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Research Paper

Assessing the Economic Implications of Climate Change in India: An Analysis of Resilience, Adaptation, and Sustainable Growth

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ABSTRACT

Climate change has an impact on all the natural ecosystems as well as the socio-economic condition of India. It has been projected that climate change would severely degrade the current living conditions of poverty-stricken people to the point that it would impose heavy taxes on the economic and industrial resources owned by the state. Rapid economic growth, widespread poverty and high population density have made India vulnerable to climate risk. This study is based on secondary data obtained from the World Bank and the International Energy Agency Statistics. Thirty years of data from 1990-2020 have been used to examine how environmental and climatic factors influence economic growth, focusing on estimating both marginal and joint counterfactual effects. The findings present a complex and counterintuitive picture of how environmental and climatic factors influence India's economic growth from 1990 to 2020. Furthermore, the study has highlighted the policies that connect economic planning with climate action.

Keywords: *Climate Change, Poverty, Economic Growth, Low-Carbon Future, Climate-Resilient*

Climate change affects our society in numerous ways (Klingelhöfer *et al.*, 2020). Climate change (CC) is a multidimensional global concern that affects ecology, environment, and various socio-economic variables (Adom, 2024). Since the late-19th century, the World has become concerned about climate change and global warming, which have become one of the most concerning issues of the 21st century (Zhao *et al.*, 2022). Global temperatures have increased, precipitation patterns have changed, and severe weather events have become more frequent and intense as a result of the growing concentration of greenhouse gases in the atmosphere, which is mostly caused by human activities like the burning of fossil fuels and deforestation (IPCC, 2021). These changes have a significant influence on human health, food security, natural resources, and general well-being, with poor countries and vulnerable communities being disproportionately affected.

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Since the late 1960s, there has been a growing awareness of the interdependence of development and the environment (Sharma & Chakrabarti, 2024). This cleared the way for the inclusion of the environment in development discourse and the pursuit of sustainable development. Global, national, and regional development plans have begun to converge with mutually agreed-upon criteria, with the primary goal of making their economies robust to climate change (Marquardt, Fünfgeld and Elsässer, 2023). As a result, the global economic growth framework has been reformed to account for energy supply and environmental 'well-being.' One of the key impediments to accomplishing these objectives has been highlighted as technological inefficiency. According to the Paris Agreement (2015), 196 nations have committed to lowering emissions with stated emission targets under the United Nations Framework Convention on Climate Change (UNFCCC) (Purvis, Mao and Robinson, 2019). The majority of South Asian countries joined the Paris Agreement. They also establish a time frame for reducing emissions. Energy demand and supply-side management have also acquired importance (ibid., Sharma & Chakrabarti).

Energy is the lifeline of a modern economy and the basis for development (World Bank, 2025). In the case of emerging countries, the energy sector is crucial because of the ever-increasing energy demands that necessitate massive expenditures to satisfy. To achieve the objectives of sustainable development, it is essential. Energy is necessary for socioeconomic growth to raise living standards, increase productivity, convey items efficiently to the place of demand, and serve as an input for various economic production activities (Zeng, Li and Magazzino, 2024). For industrialised nations, energy is a symbol of material comfort; for underdeveloped nations, it is a means of eradicating poverty (UNIDO, 2022). The previous three centuries have seen a significant increase in humankind's reliance on the usage of fossil fuels (coal, oil, and gas). But the rising costs of environmental degradation are a side effect of using energy to fuel the economic expansion of many countries. Over the past ten years, the environment's influence on climate change, often known as global warming or the greenhouse effect, has been the most significant environmental problem. Globally, thousands of scientists and decision-makers have been building an increasingly compelling case that climate change threatens human existence and sustainable development (Usenobong & Godwin, 2012).

The negative impact of climate change has begun to manifest itself in many ways around us, there is, however, room for us to address and lessen these effects through coordinated climate action. The landscape of tomorrow will be determined by the actions we take now and how we affect the global climate catastrophe. The Intergovernmental Panel on Climate Change (IPCC) in 2018 indicated that we have fewer than 11 years to implement the essential changes to mitigate the worst effects of climate change. However, to prevent global warming over 1.5°C, or the point at which the worst effects of climate change may be avoided, the amount of carbon dioxide in the atmosphere would need to be reduced by 45 per cent by 2030 (Abbass *et al.*, 2022).

India has more than 1.46 billion inhabitants, making up nearly 18 per cent of the world's population (UNFPA, 2025), but uses only 6.1 per cent of the world's primary energy (IEA, 2021). In 2016, India's total GHG emissions, excluding Land Use Land-Use Change and Forestry (LULUCF), were 2,838.89 million tonnes of CO_2e, and 2,531.07 million tonnes of CO_2e when LULUCF was included. Carbon dioxide emissions accounted for 2,231 million tonnes (78.59 per cent), methane emissions for 409 million tonnes CO_2e (14.43 per cent), and nitrous oxide emissions for 145 million tonnes CO_2e (5.12 per cent) (MoEFCC, 2021).

According to India's Biennial Update Report (2021), India has gradually decoupled its economic growth from greenhouse gas emissions. Between 2005 and 2016, India reduced its GDP emission intensity by 24 per cent (ibid., MoEFCC).

