Revisiting Environmental Kuznets Curve (EKC) and Renewable Energy Consumption in India

Abstract

The relationship between renewable energy consumption, economic growth, and environmental sustainability has been extensively studied, particularly in the context of the Environmental Kuznets Curve (EKC) hypothesis. The EKC posits an inverted U-shaped relationship between economic growth and environmental degradation, where pollution initially rises with income levels and subsequently declines after reaching a certain income threshold [1]. One of the most important issues in a current era is striking a balance between environmental sustainability and economic prosperity. Considering the said background, this study aims to find out the growth rate of renewable energy consumption per-capita, Gross domestic product per-capita and CO2 emission per-capita. Side by side, it is also trying to revisit the existence of Environmental Kuznets Curve in India and how renewable energy consumption per-capita is affected by Gross domestic product per-capita and CO2 emission per-capita. All the data has been collected from World Development Indicator (WDI), World Bank for the period 1990-2020 using a multiple regression analysis. The result suggests that the growth rate of renewable energy consumption per-capita, Gross domestic product per-capita and CO2 emission per-capita is fluctuating in nature. In case of India, Environmental Kuznets Curve (EKC) still exists and Gross domestic product per-capita is affecting renewable energy consumption positively and CO2 emission per-capita negatively.

Keywords: Environmental Kuznets Curve, Renewable Energy Consumption, environmental sustainability, Economic Growth, India

JEL classification: Q42, Q53, Q56

1. Introduction

The Kuznets curve [2] posits a theory framing the relationship between the economic growth and the long-term changes in personal distribution of income. According to him, the income inequality of a country follows an inverted U-shape curve as the economic growth takes place. During the initial stages of industrialization, as the wealth tends to gradually accumulate over time leading to biased income distribution in the society. But after reaching a certain income threshold, the inequality reduces over time due to benefits of economic growth and government intervention leading to improved standard of living, efficient infrastructural facilities, and welfare programs.

The relationship between renewable energy consumption, economic growth, and environmental sustainability has been extensively studied, particularly in the context of the Environmental Kuznets Curve (EKC) hypothesis. The EKC posits an inverted U-shaped relationship between economic growth and environmental degradation, where pollution initially rises with income levels and subsequently declines after reaching a certain income threshold [1]. This review synthesizes empirical findings, methodologies, and gaps in the literature, with a focus on India and comparable economies.

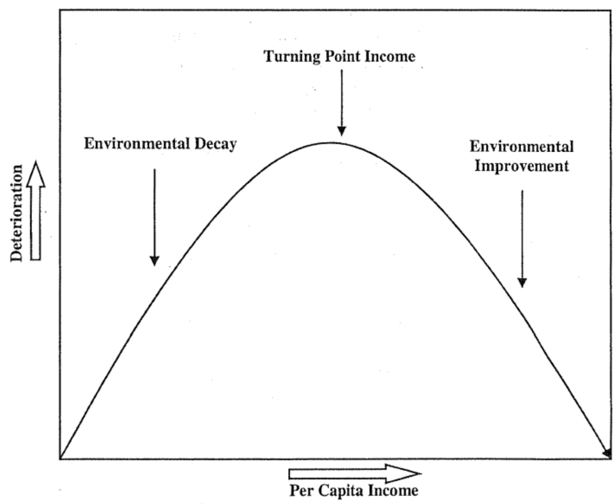

Fig 1-The Environmental Kuznets curve

Source: Yandle et al., 2002

One of the most important issues in a current era is striking a balance between environmental sustainability and economic prosperity. This concept is better explained by using the Kuznets curve, applied to environmental problems, leading to the creation of the Environmental Kuznets Curve (EKC). According to the EKC, as countries develop, environmental degradation intensifies, owing to industrialization and increased resource use. However, after a certain point, increasing wages result in increased environmental awareness, cleaner technologies, and tougher laws, resulting in a reduction in environmental impact. This theory has sparked debates about whether economic growth and environmental protection can coexist and what role renewable energy plays in achieving that balance.

