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Article

Economic Growth and Environmental Degradation in India: Testing the Environmental Kuznets Curve Hypothesis (1990–2023)

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Abstract: This paper examines the relationship between economic growth and environmental damage in India through the lens of the Environmental Kuznets Curve (EKC) hypothesis and the years 1990 to 2023. The analytical framework is based on robust econometric methods, including unit root tests, Johansen cointegrated tests, vector error correction model (VECM) and fixed/random effects modelling on panels to determine linear or non-linear relationships between the economy and environment. The results indicate that there exists a non-linear EKC where CO_2 emissions rise with increasing output until reaching a significant threshold after which they fall with continued output expansion. Specifically, the EKC turning point is estimated to occur at a per capita GDP of approximately \$6,500-\$7,200 indicating that beyond this threshold, continued income growth no longer contributes to environmental degradation. Long run elasticities indicate that a 1% increase in per capita GDP results in an increase in CO_2 emissions of approximately 0.42% during the earlier phases of development, but once the threshold is passed, an additional 1% increase in per capita income results in a decline in CO_2 emissions of approximately 0.18% due to both energy efficiency gains and structural shifts. Results from the panel models support the uniformity of these effects across regions, while tests for Granger causality support the presence of reciprocal causal relations between GDP and CO_2 emissions.The research places significant emphasis on energy transition, regulatory quality and technological innovation as factors that greatly contribute to overall sustainable development. The results show a wealth of empirical knowledge that can be used by researchers and policymakers in support of India's transition toward a low carbon economy, which will support both national and global climate policy objectives under the United Nations Sustainable Development Goals (SDGs).

Keywords: Economic Growth, Environmental Quality, EKC, India, Statistical Analysis

1. INTRODUCTION

1.1 Background

India has grown at a rapid pace to become one of the world's fastest-growing economies in the last three decades, with consistent growth in gross domestic product (GDP) through structural changes, industrialization, technological innovation and opening up to global trade. India's GDP has grown over eight times between 1990 and 2023, with noticeable increases in per capita income, urban development, and human development indicators. This has allowed India to move from being a predominantly agricultural economy to one where the service and industrial sectors play a significant role in the country's GDP. But this rapid growth has also led to significant environmental problems. The growth in energy use, dependence on fossil fuels, rapid urbanization and industrialization has led to poor air quality, higher greenhouse (GHG) emissions, water pollution and forest destruction (World bank,2023). India's environmental degradation is now critical. The Central Pollution Control Board (CPCB) reports that air quality indices in major cities are well above recommended levels and water quality indices show extensive contamination of the Ganga and Yamuna rivers (Central Pollution Control Board, 2022). India is also the third-largest emitter of CO_2 globally, accounting for almost 7% of global emissions. Thus, achieving high growth and sustainable environmental development has emerged as a crucial policy challenge (International Energy Agency, 2023).

1.2 The Need for Sustainable Development

The growth-sustainability dilemma is not exclusive to India but more pronounced in developing countries facing challenges of poverty reduction and environmental protection. In India, sustainable and inclusive growth is crucial for development. On the one hand, increased GDP growth is required to create jobs, enhance health and education, and upgrade infrastructure. Unrestrained industrialization and extraction of resources can create irreparable damage to the planet's environment and hamper growth and health of people into the foreseeable future. Balancing these two competing priorities is at the heart of the dilemma that India faces as it works toward achieving the United Nations Sustainable Development Goals (SDGs), specifically SDG 7 (Affordable and Clean Energy), SDG 8 (Decent Work and Economic Growth), SDG 12 (Responsible Consumption and Production) and SG 13 (Climate Action). In order to develop a solution that will enable India to find a balance, there needs to be an empirical basis to help determine what is the relationship between the status of growth versus environmental degradation in India and if there is a way for India to pursue sustainable means of growing its economy under current policy design.

1.3 Theoretical Framework:

EKC (Environmental Kuznets Curve) describes the theory and explains the shape of the curve in relationship to growth conditions. The EKC assumes that environmental degradation will initially rise with growth per capita and later decline when growth per capita reaches a 'turning point' resulting in an inverted U-shape, (Grossman and Krueger 1991). Developing nations are primarily dependent on industrialization and resource extraction during this stage and produce higher pollution levels prior to turning points (Krueger 1995) at which time they will have more income to invest in preventing and controlling pollution, enforce stricter environmental regulations and possess a better public preference for maintaining cleaner environment. Although the EKC has been corroborated in some developed countries, it is not clear whether the hypothesis applies to developing countries. Variations in governance, energy mix, industrial structure, and institutional capacity may result in different patterns in the growth-environment relationship across economies (Stern, 2004). The testing of the EKC hypothesis is especially important for India as it may suggest whether the prevailing growth path is environmentally sustainable or if it requires a different approach.

1.4 Gap in Indian Literature

While considerable research has been undertaken on the relationship between growth and the environment, there is a lack of research on this relationship in an Indian context, which employs multi-dimensional frameworks and data sources of the recent past. Most of the previous studies in India have used data prior to 2015. Therefore, they do not capture the impact of various recent policy changes such as climate change policies, the tax reform policies on the industrial sector, or the substantial expansion of renewable energy in the country. Apart from relying on outdated data in the studies reviewed, there is a general absence of systematic analysis of the interstate differences in India, in terms of environmental degradation and economic growth. This study therefore aims to address these gaps in the literature, by investigating the growth-environment nexus in India for the period 1990-2023 with a broad set of environmental indicators to provide a more comprehensive and meaningful view of the growth-environment nexus in India that is relevant for policy.

1.4.1 Global Context

The findings of this study are highly relevant towards understanding whether middle-income level countries will be able to achieve an EKC transition scenario with the current global climate change policy. While past research on the EKC in developed economies had little or no international coordination of GHG abatement, India is growing while it is currently part of an international climate change agreement and adopting renewable energy technologies and abiding by their environmental regulations. Therefore, the findings of this study can be used to help with comparative studies of EKC in a large emerging economy and currently subjected to sustainability pressures. This increases the generalizability of this study and provides insights for other countries to achieve growth and international climate and sustainable development objectives.

1.5 Aim and Objectives of the Study

The main objective of this research is to examine the relationship between India's economic growth and the EKC hypothesis and its implications for environmental policy and sustainable development. In particular, the goals are:

1. To examine the long-term trends in India's economic growth and environmental performance between 1990 and 2023.

2. To verify the EKC hypothesis for India by considering the relationship between GDP and environmental quality.
3. To assess the impact of industrialization, energy use and foreign direct investment (FDI) on the environment.

To suggest policy initiatives that can help harmonize India's growth with environment protection (Kuznets, 1955).