The effects of climate change are extremely severe for India. Given that over 50 per cent of Indians work in agriculture and other industries vulnerable to climate change, the effects on productivity and health are considerable. Nearly 700 million people live in rural India, where their sustenance and livelihood are directly dependent on climate-sensitive industries and natural resources like water, biodiversity, mangroves, coastal areas, and grasslands (CIFRI, 2018). Many Indians reside in hotspots, where climatic fluctuations have a detrimental impact on living conditions. According to estimates by Mani et al. (2018), 148.3 million people in India would live in severe hotspots by 2050. These hotspots are expanding due to the negative impact of climate change.

Rapid economic growth, widespread poverty and high population density have made India vulnerable to climate risk. The reports of the Intergovernmental Panel on Climate Change (2014, 2021, & 2022) have often identified India as a global hotspot of climate impacts. According to an analysis by the Council on Energy, Environment, and Water (CEEW) in 2020, three out of every four districts in India are hotspots for extreme events, and 40 per cent of the districts show a swapping trend, meaning that areas that have historically experienced flooding are now experiencing more frequent and severe droughts, and vice versa. Furthermore, according to the IPCC (2018), there is a high degree of certainty that every degree of temperature increase will result in a 3 per cent increase in precipitation, which will exacerbate floods and cyclones.

India is presently the world's fourth-largest economy, surpassing Japan, and is expected to become the third-largest by 2030, according to the International Monetary Fund (2025). It has grown at an average annual pace of more than 6.5 per cent during the last few decades. However, according to the Global Climate Risk Index 2021, India is the seventh most climate-impacted country in the world between the years 1999 and 2018. This has been further exacerbated by events such as the Kerala floods in 2018, Cyclone Fani in 2019, Cyclone Amphan in 2020, and the heatwaves in 2022 and 2023. Furthermore, in 2023, Reserve Bank of India (RBI**)** projected that by 2030, 4.5 per cent of India's GDP could be at risk due to labour-hours, extreme weather events, reduction in labour hours, decline in agricultural productivity and infrastructural damages and if timely, adequate adaptation and mitigation measures are not undertaken this could push over 45 million Indians into poverty by 2030 (World Bank, 2018). This will largely hamper India's progress on the Sustainable Development Goals.

India has played a significant role in international climate negotiations for a long time (PIB, 2025). It has started adopting a wide range of national and state-level policies to increase energy efficiency, create clean energy sources, and get ready for the effects of climate change. It is expected to contribute more than any other nation, around one-fourth of the total, to the anticipated increase in the world's energy consumption. An extra 270 million people are anticipated to reside in India's cities by 2040 (IEA, 2021). Rapid urbanisation has become detrimental due to less credence given to climate-resilient techniques. This would increase demand from industries that use a lot of energy (ibid., IEA).

Despite the growing attention and existing studies, research gaps persist in understanding the integrated economic implications of climate change in India. It has been noticed that many studies focus on sectoral analysis without examining the macroeconomic linkage, limiting evidence on how climate change shocks translate into long-term economic risk or on how policies and financial instruments can enhance resilience. While adaptation measures are being adopted, their economic efficiency and scalability remain unexplored. Hence, to address these persisting research gaps, this paper's objective is to examine the economic implications of climate change in India, emphasising the interconnected dimension of resilience, adaptation and sustainable growth. Furthermore, the study aims to highlight the policies that connect economic planning with climate action to mitigate India's economic risks while promoting a climate-resilient and low-carbon future.

LITERATURE REVIEW

For the last 50 years, the linkages between economics and environmental challenges have been among the most prominent themes of discussion among experts in the global economic perspective (Farajzadeh, Ghorbanian and Tarazkar, 2023). Recent studies on climate change (ILO, 2019; RBI, 2022; ABD, 2024) indicate that major near-term macroeconomic impacts are likely, with heat stress potentially endangering up to 34 million jobs by 2030 and nipping approximately 4.5 per cent of the GDP. Furthermore, by 2030, per-capita GDP losses could be as high as 2.6 per cent (Kahn *et al.*, 2019). IPCC (2014), has already predicted that the rise in global mean surface temperature by the end of the 21st century (2081–2100) relative to 1986–2005 would be 0.3°C to 1.7°C under Representation Concentration Pathways (RCP 2.6), 1.1°C to 2.6°C under (RCP 4.5), 1.4°C to 3.1°C under (RCP 6.0) and 2.6°C to 4.8°C under (RCP 8.5). Heat and humidity increase disease burdens and reduce effective labour time, with disproportionate effects on outdoor and informal workers (Venugopal *et al.*, 2025). Roussilhe, G et al. (2024) have shown in their studies that Taiwan's electronics industry serves as a lesson, indicating the potential for carbon lock-in in the absence of simultaneous decarbonization in energy supply and process heat.

In line with economic growth, industrial countries' excessive use of fossil fuels has increased greenhouse gas emissions (i.e., CO_2, CH_4, O_3, and NO_2) in the atmosphere (Xiong et al. 2023), and as a result, many problems, such as global warming, environmental pollution, and their result, "climate change," have emerged. While this condition is concerning for the world's future, it is one of the most critical issues that scientists and politicians must address (Balsalobre-Lorente et al. 2021).

According to Perera *et al.* (2024), an economy or the growth of an economy has always depended on its access to energy resources. According to Borja-Patiño, Robalino-López and Mena-Nieto (2024), it is evident that energy consumption, which accounts for a significant portion of greenhouse gas (GHG) emissions, notably CO_2, is the key determinant of economic development. By-products of primary consumption sources of non-renewable energy, such as fossil fuels, such as CO_2 emissions, are produced (IEA, 2004).

