Historical Gas Emissions & Economic Growth Study

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Background: Historical Gas Emissions & Economic Growth

One of the most urgent issues facing the world today is climate change, with greenhouse gas emissions playing a critical role in driving global warming. Rising global temperatures, extreme weather events, and changing climate patterns are the results of the buildup of greenhouse gases in the atmosphere, which is mostly caused by human activities such the burning of fossil fuels, deforestation, and industrial operations.

Historically, economic growth has been **positively correlated with emissions**, with if GDP increases, so does energy consumption and emissions. However, recent trends suggest that some **high-income nations** have successfully **reduced emissions while maintaining economic growth**, suggesting a possible **decoupling** between GDP and emissions.

This report analyzes **historical GHG emissions data from Climate Watch**, covering the period from **1990 to 2019** for **195** countries and regions. The dataset provides insights into emissions trends across various geographical areas and economic circumstances, allowing for a more in-depth knowledge of how emissions have changed over time. The goal of this report is to explore these trends, compare emissions across areas, and evaluate countries' progress toward lowering their carbon footprint. This data will be studied alongside **GDP per capita data** and **Population data** from **the World Bank**, providing a comprehensive view of **economic factors influencing emissions trends**. This analysis intends to add to the ongoing discussion about climate policy and mitigation measures by analyzing emission trends along with GDP and key drivers.

The Challenge: Balancing Emissions Reduction with Economic Growth

Achieving worldwide climate goals, such as those established by the Paris Agreement, which seeks to keep the increase in global temperature to well below 2°C over pre-industrial levels, depends on addressing these emissions. However, this effort must balance economic development, as countries at different income levels face unique challenges in reducing their carbon footprint.

Countries at different income levels face **unique challenges** in lowering their carbon footprint while sustaining economic growth.

- **Developed nations** may have the financial and technological capacity to **invest in clean energy** and transition toward low-carbon economies.
- **Developing nations**, however, may rely on fossil fuels for **economic expansion**, leading to increased emissions.

In order to make informed decisions on sustainability initiatives, governments, researchers, and the general public must have a thorough understanding of emissions statistics. The success of climate policy, inequalities in accountability and impact, and the basis for future climate action can all be uncovered by a thorough examination of past emissions trends.

Gas Emissions Data

The data consist of greenhouse gas (GHG) emissions measured for different countries and regions worldwide, spanning the years 1990 to 2019. GHG emissions contribute to climate change, and analyzing long-term trends helps assess mitigation efforts and policy effectiveness. The dataset records emissions values in million metric tons of CO_2 equivalent($MtCO_2e$) and categorizes emissions across different sectors.

- **Observational units**: Annual GHG emissions ($MtCO_2e$) per country or region.
- **Variables**: Year, Country, Data Source, Sector, Gas, and Unit
- **Time coverage**: 1990-2019 (30 years).
- **Geographic coverage**: 195 countries and global totals.

The table below provides variable descriptions and units for each column in our dataframe.

Table 1: Data Description Table

Variable	Description	Units
Year	Year of recorded emissions	Numeric; Years
Country	Country where emissions were recorded	Categorical; Country Name

Variable	Description	Units
Data Source	Source of the emissions data	Categorical; Source Name
Sector	Sector classification of emission (LUCF = Land Use Change and Forestry)	Categorical; Sector Name
Gas	Type of greenhouse gas measured (GHG = Greenhouse Gas)	Categorical; Gas Type
Unit	Measurement unit for emissions values	Numeric; Million metric tons of CO_2 equivalent ($MtCO_2e$)

GDP Per Capita Data (inc. Population)

To assess the impact of **economic growth on emissions**, we incorporate **GDP per capita** data from the **World Bank**. This dataset provides annual **GDP per capita values** for **195 countries and regions**, expressed in **current US dollars**.

- **Observational Unit:** Countries
- **Time Coverage:** 1961-2019
- **Geographic Coverage:** 264 countries and global totals
- **Measurement Unit:** US dollars (current prices)
- **Relevance to Emissions:** Higher GDP per capita often correlates with **higher energy consumption**, but may also indicate investments in **clean energy and sustainability measures**.

