integration and makes us reject null hypothesis of no co-integration among variables using CO_2 emission as dependent variable. We come to a conclusion that all variables are co-integrated using CO_2 emission as regressand for India over 1975 to 2014 which indicates there may exists a long run relationship between the variables in the sample period for India.

Table 2: Results of bounds test of co-integration

Estimated model	**ln (CO_2) = f (ln (GDP), ln (SQGDP), ln (EU))**			
Optimal lag length (AIC)	(1, 1, 1, 1)			
F statistics (Bounds test)	5.915**			
Critical values	10.0 percent	5.0 percent	2.5 percent	1.0 percent
Lower bound I (0)	2.72	3.23	3.69	4.29
Upper bound I (1)	3.77	4.35	4.89	5.61

Note: *, ** and *** denote 0.05, 0.01 and 0.001 level of significance, respectively. The table above shows different F statistics values for India by using AIC. The critical values are taken from [61].

In order to confirm our observations and clear out any co-integration, the Johansen test is also used. To test the null hypothesis that there is no co-integration, the Johansen co-integration test employs the trace and max-eigen value statistics. Results in Table 3 show that both test statistics reject the null hypothesis that there is no co-integrating equation in favour of at most one co-integrating equation since the tabular values (given in parenthesis) are lower than the computed values. The null of no more than one or two co-integrating equations, however, could not be disproved by any test statistic. Since there is just one co-integrating equation in the system (the natural log of CO_2 emission is used as the dependent variable), it can be said that all the variables in the system are co-integrated.

Table 3: Johansen Cointegration Test

Specifications	**Hypothesised No. of Cointegrating Eq.**	**Trace Statistic**	**Max-Eigen Statistic**	**Outcome**
ln (CO_2) = f (ln (GDP), ln (SQGDP), ln (EU))	None	63.42* (47.21)	38.8850* (27.07)	(1) Cointegrating Equation)
	At Most 1	24.5369 (29.68)	20.3341 (20.97)	
	At Most 2	4.2028 (15.41)	3.172 (14.07)	

Note: Values in the parenthesis represents the critical value of the respective statistic at 0.05 level of significance.

The long run ARDL estimates of GDP and square of GDP points out towards an EKC in India. It can be seen from table 4 that the coefficient of GDP with respect to CO_2 emission is positive and significant which indicates that with increased economic growth CO_2 emission increased very rapidly in India. Ceteris paribus, a 1 percent increase in GDP is leading to 13.78 percent increase in CO_2 emission (environmental degradation). On the other hand, the coefficient of GDP squared (SQGDP) is negative and significant (-0.24) which confirms the existence of EKC (inverted U-shaped relation between economic growth and environmental degradation) in India for study period.

Table 4: ARDL long run and short run results

Dependent variable: ln $(CO_2)_t$	**ARDL (1, 1, 1, 1)**
Long run results	

Variable	Coefficients	Standard Error
ln $(GDP)_t$	13.78965**	0.6638933
ln $(SQGDP)_t$	-0.247503***	0.0131623
ln $(EU)_t$	1.9071***	0.2113793
	ECM ARDL results (short run)	
Δln (GDP)	10.78841*	5.020055
Δln (SQGDP)	-0.2054301*	0.0940174
Δln (EU)	0.4706569	0.3265068
ECT_{t-1}	-0.658868***	0.1530453
Constant	-124.9424***	31.30984
R-squared = 0.6776	**Adj. R-squared = 0.6131**	**F (7, 35) = 9686.08*** **

Note: *, ** and *** denote 0.05, 0.01 and 0.001 level of significance, respectively.

Moreover, the coefficient for energy use or consumption is found to be positive and significant (1.90) which shows that energy use or consumption is positively linked to CO_2 emission. Ceteris paribus, a 1 percent increase in energy use or consumption leads to 1.9 percent increase in CO_2 emission in long run according to the coefficient ln (EU_t). The findings get support from previous studies like [34], [70], [33], [71] and, [72] who found energy use to be the most important contributor to CO_2 emission and in accordance with energy-growth-emission framework. For India, it is clear that energy consumption pattern is giving rise to CO_2 emission and thereby environmental degradation is a long run phenomenon with increased energy use or consumption.

