The Economic Toll of Climate Change on India: Sectoral Emissions, GDP Loss, and Strategic Fiscal Innovation for A Low-Carbon Transition

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DOI: 10.46609/IJSSER.2025.v10i08.010 URL: https://doi.org/10.46609/IJSSER.2025.v10i08.010

Received: 27 July 2025 / Accepted: 8 August 2025 / Published: 13 August 2025

ABSTRACT

Climate change poses a significant threat to India's economic stability, with rising temperatures, extreme weather events, and environmental degradation contributing to substantial GDP losses. This research paper quantifies the economic impact of climate change on India's GDP, examining sector-specific vulnerabilities. It further explores how investments in renewable energy can serve as a critical mitigation strategy, not only reducing economic losses but also fostering industrial growth, job creation, and increased participation in global trade. By analyzing trade dynamics, the paper highlights how India's transition to a green economy can enhance its export competitiveness, attract foreign investment, and strengthen its position in international climate agreements. Additionally, the study provides an overview of key policies and innovations—such as carbon pricing, green bonds, and sustainable infrastructure development—that can accelerate the shift toward a low-carbon economy. Through a combination of data-driven analysis and policy evaluation, this research offers insights into how India can balance economic growth with climate resilience, ensuring long-term sustainability and global competitiveness in an era of climate uncertainty.

Keywords: Climate Change, Indian Economy, GDP Loss, Renewable Energy Investment, Environmental Economics, Climate Finance

1. Introduction

Climate change is increasingly recognized as a major economic disruptor, posing serious risks to India's growth trajectory. The rising frequency of extreme weather events, erratic monsoons, rising temperatures, and environmental degradation threaten key sectors, leading to productivity losses and declining economic output. Reports indicate that India could lose up to 3-10% of its GDP annually by 2100[1] due to climate-induced disruptions, with agriculture, infrastructure, and industrial productivity being among the hardest-hit areas. The Asian Development Bank (ADB) projects that under a high-end emissions scenario, India could experience a 24.7% GDP reduction by 2070 due to climate change impacts, including rising sea levels and decreasing labor productivity .The Reserve Bank of India (RBI) has projected that by 2030, up to 4.5% of India's GDP could be at risk due to lost labor hours resulting from extreme heat and humidity. Additionally, a report by the Overseas Development Institute indicates that India may experience GDP losses ranging from 3% to 10% annually by 2100 due to climate change impacts. If left unaddressed, these economic damages could widen income disparities, reduce employment opportunities, and hinder India's long-term development goals. [1] - https://indianexpress.com/article/india/india-may-lose-3-10-gdp-annually-by-2100-due-to-climate-change-says-report-7350318/lite/

At the same time, global markets and trade policies are evolving to favour sustainability- focused economies. Countries investing in renewable energy and low-carbon technologies are becoming more competitive in international trade, benefiting from green financing, preferential trade agreements, and reduced reliance on volatile fossil fuel markets. For India, transitioning to a green economy presents an opportunity to mitigate economic losses, attract investment, and strengthen its position in the global trade ecosystem. However, the effectiveness of this transition depends on the implementation of strong climate policies, financial incentives, and technological innovations.

This paper examines the economic consequences of climate change on India's GDP, with a particular focus on sector-specific vulnerabilities. It also explores how investment in renewable energy can mitigate these losses, fostering sustainable economic growth and increasing India's competitiveness in global trade. Key aspects of analysis include:

- Quantifying GDP Losses Due to Climate Change– Evaluating sectoral economic damages, including agriculture, industry, and infrastructure.
- Role of Renewable Energy Investments– Assessing how clean energy adoption can reduce financial losses, create employment, and enhance trade competitiveness.
- Policies and Innovations for a Green Economy– Reviewing climate policies, carbon pricing mechanisms, green bonds, and technological solutions that can support India's transition toward a low-carbon, resilient economy.

By combining economic data analysis, policy evaluation, and trade implications, this research provides a comprehensive understanding of how India can balance economic growth with climate resilience. The findings aim to inform policymakers, businesses, and researchers on strategies that can help India navigate the economic risks of climate change while capitalizing on opportunities in the green economy.

2. Literature Review

The effects of climate change on the Indian economy and international trade have been explored by several researchers, highlighting the vulnerabilities of key sectors and the broader implications for trade dynamics.

Kumar and Parikh (2001) investigated the impact of climate change on India's agricultural productivity, noting that higher temperatures and unpredictable rainfall patterns could lead to substantial declines in crop yields, particularly for staples like wheat and rice. They estimated that a temperature increase of 2°C could reduce wheat yields by up to 15-20%, significantly affecting rural incomes and food security. This decline in agricultural output not only disrupts domestic economic stability but also reduces India's competitiveness in exporting agricultural goods such as rice and cotton.

Similarly, Dasgupta (2018) analyzed the relationship between climate change and India's export performance. The study highlighted that climate-induced production disruptions in sectors like textiles, pharmaceuticals, and agriculture have weakened India's position in global markets. The author also noted that rising energy costs associated with transitioning to sustainable energy sources have impacted export-oriented industries, increasing production costs and reducing profitability.

Aggarwal (2020) examined the vulnerability of infrastructure to climate risks, emphasizing the economic costs of extreme weather events like floods and heatwaves. This research suggested that recurring damage to transport networks and energy infrastructure poses long- term challenges to both domestic trade logistics and international trade competitiveness.

Chaturvedi (2020) explored the implications of global climate policies on India's trade. He discussed the increasing prevalence of carbon tariffs and green trade standards in developed nations, arguing that while these measures could drive Indian industries toward greater sustainability, they also risk disadvantage sizing smaller exporters who may struggle to meet stringent environmental requirements.

Research Objectives:

Following are the research objectives:

a. To analyze trends in carbon emission in India.

b. To determine there is an impact of climate change on GDP loss.

c. To propose policy recommendations and investment strategies that can enhance India's renewable energy capacity while minimizing GDP losses due to climate change.

Methodology:

This study employs a quantitative research design to examine the trend of carbon emissions in India and its relationship with GDP loss due to climate change and the. The methodology involves data collection from reliable secondary sources, statistical modeling, hypothesis testing, and model validation to ensure an accurate and meaningful analysis.

Theoretical Framework:

India is the third-largest carbon emitter globally, contributing approximately 2.9 gigatonnes of CO_2 annually. The primary sources of these emissions are coal-fired power plants (around 60% of electricity generation), industrial processes, and the transportation sector. Despite ambitious net-zero by 2070 commitments, India's carbon footprint continues to grow due to economic expansion and energy demands. This rise in emissions is projected to significantly impact GDP growth due to climate-induced economic disruptions.

Studies suggest that unmitigated climate change could cost India up to 2.5-4.5% of its GDP annually by 2030 due to extreme weather events, declining agricultural yields, and infrastructure damage. The Reserve Bank of India (RBI) has warned of climate-related financial risks, highlighting how prolonged heat waves and erratic monsoons can reduce labor productivity in manufacturing and services—key drivers of GDP. Additionally, India's export-dependent sectors (such as textiles and chemicals) could face carbon tariffs from the EU and other markets under Carbon Border Adjustment Mechanisms (CBAMs), increasing the economic burden. If left unchecked, the cumulative GDP loss from climate change could reach $35 trillion by 2070, disproportionately affecting low-income communities and rural economies.

To counteract this, India needs a strategic shift towards renewable energy, carbon pricing mechanisms, and industrial decarbonization to mitigate GDP losses. Investing in low-carbon technologies, grid modernization, and sustainable infrastructure can not only prevent economic damage but also position India as a leader in green technology exports. The key to balancing economic growth with emissions reduction lies in policy-driven green investments that ensure long-term economic resilience.