Around the world, the energy landscape is undergoing a significant transformation. For decades, fossil fuels like coal, oil, and natural gas have been the backbone of economic development, but they've also been the leading contributors to climate change and environmental pollution. In recent years, renewable energy sources—such as solar, wind, and hydropower, etc. have gained momentum as viable alternatives to fossil fuels. While the more developed nations have made significant strides, many developing and under-developed countries face obstacles like inadequate infrastructure, financial insufficiency, and limited policy implementation. This uneven progress raises critical questions about how to ensure there is balanced and just energy transition within and among the countries while acknowledging the contingent need to curb global warming.

As one of the world's fastest-growing economies, India stands out as a crucial player in the global energy transition. But it also grabs extensive attention for being the third-largest emitter of carbon dioxide. Along with many other developing countries, India faces the dilemma of fostering economic development while curbing environmental damage. In recent years, the country has made remarkable progress in adopting renewable energy. According to the ministry of new and renewable energy, India, as of 2023, renewable energy sources make up around 42% of India's installed power capacity and the government focuses on expanding it by 500GW by 2030.With India being a tropical country, an energy source such as Solar power has emerged as a cornerstone of India's renewable energy strategy, thanks to initiatives like the National Solar Mission and subsidies for rooftop solar systems. But since the usage of this energy source is not as extensive and at par till now, the country still highly depends on coal for electricity, and issues such as intermittent power supply from renewables, insufficient storage solutions, and financing constraints pose significant hurdles. Bridging these gaps will require not just domestic reforms but also international collaboration to ensure India's energy transition stays on track.

Renewable energy is increasingly seen to bring the Environmental Kuznets Curve to life by helping countries reduce environmental degradation while still growing their economies. The faster countries can adopt clean energy solutions, the sooner they can reach the turning point where economic growth no longer comes at the expense of the environment. For India and other developing countries, this means not just ramping up renewable energy production but also addressing challenges like equitable access, infrastructure development, and policy support. Understanding how the EKC framework applies to renewable energy consumption sheds light on the complex dynamics of growth and sustainability and offers hope for a future where economic prosperity and environmental protection go hand in hand.

2. Review of Literature

The EKC hypothesis has been a central point in understanding the environmental impacts of economic growth. Empirical research has shown a mixed proof on the validity of EKC in developing economies like India. [3] proposes that as the environmental quality improves at higher income levels for certain indicators (e.g., water quality, sanitation); local air pollution follows an EKC pattern. [4] conducted a Vector Autoregression (VAR) analysis with the time-frame of 20 years for India explaining that the positive shocks to renewable energy consumption increase GDP and decrease CO2 emissions. A causality test from [5,6,7] suggests that there is no long-run causality between income and CO2 however there is a bi-directional causality between the emissions and energy consumption. Further adding to this [8] also, initiated a Granger Causality test emphasizing the GDP of the country is only bi-directional to the variables, energy consumption and CO2 emissions, in a short-run. The work of [9] gives a deeper insight on the relation between the variables, proving that renewable energy consumption has a great impact on carbon emissions, however, it’s reach to GDP of is limited.

[10] imply that the change in the trend of the curve might only be noticeable for the longer period. Studies examining the role of renewable energy in this relationship highlight its potential to accelerate the transition to sustainable growth. The study conducted on 116 countries by [11] finds remarkable results stating that the economic growth negatively causes CO2 emissions globally but positively impacts the regions like Asia-pacific, hence it varies from region to region. For instance, [12] with the panel data approaches such as Fully Modified Ordinary Least Squares (FMOLS), Dynamic Ordinary Least Squares (DOLS), and Generalized Method of Moments (GMM) which address heterogeneity and endogeneity issues, discovers that there is a decline in CO2 emissions where renewable energy consumption practices are adopted, which leads to a turning of the EKC curve.