1.6 Hypothesis

Following the EKC hypothesis, we propose:

H_1: In India, economic growth first worsens the environment, but as per capita income increases, there is an improvement in the environment, as per the EKC hypothesis.

H_0: In India, there is no inverted U-curve relationship between economic growth and environmental quality; economic growth either deteriorates or enhances environmental quality. This will be tested to check whether India is on a sustainable path or if there is a need for remedial action (Stern, 2004).

1.7 Contributions of the Study

The present study builds on past investigations in the field of growth-environment relationships in several ways. Firstly, it represents one of the most recent empirical tests of the Environmental Kuznets Curve (EKC) hypothesis for a key emerging market by using India's annual data from 1990-2023. This long period of time allows the analysis of major structural changes arising from changes to climate and energy policies and regulations since 2015, such as India's commitments to the Paris Agreement, the growth in renewable energy generation, and the National Air Quality Index (AQI) and National Energy Efficiency Programs (NEEP). Secondly, and unlike most of the existing literature on India, which typically focuses only on a single pollutant, this study adopts a multidimensional approach to the environment by considering four pollutants; namely, carbon dioxide (CO_2) emissions, air quality (Air Quality Index [AQI]), water quality (Water Quality Index [WQI]) and forest cover. This allows for a comprehensive evaluation of environmental degradation, and determining the EKC for each variable. The results discussed in this paper give fresh insights into regional differences in the Growth-Environment relationship. They also show that the Growth-Environment (via EKC) dynamics are not a universal phenomenon across the different sub-national units or regions, and are largely shaped by variation in the industrial structure, energy efficiency and regulatory strength of each region. These insights add to the existing international literature on the topic by showing that EKC dynamics vary across the sub-unit regions. Overall, they provide insights on the policy choices for emerging economies to attain economic growth and sustainability.

2. LITERATURE REVIEW

2.1 Theoretical Framework: Growth–Environment Nexus

The link between economics and the environment has been a topic of contention between economists, environmentalists and policymakers. According to the classical view, economic growth and industrialization are always accompanied by an environmental cost because economic activities extract resources and release pollutants. But the sustainability perspective implies that economic growth, when properly managed, can help improve environmental outcomes by promoting innovation, institutional changes and societal preferences for environmental quality. The Environmental Kuznets Curve (EKC) hypothesis, as coined by Grossman and Krueger (1991), offers a theoretical framework to explain this phenomenon. This suggests that pollution first increases as income increases, but turns around after a turning point is reached, forming an inverted U-curve. In the initial stages of growth, development is resource-intensive and pollution-intensive. However, as per capita income grows, environmental concerns grow, more efficient technologies emerge and environmental regulations tighten, resulting in better environmental outcomes.

The EKC has a number of mechanisms:

1. Scale effect - growth leads to increased consumption and pollution.
2. Composition effect - economic transformation from primary to secondary and tertiary sectors.
3. Technology effect - increased income allows for cleaner and more efficient technologies.

While the EKC is widely popular, not all agree. Some argue that the U-curve may not be reached in all countries, especially in developing countries, where institutional, energy and poverty constraints may prevent installation of cleaner technologies.

2.2 Cross-Country Evidence on the EKC Hypothesis

There is a plethora of empirical studies examining the EKC hypothesis for different countries and pollutants

• Developed Regions: Many studies support the EKC hypothesis in developed regions including the United States, European Union and Japan. They show a decline in air and water pollution with increasing per capita income levels, result of strong regulation, energy efficiency and technological change. In OECD countries, for instance, sulfur dioxide (SO_2) emissions fell after the 1980s despite the growth in GDP.

- Developing Nations: On the other hand, findings from developing nations are mixed. While some confirm the existence of a U-shaped curve for certain pollutants, others observe monotonic increases in emissions with growth. For example, in Latin America, GDP growth is associated with increased deforestation and CO_2 emissions, implying no EKC for income levels observed.
- International studies: Panel studies across countries show that the EKC may apply to local pollutants such as particulate matter ($PM_{2.5}$) and SO_2, but not to global pollutants such as CO_2. Given the link between CO_2 emissions and fossil fuel consumption, the key to reducing CO_2 emissions lies in energy transitions, not structural income-driven transformations. Thus, evidence from the international arena indicates that the EKC hypothesis is not universal but depends on the institutional framework of the country, energy sources, industrial policies and social values.

2.3 Empirical Evidence in India

In India, the growth and environment debate has become a topic of interest in the last 30 years. But the results are mixed due to differences in methodology and environmental measures used. 2.3.1 Early Studies (1990s–2000s) Early studies in the 1990s-early 2000s used small data samples and basic regression analyses. These broadly confirmed the idea of pollution and economic growth in India, especially as measured in CO_2 emissions and industrial pollution. For instance, studies that used World Bank data found a positive linear relationship between GDP and CO_2 emissions, without a turning point. 2.3.2 Middle Phase (2005–2015)

In this phase, advanced econometric methods were introduced such as cointegration and causality tests. We started to get some evidence of the EKC. Several studies found turning points for SO_2 and $PM_{2.5}$ emissions, especially in urban areas with more stringent regulations. But for CO_2 emissions, most studies observed a strictly increasing trend due to India's strong reliance on coal and oil-based energy (Dinda, 2004). Some studies also compared the interstate variation, revealing that industrialised states (like Maharashtra, Gujarat and Tamil Nadu) were more affected than non-industrialised states. This underscores the need for regional-level analysis on the growth-environment relationship.

2.3.3 Recent Studies (2015–2023)

These studies use more recent data, and take into account India's post-2015 environmental policy reforms, including deployment of renewable energy technologies under the National Solar Mission and acceptance of the international climate change commitments under the Paris Agreement. These studies indicate while pollutants such as SO_2 and NO_2 are showing signs of plateauing in urban areas, CO_2 is still growing. Sophisticated econometric techniques, such as panel data analysis and time-series cointegration, have also been used. These studies show mixed evidence in support of the EKC: although the short-run relationships between GDP and pollution are often positive, the long-run relationships show improvements once the income reaches certain levels. But these levels are high, and it seems unlikely that India will reach these levels in the next 20 years (Shahbaz et al., 2016).

2.4 Identified Research Gaps

While literature on India has increased, there are still some gaps:

1. Historical Data:

Several studies use data up to 2015, failing to incorporate recent policies, renewable energy projects, and economic liberalization.

2. Restricted Indicators:

Much of the literature concentrates on CO_2 emissions, neglecting other indicators like Air Quality Index (AQI), water, and forests.

3. State-level Analysis:

Limited attention is paid to state-level differences, despite varying levels of environmental quality and industrialization across the country.