Variable	Description	Units
Year	Year in which GDP per capita was recorded	Numeric; Years
Country	Name of the country where GDP was recorded	Categorical; Country Name
GDP per capita	Gross Domestic Product per capita in current US Dollars	Numeric; USD
Country Code	Standardized three-letter ISO 3166-1 alpha-3 code representing each country	Categorical; ISO Alpha-3 Code
Population	The total population per year per capita	Numeric; Population Count

The Question of Interest

The key research question that guides this analysis is: ***How have global and country-specific GHG emissions changed over time, and what variables may have influenced these trends?***

This question is motivated by the increasing urgency of addressing climate change and the necessity for a data-driven strategy to assessing emissions reduction initiatives. By analyzing emissions data over a 30-year period, this study aims to identify:

- Overall trends in global GHG emissions.
- Regional variations and differences between developed and developing nations.
- The role of economic growth, policy changes, and energy transitions in shaping emissions trends.

Finding important trends and plausible causes for the observed emissions trends would be necessary to provide a satisfying response to this topic. This includes evaluating whether certain policies have been effective in curbing emissions, determining which countries or regions have made significant progress, and understanding the ways in which industrial and economic factors affect GHG emissions. Additionally, the findings will help inform discussions on future mitigation strategies and areas where further research or policy intervention may be needed.

Data Cleaning

Before conducting our analysis, we need to **clean and restructure the dataset**. Our data is **not in a tidy format**, as years are stored as **column headers** instead of a **single variable**. The cell below imports our Historical Emissions data.

To ensure proper analysis, we **tidy the dataset** by:

1. **Reshaping it into long format** (moving years from columns to rows).
2. **Ensuring Year is stored as a numeric variable**.
3. **Handling missing values** appropriately.
    - Our GDP dataset contains a significant number of missing values in the GDP per capita.To preserve data integrity and avoid unnecessary loss of information, we will apply mean imputation, replacing missing values with the mean GDP per capita for each country. In regards to our Population and Emissions dataset, we will be dropping missing NA's for simplicity.

First Looks at our Datasets (Emissions, Gdp, and Population)

Emissions Data Sneak Peek

Country	Data source	Sector	Gas	Unit
World	Climate Watch	Total including LUCF	All GHG	MtCO e
China	Climate Watch	Total including LUCF	All GHG	MtCO e
United States	Climate Watch	Total including LUCF	All GHG	MtCO e

GDP Per Capita Data Sneak Peek

Country Name	Country Code	Indicator Name
Aruba	ABW	GDP per capita (current US)$\vert\vert Afghanistan \vert AFG \vert GDPpercapita(currentUS)$
Angola	AGO	GDP per capita (current US)$\vert\vert Albania \vert ALB \vert GDPpercapita(currentUS)$
Andorra	AND	GDP per capita (current US$)

Population Data Sneak Peek

Country Name	Country Code	1960	1961	1962
Aruba	ABW	54211	55438	56225
Afghanistan	AFG	8996973	9169410	9351441
Angola	AGO	5454933	5531472	5608539

Final Merge (All Datasets)

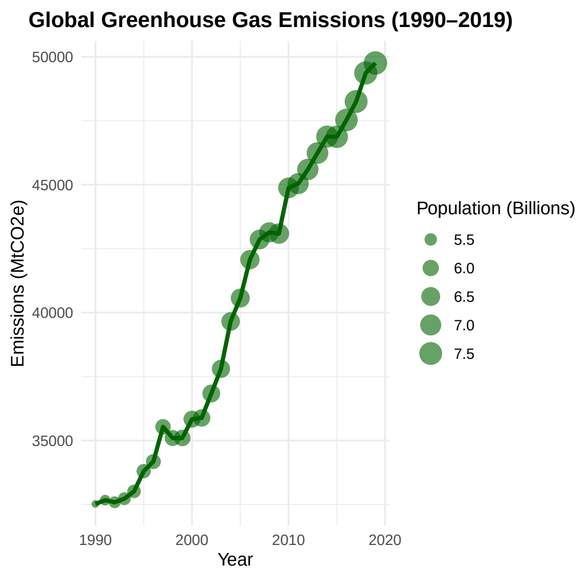
Country	Country Code	Year	Emissions	gdp	Population
World	WLD	2019	49758.23	115.3322	7673533974
World	WLD	2018	49368.04	114.8555	7591945271
World	WLD	2017	48251.88	109.2766	7509074479
World	WLD	2016	47531.68	103.8634	7424286143
World	WLD	2015	46871.77	103.4907	7338964954