The short run ARDL model illustrates that short run GDP or income elasticity (Δln (GDP)) of CO_2 emission is somewhat less that the long run income elasticity. Ceteris paribus, a 1 percent increase in GDP leads to 10.78 percent increase in CO_2 emission in short run which was 13.78 percent in long run. Moreover, the short run coefficient of energy use illustrates that in short run too energy use is positively and significantly linked to CO_2 emission but the short run energy use elasticity is very low compared to long run elasticity which is not a welcoming situation for Indian economy and pointing out towards inefficient energy systems in India.

The results may indicate excessive use of non-renewable energy sources or consumption in long run mainly fossil fuel-based energy use which is resulting in higher GDP or income elasticity of CO_2 emission in long run compared to short run. Here it is very important to mention that higher income elasticities of CO_2 emission both in short and long run must be achieved in order to nullify or at least maintain the negative environmental effects (carbon footprints).

The adjustment term (ECT_{t-1}) indicates that the errors of the previous periods will be corrected in current period which is negative and significant at 1 percent level of significance. The adjustment speed, which is -0.65, is therefore highly statistically significant and points to a reasonably swift rate of adjustment back to the long-run equilibrium. According to the outcome, the long-term CO2 emission route is deviated from by 65.0 percent over the ensuing year, which is significant at a 1 percent level.

Table 5: Diagnostic tests

Diagnostic test	DW statistics	B-G LM test (1)	White test	J-B Normality test
Result	1.884002	0.000 (0.9998)	30.16 (0.3070)	0.3351 (0.8457)

Note: Figures in parentheses are corresponding p values.

The specified ARDL model satisfies all diagnostic tests and results have been shown in table 5. Firstly, the DW statistic of 1.88 implies that there is no autocorrelation in the residuals, which is supported by Breusch-Godfrey LM test (p>0.05) and indicate no serial correlation and lastly, white test for heteroskedasticity, and Jarque Bera normality test indicate the absence of heteroscedasticity and non-normality in the model.

Further CUSUM and CUSUMsq tests have been applied to check the stability of specified ARDL model (Fig 1). It can be seen from Fig 1 that both CUSUM and CUSUMsq are between upper and lower critical bound of 5.0 percent level of significance and hence we conclude that our specified ARDL model and estimates are stable.