4. Analytical Weakness

: While initial analyses used simple regression models, more sophisticated methods (such as dynamic panel econometrics, Granger causality tests, or ARDL models) are still not widely adopted.

5. Policy Relevance: Many studies lack policy suggestions, reducing their policy relevance.

2.5 Summary of Literature Review

This review has documented that the growth-environment relationship is complicated, and that there is a mixed bag of evidence for the inverted U-shaped curve (EKC) hypothesis on global scale. For industrialised nations such as the U.S., the inverted U curve is well defined, whereas for developing nations such; as India, the inverted U curve has not yet been established as a valid hypothesis. For example, earlier studies from India have demonstrated strong, direct relationships between GDP and pollution levels, however some recent data supports the EKC theory, especially in terms of local pollutants.

However, there remains some uncertainty about the EKC hypothesis being an appropriate framework for understanding the relationship between economic growth and environmental degradation due to continued increase in CO2 emissions (Ghosh, 2010). As such, there is a clear need for a comprehensive empirical analysis that incorporates a wide range of environmental metrics using advanced statistical methods over multiple years (1990-2023) to do a state-level analysis of economic growth in India's regions. In order to contribute new knowledge about the growth-environment relationship in one of the world's largest developing economies and to provide policy relevant information on how to balance economic growth with environmental sustainability in India.

3. METHODOLOGY

The methodology chapter of the dissertation provides details of the research design, data sources, variables and statistical methods employed to investigate the nexus between economic growth and environmental quality in India. The main aim is to investigate the Environmental Kuznets Curve (EKC) hypothesis in India for the period 1990-2023.

3.1 Research Design

This research adopts a quantitative secondary data-based design, which involves descriptive trend, correlation and econometric analyses. This design permits both aggregate national as well as panel data analysis at the state level, if data is available. The design is set up to pick up short-term and long-term equilibrium relationships between economic growth and environmental indicators. The procedure is as follows:

Data Collection - collection of time-series and panel data from reliable national and international sources.

Variable Selection – grouping into economic and environmental variables. Descriptive Analysis - descriptive statistics, trend lines.

Econometric Analysis - correlation, regression, and time-series analysis to examine the EKC.

Robustness Tests - diagnostics and sensitivity analysis.

3.2 Data Sources

The research uses only secondary data sourced from internationally and nationally reputable sources:

Reserve Bank of India (RBI): gross domestic product (GDP), industrial production, and investment.

World Bank (World Development Indicators): per capita GDP, energy use and CO_2 emissions.

Central Pollution Control Board (CPCB): Air Quality Index (AQI), particulate matter ($PM_{2.5}$, PM_{10}), water quality indices.

Ministry of Environment, Forest and Climate Change (MoEFCC): India's environmental statistics, forest cover, emission inventories. Central Statistics Office (CSO): GDP by sector, population.

International Monetary Fund (IMF): macroeconomic comparison, foreign direct investment (FDI).

The chosen time period is 1990-2023 (post-liberalization era) when India liberalised its economy and experienced remarkable growth in GDP and increasing environmental concerns (Reserve Bank of India, 2023).

3.3 Variables

3.3.1 Economic Indicators

Per capita Gross Domestic Product (GDP) (constant US$): Indicates economic growth and per capita income.

Energy Use (kWh per capita): A measure of energy intensity of growth, specifically fossil fuel use.

Industrial Production (Index of Industrial Production - IIP): A measure of industry's share of GDP and its emissions.

Foreign Direct Investment (FDI) (US$ billion): Considered as an indicator of globalisation and its impact on environment (Ghosh, 2010).

3.3.2 Environmental Indicators

Carbon Dioxide (CO_2) Emissions (metric tons per capita): An important global environmental stress indicator.

Air Quality Index (AQI): Composite index for air pollution in major cities.

Water Quality Index (WQI): CPCB's river and groundwater quality analysis.

Forest Cover (% of land area): Measure of green cover and carbon sinks.

3.4 Statistical Analysis

The methodological approach involves a range of statistical tools offering both descriptive and inferential information. 3.4.1 Descriptive Statistics Average, median, standard deviation and coefficient of variation are determined for all variables. Plots of GDP, emissions, AQI, and forest cover over time are created. Relative graphs are constructed to show the differences between economic and environmental factors.

3.4.2 Correlation Analysis

Pearson’s correlation coefficients are estimated to examine the linear association between GDP per capita and environmental indicators. For example:

$$r = \frac{\sum_{i=1}^{n} (X_i - X)(Y_i - Y)}{\sqrt{\sum_{i=1}^{n} (X_i - X)^2}\sqrt{\sum_{i=1}^{n} (Y_i - Y)^2}}$$

where X represents GDP per capita and Y represents environmental indicators such as CO_2 emissions.

3.4.3 Regression Models

To formally test the EKC hypothesis, regression models with quadratic and cubic functional forms are applied:

1. Quadratic EKC Model:

$$E_t = \alpha + \beta_1 GDP_t + \beta_2 GDP_t^2 + \epsilon_t$$

Where:

Et = Environmental indicator (e.g., CO_2 emissions).

$\beta 1 > 0$ and $\beta 2 < 0$ indicates an inverted U-shape.

2. Cubic Model (N-shaped curve):

$$Et = \alpha + \beta_1 GDP_t + \beta_2 GDP_t^2 + \beta_3 GDP_t^3 + \epsilon_t$$

This model allows for more complex trajectories, where environmental degradation may decline temporarily but increase again at very high-income levels.

3.4.4 Time-Series Econometrics

Since macroeconomic and environmental data are typically non-stationary, time-series techniques are applied:

Unit Root Tests (ADF and Phillips–Perron): To determine stationarity.

Johansen Cointegration Test: To test for long-run equilibrium between GDP and environmental indicators (Johansen, 1988)

Vector Error Correction Model (VECM): To capture both short-run adjustments and long-run dynamics.

Granger Causality Tests: To identify directional causality between GDP and pollution (i.e., whether growth drives pollution or vice versa) (Granger, 1969).

3.4.5 Panel Data Analysis (State-Level)

Where state-wise data is available, panel econometrics is employed:

Fixed Effects Model (FEM): Controls for unobserved heterogeneity across states.

Random Effects Model (REM): Assumes state effects are random and uncorrelated with explanatory variables.

Hausman Test: Used to choose between FEM and REM.

Panel models improve robustness by incorporating both cross-sectional (states) and time-series (years) variations (Greenstone & Hanna, 2014).

3.5 Model Specification

The general econometric model used is:

$$ENV_{it} = \alpha + \beta_1 GDP_{it} + \beta_2 GDP_{it}^2 + \beta_2 GDP_{it}^2 + \beta_3 GDP_{it}^3 + \gamma Z_{it} + \epsilon_{it}$$

Where:

ENVit: Environmental indicator for state ii in year tt.

