The Influence of the Growth of Renewable Energy on India's National CO_2 Emissions - A Quantitative Analysis (2012-2021)

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Research Question: To what extent has the growth of renewable energy generation in India been associated with changes in national CO_2 emissions between 2012 and 2021?

Abstract

This study investigates the extent to which the growth of renewable energy generation in India has been associated with changes in national CO_2 emissions over the period 2012 to 2021. Using secondary data obtained from the World Bank, the analysis focuses on two key variables: CO_2 emissions and renewable energy consumption as a percentage of total final energy consumption. The data were analyzed using graphical trend analysis and a scatter plot, followed by calculation of the line of best fit, coefficient of determination (R^2), and Pearson's correlation coefficient (r). The findings reveal a weak negative correlation between renewable energy consumption and CO_2 emissions, indicating that while increases in renewable energy share are associated with slight reductions in emissions, the relationship is neither strong nor consistent. The results suggest that broader structural factors, including rising energy demand and continued reliance on fossil fuels, limit the effectiveness of renewable energy in reducing emissions. The study concludes that renewable energy expansion alone is insufficient to drive substantial decarbonization, highlighting the need for a more comprehensive policy approach.

Keywords: renewable energy, CO_2 emissions, India, Pearson correlation, energy transition

Introduction

With Delhi's skies turning hazardous each winter, is India's renewable energy boom actually making a dent in CO_2 emissions?

Climate change is a long-term shift in Earth's average weather patterns, primarily driven by human activities, such as burning fossil fuels since the 1800s, which release heat-trapping greenhouse gases (like carbon dioxide and methane) into the atmosphere. This causes the planet to warm, leading to more extreme weather, rising sea levels, and ecosystem disruptions. Climate change is a pressing issue worldwide as it affects natural ecosystems, human health, economic stability, and beyond. A recent report by Martinich and Crimmins (2019), for instance, examined how climate change could affect 22 sectors of the US economy under two scenarios: if global temperatures rose by 2.8˚ C from pre-industrial levels by 2100, and by 4.5˚ C. The study projected that if the higher-temperature scenario prevails, climate change impacts on these 22 sectors could cost the U.S. $520 billion each year. If we can keep it to 2.8˚C, it would cost $224 billion less. In any case, the U.S. stands to suffer large economic losses due to climate change, second only to India, according to another study.

India is recognized as one of the largest emitters of greenhouse gases, largely due to its massive population, rapid economic growth, and heavy reliance on fossil fuels (especially coal). While India's per capita emissions remain significantly below the global average, its total emissions make it the third-largest emitter globally, behind China and the United States. As the third-largest global GHG emitter, India accounted for just over 7% (22 billion tonnes CO_2) of global emissions during 2015-2020, excluding land-use change. Since adopting the Paris Agreement, India's emissions have continued to grow at an average rate of 1.8%, except in 2020, when emissions from activities were likely affected by COVID-related lockdowns (Climate TRACE, 2022). Two sectors, energy and manufacturing, are responsible for more than half of the country's emissions. India is also ranked among the top for agricultural emissions in 2026; in 2015, it was first.

Despite the rapid expansion of renewable energy generation in India over the past decade, the question of whether this growth has led to a significant reduction in overall CO_2 emissions remains unanswered. Even though installed capacity from solar, wind, and other renewable sources has grown significantly, fossil fuels, especially coal, remain a major source of energy due to population growth, urbanization, and economic expansion (Chaturvedi Shharma et al., 2025). This uncertainty highlights the core research problem of this study, leading to the following research question: **To what extent has the growth of renewable energy generation in India been associated with changes in national CO_2 emissions over time?**

This research paper aims to analyze the correlation between renewable energy use and CO_2 emissions in India by examining data on these variables over a 10-year period.

