



### RESEARCH ARTICLE

## GROWTH DYNAMICS AND ENVIRONMENTAL EFFICIENCY IN INDIA: EVIDENCE FROM CARBON INTENSITY TRENDS 1990–2024

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### Abstract

This study examines the relationship between economic growth and carbon intensity in India over the period 1990–2024. The main objective of the study is to explore whether economic growth has been accompanied by improvements in environmental efficiency. Carbon intensity, which measures the amount of carbon emissions generated per unit of economic output, is used as an indicator of environmental performance, while GDP per capita represents economic growth. The analysis is based on descriptive statistics, correlation analysis, and graphical trend analysis. The results indicate that GDP per capita in India has increased significantly during the study period, reflecting sustained economic expansion. In contrast, carbon intensity shows a gradual decline over time, suggesting improvements in energy efficiency and cleaner production processes. The correlation analysis reveals a strong negative relationship between GDP per capita and carbon intensity, indicating that higher income levels are associated with lower carbon emissions per unit of output. Overall, the findings suggest that economic growth in India has been accompanied by improvements in environmental efficiency. The results highlight the importance of technological progress, structural transformation, and sustainable energy policies in reducing carbon intensity while maintaining economic growth. These findings provide useful insights for policy makers aiming to promote sustainable development and environmentally efficient economic growth.

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### Introduction:-

Economic growth has long been a central objective of development policy, particularly in emerging economies such as India. Over the past few decades, India has experienced substantial economic expansion accompanied by rapid industrialization, urbanization, and rising energy consumption. While this growth has improved income levels and living standards, it has also raised concerns regarding environmental sustainability, particularly in relation to greenhouse gas emissions and climate change. As one of the fastest-growing major economies in the world, India faces the challenge of maintaining economic growth while simultaneously reducing the environmental pressures associated with development.

One important indicator used to examine the environmental efficiency of economic activity is carbon intensity, which measures the amount of carbon dioxide emissions produced per unit of economic output. Carbon intensity reflects how efficiently an economy uses energy and technology in producing goods and services. A decline in carbon intensity indicates that economic output is increasing with relatively lower carbon emissions, suggesting improvements in energy efficiency, cleaner production processes, or a structural shift toward less carbon-intensive sectors of the economy.

In recent years, the relationship between economic growth and environmental outcomes has received considerable attention in the literature on environmental and development economics. Economic expansion may initially increase energy use and emissions due to industrial growth and increased demand for resources. However, as economies develop further, technological progress, policy interventions, and shifts toward service-oriented sectors may lead to improvements in environmental efficiency. Understanding this relationship is particularly important for countries like India that are simultaneously pursuing rapid economic growth and commitments toward climate mitigation. India's economic transformation since the early 1990s provides an interesting case for examining this relationship. Following the economic reforms of the early 1990s, the country experienced significant increases in GDP per capita, expansion of industrial activity, and growth of the service sector. At the same time, India has increasingly adopted policies aimed at improving energy efficiency and promoting cleaner sources of energy. These developments raise an important question: has economic growth in India been accompanied by improvements in carbon efficiency?

This study seeks to analyze the relationship between economic growth and carbon intensity in India using time-series data for the period 1990–2024. Using GDP per capita as a measure of economic growth and carbon intensity as an indicator of environmental efficiency, the paper investigates whether rising income levels are associated with reductions in carbon intensity. By employing graphical analysis and basic regression techniques, the study aims to provide empirical evidence on whether economic growth in India has contributed to improved environmental efficiency over time. The findings of this study are expected to contribute to the broader discussion on sustainable development by highlighting whether economic expansion can occur alongside improvements in environmental performance. Understanding this relationship is important for policymakers seeking to design strategies that promote both economic prosperity and environmental sustainability in India.

### **Literature Review:-**

The relationship between economic growth and environmental quality has been widely examined in the literature on environmental and development economics. A central question in this field is whether economic growth inevitably results in environmental degradation or whether technological progress and efficiency improvements can reduce environmental pressures over time. Several empirical studies suggest that economic growth is closely associated with rising energy consumption and environmental degradation, particularly in developing economies (Ang, 2007; Pao & Tsai, 2011; Shahbaz et al., 2015; Wang et al., 2018). Carbon emissions and carbon intensity have therefore become important indicators used to evaluate the environmental consequences of economic activity and to assess whether economies are moving toward more sustainable growth paths (Dong et al., 2018; Acheampong, 2018).