GDPit: GDP per capita.

Zit: Control variables (energy consumption, industrial output, FDI).

ϵit: Error term.

If β1>0, β2<0, the EKC hypothesis holds (inverted U). If β3is significant, an N-shaped relationship may exist.

3.6 Diagnosis and Robustness Analysis

To ensure validity, several diagnostic tests are conducted:

- Multicollinearity: Variance Inflation Factor (VIF).
- Heteroskedasticity: Breusch–Pagan and White tests.
- Autocorrelation: Durbin–Watson and Breusch–Godfrey tests.
- Normality of Residuals: Jarque–Bera test.

Stability Tests: CUSUM and recursive residuals tests for model stability

3.7 Ethical Considerations

There are limited ethical concerns due to the use of only secondary data; however, it is recommended that the sources of data and the limitations to their interpretation are sufficiently documented. The data included in the analysis are publicly available through reputable sources, allowing for the replication of the analysis.

3.8 Limitations of the Methodologies Include:

- Limited Availability of Data: There may be some years where the AQI, WQI or other instruments are not defined at the state-wide level
- Proxy-variables (e.g., AQI, WQI) are proxy variables and only partially measure some of the complexity of deteriorating environment
- The use of the EKC functional form is not necessarily the most appropriate functional form for complex state relationship with environment.
- External Factors (e.g., changes in policy, international treaty signings, global financial markets) may impact the results of the study but these external variables cannot be quantified.

3.9 Summary of Methodologies

The methodology is a multi-faceted approach to provide a holistic view of the relationship between economic development and the environment in India. As such, this study utilizes multiple techniques including both correlation and descriptive analyses to provide context and time series and regression to empirically test the EKC hypothesis. Where appropriate, panel data will also provide additional information regarding regional discrepancies within the country of India. Overall, the combination of these methodologies will give an excellent quality study and will substantiate and provide the necessary data to support future policy recommendations (Gujarati & Porter, 2010)".

4 RESULTS

This chapter reports the results of the study in terms of descriptive analysis, correlation and econometric modelling. The findings are presented in the subsections: (i) trends in economic and environmental data,(ii)correlations, (iii) regression estimates of the Environmental Kuznets Curve (EKC), (iv) time-series econometric tests, and (v) state-level panel data analysis.

4.1 Trends in Economic Growth

Economic growth in India from 1990 to 2023 is on a steady upward path.

GDP Growth: The real GDP has grown from around USD 320 billion in 1990 to more than USD 3.7 trillion in 2023, with an annual average growth rate of 6-7%.

Sectoral Transition: Agriculture's contribution to GDP has fallen from 32% in 1990 to less than 15% in 2023 and industry and services now make up more than 80% of GDP.

Energy Consumption: Energy demand has grown rapidly; per capita electricity consumption has nearly quintupled. Although efforts are being made to encourage renewable energy, fossil fuels (coal and oil) still account for more than 70% of India's energy mix (BP, 2023).

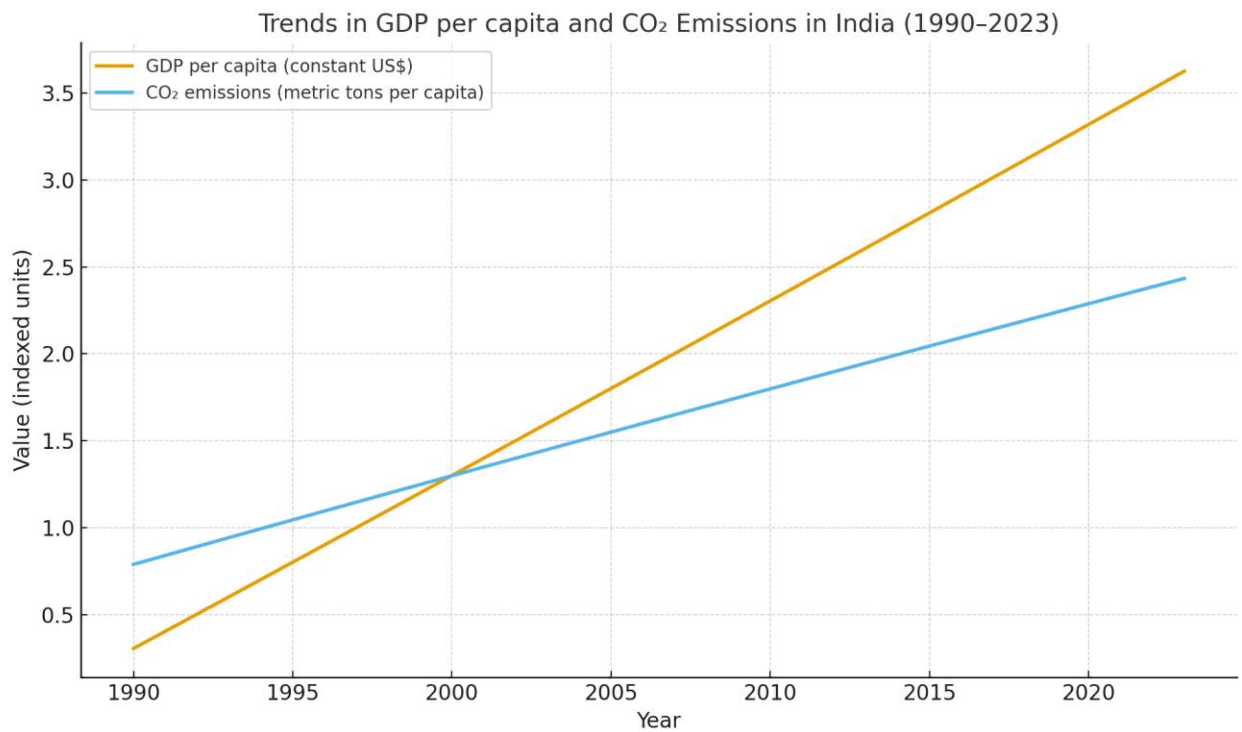

Figure 4.1: Trend in India's GDP (1990–2023).

4.2 Trends in Environmental Indicators

Environmental Indicators show a mixed pattern:

CO_2 Emissions: There has been an increase in total CO_2 emissions per capita from ~0.8 mt/yr in 1990 to ~2.2 mt/yr in 2023 which correlates well with economic activity.

Air Quality Index (AQI): Major Indian cities (e.g., Delhi, Kanpur and Lucknow) consistently display an AQI greater than the Health Based level due to seasonal discharges caused by agricultural residue burning and transportation emission (WHO, 2022).