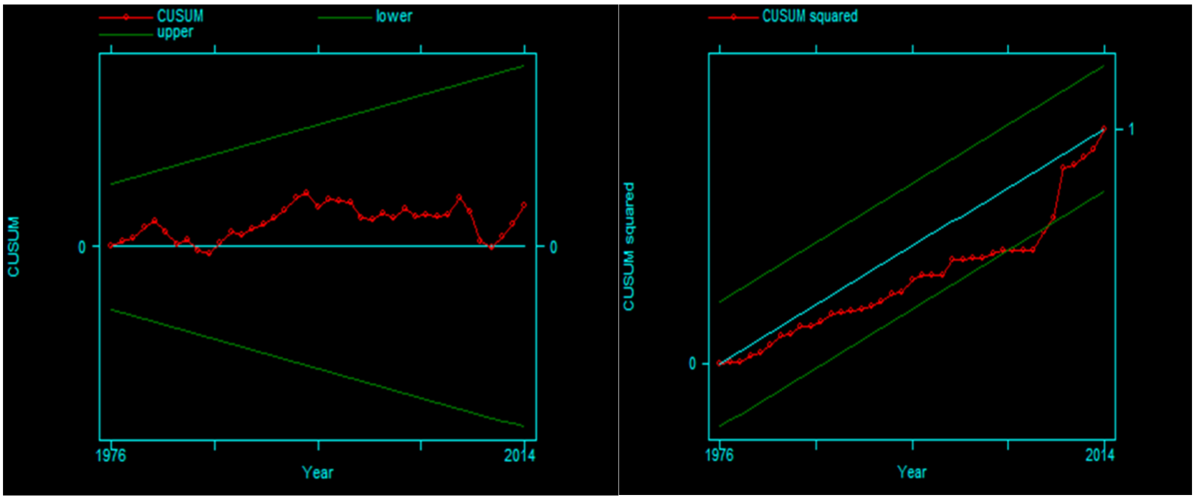

Figure 1: Plot of cumulative sum of recursive residuals and cumulative sum of squares of recursive residuals (at 5% significance).

Table 6: VAR Granger Causality/Block Exogeneity Wald Test Results (Specification 1)

	Lags (2)		
Dependent Variable	**Independent Variable**	**Df**	χ^2
	Δln (GDP)	1	0.09339
Δln (CO_2)	Δln (SQGDP)	2	566.98***
	Δln (EU)	2	0.11775
	All	5	8965.9***
	Δln (CO_2)	2	5.4631
Δln (GDP)	Δln (SQGDP)	2	97.674***
	Δln (EU)	2	10.78**
	All	6	131.35***
	Δln (CO_2)	2	5.714
Δln (SQGDP)	Δln (GDP)	1	6.2344*
	Δln (EU)	2	11.315**
	All	5	16.614***
Δln (EU)	Δln (CO_2)	2	7.617*
	Δln (GDP)	1	1.9378
	Δln (SQGDP)	2	1099.9***
	All	5	8384.7***

Note: *, **, and *** denote 5%, 1% and 0.1% level of significance, respectively.

Granger causality test results indicate economic growth and energy use do not granger cause CO_2 emission but the combined effect of economic growth (GDP), square of GDP and energy use do granger cause CO_2 emission. There is unidirectional causality between CO_2 emission and GDP running from CO_2 emission to GDP (economic growth). Similarly, energy use or consumption granger cause GDP or income suggesting increased demand of energy leads to economic growth. The study also finds unidirectional causality between CO_2 emission and energy use or consumption running from CO_2 emission to energy use or consumption and bi-directional causality between square of GDP and energy use or consumption which get supports from earlier studies like [73, 74] and [75].

5. Conclusion and policy implications

The study makes use of data from the WDI database from 1971 to 2014 on a few chosen metrics to look for any indication of EKC for the Indian economy. According to the study's ARDL model, an EKC exists for the Indian economy. We apply the relevant econometric methodologies to our model, which uses GDP, GDP^2, and energy consumption as regressors and CO_2 emission as a regressand. The analysis starts by looking for unit roots in the data. All variables are integrated of order one according to the ADF and PP test, which indicates that all variables have unit roots at all levels but that the first difference of all variables is stationary. Additionally, the study used the ARDL bounds test and the Johansen co-integration test to look into any co-integration among the variables. The tests conclude that all the variables in the system are co-integrated and there is only one co-integrating equation in system.

Both the long run and short run ARDL estimates of GDP and square of GDP points out towards an EKC in India. However, the short run GDP or income elasticity of CO_2 emission is somewhat less than that of the long run income elasticity. The positive coefficient of GDP and negative coefficient of GDP^2 illustrates that India is following the inverted U shaped EKC where in first environmental degradation will be increasing with increased national income and afterwards it (environmental degradation) will start decreasing with increased income effect and use of other renewable resources for consumption and production. However, the positive and significant coefficient of energy use or consumption illustrates that in future with increased demand for energy CO_2 emission will be increasing steadily. Further, after reaching threshold income level, increased income effect may overcome energy consumption effect and CO_2 emission may start decreasing from a threshold upper level. The results indicate towards policy implications in advancing sustainable energy sources in India because energy demand will increase over the years. National income must increase rapidly to overcome the issue of excessive emission because more resources and funding would be needing to remove carbon footprint.