Research by [13] postulates the capability of renewable energy consumption varies from country to country, hence region-specific policy implementations is required. In addition, the countries lacking adequate infrastructural amenities and financial aid cannot make an optimal usage of their renewable energy consumption sources. The impact of renewable energy on economic growth has been widely discussed. Even though actual research findings are not always in agreement, renewable energy is probably seen as a catalyst for sustainable economic growth. The literature employs a wide range of econometric tools to investigate the relationship between energy, growth, and emissions.

A published paper on effects of different renewable energies by [14] enlightens that the renewable energy sources have mixed effect. For illustration, hydro has positive influence while nuclear has a negative one. Another rather intriguing verdict by [15] was that as the evidence does support the EKC curve in the country, the CO2 levels continue rising even past the turn around point. This can be due to insufficient focus on recent renewable energy adoption, ignoring income inequalities, etc.

The results of the adoption of renewable energy are significantly shaped by institutional variables and policy frameworks.[16] found that institutional quality and trade openness have a substantial impact on the effectiveness of renewable energy programs in lowering emissions. Strong governance systems and foreign direct investment (FDI) have been shown to boost the environmental benefits of renewable energy, particularly in high-income countries. These characteristics, however, show little effect in emerging and low-income nations, indicating the need for focused institutional reforms.

Even with the expanding literature, there are still several loop-holes. First, most studies aggregate renewable energy sources, neglecting the different impacts of solar, wind, and biofuels. Policymakers may benefit from disaggregated assessments because they provide more practical information. Second, cross-country studies frequently overlook characteristics unique to each country, such as institutional quality, technology capabilities, and cultural contexts. Additionally, while econometric methodologies have improved, many studies still use outdated data, limiting their relevance to contemporary policy debates. The social and distributional repercussions of renewable energy transitions, such as their influence on employment, income inequality, and energy access, should also be investigated in future studies.

3. Objectives

The objective of this research article are as follows:

Firstly, to find out the Year-over-year Growth Rate and Compounded annual growth rate of Gross Domestic Product Per Capita (GDPPC), Carbon dioxide emissions Per Capita (CO2EPC) and Renewable energy consumption (REC) in India. Secondly, to investigate the relationship between CO2EPC and GDPPC from 1990-2020 i.e. revisiting Environmental Kuznets Curve is exist or not. Thirdly, to find out the Determinants of Renewable energy consumption in India.

4. Methodology & Data source

Data source:

The paper presented here considers three variables namely Gross Domestic Product Per Capita (GDPPC) and Carbon dioxide emissions Per capita (CO2EPC) and Renewable energy consumption (REC). The study is based on time-series data from the period 1990 to 2020 for India collected from World Development Indicators (WDI) published by the World Bank.

Gross Domestic Product Per Capita and Carbon dioxide emissions Per Capita are represented as GDPPC and CO2EPC.

Methodology:

To understand the linkage between variables, three methodologies have been used which are stated as under:

1. Year-Over-Year growth rate (YOY)
2. Compounded annual growth rate (CAGR)
3. Ordinary least square (OLS)

Year-over-year growth rate (YOY) is a rate of change observed in the current period compared to the previous period.

$$YOY = (Yt - Yt-1)/Yt-1$$

Where, Yt represents the value of variable at period t.

Yt-1is the value of variable at period t-1 and is prior to Yt.

(Yt - Yt-1) is the difference of these values in period t and t-1.

The **Compound annual growth rate (CAGR)** can be defined as

$$\text{CAGR} = [Pr/Pt]^{(1/(T-t))}$$

Where, Pr represents the value of the variable at the end of the period. Also known as the recent period.

Pt represents the value of the variable at the start of the period. Also called the initial period

T denotes the time corresponding to Pr and t denotes the time corresponding to Pt.