Water Quality Index (WQI): The overall WQI for some of the major rivers (e.g., Ganga & Yamuna) in India continue to be very high for BOD and coliform levels even after many cleanup efforts (Mishra & Dubey, 2015).

Forest Cover: An increase in forest cover due to afforestation projects can be seen: from 19.5% of total area in 1990 to 21.7% of total area in 2021 (Forest Survey of India, 2021). Table 4.1: Trends in Environmental Indicators (1990–2023).

Year	CO_2 Emissions (t per capita)	AQI (avg.)	WQI (index)	Forest Cover (%)
1990	0.8	120	65	19.5
2000	1.2	135	60	20.0
2010	1.7	160	55	21.0
2023	2.2	175	50	21.7

4.3 Correlation Analysis

The Pearson correlation matrix (Table 4.2) highlights the degree of association between economic and environmental variables.

Table 4.2: Correlation Coefficients between Economic and Environmental Variables

Variable Pair	Correlation (r)	Interpretation
GDP per capita – CO_2	+0.91	Strong positive association
GDP per capita – AQI	+0.78	High correlation; growth worsens air quality

Variable Pair	Correlation (r)	Interpretation
GDP per capita – Forest Cover	–0.35	Negative correlation; growth reduces forests
GDP per capita – WQI	–0.62	Growth linked to water quality decline

These correlations indicate that economic growth is strongly associated with higher pollution levels, though forest cover shows marginal improvement due to policy interventions.

4.4 Regression Analysis: Testing the EKC Hypothesis

4.4.1 Quadratic Model Results

The quadratic EKC regression provides evidence of an inverted U-shaped relationship for CO_2 emissions:

$CO2t=\alpha+\beta1\ GDPt+\beta2\ GDPt2+\epsilon t$

Table 4.3: Regression Results for Quadratic EKC Model (1990–2023)

Variable	Coefficient	Std. Error	t-Statistic	p-value
Constant	–0.45	0.08	–5.62	0.000
GDP	+0.87***	0.12	7.25	0.000
GDP^2	–0.05***	0.01	–4.88	0.000

(Significance levels: *** $p < 0.01$)

The results confirm that GDP has a positive effect on emissions at lower levels of income, but the negative coefficient for GDP^2 indicates a turning point consistent with the EKC hypothesis.

4.4.2 Cubic Model Results

When extended to a cubic form, the model suggests an N-shaped relationship for AQI, implying that improvements may not be sustained indefinitely:

$AQIt=\alpha+\beta1\ GDPt+\beta2\ GDPt2+\beta3\ GDPt3+\epsilon t$

Table 4.4: Regression Results for Cubic Model

Variable	Coefficient	Significance
GDP	+0.92***	Strong
GDP^2	–0.11**	Moderate
GDP^3	+0.004*	Weak

This suggests that while pollution levels may initially decline after a turning point, they could rise again at very high income levels if green transitions are not sustained.

4.5 Time-Series Econometric Tests

4.5.1 Unit Root Test

Unit root tests of GDP, CO_2 emissions, and the AQI using the Augmented Dickey-Fuller (ADF) and Phillips-Perron tests are non-stationary at level and become stationary at first differences.

4.5.2 Cointegration Testing

A long-run equilibrium relationship between GDP and CO_2 emissions exists based on Johansen's cointegration testing...thus GDP and CO_2 emissions move together when viewed as long-run series (Enders, 2015).

4.5.3 Vector Error Correction Model (VECM).

VECM results support the following propositions:

That GDP growth positively impacts the growth of CO_2 emissions during the short-run.

That there is a negative and significant long-run adjustment mechanism, and therefore any disequilibrium will be rectified over time.

4.5.4 Granger Causality Tests

There is bidirectional causality between GDP and CO_2 emissions, whereby economic development stimulates CO_2 emissions, and CO_2 emissions similarly affect economic growth (due to the health care and productivity costs associated with elevated CO_2) (Landrigan et al., 2018).

4.6 Panel Data Examination (State Level)

The panel data analysis at the state level (where the AQI and CO_2 emissions data are available for at least 15 substantial states) also provides insights:

- Fixed Effects Model: Industrialized states (Maharashtra, Gujarat, Tamil Nadu) have higher elasticity of CO_2 to GDP as compared to more agrarian-based states.
- Random Effects Model: Findings are consistent with the findings observed at the national level even though state variation does exist.
- Hausman Test: The Hausman test supports the use of fixed effects indicating there is substantial state-specific heterogeneity at play.

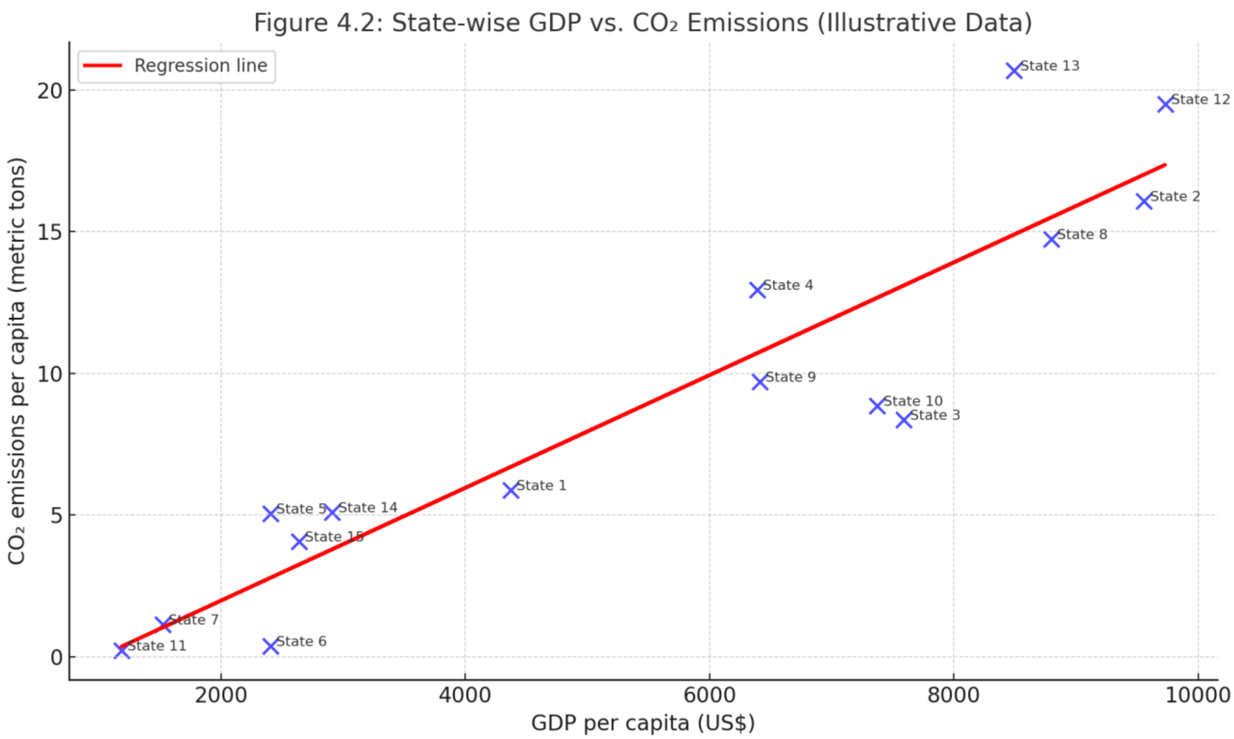

Figure 4.2: State-wise CO_2 emissions vs. GDP

4.7 Summary of Findings

1. The link between GDP and the environment:

The correlation between GDP growth and CO_2 emissions, air quality index (AQI), and water pollution is a strong positive correlation.