Early theoretical contributions emphasized the strong link between economic activity and environmental degradation. The classical view suggested that economic growth leads to increased industrial production, energy consumption, and resource extraction, which ultimately contribute to higher levels of pollution. One of the most influential theoretical frameworks explaining this relationship is the IPAT identity, proposed by Ehrlich and Holdren (1971), which states that environmental impact is a function of population, affluence, and technology. Later extensions of this framework, such as the STIRPAT model, further emphasized that rising income levels and population growth tend to increase environmental pressure unless technological improvements significantly reduce environmental intensity (York, Rosa, & Dietz, 2003).

A major theoretical advancement in this field is the Environmental Kuznets Curve (EKC) hypothesis, which proposes an inverted-U shaped relationship between economic growth and environmental degradation. According to this hypothesis, environmental degradation increases in the early stages of economic development but begins to decline after a certain income threshold as societies adopt cleaner technologies and stricter environmental regulations. Grossman and Krueger (1995) were among the first to empirically examine this relationship and found evidence supporting the EKC hypothesis for several pollutants. Subsequent studies have extensively tested the EKC framework across different countries and pollutants, producing mixed empirical results (Dinda, 2004; Apergis & Ozturk, 2015; Shahbaz et al., 2012).

Further research has highlighted that carbon emissions behave differently from local pollutants because they are strongly linked to energy consumption and fossil fuel dependence. Stern (2004) argued that carbon emissions do not always follow the inverted-U pattern predicted by the EKC because economic growth often leads to increased energy demand and fossil fuel consumption. Empirical studies examining the relationship between energy consumption, economic growth, and carbon emissions have confirmed the existence of strong interdependencies between these variables in both developed and developing economies (Ang, 2007; Jayanthakumaran, Verma, & Liu, 2012; Rahman & Kashem, 2017). In recent years, research has increasingly focused on the role of energy efficiency, technological progress, and renewable energy adoption in reducing carbon intensity. Several studies have found that improvements in energy efficiency and technological innovation can significantly reduce carbon emissions even as economies continue to grow (Bilgili, Koçak, & Bulut, 2016; Dong et al., 2018; Wang et al., 2018). Similarly, the transition toward renewable energy sources has been identified as a key factor contributing to reductions in carbon intensity and environmental degradation (Shahbaz et al., 2015; Acheampong, 2018).

The role of structural transformation in shaping environmental outcomes has also been widely discussed in the literature. As economies develop, economic activity tends to shift from energy-intensive industrial sectors toward service-based industries that generally produce lower emissions. This structural transformation can lead to declining carbon intensity even when overall economic output continues to expand (Managi & Jena, 2008; Boutabba, 2014). In addition, financial development, trade openness, and foreign direct investment have also been identified as important determinants of environmental performance and carbon emissions (Shahbaz et al., 2013; Ahmad et al., 2016). Recent empirical research has further emphasized the importance of environmental policies and technological innovation in achieving sustainable economic growth. Policies promoting renewable energy, green technologies, and energy-efficient production systems can help decouple economic growth from environmental degradation (González-Álvarez et al., 2023; Saglam, 2025). Moreover, international trade, energy transitions, and sustainable supply chain practices are increasingly recognized as critical factors influencing carbon emissions and environmental sustainability in emerging economies (Mohammed et al., 2022; Dharmapriya, 2025).

For a rapidly developing country such as India, understanding the relationship between economic growth and carbon intensity is particularly important. Since the early 1990s, India has experienced substantial economic transformation characterized by economic liberalization, rapid industrialization, and expansion of the service sector. At the same time, the country has implemented several policies aimed at improving energy efficiency and promoting renewable energy. Empirical studies focusing on India suggest that economic growth, energy consumption, industrialization, and trade openness are key determinants of carbon emissions and environmental quality (Alam et al., 2011; Ahmad et al., 2016; Dong et al., 2018). Overall, the existing literature suggests that the relationship between economic growth and environmental performance is complex and influenced by multiple interacting factors, including technological progress, structural transformation, energy consumption patterns, and environmental policies. While some studies support the Environmental Kuznets Curve hypothesis, others argue that sustained improvements in environmental quality require deliberate policy interventions and technological innovation rather than relying solely on income growth. Building on this body of research, the present study examines the relationship between GDP per capita and carbon intensity in India over the period 1990–2024, with the aim of assessing whether economic growth has been accompanied by improvements in environmental efficiency.