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Appendix

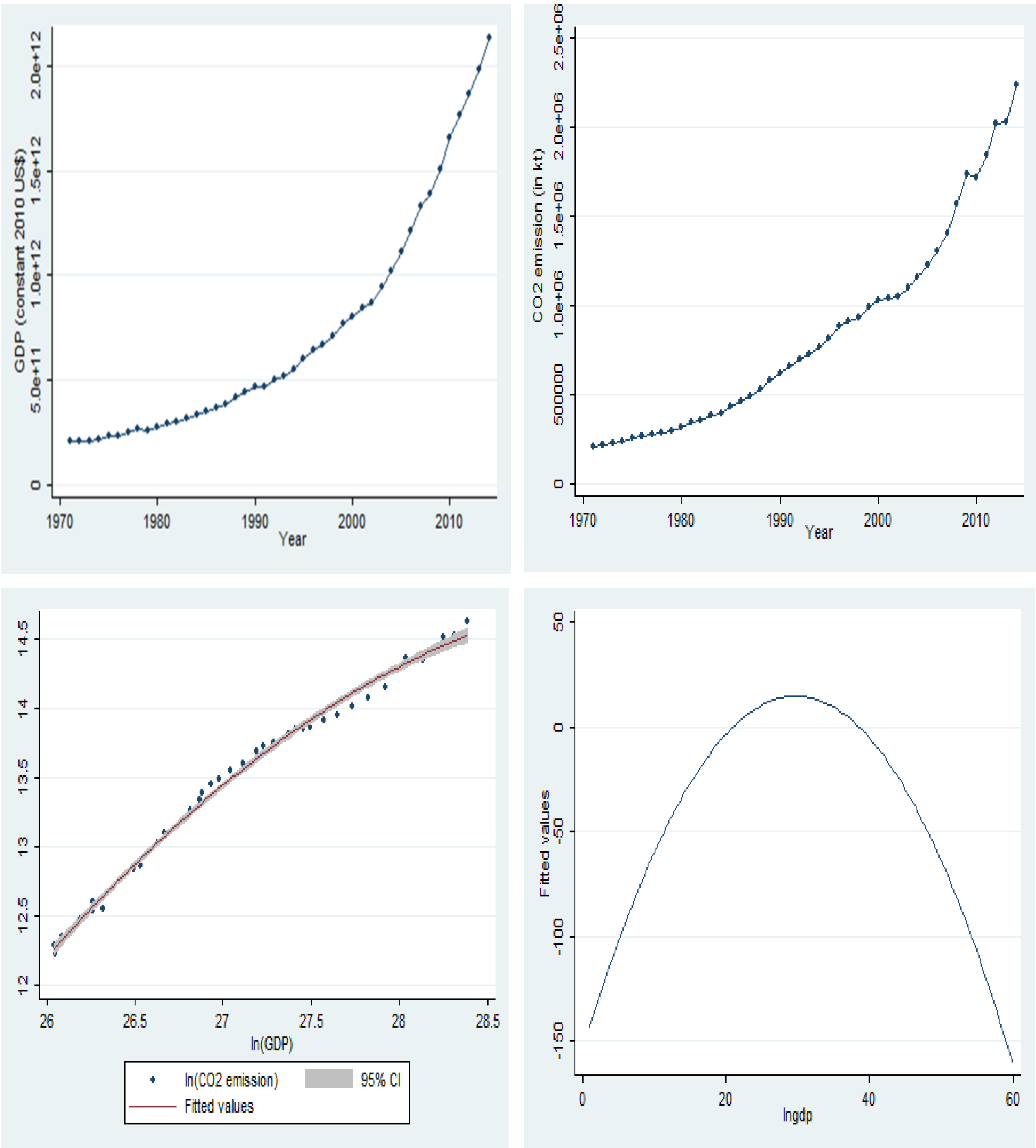

Figure A1: Plots of the data series and fitted and predicted values