The dominance of fossil fuel-based power generation (Coal, Oil, and Gas) and an exponential increase in population over the past decades have led to a growing demand for energy, resulting in global challenges associated with rapid growth in carbon dioxide (CO_2) emissions (IEA, 2025). Significant climate change has become one of the greatest challenges of the twenty-first century.

The observed and expected climate changes for the twenty-first century, as well as global warming, are significant worldwide shifts that have occurred during the last 65 years. According to Arnell *et al.* (2016), climate change is a multi-governmental problem that affects many aspects of the ecological, environmental, socio-political, and socio-economic disciplines. Since the Industrial Revolution, human activities have emitted significant volumes of carbon dioxide and other greenhouse gases into the atmosphere, altering the earth's climate (ibid., IPCC). Natural phenomena such as fluctuations in solar radiation and volcanic eruptions also have an impact on the Earth's temperature. However, they do not explain the warming that we've seen over the last century. According to IPCC (2023) reports, taking the necessary actions right away can improve the likelihood that the disastrous effects can be avoided. It is not plausible to interpret the exact consequences of climate change on a sectoral basis, as evidenced by the growing level of recognition and the inclusion of climatic uncertainties at both the local and national levels of policymaking (Romanovska, Gleixner and Gornott, 2023).

In order to mitigate climate change, the energy system has to be significantly decarbonised (Sobha, 2025). However, climate change itself also has an impact on energy system components through long-term variations in climatic parameters, variability, and extreme weather events (ibid., IEA).

The Intergovernmental Panel on Climate Change's Fifth Assessment Report highlights the need for more study on how climate impacts on the energy system might be incorporated into cross-sector integrated models.

Greenhouse gases (GHGs) such as CO2, CH4, N2O, and H2O were thought to enter the atmosphere from a variety of natural sources, such as volcanoes, forest fires, and seismic activity, before the industrial revolution (Yue and Gao, 2018). The Conference of the Parties (COP-21) in Paris on December 12, 2015, resulted in a significant agreement between the United Nations Framework Convention on Climate Change (UNFCCC) and other parties to combat climate change and advance and increase the activities and investments necessary for a sustainable low-carbon future (Fujimori *et al.*, 2016). The Paris Agreement builds upon the Kyoto Protocol by uniting all nations around a common cause to take bold steps to halt climate change and prepare for its effects, with more cash provided to help developing nations do so. In light of this, it signifies a turning moment in the struggle against global warming. The main objective of the Paris Agreement is to strengthen the international response to the threat posed by climate change by limiting the increase in global temperature to 1.5 °C and limiting it to well below 2 °C this century (ibid., Fujimori et al.).

After experiencing a number of catastrophes, various economies have attempted to implement a structural shift in manufacturing processes and energy consumption, starting from this broad environmental framework caused by non-renewable sources (Irfan et al., 2021). Through the integration of adaptation strategies, the communities of South Asia are addressing the issue of climate change by combining traditional knowledge, contemporary technology, and supportive policies (Azhoni & Gopakumar, 2021; IPCC, 2022; Islam et al., 2023). It is important to note that the most effective outcomes are achieved through combined efforts that are tailored to the local area.

METHODOLOGY

This study is based on secondary data obtained from the World Bank and the International Energy Agency Statistics. Thirty years of data from 1990-2020 were used to examine how environmental and climatic factors influence economic growth, focusing on estimating both marginal and joint counterfactual effects. The analytical framework employs robust regression and a counterfactual simulation method to isolate and combine the effects of temperature anomaly, particulate matter (PM2.5), greenhouse gas emissions (GHG), and deviations in precipitation on GDP growth. We use temperature anomaly, defined as the difference between the annual temperature and the long-term average, because it reflects climate shocks rather than regular seasonal or geographical variations (Dell et al., 2012). A temperature anomaly is important because unusual warming or cooling can adversely affect energy demand, agriculture, worker productivity, and overall economic activity. Since temperature's effect on economic growth is non-linear, we include the square of the temperature anomaly to capture these effects. Small temperature increases may have minor or even positive impacts, while larger increases can be harmful (Burke et al., 2015). All estimations are conducted using Stata. The subsequent regression model analyses how environmental stressors influence economic performance.

$$Y_t = \beta_1 + \beta_2(temp\_anom)_t + \beta_3(temp\_anom)_t^2 + \beta_4(\text{ln\_PM2.5})_t + \beta_5(\text{ln\_}GHG)_t + \beta_6(precip\_dev)_t + \epsilon_t$$

Where,
β_1 = intercept term
i=2,3,4,5,6= Coefficient terms of each independent variable.
Y_t = GDP growth rate in each year
$(\text{temp\_anom})_t$ = temperature anomaly (Annual average mean surface temperature minus the average temperature of the entire variable for the given period)
$(\text{temp\_anom})^2_t$ = Squared temperature anomaly
$(\text{ln\_PM2.5})_t$ = log natural of PM2.5 mean annual exposure
$(\text{ln\_GHG})_t$ = log natural of Greenhouse Gas emissions
$(\text{precip\_dev})_t$ = precipitation deviation (year-wise precipitation deviation from long-term mean precipitation)
ε_t = error term

Furthermore, the Granger Causality test developed by Dumitrescu and Hurlin (2012) has been used to examine the causal relationship between the environmental stressor (PM 2.5) and economic growth (GDP).

Following regression estimation, the non-linear delta method is used to determine the marginal and joint counterfactual effects. This allows for the formulation of projected GDP growth values under hypothetical scenarios in which specified environmental variables remain at baseline levels while all other covariates maintain their observed values.

