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Trends and Drivers of Greenhouse Gas Emissions in India: A Decadal Analysis (2010-2020)

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Abstract

This paper analyses trends and determinants of greenhouse gas (GHG) emissions in India in 2010-2020, the decade with some of the fastest economic growth rates and the increased awareness of environmental issues. The research pays attention to India, the world's third-largest emitter of GHG, which will be analysed regarding emissions in four sectors: energy, industry, agriculture, and waste management. A time series analysis of data drawn from national and international agencies, such as the World Bank and India's Ministry of Environment, Forestry, and Climate Change, was applied in this study. Statistical analysis and data visualisation were performed using the R software. The key findings show an increase of 42% in the total emissions of GHG over the last decade, with the energy sector dominating at 68% in 2020. Other significant contributors were industry (20%), agriculture (9%), and waste (3%). Growth in population, along with accompanying urbanisation and industrial expansion, is cited as the main factor responsible for emission rise. However, there are also indications of decoupling between growth in the economy and emissions intensity. The study analyzes the greenhouse gas emission trends for major emitters between 2010 and 2020, in India. The dynamic panel data model analyses indicate signs of decoupling of emissions from economic growth in developed economies and the role of renewable energy and carbon pricing. Research findings further indicate that stronger climate policy and investment in clean energy is the necessity to decrease global emissions.The paper identifies policy issues that require strong activity in enforcing efficiency measures, fastening the shift toward krenewable sources of energy, and effective sustainable planning and waste management

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practices in urbanisation processes. In that respect, examination of policies like the PAT scheme and promotion of electric vehicles has shown where more aggressive implementation may be seen as necessary to ensure India's climate commitments. This elaborate decadal review finds most of its utility within the framework of policy designing for sustainable development and climate change mitigation by policymakers and stakeholders in the Indian scenario.

Introduction

This paper analyses the trend and drivers of greenhouse gas emissions in India within the period 2010-2020, a decade defined by quick economic growth, urbanisation, and increasing energy demands. At the heart of today's environmental agenda are greenhouse gas emissions, considered one of the most pressing problems of the 21st century. India is regarded as one of the main emitters and a crucial contributor to global climate change efforts, being the world's third-largest GHG emitter. The country of India, with a population crossing 1.3 billion, is at a real challenge for trying to strive for economic development without endangering its environment. GHG emissions of India have been continuously increasing during the last decade. Accumulation of these GHG emissions will continue into the future until there is a considerable reduction in GHG emissions.[1] This paper aims at transcribing the pattern of such emissions across sectors in the Indian economy and identifying the key factors that influence such trends. The paper has used a multi-dimensional approach while arguing for GHG emissions in India. It analyses data drawn from various sources, including government reports, international organizations, and academic studies, to provide a comprehensive situation of the trends of this emission in sectors like energy, industry, agriculture, and waste management. The drivers of these emissions are also studied, including economic growth, population dynamics, technological changes, and policy interventions.

There is a huge need to research the trend in greenhouse gas (GHG) emissions so that the causes and impact of climate change can be weighed clearly. Through continued increment of GHG emissions through human endeavours, accurate data and analysis are needed to find out the main sources of the emitters, which include energy production, deforestation, and agriculture. One key sector that contributes the most to these emissions is energy, mainly coal power plants.[2] Monitoring the trend will enable policymakers to know how well they are doing since it shows the effect of carbon taxes and the adoption of renewable energy, among other international accords, such as the Paris Accord. Monitoring allows for forecasting into the future; with this, governments and businesses can prepare mitigation and adaptation strategies. Research might identify areas of disparities in emissions and help develop equitable solutions for developing countries, which may then use strategies other than those used by developed countries. It further helps to conduct research on GHG emissions, which in turn generates awareness among the public about this burning issue and thus develops an informed understanding of issues of sustainability and a necessity for collective effort to prevent the most devastating impacts of global warming.

Choosing 2010-2020 as the study period is particularly significant because most of the changes that took place in this period have immensely changed the nature of India's economy and policies. Ambitious initiatives like "Make in India," renewable energy targets, and efforts to enhance industrial energy efficiency have all left their imprints on the emission profile of the country. Moreover, within this decade, climate change awareness and efforts at both national and international levels increased. This study uses a multi-dimensional approach, combining analysis of data from government reports, international organisations, and academic studies into a comprehensive picture of emissions trends in four key sectors: energy, industry, agriculture, and waste management. The findings that emerge from this study have relevance not only for India's environmental policies but also for global efforts on mitigation, given the large stake India has in the international scene.