India faces significant economic risks due to climate change. The Asian Development Bank (ADB) projects that under a high-emission scenario, India could experience a 24.7% decline in GDP by 2070, surpassing the 16.9% average GDP decline anticipated across the Asia-Pacific

ISSN: 2455-8834

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region. This economic downturn is driven by factors such as rising sea levels, extreme weather events, and declining agricultural productivity, which threaten more than 80% of India's population and disproportionately impact vulnerable communities. Moreover, reduced labor productivity due to extreme heat, disruptions to supply chains, and the increasing costs of disaster recovery further exacerbate India's economic vulnerability. These losses emphasize the urgent need for a multi-pronged strategy focusing on carbon emission reduction, climate adaptation, and sustainable infrastructure development. India can mitigate these risks by expanding its renewable energy capacity, strengthening climate-resilient urban planning, and implementing market-based mechanisms such as carbon pricing and green taxation. Additionally, large-scale investments in energy-efficient industries, electrified public transport, and climate-smart agriculture will be critical to offsetting the projected economic damage while ensuring long-term sustainability and growth.

Relation between carbon emissions and GDP loss in India due to climate change:

This research follows a correlational design, using secondary data analysis and statistical regression modeling to determine the relation between carbon emission and GDP losses due to climate change in India.

The study is based on the following framework:

- **Dependent Variable:** GDP loss due to climate change (measured as a percentage of total GDP).
- **Independent Variable:** Annual Carbon emissions
- **Analysis Period:** The study focuses on a multi-year trend analysis covering at least the past decade from 2013 to 2023 to understand how changes in carbon emissions in India impact economic losses over time.

Table 1: Descriptive statistics (1993 to 2023)

	Annual CO2 emissions	GDP loss due to climate change
Mean	2486739681.82	3.56
Std. Deviation	309450258.11	1.59
Minimum	1995098100	2.5
Maximum	3062324500	8

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Analysis:

The annual CO2 emissions were the lowest in the year 1993 at 677.29926 million tons, and since then they have been rising like never before, the highest emitted so far being in the year 2023, 3062.3245 million tons.

The lowest GDP loss due to climate change was in the year 2013 when it stood at 2.6%, the highest was in the year 2022 which was at colossal 8.0%

The statistical analysis of annual CO_2 emissions and GDP loss due to climate change reveals significant variations among different regions. The mean annual CO_2 emissions stand at 2.49 billion metric tons, with a standard deviation of 309.45 million metric tons, indicating considerable fluctuation in emissions across countries. The minimum emissions recorded are 1.99 billion metric tons, while the maximum reaches 3.06 billion metric tons, reflecting disparities in industrial activity and energy policies. In terms of economic impact, the average GDP loss due to climate change is 3.56%, with some countries experiencing losses as low as 2.5% and others as high as 8%. The high standard deviation of 1.59% suggests that climate change does not affect all economies equally—developing nations with high climate vulnerability may face disproportionately severe economic consequences. This data underscores the urgent need for targeted climate policies, emission reduction strategies, and economic resilience planning to mitigate future GDP losses.

Trend of carbon emission in India:

An upward rising trend can be observed for carbon emission in India from 1993 to 2023 as depicted in figure 3 below. India can adopt China's industrial decarbonization model, focusing on sector-specific emissions targets for steel, cement, and chemicals, which together contribute significantly to national emissions. Instead of blanket mandates, India can expand its Perform, Achieve, and Trade (PAT) scheme, making carbon intensity reduction targets legally binding while offering low-interest loans for industries transitioning to hydrogen-based manufacturing. Additionally, Japan's industrial efficiency advancements—such as AI-driven energy monitoring, waste heat recovery, and automation—can be incentivized through corporate tax benefits and stricter mandatory audits for large factories. These measures ensure compliance without burdening small industries, making decarbonization economically viable.

In the energy sector, Germany's renewable energy investment model can be adapted by scaling up India's solar and wind infrastructure via state-backed Renewable Energy Certificates (RECs), allowing industries to offset emissions by purchasing clean energy. Instead of blanket fossil fuel subsidies, India can gradually implement sector-specific carbon pricing—modelled on South Korea's Carbon Trading Scheme—which taxes high-emission sectors while exempting essential

ISSN: 2455-8834

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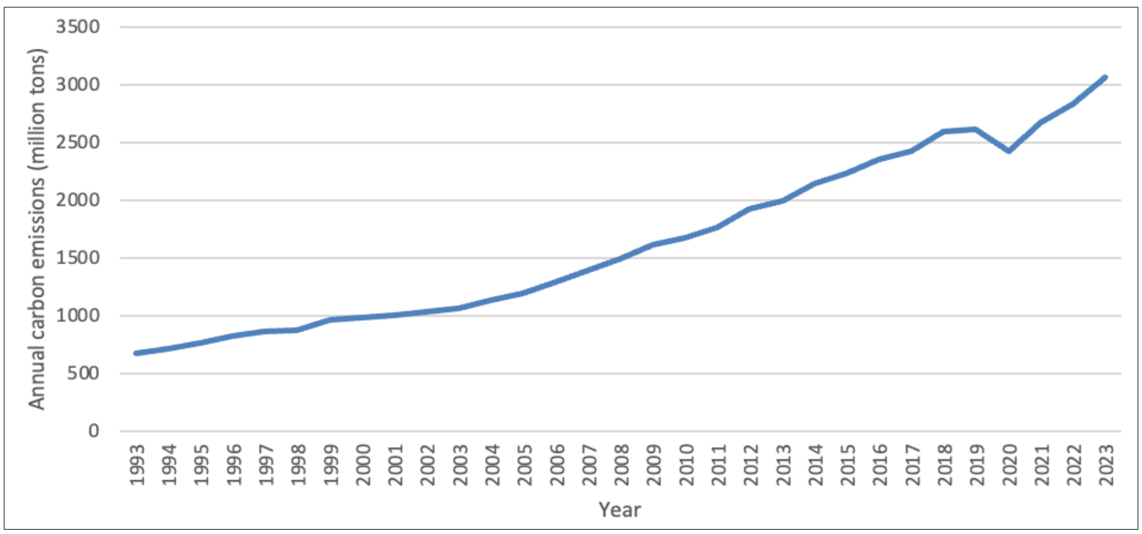
services to avoid inflationary pressure. Additionally, France's energy-efficient building regulations can be incorporated into India's Smart Cities Mission by making green certifications mandatory for all new commercial structures and offering tax rebates for retrofitting older buildings with efficient cooling and heating systems. Urban transport emissions can be tackled by expanding metro networks in Tier-2 cities, inspired by Singapore's fully integrated public transit system, while gradually implementing congestion pricing in metro hubs like Mumbai, Delhi, and Bengaluru to reduce private vehicle dependency. These strategies, if executed with sector-wise specificity and economic cushioning, can significantly curb emissions while supporting sustainable economic growth.

Figure 3: Trend of carbon emission in India



Correlation between Carbon Emissions and GDP loss due to climate change:

Null hypothesis	Alternative hypothesis
There is no association between Annual CO_2, emissions and GDP loss due to climate change	There is an association between Annual CO_2, emissions and GDP loss due to climate change

A p-value threshold of 0.05 is used for significance testing. If $p<0.05$, the null hypothesis is rejected, confirming a significant relationship.

	r	p
Annual CO_2, emissions and GDP loss due to climate change	0.62	.043

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A Pearson correlation was performed to determine if there is a correlation between variables Annual CO_2, emissions and GDP loss due to climate change. There is a high, positive correlation between variables Annual CO_2, emissions and GDP loss due to climate change with r= 0.62. Thus, there is a high, positive association between Annual CO_2, emissions and GDP loss due to climate change in this sample.

The result of the Pearson correlation showed that there was a significant correlation between Annual CO_2, emissions and GDP loss due to climate change, $r(9) = 0.62$, $p = .043$. Since the value of p is less than 0.5 so we reject the null hypothesis and accept the alternative one.