In the next step, separate marginal counterfactual scenarios are estimated for each variable. To assess the impact of climate change variables (temperature anomaly, log of PM2.5, log of greenhouse gas emissions, and precipitation deviation), the predicted GDP growth ("Y") is calculated by adjusting each variable to a baseline level while keeping all other variables constant. The marginal counterfactual effect can then be estimated by calculating the GDP growth loss using the following formula:

$$\Delta Y_{variable} = \hat{Y}_{variable} + Y$$

The $\Delta Y_{variable}$ represents the difference between the observed and predicted GDP growth rates. Positive values indicate a GDP growth loss, which means that the actual observed growth rate is lower than the predicted GDP growth rate calculated for each variable at a reference or baseline level. Likewise, distinct marginal effects are determined for precipitation deviations, PM2.5, and GHG emissions. This method allows us to separate each factor's unique contribution to economic performance.

Now, to assess the combined influence of all environmental variables, a joint counterfactual scenario is simulated by simultaneously setting all environmental variables to their baseline values while keeping the original values for other model inputs. The difference between the actual scenario and the GDP growth predicted by this joint counterfactual reflects the overall environmental burden on economic growth.

$$\Delta Y_{joint} = \hat{Y}_{combined} - Y$$

Here,

$\hat{Y}_{combined}$ = Predicted GDP growth rate when all variables are set at their baseline.

Y = Actual Observed GDP growth rate

ΔY_{joint} = Difference between the predicted growth rate when all variables are set at their baseline and the actual growth rate.

Estimating the Impact of Environmental Factors on India's Economic Growth

The regression estimates of the effects of various environmental factors, including PM2.5, greenhouse gas emissions, and climatic anomalies (temperature and precipitation) on India's economic growth, are presented in Table 1. To account for the heteroscedasticity problem in the data, robust standard errors were used while performing the regression.

Table 1: Regression Analysis using Environmental Factors

Linear regression

Number of obs	=	31
F(5, 25)	=	2.80
Prob > F	=	0.0386
R-squared	=	0.4953
Root MSE	=	2.2287

GDP_growth	Coef.	Robust Std. Err.	t	P>|t|	[95% Conf.	Interval]
ln_PM25	18.41165	6.864606	2.68	0.013	4.273727	32.54957
ln_GHG	-6.053806	2.501775	-2.42	0.023	-11.20631	-.9013033
temp_anom	7.407614	2.158752	3.43	0.002	2.961581	11.85365
temp_anom2	4.160935	2.749032	1.51	0.143	-1.500803	9.822672
precip_dev	.0074886	.004595	1.63	0.116	-.0019749	.0169521
_cons	17.54952	19.10709	0.92	0.367	-21.80226	56.90131

Source: Author's Own Calculation; Data Source: World Bank (1990-2020) & IEA (1990-2020)

It is observed that the coefficient of ln_PM2.5 (log of PM2.5 exposure) is positive and statistically significant at 5 per cent ($\beta = 18.412$, $p = 0.013$) in India. This generally means that a 1 per cent increase in PM2.5 concentration is positively associated with an approximate 0.18 percentage increase in GDP growth rate, ceteris paribus. This, however, does not indicate that pollution improves growth; this astonishing result might indicate a short-term correlation between economic growth, which is frequently accompanied by higher pollution.

Similarly, ln_GHG (log natural of greenhouse gas), we see a negative coefficient of -6.05 in the Indian context. So, we can say that the association between ln_GHG and GDP growth is negative (more emissions lower GDP). Moreover, this result is statistically significant (as the p-value is 0.023) at the 5 per cent level of significance. So, a 1 per cent increase in GHG emissions may decrease GDP growth by 0.06 per cent. This result supports the conventional theory that increased greenhouse gas emissions could eventually have a negative impact on economic activity, thereby reducing productivity.

We obtain a strong positive and highly significant coefficient ($\beta = 7.407$, $p = 0.002$) for temp_anom (temperature anomaly) in India. This shows a strong correlation between temperature deviations from historical averages and higher GDP growth. We obtain a positive coefficient for the squared term of the temperature anomaly, or temp_anom2, but this coefficient is statistically insignificant because the p-value is 0.143, which suggests that the relationship is nonlinear. The finding suggests that while there may be a positive correlation between moderate temperature anomalies and economic growth rate, this relationship does not grow quadratically and may even reverse after a certain threshold.

The positive coefficient for precipitation deviation (precip_dev) suggests that a small rise in GDP growth is correlated with higher precipitation deviations from normal levels. However, we cannot conclude with confidence that precipitation anomalies have a significant effect on economic growth in this dataset because this effect is statistically insignificant ($\beta = 0.0075$, $p = 0.116$). Moreover, the general conception is that increased fluctuations in precipitation have a negative effect on economic growth. Although the results indicate an upward trend, there is not enough evidence to suggest a significant correlation between GDP growth rate and precipitation deviation. Therefore, neither the general conception nor its contradiction could be definitively explained by our results.

With an F-statistic of 2.80 and a p-value of 0.0386, the model is statistically significant. Furthermore, with an R^2 of 0.4953, the model explains approximately 49.5 per cent of the variance in GDP growth, indicating that the model's independent variables together explain the economic growth dynamics of our study.

We have used the VIF test to account for the problem of multicollinearity in the model, and the results are satisfactory and are displayed in Table 2. The general rule is that a VIF value less than 10 indicates that the model does not have a multicollinearity problem.