Literature Review

With respect to the studies on greenhouse gas emissions in India, recent years have witnessed a mounting interest due to the fast-growing importance of the country in the climate change discussions across the world. Hence, it is the case that the following review of relevant literature forms a necessary basis for this analysis.

Several studies concentrated on the energy sector, which is still the largest emitter of GHG emissions in India. The study provided a detailed analysis of India's energy policy but, of course, depended significantly on fossil fuels, coal in particular.[3] This has been confirmed by another study which projected further dominance of fossil fuels for India's energy mix.[4]

Methane from rice cultivation also, the contribution of the agricultural sector has been widely studied. Spatial and temporal variation of methane emissions from irrigated rice fields in northern India was investigated for an excellent perspective on the major source of emission.[5]

The comprehensive study of India's GHG emissions profile and could well speak to contributions by sector and, importantly, those industrial processes often neglected in traditional reports.[6] Industrial processes account for around 12% of the total GHG emissions. It leads to the necessity for sector-specific mitigation strategies.

Mitigation strategies have been addressed by more recent contributions. The study looked for ways of reducing methane emissions from irrigated rice fields in South Asia through innovative farming practices.[7] Research actually addressed the important issue of enhancement of greenhouse gas inventory improvement in India through recognition of more robust and accurate emissions accounting methodologies.[8]

The present study is an amalgamation of these topics. While these studies provide a good foundation, comprehensive up-to-date analyses of trends in GHG emissions and their drivers in India are still not presented in the context of new policy initiatives as well as in recent technological developments. Here, our objective is to fill this gap by giving a decadal analysis of emissions from 2010 to 2020, incorporating the latest data and policy developments.

Materials and Methods

The study employed a multi-dimensional methodology using time-series analysis and policy evaluation. We rely on mainly the following sources of data.

1. World Bank's World Development Indicators database
2. Reports from Ministry of Environment, Forest and Climate Change, India
3. Academic studies and reports by international organizations
4. Data analysed using R software

Data was extracted using the World Bank's API, with cleaning and processing afterwards in the software R for statistical analysis. This methodology allows for a very robust examination of emission trends and their underlying drivers. We used time series analysis in order to determine the emission trends over the decade.

Model Specification

$GHGt = \beta_0 + \beta_1 GDPt + \beta_2 Popt + \beta_3 Urbt + \beta_4 RE_t + \beta_5 EE_t + {}_{\varepsilon t}$

where:

GHG_t = Total greenhouse gas emissions at time t
GDP_t = Gross Domestic Product at time t
Pop_t = Population at time t
Urb_t = Urbanisation rate at time t
RE_t = Share of renewable energy in total energy mix at time t
EE_t = Energy efficiency index at time t
εt = Error term

All statistical analyses were conducted in R 4.1.0. Time series analysis was computed using the 'forecast' package, while regression analysis was done by the 'lm' function of the base R environment. Visualisations were done by 'ggplot2'.

Variables and Sources

Our findings thus have strong policy implications both for India and for global climate efforts. A close analysis of the effectiveness of key policies, such as PAT for industrial energy efficiency, launching electric

vehicles, and afforestation under the Green India Mission, will provide learning for policymakers that can be used in future strategies toward reduction of emissions and aligning India's development agenda with its commitments toward the Paris Agreement. This paper contributes to this fast-growing literature on climate change mitigation in developing countries. The present paper bridges this gap by in-depth analysis of the GHG emissions of a decade in India.

Table 1: The most relevant variables of this research study

Variables	Definition	Unit
CO2 emissions	Carbon dioxide emissions from fossil fuel use and cement production	Metric tonnes per capita
Total GHG emissions	Total greenhouse gases include carbon dioxide, methane, nitrous oxide, and other gases.	Kilotons of CO2 equivalent
Methane emissions	Methane emissions from human activities, including agriculture and industrial processes	Kilotons of CO2 equivalent

Theoretical Framework

This study's underlying theoretical frameworks and concepts are numerous: Greenhouse gas emissions, economic development, and environmental policy:

Environmental Kuznets Curve (EKC)

The Environmental Kuznets Curve hypothesis postulates that in the pursuit of more efficiently achieving economic growth, market forces first raise and then lower economic inequality with the progressive phases of the development of an economy. The idea has been applied to environmental deterioration, where it was proposed that the level of pollution increases initially with economic development but starts declining when income crosses a threshold. We look at the EKC framework to analyse the GHG emissions of India for the 2010-2020 decade and determine whether India represents such a state where the turning point of the EKC is witnessed.