Conceptual and Theoretical Background

Negative externalities occur when the production and/or consumption of a good or service exerts a negative effect on a third party independent of the transaction (Loo, 2023). Take CO_2 emissions from a factory or a power plant. The firm burns fossil fuels to produce electricity or goods. This benefits the firm (profits) and consumers (lower prices, energy, and products). However, the CO_2 released into the atmosphere harms crops, buildings, and human health. The high concentration of carbon dioxide in the atmosphere affects the global climate, leading to extreme weather events, rising temperatures, sea-level rise, and health issues. The release of carbon dioxide into the atmosphere also adversely affects vulnerable populations such as children, the elderly, and patients suffering from asthma and heart disease. The key point is that the firm does not pay for these environmental and social costs. The costs are "external" to the market transaction. As a result, the marginal private cost borne by the producer is marked at the MPC, which is lower than the marginal social cost (MSC).

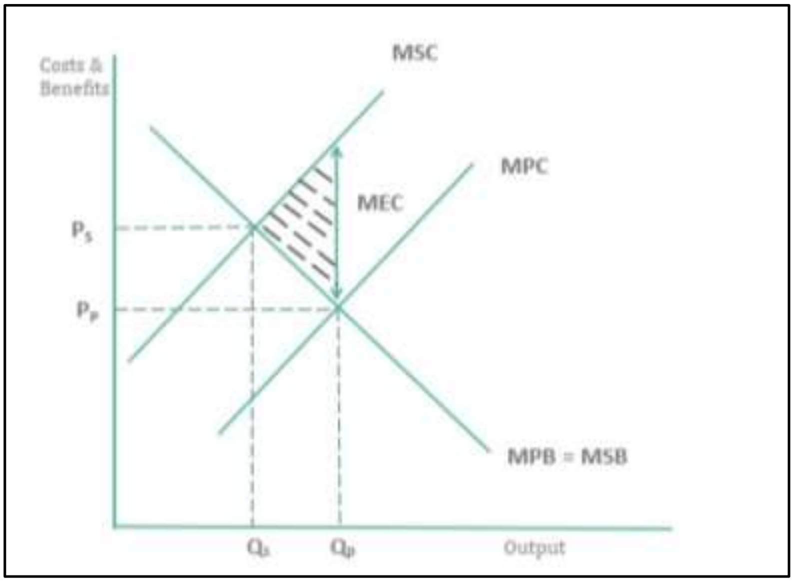

Figure 1: Negative externality of production

Negative externalities are commonly addressed through government intervention to correct market failure and reduce welfare loss. Governments may directly regulate or prohibit activities that generate high external costs, such as smoking bans to limit exposure to secondhand smoke or environmental regulations that restrict emissions and hazardous waste disposal. In addition, market-based instruments like tradable pollution permits can be used to internalize externalities. Under a cap-and-trade system, an acceptable level of pollution is set, and firms must hold permits to emit, creating price signals that reflect marginal social costs (Eldridge, 2023). This approach promotes allocative efficiency by allowing emissions reductions to occur where marginal abatement costs are lowest. British economist Arthur Pigou proposed that governments tax producers in proportion to the harm their production caused to third parties. Ideally, such Pigouvian taxes return the external effects of the transaction to the parties involved ("internalizing an externality"), thus restoring the efficiency of the markets involved (Britannica, 2025). One common example of a Pigouvian tax is a carbon tax.

Beyond these measures, renewable energy serves as an important policy response to environmental externalities by addressing the market failure associated with carbon-intensive energy production. Renewable energy is energy from sources that are naturally replenishing yet flow-limited; renewable resources are virtually inexhaustible, but their availability is limited (U.S. Energy Information Administration, 2023). Popular sources of renewable energy include solar, wind, hydropower, tidal, geothermal, and biomass (EDF, 2024). As aforementioned, fossil fuels generate significant negative externalities because their use results in CO_2 emissions whose social costs are not fully reflected in market prices. The marginal external cost of energy consumption decreases as energy production shifts toward renewable sources such as solar and wind, thereby lowering the carbon intensity of electricity generation. Even as energy demand rises, a greater reliance on renewable technologies can lower overall emissions because they generate little to no direct emissions (United Nations, 2025). Governments often support this transition through policy instruments such as subsidies, feed-in tariffs, and renewable purchase obligations, which improve the competitiveness of renewables relative to fossil fuels. Theoretically, therefore, increasing the share of renewable energy helps correct market failure (Attanayake et al., 2024).