A linear regression analysis was performed to examine the influence of the variable Annual COâ,, emissions on the variable GDP loss due to climate change.

	R^2	Standard errors	F	p
GDP Loss Due to Climate Change	0.38	1.32	5.57	0.38

Table 3: pre work for the regression table:

	R^2	**Adjusted R^2**	**Standard error of the estimate**
0.63	0.4	0.33	2

Model	**df**	**F**	**p**
Regression	1	6.02	.032

Regression table analysis:

	Unstandardized Coefficients	**Standardized Coefficients**				**95% confidence interval for B**	
Model	B	Beta	Standard error	t	p	lower bound	upper bound
(Constant)	15.44		1.54	10.04	<.001	11.96	18.92
GDP loss due to climate change	-0.97	-0.63	0.4	-2.45	.037	-1.87	-0.08

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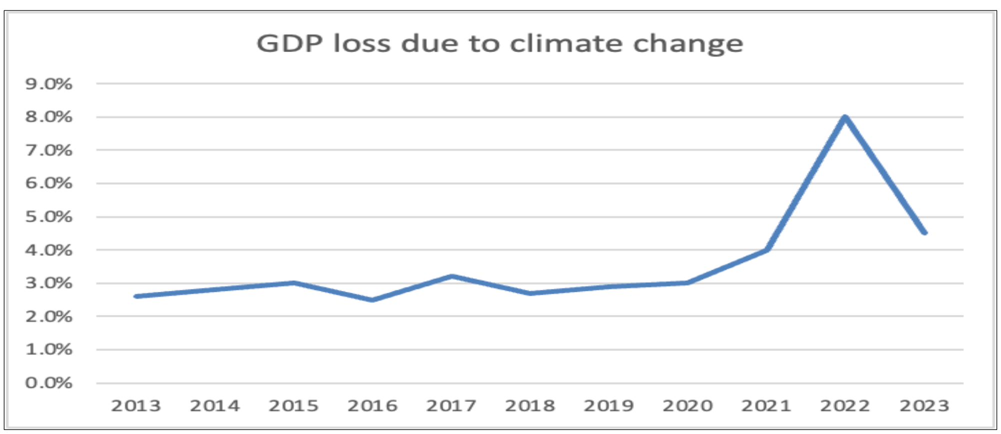
Model Summary:

The regression model showed that the variable Annual CO_2, emissions explained 38.25% of the variance from the variable GDP loss due to climate change. An ANOVA was used to test whether this value was significantly different from zero. Using the present sample, it was found that the effect was significantly different from zero, F=5.57, p = .038, R^2 = 0.38.

Increased carbon emissions directly contribute to GDP loss by triggering a series of economic disruptions. As emissions rise, the frequency and severity of climate-related disasters such as floods, heatwaves, and droughts escalate, damaging critical infrastructure, disrupting supply chains, and reducing agricultural productivity. These extreme weather events not only strain public and private resources but also increase the cost of rebuilding and adaptation. Additionally, higher pollution levels lead to severe health impacts, including respiratory diseases and heat-related illnesses, which raise healthcare costs and reduce workforce productivity. The agricultural sector, a key component of many economies, also suffers as changing weather patterns lower crop yields, deplete water resources, and drive food prices higher, contributing to inflation and economic instability. Moreover, increased carbon emissions place a financial burden on governments and businesses due to rising energy and infrastructure costs, as more funds must be allocated to climate resilience rather than economic expansion. On a global scale, carbon-intensive economies face trade restrictions, carbon taxes, and declining investor confidence, further stalling growth and competitiveness in international markets. Climate-induced migration adds another layer of economic strain, as displaced populations lead to increased social spending and labor market disruptions. Together, these factors illustrate how unchecked carbon emissions create a cascading effect on economic stability, reinforcing the urgent need for renewable energy investments and sustainable policies to mitigate GDP losses.

Figure 11: GDP loss due to climate change



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The graph illustrates the trend of GDP loss due to climate change from 2013 to 2023, highlighting significant fluctuations over the years. Between 2013 and 2020, GDP loss remained relatively stable, ranging between approximately 2% and 3%, suggesting that while climate-related economic impacts were persistent, they did not escalate dramatically during this period. However, beginning in 2021, there was a noticeable upward trend, culminating in a sharp peak in 2022 at nearly 9%. This suggests that climate change-induced disruptions intensified significantly, potentially due to an increase in extreme weather events, disruptions in key economic sectors, or delays in the implementation of effective mitigation policies.

The subsequent decline in 2023, while still above pre-2020 levels, may indicate that certain climate mitigation strategies, including investments in renewable energy and adaptive economic policies, have begun to show positive effects in stabilizing GDP losses. However, the overall trend underscores the growing vulnerability of economic systems to climate change and emphasizes the need for proactive policy interventions.

While this graph does not directly depict the trends in renewable energy adoption, it is crucial to examine whether a correlation exists between the share of renewable energy in the total energy mix and the observed GDP losses. If a higher share of renewable energy contributes to reducing GDP losses over time, this would provide strong evidence in favor of accelerating the transition to a green economy. Further analysis integrating renewable energy adoption rates, government policy shifts, and economic resilience measures is necessary to draw conclusive insights into how renewable energy investments can effectively mitigate climate-induced economic downturns.

Sector wise emissions: Particularly super sector emissions

Industry sectors	**Carbon Emissions per year**	**% contributions**
Energy Industries	1265327.56	56.42%
Manufacturing Industries and Construction	390666.56	17.42%
Transport	297371.34	13.26%
Other Sectors	258147.24	11.51%
Fugitive emissions	26896.19	1.20%

International Journal of Social Science and Economic Research

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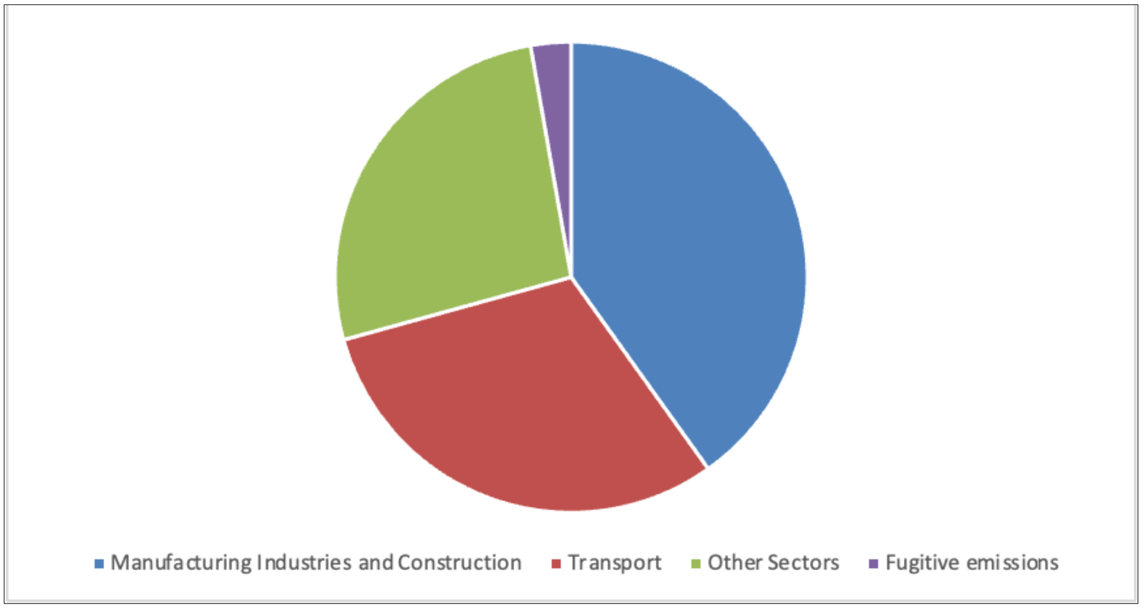
Figure 4: Sector-wise emissions



The data shows that energy industries are the largest contributor to emissions (1,265,327.56), far exceeding other sectors. Manufacturing and construction (390,666.56) and transport (297,371.34) also play significant roles, while other sectors, including residential and commercial activities, account for 258,147.24. Fugitive emissions (26,896.19) from leaks in fuel extraction and distribution, though the lowest, remain important due to their environmental impact. The dominance of energy production in emissions highlights the need for cleaner alternatives, while transport and industry require efficiency improvements to reduce their footprint.