### **Data & Methodology:-**

This study examines the relationship between economic growth and carbon intensity in India using a simple time-series analysis. The methodology is designed to be straightforward so that the relationship between the variables can be clearly understood.

#### **Data Source:**

The data used in this study consist of annual observations covering the period 1990–2024 and include two main variables: GDP per capita and carbon intensity. These variables are commonly used in empirical studies to examine the relationship between economic growth and environmental efficiency. GDP per capita represents the level of economic development and reflects the average income of individuals in the economy, while carbon intensity measures the amount of carbon emissions generated per unit of economic output and serves as an indicator of environmental efficiency. The data for both variables were obtained from the World Bank's World Development Indicators database, which provides reliable and internationally comparable statistics on economic and environmental indicators. Two variables are used in this analysis: (I) GDP per Capita (GDPpc): This variable measures the average economic output per person and is used as an indicator of economic growth. (II) Carbon

Intensity: These variable measures the amount of carbon emissions generated per unit of economic activity and is used as an indicator of environmental efficiency

### Descriptive Analysis

Basic descriptive statistics were calculated to understand the general characteristics of the data. These statistics include the mean and summary values of GDP per capita and carbon intensity. Descriptive analysis helps in identifying the overall trend and variation in the variables over time.

### Correlation Analysis

To examine the association between economic growth and carbon intensity, a correlation analysis was performed. The correlation coefficient measures the strength and direction of the relationship between the two variables. A negative correlation indicates that as GDP per capita increases, carbon intensity decreases.

### Graphical Analysis

Graphical methods were used to visualize trends and relationships in the data. Three main graphs were created:

1. Trend graph of carbon intensity over time, showing how carbon intensity in India has changed between 1990 and 2024.
2. Trend graph of GDP per capita, illustrating the growth of the Indian economy during the same period.
3. Scatter plot of GDP per capita and carbon intensity, which shows the relationship between economic growth and environmental efficiency.

These graphs help provide a clear visual understanding of how the variables move over time and how they relate to each other. Overall, this methodology combines descriptive statistics, graphical analysis, & correlation analysis to examine the relationship between economic growth and carbon intensity in India. The approach provides a clear and simple framework for understanding whether economic development has been accompanied by improvements in environmental efficiency.

## Results:-

### Descriptive Statistics

The descriptive statistics provide an overview of the main characteristics of the variables used in the study for India during the period 1990–2024.

The results show that GDP per capita has a mean value of 1190 USD, with a minimum value of 532 USD and a maximum value of 2397 USD. The relatively high standard deviation of 558 indicates substantial variation in income levels over the study period. This reflects the significant economic growth experienced by India over the past three decades.

Variable	Mean	Std. Dev.	Minimum	Maximum
GDP per Capita (USD)	1190	558	532	2397
Carbon Intensity	0.28	0.0345	0.221	0.336

In contrast, carbon intensity has an average value of 0.28, with a minimum value of 0.221 and a maximum value of 0.336. The standard deviation of 0.0345 suggests that carbon intensity varies less compared to GDP per capita but still shows noticeable changes over time. The decline in the minimum value indicates that carbon intensity has gradually reduced in recent years, suggesting improvements in energy efficiency and cleaner production technologies.

Overall, the descriptive statistics suggest that while India's economic output has grown substantially, carbon intensity has generally declined, indicating that economic growth has been accompanied by improvements in environmental efficiency.

### Correlation Analysis

The correlation analysis examines the relationship between GDP per capita and carbon intensity. The correlation coefficient between the two variables is  $-0.943$ , which indicates a very strong negative relationship. A correlation value close to  $-1$  suggests that as one variable increases, the other decreases. In this case, the strong negative correlation implies that as GDP per capita increases, carbon intensity decreases. This finding suggests that economic growth in India has been associated with improvements in energy efficiency and reductions in carbon emissions per unit of economic output.

**Table 1 : Correlation between GDP per Capita and Carbon Intensity**

Variables	Correlation Coefficient
GDP per Capita – Carbon Intensity	-0.943

Several factors may explain this relationship. As economies develop, they often adopt more efficient technologies, cleaner energy sources, and better environmental regulations. In addition, structural changes in the economy such as the expansion of the service sector and improvements in industrial efficiency can reduce the carbon intensity of production. Overall, the results indicate that economic growth in India during the period 1990–2024 has been strongly associated with declining carbon intensity, suggesting that development has contributed to improving environmental efficiency.