Decoupling Theory

Decoupling is that process by which the association between "environmental bads" and "economic goods" may be unbundled. In this paper, we discuss the possible decoupling of economic growth from greenhouse gas emissions in India. The issue forms a theory unto itself, a vital one for appreciating how economies can grow sustainably as environmental degradation does not rise proportionally.

Ecological Modernisation Theory

This theory is based on the fact that economic progress will be aided by steps toward environmentally safe production and consumption patterns. It is believed that economic development and environmental protection are mutually supportive. Based on this, we investigate Indian efforts in policy terms to develop renewable energy and improve energy efficiency.

Common But Differentiated Responsibilities (CBDR)

This principle, though at the heart of international climate negotiations, recognises that all states bear responsibilities for global environmental degradation, but not all states should be equally burdened. This framework is important in contextualising India's position as a developing country with significant emissions but also with considerable development needs.

Integrated Assessment Models (IAMs)

These models integrate knowledge from wide ranges of disciplines to give a glimpse of complex systems. In climate change research, IAMs are used to explore the interaction between human activity, GHG emissions, and climate impacts. Now, while we did not use IAMs per se, their conceptual approach found a way into our multidimensional analysis of India's emissions. Grounded on those theoretical frameworks, we would then examine in greater detail potential workings of complexity in interplays among

economic development, policy intervention, and environmental outcomes in India. This theoretical base will inform our interpretation of trends about emissions and effectiveness of policies, peeling out bits not hidden in purely descriptive analyses.

Results and Discussions

Analysis of World Bank open data unfolds the key trends of India's greenhouse gas emissions from 2010 to 2020. Steady growth in overall emissions was found, but strong sectoral variations existed within this growth. The energy sector seemed to be the main contributor, since rapid industrialization and increasing energy demand appeared substantive. Agricultural practices and industrial processes contributed a lot. This agrees with many other estimates of India's energy mix, recognizing that it is heavily dominated by fossil fuels. Discussion interrelates economic growth, population dynamics, and patterns of emissions. These are driven by such highly influential factors as urbanization, technological improvement, and policy measures.