Sub sector division:

Emission Sector	Emission Sub-Sector	Value (in Gigagram CO2 eq)	% contributions
Energy Industries	Electricity production	1171623.55	52.34%
	Refinery	85027.02	3.80%
	Manufacturing of solid fuel	8676.99	0.39%
Manufacturing Industries and Construction	Cement	49822.53	2.23%
	Iron and steel	151437.24	6.77%
	Non-ferrous metals	2318.99	0.10%
	Chemicals	2036.55	0.09%
	Pulp and paper	2570.6	0.11%

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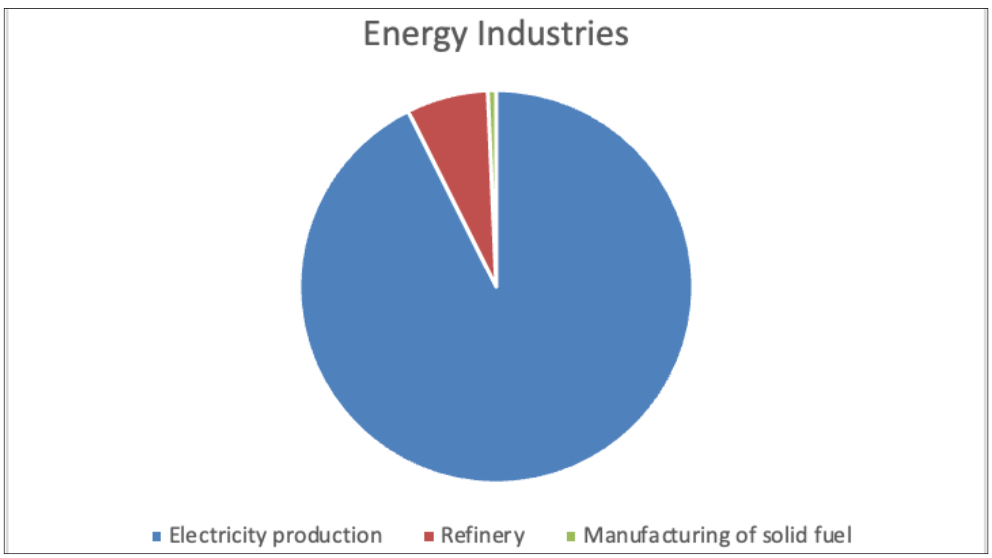
	Mining and quarrying	5483.18	0.24%
	Textile/leather	635.18	0.03%
	Non-specific industries	168456.49	7.53%
	Bricks	506.53	0.02%
	Fertilizer	4294.85	0.19%
	Engineering Sector	3104.42	0.14%
Transport	Road Transport	278109.13	21.42%
	Civil aviation	11959.26	0.53%
	Railways	4188.27	0.19%
	Navigation	3114.68	0.14%
Other Sectors	Commercial-institutional	92602.23	4.14%
	Residential	148000.67	6.61%
	Agriculture/Fisheries	2702.46	0.12%
	Biomass burnt for energy	14841.88	0.66%
Fugitive emissions	Oil and natural gas system	10187.43	0.46%
	Solid fuels	16708.76	0.75%

Figure 5: energy sector emissions breakdown



The energy sector, particularly electricity production, remains the single largest source of emissions, contributing over 1.17 million Gg CO_2 equivalent. This is largely due to the continued dominance of coal and natural gas in the power generation mix. Oil refineries add another 85,027 Gg CO_2 eq, stemming from energy-intensive processing. There's a clear need here to accelerate the shift towards clean energy sources such as solar, wind, and hydropower, supported by grid efficiency upgrades and better transmission infrastructure. Technological advancements like carbon capture and storage (CCS) can help decarbonize legacy systems, especially in sectors like oil refining where full electrification remains challenging.

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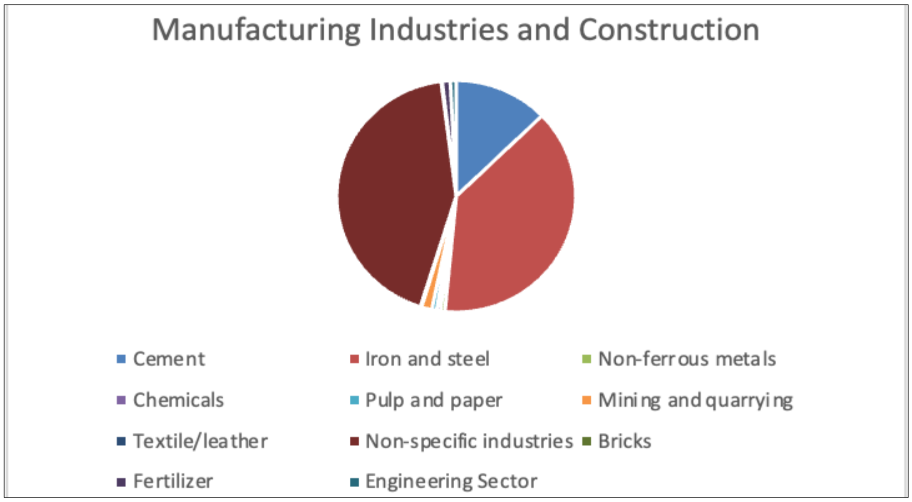
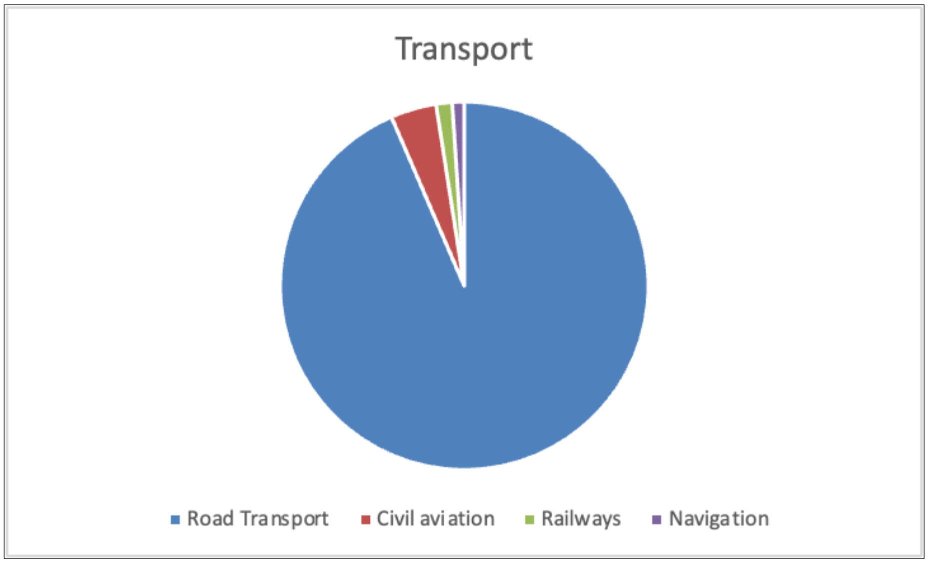
Figure 6: Manufacturing and construction sector emissions breakdown



Manufacturing-related emissions, particularly from steel (151,437 Gg) and cement (49,822 Gg), are among the most difficult to abate, yet critical to address. These are inherently carbon-intensive processes due to the chemical reactions and high heat requirements involved. Here, solutions lie in developing low-carbon alternatives, such as green hydrogen for steel production, and alternative binders in cement. Encouraging recycling, especially in non-ferrous metals and textiles, and mandating energy-efficient technologies in industries like pulp and paper or fertilizers will also significantly reduce emissions while cutting production costs.