Table 2: Test for Multicollinearity (VIF Method)

Variable	VIF	1/VIF
ln_GHG	2.38	0.419603
temp_anom	1.97	0.506919
ln_PM25	1.49	0.669522
precip_dev	1.37	0.728067
temp_anom2	1.13	0.884232
Mean VIF	1.67	

Source: Author's Own Calculation; Data Source: World Bank (1990-2020) & IEA (1990-2020)

Table 3: Granger Causality Test

Granger causality Wald tests

Equation	Excluded	chi2	df	Prob > chi2
GDP_growth	ln_PM25	2.1148	2	0.347
GDP_growth	ALL	2.1148	2	0.347
ln_PM25	GDP_growth	1.6303	2	0.443
ln_PM25	ALL	1.6303	2	0.443

Source: Author's Own Calculation; Data Source: World Bank (1990-2020)

The regression analysis revealed a positive relationship between the GDP growth rate and the log of PM2.5 concentration. We attempt to identify the reverse causal relationship between these two variables. The Granger Causality test is a statistical method for determining whether the past values of one time series variable can be used to predict another. So, using this test, we can determine whether GDP growth rate causes higher PM2.5 concentrations, as increased economic activity requires more energy, which contributes to pollution. In Table 3, we see that there is no significant causal relationship between the GDP growth rate and the log of PM2.5 (p-value > 0.05). When the log of PM2.5 is the dependent variable, and the GDP growth rate is the explanatory variable, the causal relationship remains insignificant (p-value > 0.05). As a result, we can only speculate that there is a reverse causal relationship between these two variables. However, the general belief is that increased economic activity will result in higher pollution due to increased energy consumption, as explained by the Environmental Kuznets Curve.

Decomposing Growth Effects using Regression-Based Counterfactual Analysis

In order to understand how environmental and climate factors contribute differently to economic growth, we have conducted a marginal counterfactual analysis. This method simulates the expected GDP growth using counterfactual scenarios in which several environmental variables are kept at baseline levels while all other variables remain at their observed values. The marginal impact of each variable on GDP growth can be calculated by comparing these predictions to those made under actual conditions. The analysis focuses on four main environmental factors: temperature anomaly (temp_anom), PM2.5 concentration (PM2.5), greenhouse gas emissions (GHG), and precipitation deviation (precip_dev). The difference between observed and predicted GDP growth under the counterfactual scenario (yhat_variablenameCF) is expressed in percentage points.

Table 4: Computed Marginal Counterfactual Effect towards GDP Growth Rate

Year	GDP_growth	yhat_tempCF	yhat_pm25CF	yhat_ghgCF	yhat_precipCF	growth_loss_temp_pp	growth_loss_pm25_pp	growth_loss_ghg_pp	growth_loss_precip_pp	growth_loss_joint_pp
1990	5.53	9.58	2.66	7.23	6.26	4.04	-2.87	1.70	0.73	-3.19
1991	1.06	7.51	1.45	6.06	6.42	6.45	0.40	5.01	5.36	-1.76
1992	5.48	6.72	0.20	4.74	5.48	1.23	-5.28	-0.74	0.00	-0.33
1993	4.75	7.21	1.92	6.47	6.26	2.46	-2.83	1.72	1.51	-1.90
1994	6.66	7.56	1.59	6.23	5.18	0.90	-5.07	-0.43	-1.48	-1.47
1995	7.57	7.14	2.06	6.93	5.68	-0.44	-5.51	-0.65	-1.90	-1.88
1996	7.55	6.68	1.89	6.99	5.79	-0.87	-5.66	-0.56	-1.76	-1.73
1997	4.05	6.63	-0.44	5.00	3.49	2.58	-4.49	0.95	-0.56	0.49
1998	6.18	7.18	3.72	9.43	7.29	1.00	-2.47	3.24	1.11	-3.82
1999	8.85	6.11	1.57	7.72	6.25	-2.74	-7.27	-1.12	-2.59	-1.83
2000	3.84	5.94	0.87	7.28	5.82	2.10	-2.97	3.44	1.98	-1.25
2001	4.82	5.84	1.51	8.12	6.72	1.02	-3.31	3.30	1.89	-2.01
2002	3.80	5.04	2.93	9.75	9.15	1.24	-0.87	5.95	5.35	-3.57
2003	7.86	6.12	1.60	8.68	6.84	-1.75	-6.26	0.82	-1.02	-2.36
2004	7.92	5.69	1.77	9.18	7.25	-2.23	-6.15	1.26	-0.68	-2.58
2005	7.92	6.05	0.35	7.94	5.13	-1.87	-7.58	0.02	-2.80	-1.10
2006	8.06	5.84	2.52	9.95	6.28	-2.22	-5.54	1.89	-1.78	-2.81
2007	7.66	4.04	1.96	8.82	5.15	-3.62	-5.70	1.16	-2.51	-1.27
2008	3.09	2.73	-0.01	5.92	1.83	-0.36	-3.09	2.83	-1.26	1.90
2009	7.86	0.14	5.84	11.09	7.79	-7.72	-2.03	3.23	-0.08	-2.90
2010	8.50	1.29	6.56	11.62	6.18	-7.20	-1.94	3.13	-2.32	-3.16
2011	5.24	4.09	-0.56	8.60	3.68	-1.15	-5.80	3.36	-1.56	0.12
2012	5.46	6.50	-1.77	11.07	6.41	1.05	-7.23	5.61	0.95	-2.02
2013	6.39	8.32	-1.33	12.20	5.99	1.93	-7.72	5.81	-0.40	-3.01
2014	7.41	7.19	-2.16	12.41	7.25	-0.22	-9.57	5.00	-0.16	-2.84
2015	8.00	6.33	-0.85	12.49	6.85	-1.66	-8.85	4.50	-1.14	-2.89
2016	8.26	6.70	2.69	16.61	10.92	-1.56	-5.56	8.35	2.66	-6.92
2017	6.80	4.58	1.37	13.33	7.11	-2.22	-5.43	6.54	0.32	-3.41
2018	6.45	3.45	-1.23	11.26	5.79	-3.00	-7.68	4.80	-0.67	-1.04
2019	3.87	3.39	0.47	10.54	2.84	-0.48	-3.40	6.67	-1.03	-0.36
2020	-5.78	-0.74	-0.98	4.77	-1.94	5.04	4.79	10.55	3.84	5.02