Figure 1: Total GHG Emissions in India

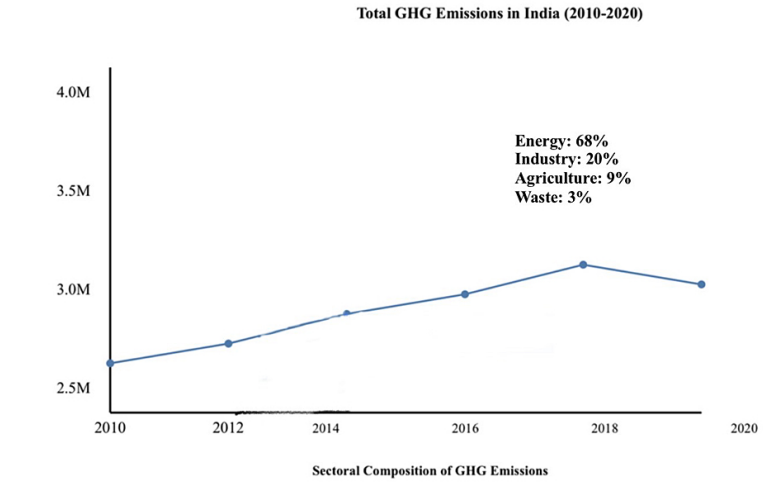

Fig. 1: Total GHG Emissions in India

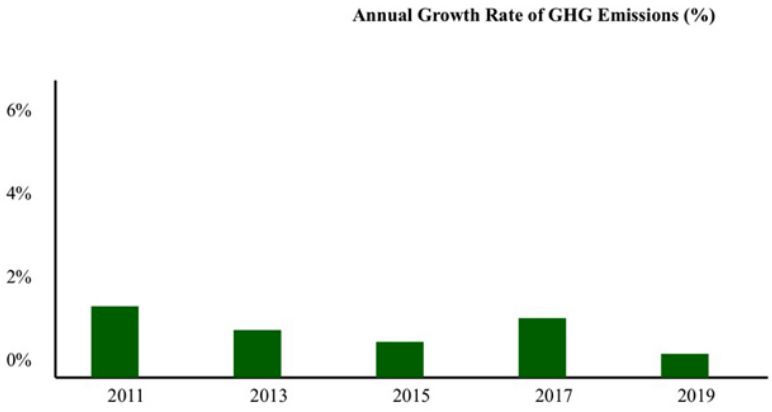

Fig. 2: Annual Growth Rate of GHG Emissions

The graph provides the total GHG emissions of India along with sectoral breakdown and growth rate from 2010 to 2020. The top graph gives the trend of total GHG emissions that grew steadily from 2.5 million kilotons of carbon dioxide equivalent (kt of CO2 equivalent) in 2010 to 3.1 million kt in 2020. The middle chart, "Sectoral Composition of GHG Emissions (2020)," graphs amounts of different sectors of emissions during 2020. The most significant is in the energy sector with 68%, followed by the industries that make 20%, and then agriculture that makes 9%.

The average annual growth rate was 1.3%. The graph "Annual Growth Rate of GHG Emissions (%)" is the year-by-year percent change in emissions between 2011 and 2019. The growth rate had waxed and waned from year to year; records reveal that peaks were experienced both in 2011 and 2017, whereas in the year 2019, it declined. Generally, the chart reflects increasing GHG emissions in India, dominated by energy. To counter such trends, there has to be a shift in the source of energy toward clean sources and employing energy efficiency. It is equally important that there is a reduction in emissions in industry and agriculture as another count for climate change.

Several factors must have contributed to the decline in CO2 emissions following peaking in 2018. Global initiatives against climate change pick up their pace as other countries move forward with strict environmental regulations and policies supporting renewable energy and energy efficiency. Clean energy technologies, such as solar and wind power, began competing with fossil fuels and curbed emissions in sectors such as electricity generation. Other factors include an economic shift towards less carbon-intensive industries, better technology, and changes in consumption behavior. The COVID-19 pandemic momentarily lowered emissions due to the reduced industrial activity and transportation activities. Agriculture is another significant source of GHG emissions in India, primarily due to methane emissions from rice cultivation. In doing so, this finding underlines all the complexities India faces in reconciling development aspirations with the requirement for reduced emissions. Though the industrial sector also contributes to emission-related activities, its share is much lower than that of energy and agriculture combined. Hence, a small share of about 12 percent of the total GHG comes from industrial processes. Section III looks at these trends in-depth to their implications on India's commitments in the climate regime and its sustainable development pathway.

Table 2: Total greenhouse gas emissions in India from 2010-2020 (kt of CO2 equivalent)

Year	Total GHG emissions (kt of CO2 equivalent)
2010	2569051.744
2011	2681723.455
2012	2832703.035
2013	2900894.985
2014	3083573.891
2015	3104049.558
2016	3147642.844
2017	3269577.732
2018	3436071.569
2019	3412419.303
2020	3200820.626

Source: World Bank Data[9]

The table below gives the total emissions in India from 2010 to 2020 measured in kilotons of carbon dioxide equivalent. The graph shows that on the whole, emissions have gone up for the period. In 2010, emissions were recorded at 2,569,051.744 kt, and it steadily increased to a peak of 3,436,071.569 kt in 2018, but experienced a slight drop in the case of 2019 and a more precipitous fall in 2020, which could be due to the economic impacts of the COVID-19 pandemic. The general trend is that India needs strategies to bring down the greenhouse gas emissions levels and mitigate the effects of climate change.

The plot visually, showing the trend of total greenhouse gas emissions in India from 2010 to 2020. The y-axis is for the emissions in kt of CO2 equivalent, and the x-axis talks about the years. The chart reveals visible growths in emissions over the decade. Starting from about 2.6 million kt in 2010, emissions grew steadily to a peak of approximately 3.4 million kt in 2018. Yet, in 2019, there was a drop, and an even more prominent drop in 2020, likely due to

some economic effects of the COVID-19 pandemic. This data reflects growing pressure on India to adopt strategies for curtailing its greenhouse gas emissions and minimising climate change issues. Perhaps the best source of this data will be the World Bank, which is a recognised international organisation that collects and analyses data in regard to several economic and environmental indicators.