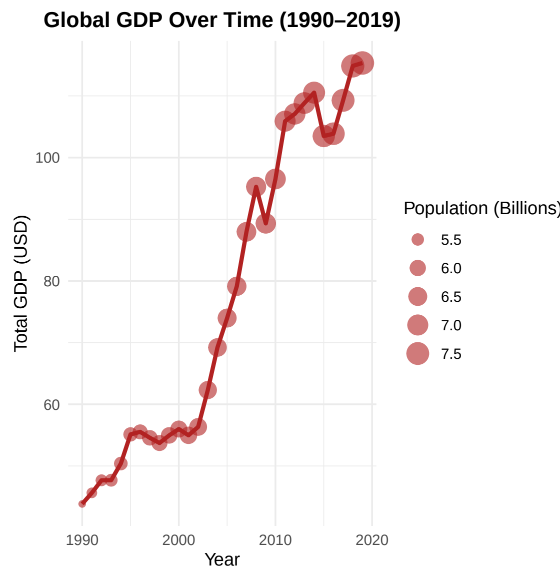
Our dataset has been tidied, and no longer contains any missing NA's. We can now move onto our **EDA** (Exploratory Data Analysis) section.

Exploratory Data Analysis

Global Emissions & GDP Overtime

To understand long-term trends in greenhouse gas output, we first examine global emissions from 1990 to 2019. The dataset includes a special "World" entry, which aggregates emissions across all reporting countries and sectors. This allows us to visualize the overall trend of human impact on the atmosphere over the past three decades. Also, by integrating global GDP data and scaling both metrics by total population, we reveal how demographic expansion and economic growth have jointly shaped the trajectory of greenhouse gas emissions over time.





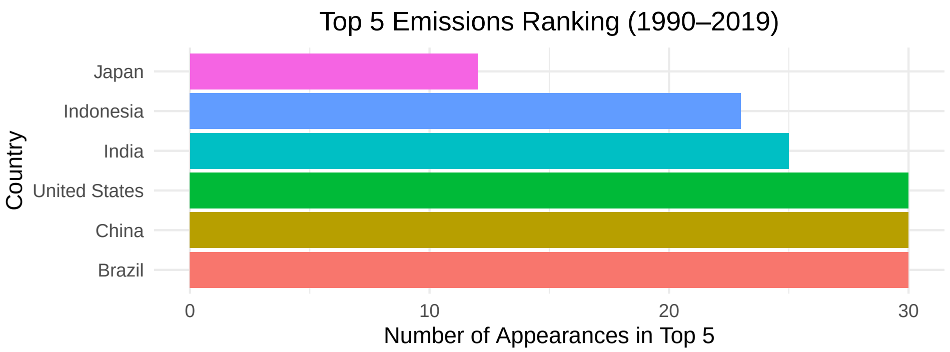
Global greenhouse gas emissions and GDP have both shown a steady and significant increase from 1990 to 2019. Emissions rose gradually in the early 1990s, followed by a sharp acceleration after 2000, closely reflecting patterns of economic growth during the same period. This rise was largely driven by the rapid industrial expansion of countries such as China and India which experienced significant industrial growth, leading to a surge in energy consumption, much of it powered by fossil fuels. While some fluctuations in emissions growth can be observed, such as temporary slowdowns during economic recessions or during brief periods of policy intervention, the overall pattern remains one of continued growth.