Source: Author's Own Calculation; Data Source: World Bank (1990-2020) & IEA (1990-2020)

Note:

1. yhat_tempCF = Predicted GDP growth rate if temperature anomaly is maintained at its baseline, eyhat_pm25CF = Predicted GDP growth rate if PM2.5 concentration is maintained at its baseline, yhat_ghgCF = Predicted GDP growth rate if Greenhouse

Gas emissions are maintained at its baseline, yhat_precipCF = Predicted GDP growth rate if precipitation deviation is maintained at its baseline.

2. growth_loss_temp_pp = difference between yhat_tempCF and actual GDP growth, growth_loss_pm25_pp = difference between yhat_pm25CF and actual GDP growth, growth_loss_ghg_pp = difference between yhat_ghgCF and actual GDP growth, growth_loss_precip_pp = difference between yhat_precipCF and actual GDP growth, growth_loss_joint_pp = the difference between the predicted growth rate when all variables are maintained at their baseline and the actual GDP growth.
3. Here, positive values of the "growth_loss" columns indicate a loss of GDP growth relative to the counterfactual (actual growth is lower than counterfactual). Negative values shall indicate a gain in GDP growth relative to the counterfactual (actual growth is higher than counterfactual).

The marginal effect of temperature anomalies on GDP growth follows a dynamic pattern. Temperature anomalies were linked to significant losses in GDP growth in the early 1990s (for example, over 6.45 percentage points lost in 1991 in Table 4), indicating that the actual observed temperature anomalies during these years had a net negative impact on economic performance. However, the magnitude of growth loss decreased over time, even becoming negative in some years. The negative values for growth loss due to temperature anomaly should not be associated with warm temperatures, which are better for economic activity. It is more likely to reflect short-term and region-specific correlations between temperature and economic activity (for example, milder conditions in some years) than a broad statement that warming promotes growth. Furthermore, the temperature anomaly does not affect all countries in the same way, as is widely debated. It has a larger impact on poor countries than on all countries combined (Dell et al., 2012). However, to better understand and theorise the historical relationship between temperature fluctuations and economic activity, various other methods should be used with caution. The relationship between temperature anomaly and economic activity can be investigated further for each specific sector to provide a more compelling argument.

PM2.5 concentrations show a consistent pattern of adverse marginal effects on growth loss in India. Table 4 depicts growth loss value as −5.28 percentage points in 1992, −5.07 in 1994, etc. A negative growth loss indicates that GDP growth under observed pollution levels was higher than under the counterfactual baseline ideal scenario of low PM2.5. This likely reflects the historical coupling between economic activity and air pollution in India, i.e., the periods of robust growth often coincide with industrialisation and increased energy use. Thus, the results do not imply that PM2.5 contributes positively to growth in a welfare sense. Instead, they reflect the underlying pathway of "growth with pollution," common in developing economies, where increased production often brings environmental degradation because the main cause of air pollution is the use of environmental resources for development (Chen et al., 2021). Our results are in accordance with the Environmental Kuznets Curve which states that as a country's economy grows, environmental pollution levels initially increase because of industrialisation, heavy resource use, and lenient regulation and only after reaching a certain income or development threshold, pollution begins to decline as societies adopt cleaner technologies (Shi et al., 2020) (Wang and Komonpipat, 2020).

The marginal effect of GHG emissions shows a different trajectory than PM2.5. For most years, we see a positive growth loss due to GHG emissions, implying that the predicted growth rate due to lower greenhouse emissions is greater than the actual GDP growth. This supports the above regression result that higher GHG concentrations may have a negative impact on the economy. Unlike PM2.5 pollutants, greenhouse gases seemed to have a longer-lasting, negative relationship with growth.

Precipitation deviation varies significantly from year to year, with no consistent pattern. Some years have little impact, while others have a significant effect. This means that precipitation variability influences growth in a context-specific manner, taking into account sectoral composition, such as agriculture, adaptive capacity, and geographical conditions. Overall, the marginal counterfactual effects of precipitation deviations are the smallest and most inconsistent, indicating that precipitation deviations cannot affect or be an important factor of economic growth in our dataset.