Overview of Sectoral Emissions and Renewable Energy Expansion in India

Energy sector: India's power sector is heavily reliant on coal, which accounted for roughly 95% of the sector's emissions in 2023. Coal remains the primary energy source, accounting for 46% of the total energy supply as of

2023. Thermal power plants (coal and gas) represent about 50.5% of India's total installed capacity (240 GW out of 476 GW as of June 2025). These plants are the primary sources of scope 1 emissions, which are estimated to reach 1,200 million tonnes per annum (mtpa) by 2030. Power sector emissions surged by 7% in 2023, reaching a high of 1.4 billion metric tons of CO_2 (Statista, 2023). This rise has been driven by rapid economic growth and rising energy demand across the industrial, domestic, and agricultural sectors. This structural reliance on coal makes decarbonization heavily dependent on the scale and pace of renewable substitution

Transportation sector: Roughly 90% to 94% of all transportation-related CO_2 emissions come from road transport, making it one of the most carbon-intensive sectors. 95% of its energy needs are met by gasoline and diesel, indicating a highly fossil fuel-dependent energy structure. Despite making up only 3% of all vehicles on the road, heavy-duty vehicles (trucks) are the sector's biggest contributors, accounting for 44% to 45% of transportation emissions. This indicates a disproportionate emissions intensity and a higher marginal social cost (Leichter, 2025). India's transportation emissions increased by 429% between 1990 and 2024, driven by rising vehicle ownership and freight demand, fueled by higher incomes, urbanization, and the expansion of supply chain and logistics networks.

Manufacturing sector: India's manufacturing sector accounts for nearly 25% of energy-related CO_2 emissions**,** driven largely by hard-to-abate industries such as steel and cement. This high carbon intensity stems from a heavy reliance on captive coal power and high-heat thermal processes.

Agricultural sector: Agriculture generates emissions mainly from methane produced by enteric fermentation in livestock and from anaerobic paddy cultivation, as well as nitrous oxide from nitrogen-intensive fertilizers. Diesel-based mechanization further adds to fossil-fuel emissions. While agriculture is a major source of emissions overall, its contribution to CO_2 is comparatively lower but still significant in aggregate (Joiner and Toman, 2023).