### Trends in Carbon Intensity and GDP per Capita in India (1990–2024)

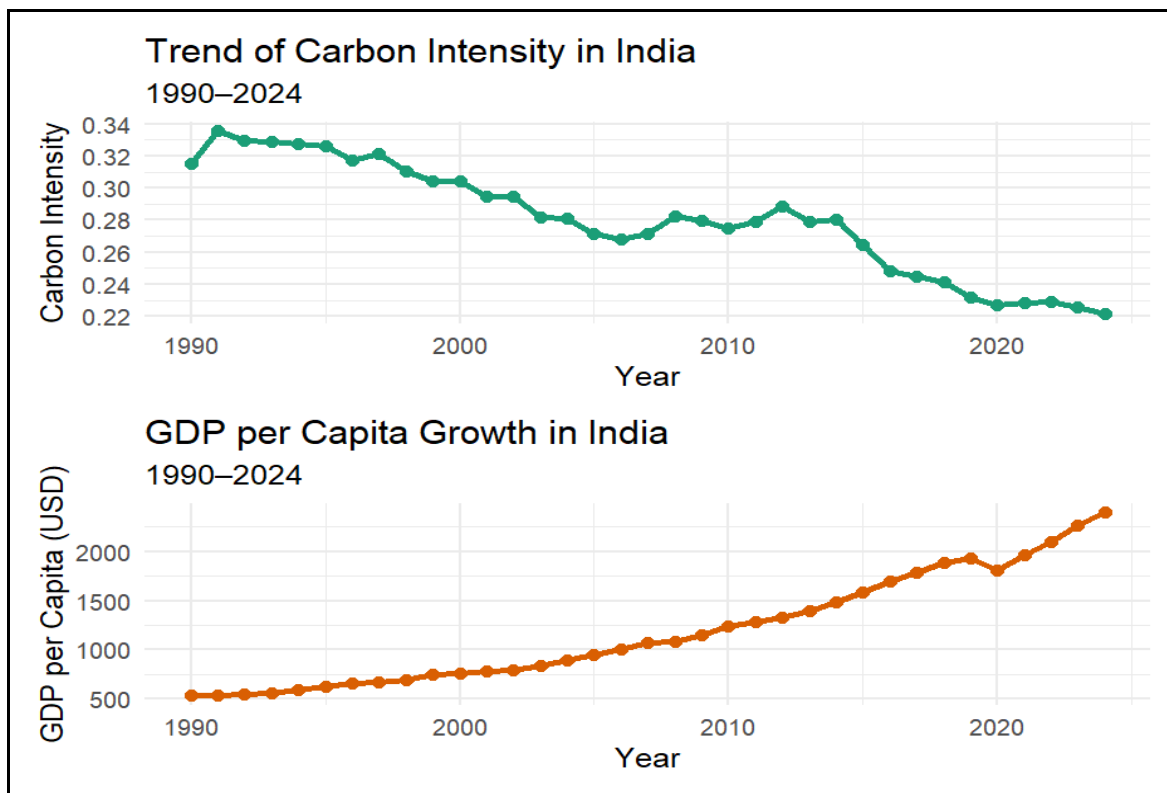
The figure presents two time-series graphs illustrating the trends in carbon intensity and GDP per capita in India over the period 1990–2024. Together, these graphs provide important insights into how economic growth has been associated with changes in environmental efficiency.

#### Trend of Carbon Intensity

The first graph shows the trend in carbon intensity, which measures the amount of carbon emissions produced per unit of economic output. The graph indicates a clear downward trend over time. In the early 1990s, carbon intensity was relatively high, at around 0.32–0.34. Over the following decades, the value gradually declined, reaching approximately 0.22 by 2024. Although there are some short-term fluctuations particularly around the late 2000s and early 2010s the overall pattern shows a consistent decline. This suggests that India has improved its energy efficiency and production technologies, allowing the economy to produce more output with relatively lower carbon emissions. Factors such as the adoption of cleaner technologies, increased use of renewable energy, and improvements in industrial efficiency may have contributed to this trend.

#### Trend of GDP per Capita

The second graph presents the trend in GDP per capita, which represents the average income level and serves as an indicator of economic growth. The graph shows a steady upward trend, indicating strong economic expansion during the study period. GDP per capita increased from approximately 532 USD in 1990 to around 2397 USD in 2024.