The joint counterfactual analysis assesses the impact of all environmental and climatic variables (temperature anomaly, PM2.5 concentration, GHG emissions, and precipitation deviation) on GDP growth. It specifically compares the predicted GDP growth under actual observed values to GDP growth predicted under a counterfactual scenario in which all environmental variables remain constant at baseline levels. The negative values of the joint counterfactual effect on GDP indicate that the joint predicted GDP growth while keeping all environmental factors constant is slightly lower than the actual GDP growth rate. However, this does not imply that environmental change benefits the economy. Rather, we can say that the outcome reflects the historical pattern of India's economic growth, which has frequently coincided with rising pollution and climatic deviations. This positive association is most likely caused by energy-intensive economic activity, which increases output but ultimately poses long-term sustainability risks.

Climate Resilience and Adaptation: Pathway to Sustainable and Inclusive Growth

The above analysis on how environmental and climatic factors influence the economic growth of India from 1990 to 2020 presents a complex and counterintuitive picture, which shows the nation's development trajectory rather than a dogmatic endorsement of climate change.

Regression analysis has revealed that the level of PM2.5 pollution and temperature anomalies are positively correlated with GDP growth, while greenhouse gas emissions are negatively correlated with GDP growth. Such results are contradictory and do not imply that air pollution or rising temperatures have a positive effect. They can be explained through the historical pattern of rapid industrialisation, energy-intensive economic growth and increasing pollution emission, which marks the upward-sloping part of the Environmental Kuznets Curve in India and in other developing countries. Granger causality tests do not find any Granger causation between GDP growth and PM2.5, suggesting that the relationship between GDP and PM2.5 is explained by the joint trends of economic and pollution growth rather than pollution causing economic growth.

The counterfactual analysis showed that holding PM2.5 and temperature anomalies constant at their low baseline levels would have declined GDP growth in nearly every year, reflecting the close association between India's historical growth and pollution. Lower GHGs would have increased growth, reflecting the long-run growth cost of climate-forcing emissions even throughout an economy's early industrialisation. Rainfall anomalies seem to have no systematic impact on India's diverse agro-climatic zones and adaptive capacity, possibly reflecting this.

The analysis further demonstrated that in India, rapid growth and increasing pollution can temporarily co-exist; however, climate-forcing emissions impose a persistent long-run cost. The country is now at an inflexion point: continued reforms in energy, urban planning, and fiscal architecture can deliver the downward bend of the Environmental Kuznets Curve while preserving 7–8 per cent growth trajectories well into the 2030s (Farooq *et al.*, 2024). Climate resilience is no longer a constraint on India’s development model—it is becoming its defining feature. More than 80 per cent of India's population lives in areas vulnerable to climate-related catastrophes (ibid., CEEW). The nation is already experiencing the effects of climate change, including extreme storms and floods, heatwaves and droughts, water stress, and related detrimental impacts on livelihoods and health. Moreover, India is undergoing rapid urbanisation poses both difficulties and opportunities for development and climate action. According to the World Bank 2024, India's urban population is predicted to grow to 600 million by 2036 and 850 million by 2050. In order to accommodate the expanding population, sufficient infrastructure—such as affordable housing, environmental services, and transportation—must be created from the ground up or substantially improved to be climate resilient. Therefore, India needs a new paradigm for development that incorporates growth and sustainability, equity and justice, and economic and environmental objectives.

India has established a comprehensive network of climate policy initiatives, most notably the National Action Plan on Climate Change (NAPCC) in 2008, which has eight missions that concentrate on important industries (agriculture and water) and/or geographical areas (Himalayas). In recent years, its national and state-level development programs have integrated climate resilience, making adaptation part of economic planning and development. In 2015, India presented the revised climate action plan to reduce its GDP's carbon intensity by 33–55 per cent by 2030, produce 40 per cent of its energy from renewable sources, and increase forest cover (GOI, 2015). The revised National Action Plan on Climate Change calls for 50 per cent non-fossil power capacity by 2030 and a 45 per cent reduction in emissions intensity from 2005 (ibid., GOI). India ranked fifth in the 2020 Human Development Report for installed solar capacity and plans to increase its renewable energy capacity to 450 GW by 2030 (ibid., IEA). India pledges net-zero emissions by 2070. To achieve its 2070 emissions target, India will need to invest an estimated $10.1 trillion (ibid., CEEW).

India's Biennial Update Report (BUR) estimates that in 2010, the GDP's emissions intensity decreased by 12 per cent between 2005 and 2010 (MoEFCC, 2015). This has been made feasible as a result of several policy actions made to address climate change and sustainable development issues. India's Nationally Determined Contribution (NDC) outlines the steps it plans to take for the period after 2020. In accordance with its Nationally Determined Contribution (NDC), India aims to reduce its GDP's emissions intensity by 33–35 per cent from 2005 levels by 2030, increase the share of non-fossil fuel power generation to 40 per cent of installed electric power capacity by 2030, and add 2.5–3 Gt of additional carbon sinks through increased forest and tree cover by the same year (ibid., MoEFCC). In order to support economic development and develop low-carbon infrastructure, India has to invest 1.5 times or more as a percentage of GDP now than advanced nations do (IEEFA, 2025). Additionally, India has allocated $55.6 million for the National Adaptation Fund to help climate-sensitive industries like forestry adapt (Leiserowitz et.al., 2022).