The exponent 1/(T−t) represents the adjustments made for the number of periods between T and t, effectively calculating the average annual rate of change over the time.

The **Ordinary least square (OLS)** has been employed as a part of regression analysis. Two models can be determined with the variables.

First model is established to determine the relation between dependent variable (CO2EPCC) and independent variable (GDPPC) and its quadratic form ($GDPPC^2$). The equation being,

$$\mathrm{CO2EPC} = \alpha + \beta_1 GDPPC + \beta_2 GDPPC^2 + Ei$$

Second model is constructed to find out the determinants of REC. The model being,

$$\mathrm{REC} = \alpha + \beta_1 GDPPC + \beta_2 GDPPC^2 + \beta_3 CO2EPC + Ei$$

5. Analysis of Result:

This section represents the analysis of the result.

Table 1: Year-over-year Growth Rate of GDPPC, CO2EPC and REC in India.

	Year-over-year growth rate		
Year	**REC**	**GDPPC**	**CO2EPC**
1990	-	-	-
1991	-1.79%	-17.55%	5.57%
1992	-0.65%	4.59%	1.09%
1993	-0.43%	-4.98%	1.97%
1994	-2.50%	14.92%	3.28%
1995	-1.93%	7.99%	5.53%
1996	-1.32%	7.01%	2.94%
1997	-2.38%	3.89%	3.88%
1998	0.43%	-0.53%	0.21%
1999	-1.89%	6.94%	5.85%
2000	-9.35%	0.30%	2.23%
2001	0.49%	1.86%	-0.07%
2002	-2.89%	4.30%	1.62%
2003	-0.26%	16.08%	0.99%
2004	-1.56%	14.82%	5.58%
2005	-1.69%	13.87%	3.04%
2006	-2.26%	12.85%	5.29%
2007	-3.78%	27.47%	8.35%
2008	-5.20%	-2.90%	5.01%
2009	-4.98%	10.36%	8.33%
2010	-3.34%	23.20%	4.65%
2011	-3.18%	7.41%	4.47%
2012	-0.74%	-0.98%	7.36%

2013	0.29%	0.40%	2.08%
2014	-2.87%	8.57%	7.62%
2015	-1.33%	2.02%	-0.61%
2016	-1.14%	7.91%	0.62%
2017	-1.85%	14.32%	4.58%
2018	1.27%	0.89%	4.58%
2019	0.34%	3.70%	-0.83%
2020	-13.93%	-6.71%	-0.60%

Source: Author’s calculation

The table here indicates that the variables, over the period of 30 years highlighted a certain number of fluctuations. Firstly, in the case of Renewable energy consumption (REC), during the initial stages a deficient growth can be seen. The time-frame has majorly remained on a negative path but during the early 2000’s it reached its second lowest point for the REC in India which reached to -9.35%. The late 2010s showed the signs of recovery and growth stabilization and marginal growth structure was visible in the year 2013, 2018 and 2019. However, with the hit of COVID-19 in the year 2020, a sharp decline was noted making it as the lowest the REC has ever fallen.

Secondly, GDPPC showed volatility at the beginning of the analysis period. However the reforms and policy amendments in the year of 1991 led the GDP of India to grow at a steady and gradual rate, which was also affected by the financial crisis experienced across the globe. Thirdly, the CO2 emission in India, has witnessed a growth in the early stages. Interestingly, as the GDPPC grew in India the CO2EPC rose simultaneously, indicating a direct relationship. Over the years, the rate did hit a stable point with slow growth due to the sustainable approaches but the traditional practices of Co2 emission are still very prominent.

Table 2: Compounded annual growth rate of REC, GDPPC, CO2EPC

VARIABLE	**REC**	**GDPPC**	**CO2EPC**
CAGR	-2%	6%	3%

Source: Author’s calculation

The provided table estimates the compound annual growth rate of all the three variables for the period of 1990-2020. Considering the negative CAGR of REC, it indicates a long-term decline in renewable energy consumption over the 30-year period. Albeit the occasional positive rise in certain years, the overall trend has been a shrinking. This can occur due to variety of reasons such as inadequate financial investments, lack of sustainable infrastructures, policy constraints, conventional polluting practices, etc.