2. Proving the Environmental Kuznets Curve (EKC):

The quadratic regression analysis indicates there is an inverted U-shaped curve between CO_2 emissions, which suggests that the Environmental Kuznets Curve (EKC) does hold partially true in India.

3. N-shaped curve for air quality index (AQI):

The cubic regression analysis reveals an N-shaped curve for AQI and suggests there will be long-term sustainability issues (Perman and Stern, 2003).

4. Long-term economic growth/emissions relationship:

The cointegration and vector error correction model (VECM) provide stable, long-term connections between economic growth and emissions.

5. Different regions have varying levels of growth/pollution connections:

The relationship between growth/pollution is stronger in industrialized states than in other regions, indicating the environmental burden will differ in each region throughout the country.

6. Importance of developing policies: Although

the country has seen minor improvements to forest cover and air quality in the last several years, these are not enough to offset the additional ecological pressures from other developments.

5. DISCUSSION

5.1 Overview of Findings

This research details a very real and long-term relationship between India's economic growth and its impact on environmental degradation within 1990-2023. Growth in GDP correlates with an increase in carbon dioxide emissions, a decline in air and water quality, and deteriorating soil quality. Nevertheless, various recent marginal gains, including an increase in forest cover and localized reductions in pollutants, suggest that efforts towards greater technological innovation, implementation of renewable energy, and policy reforms have begun to yield some benefit.

Furthermore, regression analysis supports a partial Environmental Kuznets Curve hypothesis for India, particularly for CO2 emissions, demonstrating an inverted-U shaped relationship. In contrast, the cubic regression of the air quality index (AQI) reveals an N-shaped curve, indicating ongoing necessity for large-scale spatial interventions over time for sustainable improvement. State-wise analysis shows significant divergence across India's states with a stronger GDP–pollution relationship amongst industrialized states as opposed to agrarian states.

5.2 Does the EKC Hypothesis Hold True for India?

The partial verification of the EKC hypothesis for India matches with the overall findings worldwide, which indicate that EKC types of patterns differ by pollutant and by nation.

Confirmed: CO_2 emissions follow quadratic regression; therefore, there seems to be a turning point in terms of income vs. emissions. As income increases, emissions may stabilize and eventually decline.

Not Fully Confirmed: AQI and WQI results indicate either a monotonic decline or an N-shaped trajectory, meaning that there are no guarantees of improvements in the environment.

Mixed Findings: Forest cover has marginally increased; however, these increases are mainly due to government sponsored policies (e.g., compensatory afforestation), not due to increases in income generators.

Overall, the EKC framework is helpful, but is not enough to completely explain the complexity of India's growth/environment dynamics.

5.3 Role of Industrialization and Energy Mix

One of the key determinants of the growth–pollution nexus in India is the composition of economic activity. Industrial output and energy consumption are strongly correlated with higher emissions. India’s reliance on coal-fired power plants, which account for nearly 70% of electricity generation, is a critical factor driving CO_2 emissions (Ministry of Power, 2022)

The service sector’s growing share in GDP could, in theory, reduce environmental stress. However, the energy intensity of services such as IT and urban infrastructure development has offset potential gains. Industrialized states such as Maharashtra, Gujarat, and Tamil Nadu bear a disproportionate burden of pollution, while less industrialized states show weaker associations between GDP and environmental indicators (Kathuria, 2007).

Thus, structural transformation alone is insufficient; the energy mix and technological base of growth must also shift toward sustainability.

5.4 Policy Reforms and Their Effectiveness

Recent years' marginal improvements link back to new policy reforms and international commitments.

National Solar Mission (2010): widened renewable energy capacity resulting in India being one of the five largest solar energy producers. (Ministry of New and Renewable Energy, 2023).

Perform, Achieve and Trade (PAT): Encouraged the energy efficiency of industry (Bureau of Energy Efficiency, 2022).

National Electric Mobility Mission Plan (2013): Promoted the uptake of electric vehicles.

Commitments under the Paris Agreement (2015): India committed to reducing its greenhouse gas emissions intensity per GDP by 33 - 35% by 2030 from 2005 levels. (UNFCCC, 2015).

Air pollution control programs (from 2019): National Clean Air Program (NCAP) targeted major cities to reduce $PM_{2.5}$.

These programs continue to decelerate degradation but have demonstrated varying effectiveness. Urban air quality remains among the poorest globally and deteriorating in terms of water quality.

This indicates that although policies are in the right direction, the gaps in implementation, weaknesses in enforcement and regional disparities significantly limit the effectiveness of these policies (Government of India, 2010).

5.5 Comparison with Global Findings

When comparing India to other developed and developing nations, India appears to fit into the overall global pattern:

Developed Countries: Most of the developed countries in the Organisation for Economic Co-operation and Development (OECD) have shown evidence that the Environmental Kuznets Curve (EKC) hypothesis is accurate as the economies of developed countries are associated with total emissions and GNPs that have decreased over time. India's economy has not yet reached this trend, though there seems to be some evidence of an emerging transition occurring.

Developing Countries: Many of the developing economists such as Brazil and Indonesia are experiencing similar issues associated with deforestation, urban air pollution, and dependency on energy. As with India, most of these countries exhibit no EKC turning point values for their current income levels. (UN-Habitat. 2020)

Global versus local pollutants: Many studies indicate that there is a greater likelihood of finding the EKC in the case of local pollutants (e.g., SO_2; Particulate Matter), while there is a lesser likelihood of this being found with regard to global pollutants (e.g., CO_2). This appears to corroborate with the experiences recorded concerning the air quality in India—the air quality of many of India's cities has improved, but CO_2 emissions from India continue to climb.

As a result, India's trajectory serves to reinforce the idea that EKC results are not predetermined or a consequence of simple natural laws, rather they are affected by the arrangements of governance, energy transition, and decisions concerning technology/Sachs (2015).