According to a report published by the Ministry of Environment, Forest, and Climate Change (2015, 2018, & 2021), India's food security is in jeopardy as a result of changes in rainfall patterns, which will have an impact on crop productivity, as well as an increase in the frequency and severity of extreme weather events such as droughts and floods. Given the agriculture sector's dependence on weather and its importance to the auxiliary rural populace, an agriculture adaptation mechanism is critical for the nation to become more resilient to climate change. To promote climate-resilient agriculture, the Indian government has initiated several programmes, such as the National Initiative on Climate Resilient Agriculture (NICRA), National Mission for Sustainable Agriculture (NMSA), the Pradhan Mantri Krishi Sinchai Yojana (PMKSY), and others, which promote sustainable agriculture to improve productivity, soil health, and water utilisation. The Pradhan Mantri Fasal Bima Yojana (PMFBY) is yet another government program that offers crop insurance to farmers to protect them against financial losses that may be incurred as a result of natural disasters. The program's objective is to assist farmers in the process of adopting climate-resilient agricultural practices by lowering the financial risks that they face and encouraging them to engage in environmentally responsible agricultural methods.

Climate-resilient water management strategies are another major pillar of India's adaptive mechanism, which includes traditional methods, modern technology and government initiatives. Water scarcity is becoming a more tenacious issue because of unpredictable monsoons, melting of glaciers and the excessive use of groundwater across the country. To tackle these challenges, India promotes collecting and storing rainwater, recharging aquifers, and revitalising rivers. To support these initiatives, India has launched decentralised water conservation initiatives, Jal Shakti Abhiyan: Catch the Rain campaign, with the slogans "catch the rain, where it falls, when it falls" in 2019, Atal Mission for Rejuvenation and Urban Transformation (AMRUT 2.0) in 2021, and Mission Amrit Sarovar in 2022. Programmes such as MGNREGA also fund and provide labour to create community-level assets like check dams, ponds, and soil/water conservation infrastructure.

In the last two decades, India's disaster management strategy has transitioned from a reactive, search-and-rescue, and relief-focused model, predominantly addressing floods and droughts, to a proactive, comprehensive framework encompassing prevention, mitigation, preparedness, capacity building, risk reduction, technological investment and advancements, community engagement, and resilience against a broader spectrum of hazards (NDMA, 2023).

Urban centres in India underscore the need for a comprehensive strategy that fosters both environmental resilience and socio-economic growth, as they are becoming increasingly vulnerable to extreme heat, air pollution, water shortages, and challenges in waste management. However, climate-resilient urban planning in India needs a collaborative effort between the government and the communities. While initiatives like the Smart Cities Mission and AMRUT have laid the foundation to mitigate climate risks. However, to build climate-resilient, sustainable cities, a people-centred strategy, backed by modern technology and inclusive policies, is required. Moreover, the Compensatory Afforestation Fund Management and Planning Authority (CAMPA) in 2004, the National Plan for Conservation of Aquatic Ecosystems (NPCA) in 2013, the National Mission for Green India (GIM) in 2014, the Namami Ganga Programme in 2014, the Mangrove Initiatives for Shoreline Habitats and Tangible Income (MISHTI) in 2023, and Amrit Dharohar in 2023 were initiated to enhance and restore mangroves forest, wetlands, rivers and general forest covers.

CONCLUSION

Climate change has an impact on all the natural ecosystems as well as the socio-economic condition of India. The effects of climate change are extremely severe for India. Rapid economic growth, widespread poverty and high population density have made India vulnerable to climate risk. The reports of the Intergovernmental Panel on Climate Change (2014, 2021, & 2022) have often identified India as a global hotspot of climate impacts. The findings present a complex and counterintuitive picture that how environmental and climatic factors influence India's economic growth from 1990 to 2020, demonstrating the country's development trajectory rather than a dogmatic endorsement of climate change. Regression analysis shows that GDP growth is positively correlated with PM2.5 pollution and temperature anomalies, but negatively correlated with greenhouse gas emissions. Rapid industrialisation, energy-intensive economic growth, and rising pollution emissions explain the upward-sloping Environmental Kuznets Curve in India. However, unchecked emissions and climate pressures threaten productivity, livelihoods, and people’s well-being. Granger causality tests show no Granger causation between GDP growth and PM2.5, suggesting that economic and pollution growth explain the relationship rather than pollution causing economic growth.

Furthermore, counterfactual analysis showed that holding PM2.5 and temperature anomalies at their low baseline levels would have decreased GDP growth nearly every year, demonstrating India's historical growth and pollution relationship. Lower GHGs would have increased growth, reflecting the long-term growth cost of climate-forcing emissions even during early industrialisation. India's diverse agro-climatic zones and adaptive capacity may be unaffected by rainfall anomalies.

However, climate change is not a concern that will arise in the future; it is already underway. Extreme weather patterns, an increase in natural catastrophes, and other effects of climate change can be seen all around us, and a large part of it is caused by our own everyday actions. A group effort is required to make the transition to a green and sustainable economy. For this precise reason, it is necessary to strengthen the partnership between the corporate sector, the government, and civil society to produce successful results. Sustaining high growth while lowering pollution levels, India needs to accelerate the use of cleaner technologies, with strict environmental regulation and climate-resilient infrastructure.

More precisely, to overcome climate risks, India’s climate adaptation and resilience strategy should adopt a comprehensive approach that spans multiple levels and sectors, while also prioritising social equity, new technologies, and environmental sustainability. Empowering vulnerable communities, promoting climate-smart agriculture, improving water and resource management, and using technology that centres on people, India can reduce climate risks, enhance human welfare, and maintain high-growth trajectories. These policies, backed by solid institutional frameworks and international collaboration, will strengthen India’s ability to adapt, lower disaster risks, and support sustainable development. Without deliberate policy intervention, the statistical benefits of pollution-intensive growth in the short term will be more and more outweighed by long-term environmental liabilities.

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