The financial roots of Indian economy stay stout and mostly steady with the liberalization reforms of 1991 displaying the GDPPC of 6%. This highlights India's growing economic progress, industrialization, and rising incomes. The justification for this rise can be the country's advancements in the fields of technology, banking, manufacturing, services, etc. And despite the periods of volatility, the overall trajectory, and future predictions of the growths of the economy showcases an upward trend.

The positive CAGR of CO2EPC indicates a steady increase in emissions per capita over time. India being majorly relied on fossil fuels and other non-renewable energy sources, the trend, thus, aligns with the economic growth and industrial expansion driving higher energy consumption and higher emissions of gases. It is worthy to note that, though the CO2EPC is at 3%, it is still comparatively lower than GDPPC, suggesting a certain progress in improving energy efficiency and reducing emissions intently.

Table 3: Relationship between CO2EPC *and GDPPC from 1990-2020*

Dependent variable: CO2EPC			
Variable	Coefficient	t- Statistic	Prob.
C	0.48	12.67	0
GDPPC	0.000798	8.98	0
$GDPPC^2$	-7.10E-08	-1.78	0.09
Adjusted R2: 0.98			
F-Statistic: 707.26			
Prob(F-Statistic): 0			

Source: Author's calculation

This table is the tabular representation of the regression analysis between the dependent variable, CO2EPC and the independent variables, GDPPC and its quadratic form $GDPPC^2$. The constant term being statistically significant, represents the base level of Co2 emissions per capita when GDPPC and $GDPPC^2$ are zero. In the matter of GDPPC, the positive coefficient signifies with the rise in GDP per capita, the CO2 per capita also rises. Hence, this variable has a robust and statistically significant impact on the Co2 emission over a long duration. On the other hand, $GDPPC^2$ has a negative coefficient suggesting a non-linear relationship where the growth rate of CO2 emissions slows as GDP per capita increases over a prolonged period indicating that the country having reached a certain income threshold which ideally satisfying the theory by [1] on Environmental Kuznets curve. However, the p-value of 0.09 indicates marginal significance, meaning this effect might not be highly reliable. The model demonstrates an excellent fit accounting for 98% of variation in CO2 emissions per capita. The higher value of F-stat and its p-value of 0 remarks the model is statistically significant.

To summarize, GDPPC has a linear positive effect on co2 emissions reflecting the growth of GDP leads to higher energy consumption resulted by the industrial activities. $GDPPC^2$, a quadratic term implies a non-linear equation showing with the growth in economy, the country starts adopting more cleaner and sustainable practices and technologies.

Table 4: Determinants of Renewable energy consumption

Dependent variable: REC			
Variable	Coefficient	t- Statistic	Prob.
GDPPC	-0.02	-2.95	0.01
$GDPPC^2$	8.4E-06	6.20	0
CO2EPC	-24.64	-3.99	0.0005
Adjusted R2: 0.96			
F-Statistics: 252.28			
Prob(F-Statistic): 0			

Source: Author's calculation

This table explains the result of the regression analysis where the dependent variable is Renewable energy consumption (REC) and the explanatory variable being, GDP per capita (GDPPC), its quadratic term ($GDPPC^2$), and Co2 Emission per capita (CO2EPC). The negative coefficients of GDPPC connotes that with the increase in GDP of the country, it becomes less reliant of its renewable energy sources suggesting that with higher exposure to development opportunities and financial independency, the country has greater availability and affordability to fossil fuels. In the long run, however, the $GDPPC^2$ speculates a positive and non-linear relationship with REC explaining that after the country reaches a certain threshold for income level, they shift their focus back to renewable energy as they grow and prioritize sustainability.