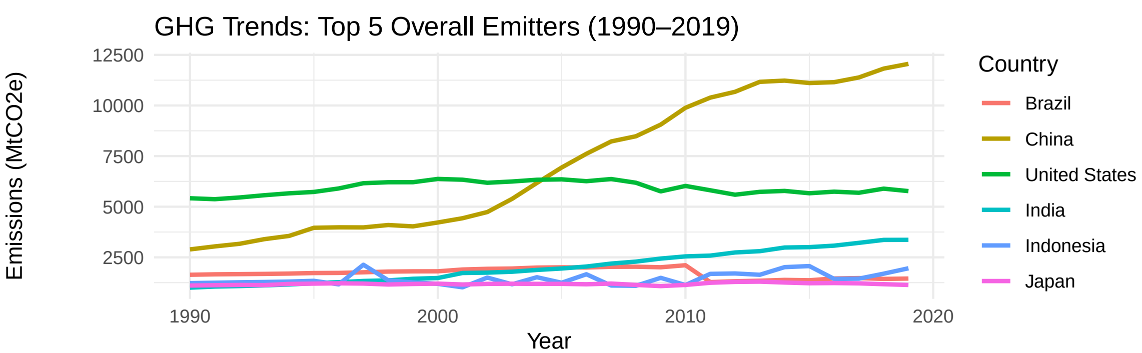
A slowdown in the rate of emissions growth appears in the most recent years, possibly reflecting the increasing adoption of renewable energy sources, improvements in energy efficiency, and stricter environmental policies in some parts of the world. However, emissions remain significantly higher than they were in previous decades, underscoring the fact that global efforts to curb emissions have not yet resulted in a meaningful reduction in overall greenhouse gas output.

The key takeaway from this trend is that economic and industrial growth remain primary drivers of emissions, and while policies and cleaner technologies may help slow the rate of increase, they have not yet led to a global-scale reduction. Future emissions reductions will likely depend on the successful implementation of more ambitious climate policies, accelerated investments in renewable energy, and international cooperation to enforce emissions limits more effectively.

Top 5 Contributors to Overall Global Emissions since 1990

Rather than focusing on a single year, we examined which countries repeatedly ranked among the top 5 greenhouse gas emitters from 1990 to 2019. This long-term view reveals which nations have played the most significant roles in driving emissions over the past three decades. China and the United States appear most frequently, with India, Russia, and the European Union also showing up regularly.





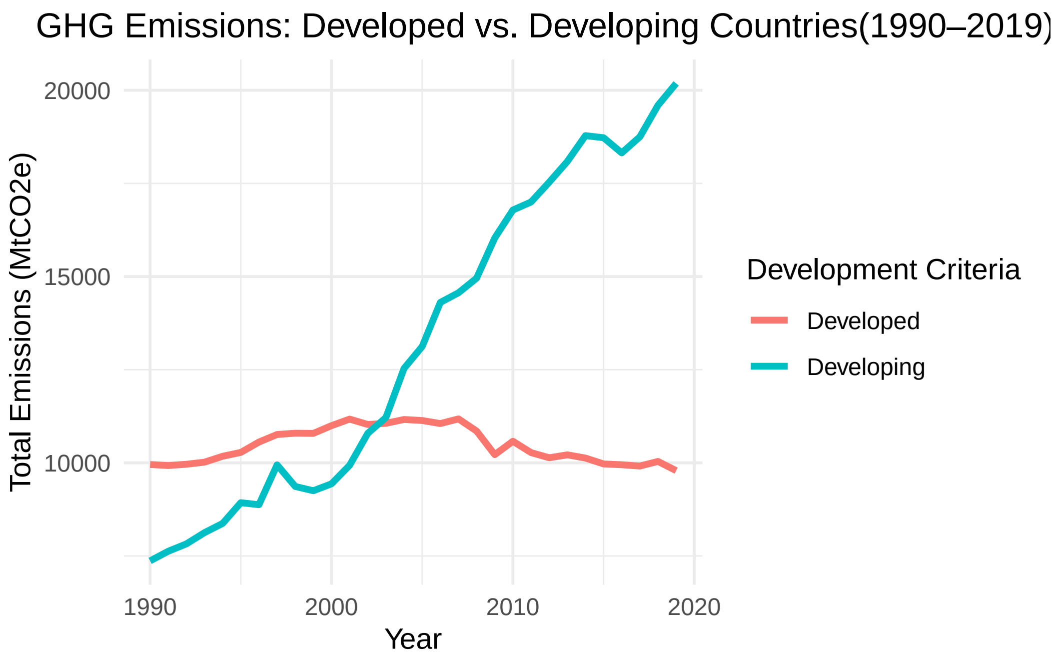
From 1990 to 2019, the United States, China, and Brazil have been the most consistent contributors to global greenhouse gas emissions, each appearing in the top 5 every single year. Meanwhile, India and Indonesia have steadily risen in the rankings, with frequent appearances in the top 5.