Figure 7: Transport sector emission breakdown



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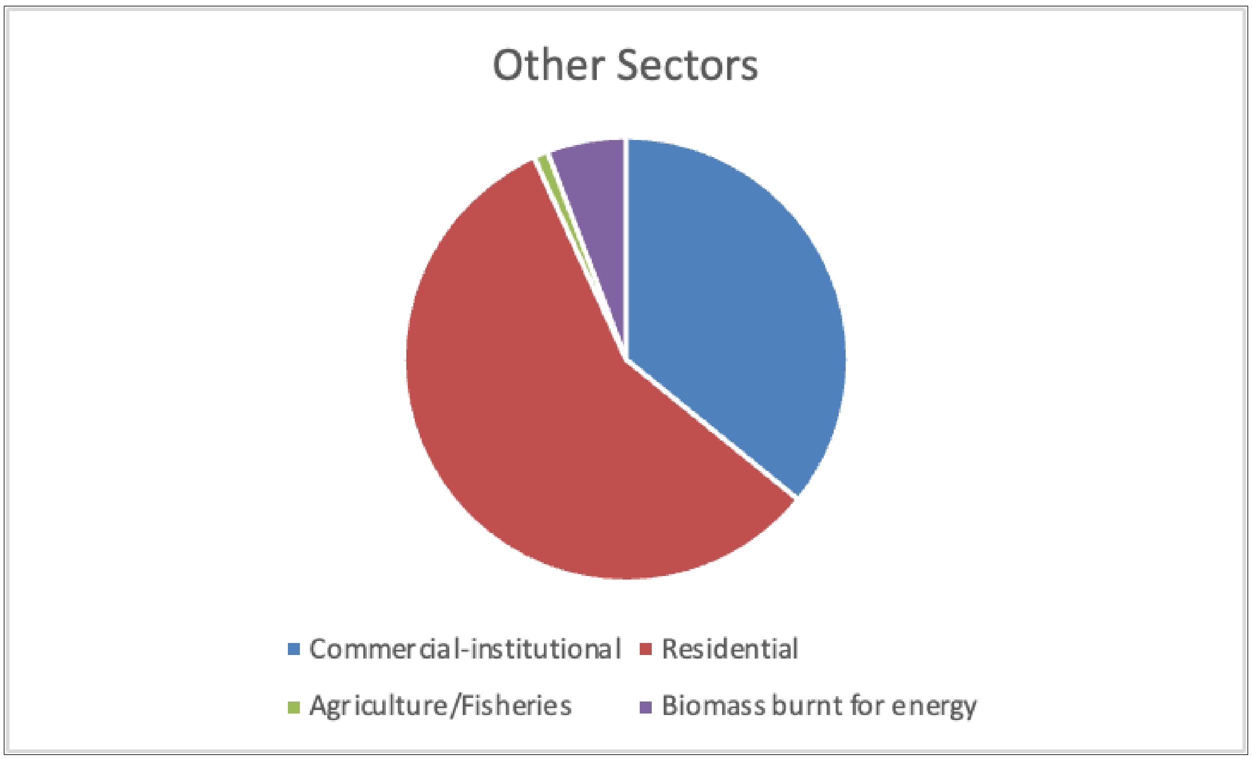
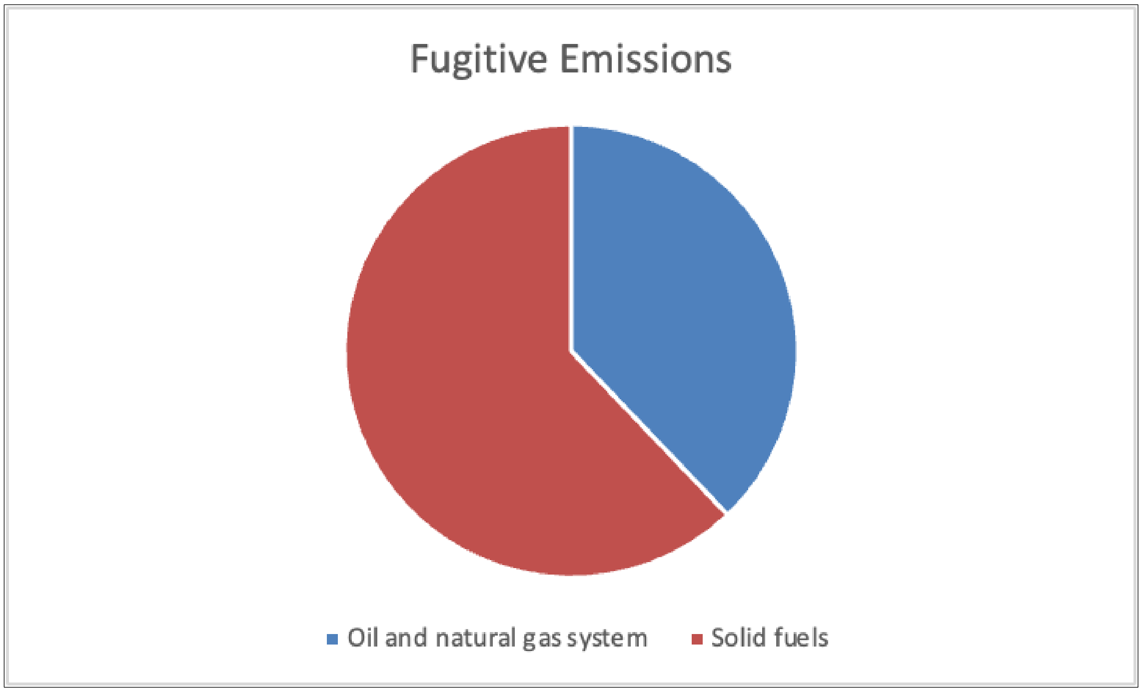
Transport, particularly road transport, is one of the highest-emitting sectors at 278,109 Gg CO_2 eq, followed by emissions from aviation (11,959 Gg) and railways (4,188 Gg). India must accelerate the electrification of vehicles, not just for private use but across public transport and freight systems. This includes expanding EV charging infrastructure, incentivizing electric two-wheelers, and developing hydrogen fuel cell technologies for long-distance transport. Civil aviation and maritime transport also require targeted investments in sustainable aviation fuels (SAFs) and energy-efficient ship designs to reduce emissions from growing global connectivity.

Figure 8: miscellaneous sectors emission breakdown



Emissions from residential (148,000 Gg) and commercial buildings (92,602 Gg) are primarily linked to energy used in heating, cooling, and daily operations. A transition to energy-efficient buildings, advanced insulation techniques, and solar rooftop systems can significantly reduce urban emissions. In agriculture, emissions may appear modest (2,702 Gg) but are deeply impactful due to methane from livestock and nitrous oxide from fertilizers. Promoting precision farming, biofertilizers, and climate-resilient crops can offer dual benefits of productivity and sustainability. Even sectors like bricks, mining, and engineering contribute notable emissions and require cleaner production standards, fuel substitution, and technological modernization.

Figure 9: Fugitive sector emission breakdown



Fugitive emissions—those released unintentionally during extraction and processing—are significant. From oil and natural gas systems (10,187 Gg) to solid fuels like coal (16,708 Gg), these emissions often go unaddressed. India must prioritize leak detection systems, methane recovery, and enforce best practices in fuel storage and transportation, particularly in states heavily reliant on coal mining and oil refining.