The strong negative coefficient implies that there exists an inverse relationship between co2 emission per capita (CO2EPC) and Renewable energy consumption (REC). This reflects that with the country's higher preference for the fossil fuels challenges its shifting towards cleaner energy sources. This transition can be difficult due to reasons naming discounted and extensive availability of fossil fuels, resistance from fossil fuel-dependent industries and the need to balance energy demands with environmental concerns. The model further explains 96% of variation in REC, indicating a rather strong fit. The results here show a complex relationship. To sum up, initial levels of GDP rely comparatively less on REC than after it has reached a point of significant economic growth, then transitioning and shifting practices towards the sustainability. There is also a need for lesser dependency on fossil fuels and other forms of non-renewable energies to attain a healthier and environmental-friendly status for the country.

6. Summary & Conclusion:

The analysis clearly determines the relationship between the variables over the prolonged period of three decades, signifying the environmental and economic stability of India and how it manages its functioning simultaneously. The progression of GDP per capita led to higher emissions for the country, however reaching at a certain equilibrium point the curve slops downwards showing the country's comprehension towards a sustainable advancement. Hence, demonstrating the Environmental Kuznets Curve condition. This transition leads to a rise in renewable energy consumption. But this shift can be a bit arduous to achieve due to long-established emission exercises. Higher CO2 emissions are associated with a decline in renewable energy usage, reflecting the persistent dominance of fossil fuels in energy systems. The models demonstrate strong explanatory power, with adjusted R^2 values of 0.98 and 0.96 for CO2EPC and REC, respectively, indicating healthy relationship among variables. With India, becoming one of the fastest growing economies, with a potential growth rate of 7%, balancing environmental sustainability is a challenge. While renewable energy usage shows potential for growth as income rise, its overall decline highlights the urgent need for policy interventions to promote cleaner energy adoption. The larger dependency of non-renewable energy sources ought to be reduce by setting a scale on it. Accelerating investments in renewable energy infrastructure, incentivizing sustainable practices and adopting a rigid mechanism to regulate emissions. These measures would not only propagate a vigorous and wider sustainable path but also help the country achieve its goals in both prospects simultaneously.

7. Policy Prescription:

India being a tropical country, relishes many ecological advantages. The coastal lines of the country have seen establishment of wind energies in recent years. The government has also promoted the usage of solar energy as an alternative to fuel and electricity. Though these measures stand strong against carbon emission levels, they are not enough. Here are some potential policies which can help India balance its economy and environment simultaneously are:

i. The negative CAGR of Renewable energy consumption (REC) demands that there is a need for the country to indulge themselves more in sustainable development practices.

ii. Adequate infrastructural and fiscal assistance is to be provided by the authorities to help the country attain its sustainable growth.

iii. Sector-specific investments in needed in areas of renewable energies.

iv. Research & Development (R&D) in the field of energy consumption is highly recommended to know India’s potential in boosting itself a green economy.

v. There is still the need for India to cross a certain income-level threshold to attain environmental stability as posited by Grossman and Krueger, 1991.

vi. The government can promote renewable energy consumption to private entities by helping them subscribing to subsidies and schemes launched by the state.

8. Limitation:

This paper only captures the observation and their relativity for 30 years. This may not fully capture long-term structural changes or policy shifts, especially considering renewable energy's increasing momentum in the post-pandemic era. For a deeper insight, a longer timeframe could be considered. While the study focuses on India, it does not necessarily consider the regional disparities of the country. Variation in renewable energy consumption, infrastructure and financial state differ from one region to that of another. The study does not put a light on distributional and social consequences of shifting to renewable energy consumption like employment, pricing strategies, finances, energy access, etc. The analysis majorly focuses on one area of sustainability and cleaner environmental practices, renewable energy consumption. While there are also other energy sources which affects GDP and CO2 emissions of the country significantly.

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