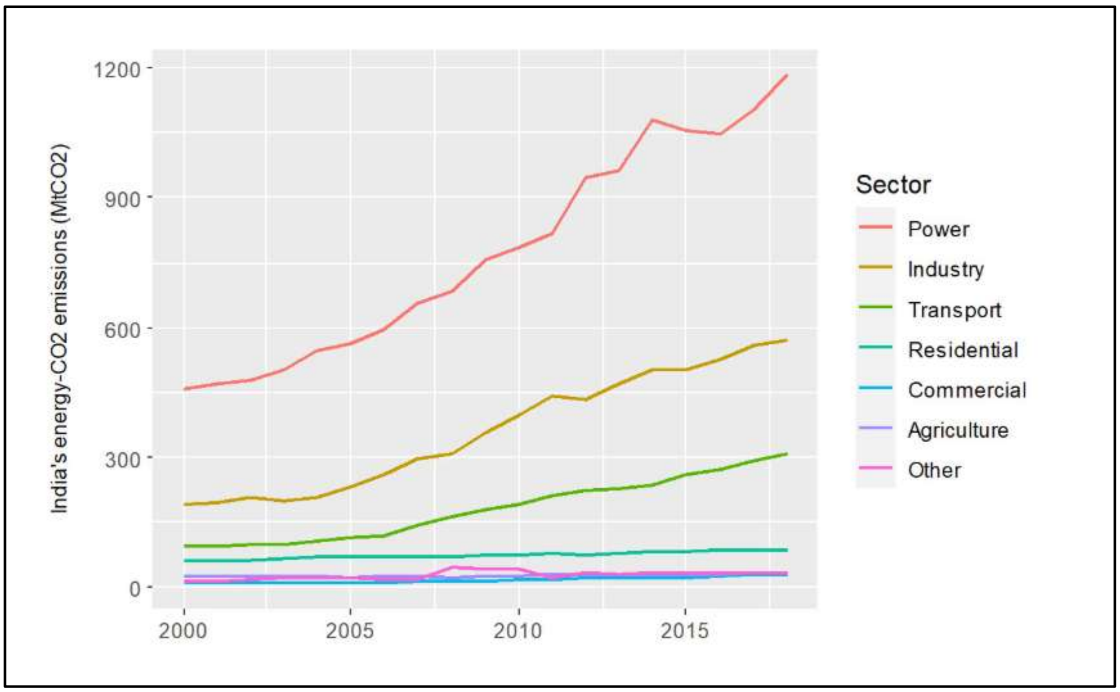

Figure 2: Sector-wise trends in CO2 emissions from energy use in India (Jain, 2018)

India's commitment to renewable energy is anchored in its Nationally Determined Contributions (NDCs) under the Paris Agreement, which were significantly augmented in 2022. The country now aims to achieve 50% of its cumulative installed electric power capacity from non-fossil-fuel-based energy resources and to reduce the emissions intensity of its GDP by 45% by 2030 (PIB, 2025b). In June 2025, India achieved a significant milestone by surpassing the 50% non-fossil capacity threshold five years ahead of schedule (Pandey, 2025). By late 2025, the country's total non-fossil capacity exceeded 262 GW (PTI, 2026). This progress reflects a structural shift toward a low-carbon growth paradigm, underpinned by strategic policy interventions and long-term regulatory certainty.

The scale of investment in this sector has reached unprecedented levels, with total investments in the first quarter of 2025 hitting $9.84 billion, a nearly eight-fold increase compared to the same period in 2024 (PIB, 2025a). While public sector undertakings like NLC India Limited receive significant capital infusions to expand their renewable arms, the majority of the sector's growth is fueled by private sector participation, encouraged by 100% Foreign Direct Investment (FDI) under the automatic route. Large-scale projects, such as the sanctioned 55 solar parks with a combined capacity of 40 GW (IBEF, 2025), provide the necessary infrastructure for these investments. Institutional and regulatory frameworks have been critical catalysts; specifically, the Renewable Purchase Obligation (RPO) trajectory mandates that distribution companies (discoms) procure an increasing share of their power from renewable sources, reaching a target of 43% by 2030. Furthermore, the shift from fixed tariffs to transparent, competitive bidding auctions conducted by the Solar Energy Corporation of India (SECI) has led to record-low tariffs and increased market confidence, effectively de-risking long-term projects for international and domestic financiers alike.

Building on this policy and investment landscape, the subsequent section undertakes an empirical analysis of India's energy transition. It quantitatively examines trends and evaluates the statistical relationship between CO_2 emissions and renewable energy consumption, offering data-driven insights into the effectiveness of decarbonization strategies and their broader macroeconomic and environmental implications.

Methodology

This study adopts a quantitative, secondary data-based approach to examine the relationship between renewable energy growth and CO_2 emissions in India. Using the World Bank's data bank, data on two variables were collected: CO_2 emissions and renewable energy consumption (% of total final energy consumption). The World Bank was chosen as the source to obtain this data due to its credibility and consistency in data collection and reporting.

The dataset covers the period from 2012 to 2021. These years were chosen because consistent data were available for both variables. The time frame was considered appropriate because it captures medium-term trends while minimizing short-term volatility, enabling meaningful analysis of structural changes in India's energy transition.

After data collection, the data were first visualized using line charts to identify individual trends in CO_2 emissions and renewable energy consumption over time. This provided a descriptive foundation for understanding directional changes in each variable. Subsequently, a scatter plot was constructed, plotting renewable energy consumption against CO_2 emissions for each year. A line of best fit was derived to model the relationship between the two variables, and the coefficient of determination (R^2) was calculated. To further quantify the strength and direction of the relationship, Pearson's product-moment correlation coefficient was calculated by taking the square root of the R^2 value. The resulting value was interpreted using this scale to assess the extent of association between the two variables.