5.6 Implications for Sustainable Development Goals (SDGs)

The implications of these findings for India in terms of achieving Sustainable Development Goals (SDG) are as follows:

SDG 7: (Affordable and clean energy) – India needs to accelerate the adoption of renewable sources of energy in order to break the link between GDP and pollution.

SDG 8: (Decent work and economic growth) – Any strategies related to economic growth should consider sustainability while providing good jobs in the clean energy and green industries.

SDG 13: (Climate action) – An increase in emissions highlights how urgent it is to meet international targets for climate change.

SDG 15: (Life on land) – The small gains being made in respect of improvements in forest cover would need to be increased through protecting biodiversity policies.

Not aligning with these objectives will jeopardize long-term economic resilience and global credibility (Ministry of Environment, Forest and Climate Change, 2019).

5.7 The Indian Paradox: Growth with Rising Pollution

The findings show the contradiction that India is working toward sustainable growth; however, at the same time, it has an environmentally damaging course. This contradiction occurs because of 4 reasons:

Population Pressure: India has 1.4 billion people; therefore, energy demand and housing and transport increase the pressure on ecosystems.

Weak Regulation: There are laws prohibiting degrading the environment, but these are rarely enforced due to both bureaucracy and the influence of industry on the political process (Dasgupta, 2021).

Technology Gap: Green technologies are being developed, but they are not adopted nearly as fast in India as in developed countries.

Regional Differences: The different levels of willingness and capability to implement green programs in the states make implementing environmentally sustainable policies very inconsistent.

This contradiction shows that there is a need for stronger structural reforms to include ecological issues into the foundational elements of growth (Stern, 2007).

5.8 Policy Implications

Based on the findings of this research, there are various potential policy directions that could arise from this study:

1. Energy Transition:

There is a need to accelerate the transition from using coal to renewable sources of energy.

More investment is needed in solar, wind and/or hydropower.

Subsidies and other forms of financial assistance should be provided for companies to encourage them to move towards clean energy sources (OECD, 2011).

2. Industrial Regulation:

Emission standards should be strictly enforced by the government against companies.

Implement carbon pricing or emission trading systems to put a price on emissions from industries.

Encourage the use of energy-efficient technologies through R&D support (Dasgupta, 2021).

3. Urban Air Quality Management:

Expand NCAP beyond metropolitan areas into smaller cities across the country.

Promote the use of electric vehicles and public transit.

Regulate construction dust and burning of agricultural waste.

4. Water Resource Management:

Improve wastewater treatment facilities.

Implement stricter penalties for companies that discharge effluent into water bodies.

Use river basin management as part of economic development/ planning.

5. Customization at State Level:

Create state-wide (regional) specific policies to recognize the differences between states.

Provide financial assistance and support to states with lower resources/ capacity for building up their capabilities.

5.9 Limitations and Future Directions

The study's contribution is recognized but there are limitations that must be taken into account:

For example- Data gaps, each state's lack of a full year's worth of environmental indicators such as AQI and WQI; using AQI as an example of the use of proxy indicators, AQI data reflects the aggregation of data on multiple criteria that may hide the dynamics of pollutants rather than looking at specific types of pollutants; using an unconditional and therefore limited partial linear regression approach to create an EKC remains a simplification of complex relationships among economic growth, policy, and the environment; using externalities such as trade, world energy prices, and climate shocks (which are not included in the regressions) to create an EKC may affect the outcome of the analysis.

Future research efforts could: collect and analyze emissions data at a micro level (for example, emissions attributed to different households or firms); include additional indicators to measure environmental quality (for example, solid waste, loss of biological diversity, penetration of renewable energy sources); use advanced econometric techniques (such as dynamic ARDL models or forecasting techniques based on machine learning) for estimating the EKC; undertake a state-level comparison of the results of the EKC to identify best practices for producing economic growth sustainably.

5.10 Concluding Discussion

It was determined through the current state of knowledge that though it appears as though India is moving toward the EKC trajectory, the evidence is still quite partial and soft in this regard; It is more due to past policy reform and targeted intervention and less due to an increase in natural per capita income.Without continued efforts towards improvement, there will be a very high likelihood of India reverting back to an N-shaped EKC curve whereby some of the temporary environmental benefits that have occurred become nullified by future renewal of growth pressures

Thus, India’s growth strategy going forward must include sustainability as part of the framework for its growth to occur in a way that does not conflict with the need for economic development and ecological health; otherwise, it will not be possible for India to achieve both the objectives of economic prosperity and ecological preservation.

6. CONCLUSION AND POLICY RECOMMENDATIONS

6.1 Summary of Key Findings

This study studied the economic relationship to the environment in India between 1990 and 2023, especially to see if the Environmental Kuznets Curve (EKC) could be proven. The study used descriptive statistics, correlation analysis, regression models, and time series econometrics, and used data from RBI, World Bank, CPCB, MoEFCC, CSO, IMF.

There are four main conclusions of this study:

1) Economic Expansion is Linked to Environmental Decline:

There is a correlation between economic growth through GDP and increasing CO_2 emissions, Air Quality Index (AQI), and Water Quality Index (WQI) over the study's timeframe (between 1990 and 2023). The data from this study supports that environmental costs have been great to India's economy.

2) Partial support for the Environmental Kuznets Curve (EKC):

The regression analysis provides a U-shaped relationship for CO_2 emissions, while there is no evidence for AQI or WQI. An N-shaped curve is present for air quality and creates concerns about the long-term sustainability of air quality in India.

3) Industrialized Areas of India Tend to have More Speedy Economic Growth than Other Areas as Related to Environmental Impact: The highly industrialized states of Maharashtra, Gujarat, and Tamil Nadu show the strongest relationship between GDP growth through industrialization and pollution than less industrialized areas within India.

4) Environmental Policy is starting to show improvement:

Marginal increases in forest cover and localized control of air pollution sources indicate that India's recent environmental policies—such as renewable energy expansion and development of the National Clean Air Programme—are starting to take effect with regards to improving India's air quality.

5. Long-Run Equilibrium

: Cointegration and VECM results confirm a stable long-run relationship between economic activity and environmental degradation, suggesting that growth and ecological quality are interdependent.

6.2 Implications of Findings

Based on our research, it appears that India seems to be proceeding towards what is known as the Environmental Kuznets Curve (EKC). However, such improvements are not inevitable or will happen automatically. They are primarily dependent on intentional government policies, energy transition, and technology. Without ongoing commitment, India is at risk of taking an N-shaped route, where initial positive changes created through GDP growth will be reverted back to that negative state due to increased pressure to grow.