To address GDP losses due to climate-related disruptions, India must implement a comprehensive strategy that harmonizes economic growth with carbon reduction, while simultaneously creating new trade and employment opportunities.

1. Enhancing Renewable Energy Investment and Infrastructure

a. Mobilize Public and Private Capital

- The government should expand subsidies, tax incentives, and low-interest green loans to attract private sector investment in the solar, wind, and hydroelectric sectors. Public-Private Partnerships (PPPs) can expedite the development of large-scale projects, while state-led green energy initiatives can facilitate growth in rural and semi-urban areas.

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b. Modernize the Power Grid

- Develop smart grids and energy storage solutions to enhance the integration of renewable energy and effectively manage variability. This encompasses battery storage, pumped hydro systems, and AI-driven energy forecasting technologies.

2. Implementing Robust Policy and Regulatory Frameworks

a. Mandate Ambitious Renewable Energy Targets

- Establish stricter Renewable Purchase Obligations (RPOs) and create a legally binding framework to achieve a 60–70% share of renewable energy by 2040. Encourage the formulation of state-level targets to enhance local accountability.

b. Carbon Pricing and Emission Caps

- Gradually implement a carbon pricing mechanism, starting with high-emission industries. An Emission Trading System (ETS) can provide flexibility while generating revenue for climate resilience initiatives.

3. Promoting International Trade and Green Financing

a. Engage with Global Climate Funds

- India should actively participate in the Green Climate Fund (GCF), World Bank Climate Investment Funds, and the IMF Resilience and Sustainability Trust, while also expanding its green bond market to direct climate finance toward infrastructure, transportation, and industry.

b. Strengthen Green Exports

- Promote domestic manufacturing of solar panels, wind turbines, and green hydrogen for export. By becoming a significant supplier in the global low-carbon economy, India can attract investment and forge trade partnerships.

4. Addressing Climate-Induced Economic Vulnerabilities

a. Integrate Climate Risk into Economic Planning

- Incorporate climate vulnerability assessments into budgeting and investment strategies to proactively address potential GDP shocks. Establish disaster risk financing mechanisms at both central and state levels.

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b. Develop a Green Workforce

- Initiate skill development programs to retrain workers transitioning from coal, oil, and outdated manufacturing sectors. Support green startups and entrepreneurship incubators focused on clean technology, circular economy practices, and agricultural innovation.

5. Fostering Public Awareness and Community Involvement

a. Localize Renewable Energy Solutions

- Expand solar rooftop initiatives, biogas installations, and community microgrids, particularly in energy-deficient regions. Empower local governments and panchayats to act as facilitators of clean energy distribution.

b. Encourage Behavioral Change

- Launch nationwide awareness campaigns that emphasize the economic and health benefits of clean energy, while incentivizing businesses to implement CSR-funded green projects within their communities.

Lessons from other Countries:

India, facing significant GDP losses due to climate change, can adopt proven strategies from other countries while tailoring them to its unique economic and infrastructural landscape. A key approach is expanding renewable energy capacity by enhancing solar and wind investments, as seen in China and Denmark. China's large-scale solar production, driven by state-backed policies and financial incentives, drastically lowered solar costs globally. India can build on its existing solar push under the PM-KUSUM scheme by providing further subsidies, easing land acquisition hurdles, and ensuring efficient grid integration to maximize renewable energy usage. Additionally, wind energy expansion, as observed in Denmark and Texas, can be accelerated through improved storage solutions and infrastructure development in high-wind regions like Tamil Nadu and Gujarat.

Another critical step is carbon pricing and incentives for businesses, drawing lessons from Sweden's carbon tax model. While a direct carbon tax may be challenging in India's economic structure, a phased approach to carbon credits and tradable permits can encourage industries to transition towards cleaner alternatives without excessive economic disruption. Similarly, India can learn from California's cap-and-trade system, gradually incorporating sector-wise emission trading, especially in high-emission industries like cement and steel. Furthermore, state-level policy leadership—as seen in Texas and California—can be encouraged within India's federal

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system, with states like Maharashtra, Karnataka, and Rajasthan pioneering renewable energy transitions. By ensuring a mix of government incentives, industry participation, and regional policy leadership, India can not only mitigate GDP losses from climate change but also position itself as a global leader in sustainable economic growth.

India's Renewable Transition in the Context of Sectoral Emissions & Cross-Country Co_2 Trends

As climate change intensifies, India's renewable energy transition must be strategic, economically viable, and globally competitive. The cross-country and sectoral emissions analysis reveals that while India's total CO_2 emissions are among the highest globally, its per capita emissions remain significantly lower than developed nations. This suggests that India has the potential to industrialize sustainably while prioritizing a low-carbon growth trajectory. However, the sector-wise breakdown of emissions highlights critical areas that demand targeted decarbonization efforts—namely, energy production, manufacturing, and transport, which together account for the largest share of global CO_2 emissions.

With economic constraints often limiting renewable energy expansion, India must look to successful international models, leveraging policy innovations, technological advancements, and sustainable finance mechanisms to accelerate its green transition. Countries such as Germany, Norway, Japan, and Singapore offer valuable insights on balancing economic growth with sustainability, many of which can be adapted to the Indian context.

Lessons from Global Emission Trends & Adaptable Strategies for India

1. Decarbonizing Energy Production: The Cornerstone of India's Green Transition

The energy sector remains the largest global CO_2 emitter, primarily due to the continued reliance on fossil fuel-based electricity generation. India, as one of the world's fastest-growing economies, faces the dual challenge of meeting rising energy demands while reducing dependence on coal and natural gas. Currently, emissions from energy industries, including electricity production (1,171,623.55 Gg CO_2 eq) and oil refining (85,027.02 Gg CO_2 eq), underline the urgency of an accelerated shift toward renewables.

- Germany and Denmark have significantly reduced coal dependence by implementing strong carbon pricing mechanisms, phasing out subsidies for fossil fuels, and investing in large-scale solar and wind farms. India can replicate this success through:

- Higher carbon taxes and stricter emissions trading systems to discourage reliance on coal.
- Green finance instruments, such as green bonds and sustainability-linked loans, to mobilize capital for renewable energy projects.
- Advanced battery storage systems to address intermittency challenges in solar and wind energy.

- Norway's investments in Carbon Capture and Storage (CCS) present an opportunity for India to mitigate emissions from coal-fired power plants, oil refineries, and cement production. By integrating CCS technologies and incentivizing low-carbon alternatives, India can transition toward a cleaner energy matrix without sacrificing energy security.
- India's solar energy potential is immense, yet underutilized compared to China, which leads in solar PV manufacturing and exports. Investing in domestic solar manufacturing, supported by government incentives, can enhance energy security and position India as a leader in global renewable energy trade.

2. Reducing Industrial & Manufacturing Emissions: Innovation as a Solution

The industrial sector remains one of the highest CO_2 emitters globally, driven by energy-intensive processes in cement production (49,822.53 Gg CO_2 eq) and steel manufacturing (151,437.24 Gg CO_2 eq). These industries are essential for infrastructure development but must be decarbonized through technological and policy interventions.

- Japan has pioneered hydrogen-based steel production, significantly reducing emissions from conventional coke-based methods. India can adopt similar hydrogen-based smelting technologies, supported by incentives for green hydrogen production.
- Sweden's investment in fossil-free steel (HYBRIT technology) highlights the potential for zero-carbon industrial processes. If India adopts such innovations, it could enhance its competitiveness in global trade by producing low-emission materials for export.
- Circular economy models in Europe have significantly reduced industrial emissions by increasing recycling rates and promoting energy-efficient manufacturing processes. India can follow suit by incentivizing waste-to-energy solutions and implementing stricter energy efficiency regulations in manufacturing.