Data Collection

Year	CO_2 emissions	Renewable energy consumption (% of total final energy consumption)
2012	2015.3	34.8
2013	2072.6	34.9
2014	2237.7	33.9
2015	2278.2	33.4
2016	2312	33
2017	2441.2	32.5
2018	2556.7	32.9
2019	2551.5	33.5
2020	2357	36.1
2021	2597.9	34.9

Data Analysis

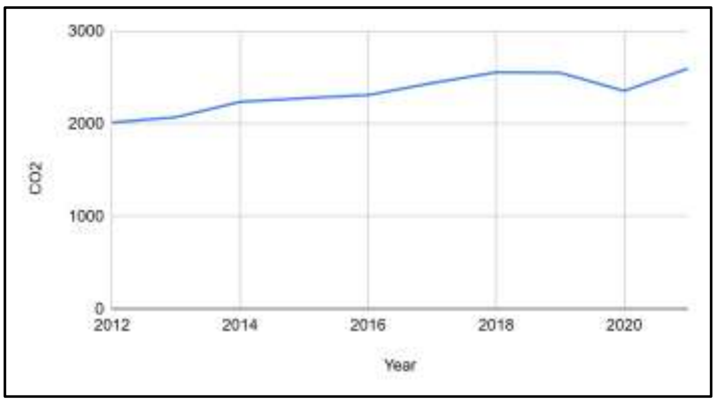

Figure 3: CO_2 Emissions in India (2012–2021)

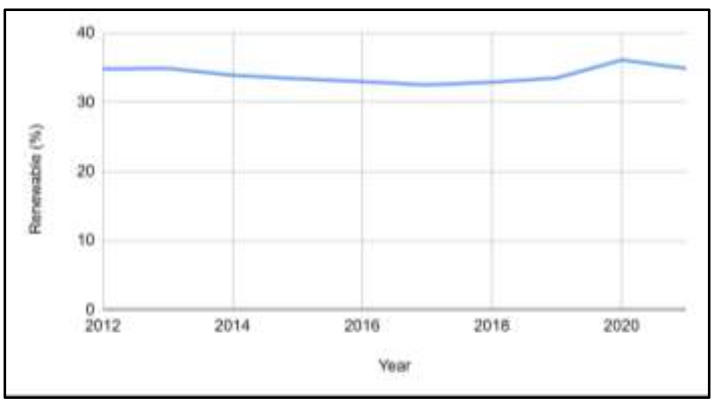

Figure 4: Renewable Energy Consumption (% of Total Final Energy) in India (2012-2021)

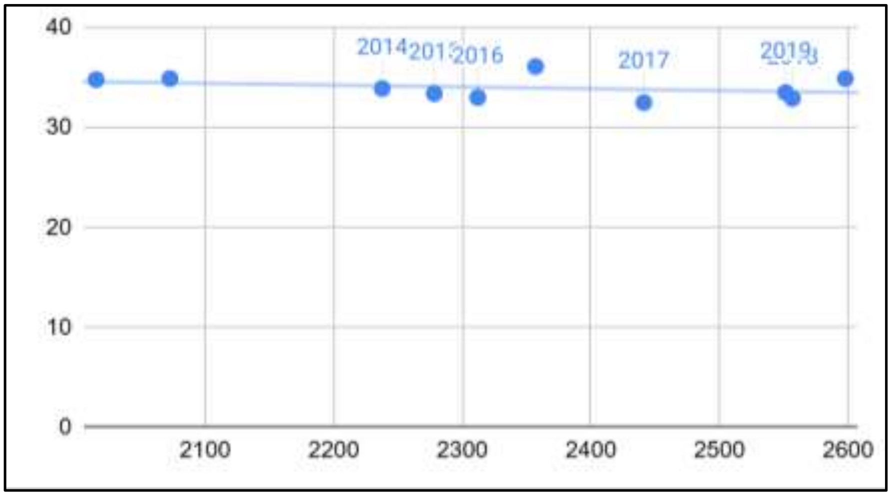

Figure 5: Scatter Plot Showing Relationship Between Renewable Energy Consumption and CO_2 Emissions (2012-2021)

Based on the plotted scatter graph and the line of best fit, the coefficient of determination is □$^2 = 0.101$. Pearson's correlation coefficient (r) is calculated by taking the square root of this value and assigning a negative sign due to the downward slope of the line of best fit, giving □ $= -0.318$. This value indicates a weak negative correlation, suggesting that as the share of renewable energy increases, CO_2 emissions tend to decrease slightly. However, this inverse relationship is neither strong nor consistent, as reflected in the variability of the data over time.