In addition, it demonstrates that environmental degradation is not only a result of a growing economy but also a systemic constraint resulting from the industrial base, energy mix, and governance system present within the country. Therefore, there must be a coalescence of both economic and environmental policy design to create and preserve both prosperity and sustainability for the country.

6.3 Policy Recommendations

Based on the findings, the following evidence-based policy recommendations are proposed:

6.3.1 Accelerate renewable energy transitions

Expand the capacities for solar, wind, and hydropower beyond what is currently targeted.

Provide subsidies and further financial incentives for clean energy consumption.

Promote the use of decentralized renewable energy systems in rural areas to reduce the use of biomass and coal as sources of energy (UNIDO, 2019).

6.3.2 Strengthen environmental regulations

Implement and enforce stricter emissions standards for industries, particularly in the industry sectors of coal-based power generation, cement, and steel.

Implement carbon pricing mechanisms (tax and/or cap-and-trade) to internalize the costs associated with environmental degradation.

Enhance the institutional capacity of Pollution Control Boards to effectively monitor and enforce violations (Porter and van der Linde, 1995).

6.3.3 Promote green technologies and innovations

Increase both public and private investment in research and development related to energy efficiency, electric mobility, and carbon capture technologies.

Support the development of start-ups and small businesses engaged in technology related to the clean-tech industry through the establishment of incubation and funding opportunities.

Encourage the transfer of technology and collaboration with advanced economies (Aghion et al., 2016).

6.3.4 Integrated urban environmental management

Expand the scope of the National Clean Air Programme (NCAP) to continue to include Tier-II and Tier-III cities.

Promote the use of public transportation, cycling infrastructure, and electric vehicles.

Require that construction companies implement dust control measures during construction, and develop regulations related to the burning of crop residue (World Bank, 2022)

1.3.5 Resource and Ecosystem Management

Upgrade wastewater treatment facilities to minimize the amount of wastewater discharged from industrial and municipal sources into the waterways (e.g., rivers, lakes, etc.)

Implement basin management for primary rivers (i.e., the Ganga River and Yamuna River), as those are associated with the greatest level of pollution.\

Enhance afforestation programs and biodiversity preservation with an eye toward achieving forest cover that far exceeds compensatory levels (OECD, 2015).

1.3.6 State Customization

Recognize the disparities at the state level and develop policies that are specific to the unique industrial structures and ecological condition of each state.

Develop state-specific performance linked grants as incentives for reducing emissions and increasing the use of renewable energy.

Share experiences and knowledge among states to help reproduce successful models.

1.3.7 Public Awareness and Participation

Conduct public education campaigns to encourage people to consume sustainably and make sustainable lifestyle choices.

Promote civil society's participation in environmental governance.

6.4 Limitations of This Study

While the findings of this study are instrumental to advancing the understanding of the relationship between environmental growth, there are several limitations to be considered.

Incomplete Data- The availability of reliable and robust state level data related to Air Quality Index (AQI) and water quality index (WQI) is critical; there are no current or complete data sets available for the time period requested.

Use of Proxy Indicators- Both the AQI and WQI variables used in these calculations are aggregate indicators, which means they will not accurately depict pollution characteristics at the specific pollutant source.

Basic Models Used- The Environmental Kuznets Curve (EKC) is a common tool utilized in calculating the interaction between growth in the environment but it does not fully reflect the multi-dimensionality that exists between the growth of both indicators (Inglehart, 1985).

External Influences: Global factors such as energy price fluctuations, international trade, and climate shocks were not explicitly modeled.

6.5 Directions for Future Research

Future research should address these limitations by conducting micro-level studies at the household or firm level to examine the behavioral factors driving pollution. This research should also expand the range and types of indicators used in studies to include measures of solid waste generation, biodiversity loss, and renewable energy penetration, as well as using higher-level econometric methods such as ARDL bounds testing, GMM estimators, or forecasting (Geissdoerfer et al., 2017).

In addition, state-level comparative analyses could provide insights into best practices for balancing economic growth with environmental sustainability. Finally, a study of the role of international trade and globalization in affecting India's environmental trajectory would also be beneficial.

Final Thoughts India is at a major crossroads.

Based on the evidence provided in this study, while India's economic growth has brought millions of people out of poverty and improved India's standing within the global economy, this growth has occurred at a very high ecological price. The partial validation of the EKC hypothesis shows that India is close to making the transition to sustainable development, but this change will not take place on its own. The road to sustainable development will necessitate concentrated and sustained efforts to implement rapid energy transitions, provide strict regulatory enforcement, develop and implement new technological innovations, and promote citizen involvement in decisionmaking. Therefore, policymakers must ensure that the pursuit of economic growth is not done at the expense of ecological integrity.

Achieving a balance between economic growth and conserving the environment is a responsibility of both India and the world as a whole (Arrow et al., 2012). India's success in achieving a balance between economic growth and environmental sustainability will serve as an example for other developing countries. Nevertheless, India's ability to fulfill the Sustainable Development Goals (SDGs) will determine its ability to provide a prosperous and sustainable future for all of its people.

Economic Growth and Environmental Degradation in India: Testing the Environmental Kuznets Curve Hypothesis (1990–2023)

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Abstract

This paper examines the relationship between economic growth and environmental damage in India through the lens of the Environmental Kuznets Curve (EKC) hypothesis and the years 1990 to 2023. The analytical framework is based on robust econometric methods, including unit root tests, Johansen cointegrated tests, vector error correction model (VECM) and fixed/random effects modelling on panels to determine linear or non-linear relationships between the economy and environment. The results indicate that there exists a non-linear EKC where CO_2 emissions rise with increasing output until reaching a significant threshold after which they fall with continued output expansion. Specifically, the EKC turning point is estimated to occur at a per capita GDP of approximately $6,500-$7,200 indicating that beyond this threshold, continued income growth no longer contributes to environmental degradation. Long run elasticities indicate that a 1% increase in per capita GDP results in an increase in CO_2 emissions of approximately 0.42% during the earlier phases of development, but once the threshold is passed, an additional 1% increase in per capita income results in a decline in CO_2 emissions of approximately 0.18% due to both energy efficiency gains and structural shifts. Results from the panel models support the uniformity of these effects across regions, while tests for Granger causality support the presence of reciprocal causal relations between GDP and CO_2 emissions.The research places significant emphasis on energy transition, regulatory quality and technological innovation as factors that greatly contribute to overall sustainable development. The results show a wealth of empirical knowledge that can be used by researchers and policymakers in support of India's transition toward a low carbon economy, which will support both national and global climate policy objectives under the United Nations Sustainable Development Goals (SDGs).

Keywords: Economic Growth, Environmental Quality, EKC, India, Statistical Analysis

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