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3. Sustainable Transport: India's Role in the Global Low-Carbon Mobility Revolution

With road transport emissions reaching 278,109.13 Gg CO_2 eq globally, decarbonizing transportation is critical. India's rapidly expanding urban centers demand sustainable mobility solutions to curb pollution and reduce dependence on fossil fuels.

- Norway leads the world in electric vehicle (EV) adoption, with over 80% of new car sales being EVs. India can replicate this success by:
  - Expanding EV charging infrastructure across major cities and highways.
  - Offering higher subsidies for electric vehicles and battery technology R&D.
  - Mandating EV adoption in public transport systems, including buses, taxis, and rickshaws.
- Sustainable Aviation Fuels (SAFs) in the EU and the U.S. have demonstrated a feasible path to reducing airline emissions (11,959.26 Gg CO_2 eq). India should incentivize domestic airlines to integrate SAFs and invest in green aviation technologies to reduce the environmental footprint of its fast-growing aviation sector.
- Singapore's carbon-neutral shipping initiatives highlight the potential for green maritime transport. India's major ports can transition to LNG-powered or electric vessels while implementing stricter emission standards for shipping industries.

4. Green Buildings & Energy-Efficient Infrastructure: Learning from Global Leaders

Emissions from residential (148,000.67 Gg CO_2 eq) and commercial buildings (92,602.23 Gg CO_2 eq) underscore the need for sustainable urban planning. The Netherlands and Singapore have successfully integrated green building policies, achieving significant reductions in energy consumption.

- Stronger enforcement of green building codes can ensure net-zero energy buildings become the norm in India's urban expansion.
- Solar rooftop adoption in China and Germany has transformed residential energy consumption. India must scale up subsidies for rooftop solar systems to encourage decentralized clean energy generation.
- Smart grid investments can optimize electricity distribution and reduce transmission losses, contributing to overall energy efficiency.

ISSN: 2455-8834

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5. Addressing Fugitive & Biomass Emissions: The Hidden Challenge

- Fugitive emissions from oil and gas extraction (10,187.43 Gg CO_2 eq) and coal mining (16,708.76 Gg CO_2 eq) remain a hidden yet significant contributor to greenhouse gases.
    - India must invest in methane capture technologies and enforce stricter emission monitoring in extractive industries.
    - Transitioning away from coal while ensuring just economic alternatives for coal-dependent communities is essential for long-term sustainability.
- Biomass burning (14,841.88 Gg CO_2 eq) presents a challenge in India's rural areas, where it is still used as a primary energy source.
    - Sustainable biomass certification systems, similar to those in Europe, can ensure responsible biomass usage.
    - Promoting biogas alternatives and clean cooking solutions can significantly lower household carbon emissions.

"Redefining the Rupee: ₹eco as a Climate-Responsive Monetary Innovation"

This research paper's regression analysis reveals a significant negative correlation between India's renewable energy investment and GDP loss due to climate change. This relationship, when interpreted beyond linear causality, raises a critical hypothesis:

Could national spending behavior be gently redirected toward climate-aligned sectors through fractional monetary adjustments based on real-time carbon performance?

Policy Innovation: ₹Eco – A Climate-Responsive Monetary Framework for India

To explore this, I propose a pilot-level monetary innovation titled ₹eco — a climate-responsive currency adjustment framework that slightly shifts the relative purchasing power of the Indian rupee within specific emission-sensitive sectors. Grounded in the principle of Pigouvian correction and built upon existing digital finance infrastructure (e.g., the RBI's Digital Rupee), ₹eco would operate as an experimental monetary nudge.

A programmable, climate-responsive layer integrated into India's existing digital currency infrastructure, unlike traditional fiscal measures or carbon taxes, ₹eco aims to shift purchasing behavior through micro-adjustments in sector-specific currency value, thereby embedding environmental accountability directly into the rupee's functionality.

ISSN: 2455-8834

Volume:10, Issue:08 "August 2025"

₹eco – A Climate-Responsive Rupee Layer

As India braces against the rising economic costs of climate change — from erratic monsoons and agricultural disruption to infrastructure damage and productivity loss — it becomes increasingly clear that traditional fiscal tools are insufficient. While this paper has demonstrated the significant relationship between renewable investment and GDP preservation, one insight remains: India's economy is reacting to climate threats, but not yet evolving with them.

Conceptual Framework Of ₹eco

I propose the introduction of ₹eco —not a replacement for the Indian rupee, rather, is a smart-layer monetary adjustment mechanism designed to modify the effective purchasing power of the rupee based on India's Carbon Performance Index (CPI) — a quarterly index reflecting national emissions data, climate disaster costs, and renewable investment levels. It Reflects the country's real-time environmental performance. ₹eco is not a new currency, but a programmable, climate-responsive layer applied to India's digital financial system (such as the Digital Rupee or UPI-linked wallets). Its core function is simple: to subtly adjust the spending power of the rupee in high-emission versus green-aligned sectors, based on a dynamic national Carbon Performance Index (CPI).

When India's emissions rise, extreme weather events increase, or renewable investments fall short — the CPI worsens, and ₹eco adjusts accordingly:

- In carbon-heavy sectors (coal, diesel transport, fast fashion), ₹eco has slightly reduced purchasing power
- In climate-positive sectors (EVs, solar, organic agriculture), ₹eco has slightly increased purchasing power

If the rupee's sectoral spending value were adjusted (by +/- 2–3%) according to India's real-time climate performance — measured through a Carbon Performance Index (CPI) — then:

- High-emission sectors would experience slight relative inflation
- Low-carbon sectors would see slight demand increases
- Consumer and producer behaviour would gradually shift in favour of sustainability

For example, in a given quarter, ₹100 might buy ₹97 worth of goods in coal logistics, but ₹103 worth in electric vehicles or green technologies. These adjustments are micro-level, but their behavioural and market impact is potentially transformative — encouraging both consumers and industries to shift toward sustainability without requiring bans, taxes, or heavy enforcement.

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₹eco would be updated quarterly through a government-backed CPI dashboard, which tracks national emissions, renewable capacity growth, and climate damage costs. It could be piloted in high-emission states, subsidy programs, or youth wallets — allowing for climate-aligned finance without altering macroeconomic stability.

Justification: Why ₹eco is economically and institutionally feasible for India

- **Market Nudges over Market Controls:** Instead of directly taxing polluters — a method often met with political resistance and administrative complexity — the ₹eco framework allows the market to self-correct. By applying fractional shifts in purchasing power (e.g., +2% for green sectors, −2% for carbon-intensive ones), it rewards climate-positive behavior without imposing explicit penalties.

This mechanism is grounded in Pigouvian principles, which suggest that economic activities with negative externalities (like pollution) should be priced accordingly. However, rather than using heavy-handed taxation, ₹eco draws from nudge theory (Thaler & Sunstein, 2008), leveraging small, psychologically effective financial cues to guide behavior.

The ±2–3% adjustment range is intentionally subtle — staying below the typical price-sensitivity threshold of most consumers — but it is designed to create cumulative market impact over time. These micro-incentives can gradually shift demand toward sustainable goods and services, prompting industries to adjust supply chains, investment strategies, and carbon footprints in response.

- **Currency with Conscience:** ₹eco embeds environmental accountability into the most fundamental economic unit — the rupee. According to India's Ministry of Finance and RBI's Financial Stability Reports, climate-induced disasters pose a substantial threat to productivity, agriculture, insurance, and infrastructure investment. The ₹eco framework directly links economic stability to climate mitigation, encouraging sectors to align with national decarbonization goals without sacrificing growth.