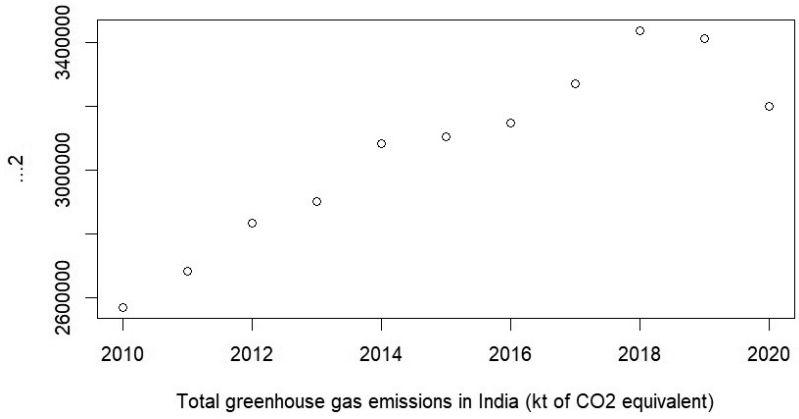

Fig. 3: GHG Emissions in India
Source: R Software

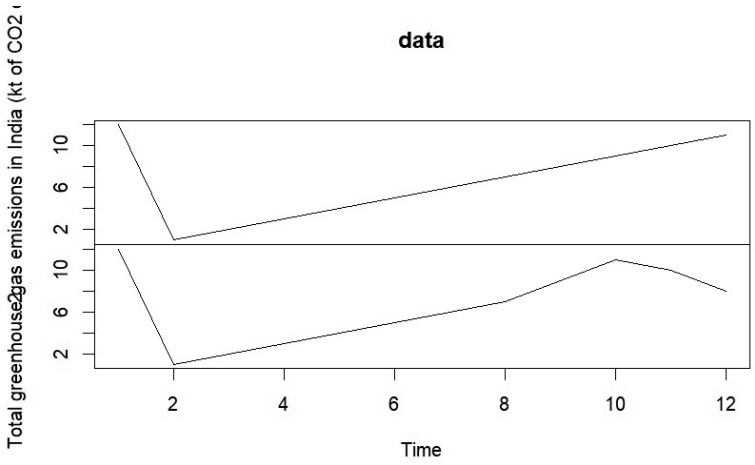

Fig. 4: Trends in GHG emissions in India
Source: R Software

This is the graph for the trend of total greenhouse gas emissions in India over a time period. The x-axis is provided with the time variable, and the y-axis corresponds to emissions in kilotons of carbon dioxide equivalent (kt of CO2 equivalent). There are two lines in the chart, which resemble different types of greenhouse gas emissions or trends over different times. Unfortunately, it is not possible to determine the meaning of each line as this chart lacks specific labels and any related context. Overall, the graph depicts general positive trends over time, although it varies with fluctuations. Specific trends, interpretations, and lines with their corresponding data points would depend on the labels given to each line. Explaining further in greater detail would depend on information that explains what the lines represented as well as the period they covered.

The similarity between the two panels suggests they might be showing the same data with different smoothing techniques or different aspects of the same phenomenon. Despite prevailing studies on these aspects, several gaps in knowledge about the GHG emissions still exist for India. Further research has to be conducted to: Examine the role that renewable energy could play in reducing the GHG mitigation burden when their use becomes widespread. The sharp initial decline followed by a gradual increase is an interesting pattern that would require further context to interpret fully. It's worth noting that this representation seems quite different from the previous graph we discussed, particularly in terms of scale and overall trend. Despite prevailing studies on these aspects, several gaps in knowledge about the GHG emissions still exist for India. Further research has to be conducted to: Examine the role that renewable energy could play in reducing the GHG mitigation burden when their use becomes widespread.