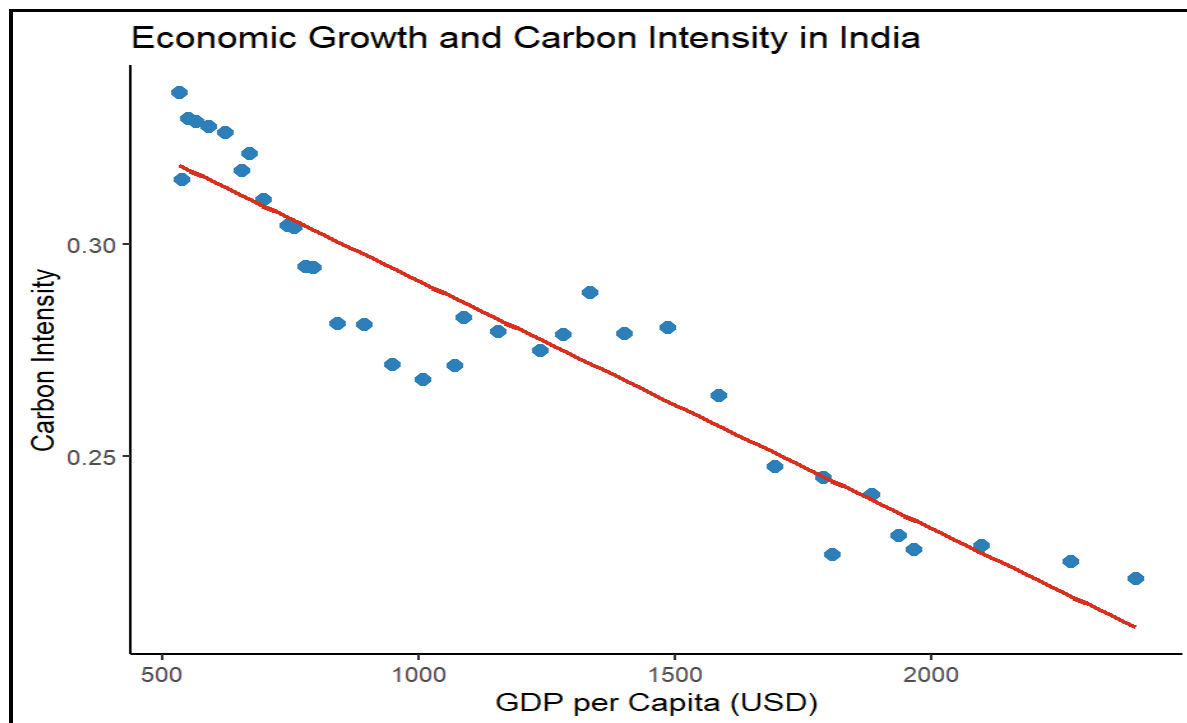


**Figure 1: Trends in Carbon Intensity and GDP per Capita in India (1990–2024)**

The growth appears gradual during the 1990s and early 2000s, followed by a more rapid increase after the mid-2000s. Although there is a slight dip around 2020 likely reflecting economic disruptions during that period the overall trajectory remains strongly positive.

#### **Relationship between Economic Growth and Carbon Intensity in India (1990–2024)**

The figure presents a scatter plot illustrating the relationship between GDP per capita and carbon intensity in India during the period 1990–2024. Each point in the graph represents an annual observation, while the red line represents the fitted regression line that shows the overall trend between the two variables. The graph clearly shows a negative relationship between GDP per capita and carbon intensity. As GDP per capita increases, carbon intensity declines. In the early years of the sample, when GDP per capita was relatively low (around 500–700 USD), carbon intensity was higher, exceeding 0.32–0.33. However, as economic growth progressed and GDP per capita increased beyond 1500–2000 USD, carbon intensity gradually declined to approximately 0.22–0.24. The downward slope of the regression line indicates that higher income levels are associated with lower carbon intensity. This suggests that economic growth in India has been accompanied by improvements in energy efficiency, technological development, and structural transformation of the economy. As countries develop, industries often adopt cleaner technologies, improve energy efficiency, and shift toward less energy-intensive sectors such as services. Overall, the figure provides visual evidence supporting the empirical results of the study. It indicates that economic growth in India during the period 1990–2024 has been associated with a steady reduction in carbon intensity, suggesting that development has contributed to improving environmental efficiency.