- **Digital-Ready:** India's financial infrastructure is uniquely positioned to support a programmable, climate-responsive currency layer like ₹eco. With the Unified Payments Interface (UPI) processing over 10 billion transactions per month, and Aadhaar-enabled Direct Benefit Transfers (DBTs) reaching over 500 million citizens, India already operates one of the world's most advanced and inclusive digital finance ecosystems.

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Moreover, the Reserve Bank of India's Central Bank Digital Currency (CBDC) — the Digital Rupee (e₹) — is being piloted for both wholesale and retail use, offering programmable features, secure ledgers, and transaction traceability. This opens up the possibility of integrating ₹eco directly into the digital rupee's code — allowing conditional logic such as "+2% value if spent in green-certified sectors" or "−2% in high-emission industries."

Additionally, India's stack includes:

- Aadhaar + UPI linking, allowing identity-authenticated transactions for sector-targeted incentives
- Account Aggregators and open banking APIs, which enable secure, cross-platform data flow
- ONDC (Open Network for Digital Commerce), which can tag products by emissions footprint, helping classify eligible green or polluting sectors for ₹eco application

With such tools already deployed at scale, ₹eco's implementation does not require new currency issuance or infrastructure overhaul. Instead, it can be deployed as a programmable layer using smart contracts or centralized algorithms tied to a Carbon Performance Index (CPI) dashboard updated quarterly by the Ministry of Finance or NITI Aayog. This makes ₹eco scalable, sovereign, and secure, while fully aligned with India's ambitions for digital public infrastructure and green growth.

- Avoids Pitfalls of Carbon Taxes or Carbon Coins : Unlike carbon taxes, which often face public and political resistance, or carbon-backed coins (e.g., KlimaDAO) that exist outside sovereign monetary control, ₹eco works within the existing rupee framework, minimizing systemic disruption. It avoids surveillance-based individual scoring (as seen in social credit systems), focusing instead on sector-level signals and public CPI dashboards for full transparency.

- Scalable and Sovereign: ₹eco is designed to function within India's existing rupee ecosystem, requiring no new currency — just a programmable adjustment layer that can be piloted easily across digital platforms. Its scalability lies in three high-impact applications:

- High-Emission Sectors: Slightly reduce rupee value (e.g., ₹100 = ₹97) in polluting industries like coal logistics or fast fashion to discourage overconsumption without bans.

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- Green Subsidy Schemes: Embed ₹eco in government programs (like EV or rooftop solar subsidies) to reward climate-positive spending with enhanced value (e.g., ₹100 = ₹103).
- Youth Climate Wallets: Launch digital wallets for students that reward sustainable choices (e.g., public transport, eco-certified goods), building habits and data for future policy.

Together, these pilots allow for real-world testing of ₹eco's impact — enabling a gradual, data-backed transition toward climate-aligned consumer and producer behavior, without disrupting macroeconomic stability.

India is poised to become the world's third-largest economy, but this trajectory is threatened by the rising fiscal and human costs of climate volatility. While this paper has quantitatively shown the link between GDP loss and renewable investment shortfalls, it is imperative to think beyond traditional fiscal responses.

₹eco represents a paradigm shift — not in what money is, but in how it behaves in response to planetary risk. By embedding climate intelligence into currency behavior, ₹eco transforms the rupee from a passive unit of exchange into an active signal of sustainability. It leverages technology, behavioral insight, and economic necessity to gently shift the nation's trajectory from reactive spending to regenerative growth.

If climate change is the defining economic challenge of our time, then ₹eco is not merely a policy tool — it is a prototype of a future-ready economy.

The paper's regression findings validate that economic outcomes (GDP stability) are linked to emission patterns. Introducing ₹eco as a test mechanism explores whether money supply sensitivity can reinforce this link.

I began by examining the cost of inaction. I end by proposing ₹eco — a rupee that doesn't just count value, but creates it, sustainably.

Limitations of Study:

- **Data availability constraints**: Some GDP loss estimates are based on approximations rather than direct economic measurements, limiting precision.
- **External economic influences**: Variables such as government policy shifts, global fuel prices, and political developments may influence renewable energy adoption independently of climate trends.

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- **Causality vs. correlation**: While the study identifies a strong association between renewable energy investment and GDP loss, it does not establish direct causation.
- **Time lag in renewable energy impact**: Economic benefits from renewable energy investments often manifest after several years; the study does not fully account for these delayed effects.
- **Limited timeframe**: The analysis is restricted to a 10-year period due to insufficient long-term data availability, which may affect trend reliability.
- **Behavioral unpredictability**: Consumer and producer responses to minor rupee adjustments remain untested and may vary widely.
- **Lack of CPI infrastructure**: India currently lacks a standardized, real-time Carbon Performance Index for accurate implementation.
- **Digital divide**: Not all citizens have equal access to digital payment systems, risking exclusion in early ₹eco rollout.
- **Regulatory hurdles**: Implementation would require RBI and government approval, which may face political or institutional resistance.
- **Sector classification ambiguity**: Defining sectors as “green” or “polluting” could be contested and prone to lobbying or misclassification.
- **Attribution challenges**: Measuring the isolated impact of ₹eco in a live economy could be difficult due to overlapping variables.

Final Thought: India's Strategic Imperative for a Low-Carbon Future

India’s energy transition is no longer a matter of environmental concern alone — it is an **economic and strategic necessity**. Rising climate-induced GDP losses, a global shift toward sustainability in trade and investment, and accelerating technological disruption demand that India urgently redefine its growth model for a low-carbon future.

This study’s cross-country insights and sectoral emissions analysis illuminate critical intervention points where India can act decisively — balancing **economic expansion**, **climate responsibility**, and **energy security**. Solutions lie in **scaling clean technologies**, **strengthening policy enforcement**, and fostering **international cooperation** to build climate-resilient infrastructure and inclusive green growth.

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But as India stands at this crossroads, one additional insight emerges: **monetary innovation itself can become a tool for climate alignment**.

By introducing **₹eco**, a programmable, climate-responsive layer to the Indian rupee, the country could embed environmental accountability directly into its financial system. ₹eco would subtly adjust rupee spending power based on sectoral emissions and national climate performance — nudging both consumers and industries toward sustainable choices **without relying on taxes or bans**. This idea, grounded in the paper's regression findings, presents a bold vision: a currency that doesn't just measure economic value but actively **shapes it in service of sustainability**.

Ultimately, the choices India makes today — including **how it spends, invests, and values money** — will determine its role in the future global economy. It is a choice between reactive crisis management and **proactive leadership through innovation, foresight, and bold policy reform**. ₹eco is just one step in that direction — but perhaps, a transformational one.

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Appendix

Annual CO_2, emissions (million tons) in India:

Year	Annual CO_2, emissions (million tons)
1993	677.29
1994	714.06
1995	760.46
1996	823.62
1997	858.01
1998	875.77
1999	960.76
2000	986.44
2001	1000.52
2002	1032.13
2003	1067.73
2004	1133.82
2005	1194.59
2006	1292.48
2007	1392.50
2008	1489.43
2009	1612.21
2010	1677.33
2011	1764.71
2012	1925.69
2013	1995.09
2014	2148.34
2015	2234.21
2016	2354.65
2017	2426.60
2018	2593.05
2019	2612.88
2020	2421.55
2021	2674.22
2022	2831.16
2023	3062.32

Share of renewable energy in total energy mix:

Year	Share of renewable energy in total energy mix
2013	17.20%
2014	17.20%
2015	17%
2016	16%

ISSN: 2455-8834

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2017	16.50%
2018	17.50%
2019	19.10%
2020	21.30%
2021	21.70%
2022	21.70%
2023	22.60%

GDP loss due to climate change:

Year	**GDP loss due to climate change**
2013	2.6%
2014	2.8%
2015	3.0%
2016	2.5%
2017	3.2%
2018	2.7%
2019	2.9%
2020	3.0%
2021	4.0%
2022	8.0%
2023	4.5%