Discussion

The weak negative correlation indicates that, while there is a slight tendency for increased renewable energy utilization to be associated with reduced CO_2 emissions, the relationship is insufficiently strong to establish causation. This suggests that the growth of renewable energy was not the primary driver of emissions trends in India between 2012 and 2021.

The data instead point to a broader structural issue: although the share of renewable energy is slowly growing, total emissions continue to rise. This can be explained by underlying macroeconomic and demographic factors. India's rapid population growth, urbanization, and industrialization have led to a significant increase in energy demand, with total energy use more than doubling since 2000. At the same time, fossil fuels continue to dominate the energy mix, accounting for over 70% of total energy consumption in recent years (IEA, 2021). As a result, increases in renewable energy capacity often occur alongside continued growth in fossil fuel use, particularly in sectors such as transportation, industry, and infrastructure.

This dynamic highlights an issue of scale and substitution. While renewable energy contributes to the overall energy mix, it has not yet expanded sufficiently to replace fossil fuels. Instead, it is frequently added on top of existing energy sources to meet rising demand instead of replacing them. Consequently, an increase in the proportion of renewable energy does not necessarily correspond to an absolute decline in fossil fuel consumption (Macrotrends, 2025).

Structural and infrastructural constraints further limit the impact of renewables. Renewable sources like solar and wind are intermittent, and the lack of advanced energy storage technologies reduces their reliability. In addition, grid capacity constraints and integration challenges limit efficient distribution. Policy implementation gaps and regional disparities in infrastructure development also slow the transition toward a low-carbon energy system.

Overall, the findings suggest that increasing the share of renewable energy alone is insufficient to significantly reduce CO_2 emissions. Effective climate policy must also address total energy demand, improve energy efficiency, and invest in supporting infrastructure such as storage and grid systems. A more comprehensive approach is therefore required to achieve meaningful emissions reductions.

Conclusion

India's move toward renewable energy is a major policy and structural shift aimed at addressing the problems associated with fossil fuels. The goal of this study was to determine how much renewable energy generation has affected national CO_2 emissions. Although renewable capacity has grown quickly and policy frameworks have strengthened, the data show that this change has not led to a proportional reduction in overall emissions. The statistical analysis revealed a weak negative correlation between the share of renewable energy and CO_2 emissions, suggesting that while renewables may help reduce emissions, their effect remains limited.

Total energy demand has increased significantly due to rapid economic growth, industrialization, and population expansion. This is often faster than the growth of renewable energy sources. As a result, fossil fuels, especially coal, remain dominant, with renewable energy often added to carbon-intensive systems rather than replacing them. Furthermore, infrastructural bottlenecks such as limited grid capacity, storage inefficiencies, and asymmetric policy implementation reduce the operational efficiency and scalability of renewable integration. Persistent sectoral dependence on carbon-intensive inputs**,** particularly in transport and manufacturing, further entrenches this trajectory. Collectively, these factors underscore that the relationship between renewable energy expansion and emissions reduction is non-linear and constrained by broader macroeconomic conditions, including rising energy demand and fossil fuel lock-in.

The findings have important policy implications. Focusing solely on increasing the share of renewable energy is not enough to achieve meaningful decarbonization. Instead, a multidimensional policy framework is required that facilitates the gradual replacement of fossil fuels, improves energy efficiency through technological optimization, and encourages capital-intensive investments in grid modernization and energy storage systems. Also, a good climate strategy needs to include demand-side management and consumption rationalization to deal with the real causes of emissions growth.

Therefore, in response to the research question, the growth of renewable energy in India has reduced CO_2 emissions only **to some extent**, with its effectiveness limited by structural rigidities, macroeconomic pressures, and the continued dominance of fossil fuel-based energy systems.

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