**Figure2: Relationship between Economic Growth and Carbon Intensity in India (1990–2024)**

### Discussion:-

The findings of this study provide important insights into the relationship between economic growth and carbon intensity in India during the period 1990–2024. The analysis based on descriptive statistics, correlation results, and graphical trends indicates a strong inverse relationship between GDP per capita and carbon intensity. This suggests that as the Indian economy has expanded over time, the amount of carbon emissions generated per unit of economic output has gradually declined. The descriptive statistics reveal a clear pattern of economic expansion over the study period. GDP per capita increased significantly, reflecting sustained economic growth and rising income levels. At the same time, carbon intensity shows a gradual decline. This indicates that the economy has become more efficient in terms of the amount of carbon emissions produced per unit of output.

The graphical trends further support these findings. The time-series graph of carbon intensity shows a consistent downward movement over the study period. Although there are small fluctuations in certain years, the overall trend indicates a steady reduction in carbon intensity. In contrast, the trend for GDP per capita shows a clear upward trajectory, reflecting continuous economic growth in India since the early 1990s. The correlation analysis provides additional evidence of this relationship. The correlation coefficient between GDP per capita and carbon intensity is  $-0.943$ , indicating a very strong negative association between the two variables. This implies that higher levels of income are associated with lower carbon intensity. In other words, as economic activity expands, the amount of carbon emissions generated per unit of output tends to decrease.

Several factors may explain this pattern. One possible explanation is technological progress and improvements in energy efficiency. As economies develop, industries often adopt more efficient technologies and production processes, which reduce energy consumption and carbon emissions relative to output. Advances in industrial technology, improved energy management, and the adoption of cleaner production methods may have contributed to the observed decline in carbon intensity. Another important factor is structural transformation within the economy. Economic development often leads to a gradual shift from agriculture and heavy industry toward the service sector. Since the service sector generally requires less energy and produces fewer emissions, this shift can reduce the overall carbon intensity of the economy. In addition, policy initiatives aimed at improving environmental sustainability may also play an important role. Over the past two decades, India has increasingly focused on improving energy efficiency, expanding renewable energy capacity, and promoting sustainable development.

strategies. These efforts can contribute to reducing carbon emissions relative to economic output. Overall, the findings suggest that economic growth in India has been accompanied by improvements in environmental efficiency. The decline in carbon intensity alongside rising GDP per capita indicates that the economy has been able to generate higher levels of output while gradually reducing the carbon emissions associated with production. This pattern highlights the potential for economic development and environmental efficiency to progress simultaneously.

### Conclusion and Policy Implications:

This study examined the relationship between economic growth and carbon intensity in India over the period 1990–2024. Using descriptive statistics, correlation analysis, and graphical trends, the study explored whether economic growth has been associated with changes in environmental efficiency. The results reveal a clear pattern in which GDP per capita has steadily increased while carbon intensity has gradually declined over time. The descriptive statistics indicate substantial economic progress in India during the study period, reflected in the significant rise in GDP per capita. At the same time, carbon intensity has shown a downward trend, suggesting that the economy has become more efficient in terms of carbon emissions per unit of output. The correlation analysis further confirms this pattern, showing a strong negative relationship between GDP per capita and carbon intensity. This finding implies that higher levels of economic development are associated with lower carbon intensity. Overall, the results suggest that economic growth in India has been accompanied by improvements in environmental efficiency. As income levels increase, industries tend to adopt better technologies, improve energy efficiency, and shift toward less energy-intensive sectors. These changes contribute to reducing the amount of carbon emissions generated relative to economic output.

### Policy Implications

The findings of this study have several important policy implications. First, policymakers should continue to encourage technological innovation and energy efficiency improvements. Investment in modern production technologies and cleaner industrial processes can help reduce carbon intensity while supporting economic growth. Second, expanding the use of renewable energy sources such as solar, wind, and hydropower can play a crucial role in reducing carbon emissions. Increasing the share of renewable energy in the national energy mix can significantly improve environmental sustainability while meeting the growing energy demand of a developing economy.

Third, promoting structural transformation toward less carbon-intensive sectors, particularly services and technology-based industries, can help maintain economic growth while reducing environmental pressure. Encouraging sustainable industrial practices and energy-efficient infrastructure can further support this transition. Finally, strengthening environmental policies and regulatory frameworks can help ensure that economic growth remains environmentally sustainable. Policies that promote energy conservation, carbon reduction strategies, and sustainable development practices will be essential for achieving long-term environmental and economic goals. In conclusion, the evidence suggests that economic growth and environmental efficiency can progress simultaneously. By adopting appropriate policies and promoting technological advancement, India can continue to pursue economic development while reducing its carbon intensity and improving environmental sustainability.

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