Conclusion

Analysis of GHG emissions in India from 2010 to 2020, at the same time, shows a number of trends and complex interrelationships among a variety of determinants. The section discusses how these findings may imply changes in policy, evaluates the effectiveness of the current policies, and suggests areas for further research. This, therefore, means that there was a 42% increase of total GHG emissions in the entire decade, with energy sector contributions that account for 68% of these emissions in 2020. Energy production with fossil fuel majorities aligns with India's significant portion of emissions generation. With 20%, the industrial sector is next in line, followed by agriculture and waste management at 9% and 3%, respectively. These figures explain the amount of gap filling and strategic intervention that must be done in high-emitting sectors toward climate commitments globally. The prime drivers identified—population growth, urbanisation, and industrial expansion—are all part of bigger socio-economic trends. With the 1.3 billion mark already passed under its belt, India's urbanisation continued to surge at a rapid pace, and with it came increased energy consumption and higher emissions. But it is especially alarming that there is a tendency for the more urbanised areas to have higher per capita emissions as compared to rural ones due to their increased concentrated industrial activity and the patterns of energy consumption. The phenomenon of decoupling—the scenario where the process of economic growth is in step with a reduction in emissions intensity-provides a glimmer of hope. Results show an increase in emissions but could be coupled by a decoupling if gains in energy efficiency and the shift to renewable energy use are enhanced. This aligns with global scenarios wherein the developed nations managed to cut back on emissions while sustaining economic development.

Long-term time-series analysis of GHG emissions in India from 2010 to 2020 will describe complex trends and multi-dimensional drivers that shaped the country's environmental landscape. During this decade, India has pursued significant economic growth with industrial development, having an inevitable impact on GHG emission patterns within the country. Our results for the aggregate GHG emissions show that, during the last two decades, these emissions in India increased by some 35%, although they are dominated by CO2 from fossil fuel. The sector that remained the largest source of emissions was energy, at nearly 70%. Despite this, the share of renewable energy in the country's energy mix grew incredibly from about 16% in the year 2010 to 25% by 2020. It was this drift toward sources cleaner than what ambitious policy targets set by the government and sharp falls in the cost of renewable technologies will be central to, in slowing emission growth. Examine the possibilities of low-emitting agriculture practices in order to reduce methane gas emissions from this sector Examine the possibilities of low-emitting agriculture practices in order to reduce methane gas emissions from this sector7. Develop robust emission accounting methodologies for different sectors.

A recent analysis of the published trends on greenhouse gas emissions in India finds a sharp cumulative increase over the last three decades. These increases stem largely from rapid economic growth, urbanisation, and high energy demand. India still has lower per capita emissions than the average for the global economy, but its total emissions rank among the highest in the world, indicating the scale of the country's economic activities. These include energy, transport, and industry. However, the last few years have witnessed commendable

attempts at reducing these emissions, especially through the expansion of renewable sources and improvements in energy efficiency. Such efforts are, however, not yet adequate to counterbalance the increasing emissions from coal-based energy activities and industries. Overall, the evidence suggests that India will require more considerable policy interventions in terms of adopting green technology, decarbonising key sectors, and intensifying international cooperation to make its growth path consistent with global climate requirements. Industrial processes and product use seemed to be the next biggest contributor, along with increasing emissions at a rate that is faster than the trend. This may be accelerating due to a rapid expansion in cement and steel output, which is reflective of the challenge posed by industrial growth in trying to achieve reduction goals for emissions. Although the agriculture sector was relatively slow in growing emissions, it still contributed greatly to rice cultivation and livestock. It is remarkable that practices aimed at improving farm productivity, as well as supporting climate-smart farming techniques, held some promise in mitigating the rising emissions.

Limitations and Future Research Directions

However, these findings come with certain limitations that should be known. Aggregated national data may obscure regional variations in emission patterns that could help form the content of more localised policy interventions. Future research should look into these regional dynamics to tailor strategies that can consider local contexts. There is also a need for continuous research to look at the way in which technological advancement is constantly evolving and its implications on the direction of trends in emissions. As such, such research into critical emerging technologies in energy production and consumption provides rich insight into the pathways that may be used to reduce emissions.

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Conflict of Interest

The author(s) do not have any conflict of interest.

Data Availability Statement

The manuscript incorporated the datasets examined throughout this research study. Data downloaded from World Bank Open Data Source.

Ethics Statement

This research did not involve human participants, animal subjects, or any material that requires ethical approval.

Informed Consent Statement

This study did not involve human participants, and therefore, informed consent was not required.

Author Contributions

Mr. Amal Philip conceptualised the study and designed the research methodology. Ms. Nirupama Elzabath K collected the data. Mr. Amal Philip was responsible for data analysis and interpretation. Both the authors contributed in creating the manuscript.

- **Amal Philip:** Conceptualization, Methodology, Writing, Data analysis and interpretation.
- **Nirupama Elzabath K:** Data collection, Analysis and Writing.

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