China's emissions rose sharply after 2000, making it the dominant global emitter. The U.S. remained relatively stable, whereas Indonesia balanced between increasing and decreasing.

India's emissions steadily increased, reflecting economic growth, while Brazil saw a modest rise with a notable drop around 2010.

Developed Countries vs. Developing Countries

To explore differences in emissions behavior, we compare greenhouse gas emissions between a subset of developed (e.g., U.S., EU, Japan) and developing countries (e.g., India, Indonesia, Brazil). While our full dataset contains 168 countries, we focus on a selected group of representative nations to illustrate broader trends. Developed countries have historically emitted more due to early industrialization, while emissions in developing countries are rising alongside economic growth. This comparison helps us assess whether developed nations are successfully reducing emissions and how developing economies are contributing to current global trends.



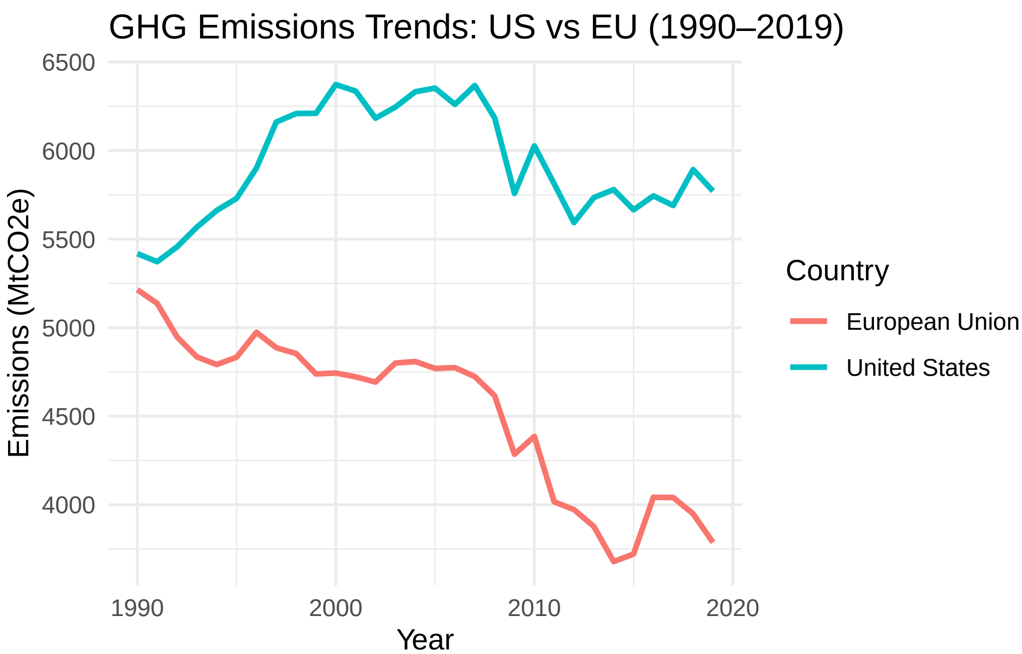
This plot shows the aggregated annual greenhouse gas emissions from selected developed and developing countries between 1990 and 2019. Emissions from developing countries increased dramatically over this period, surpassing those of developed countries around 2007. While the group includes multiple nations, the sharp rise is primarily driven by China and India, whose rapid industrialization and economic growth contributed significantly to the upward trend.

In contrast, emissions from developed countries remained relatively stable or declined slightly, reflecting policy efforts, cleaner technologies, and shifts away from carbon-intensive industries. This divergence highlights how emerging economies are becoming key drivers in global climate dynamics as contributors to emissions.

Country Level Analysis

GHG Emissions Trends: US vs. EU (1990–2019)

Over the past three decades, the United States and the European Union have taken different paths in addressing GHG emissions. While both have historically contributed significantly to global emissions, the EU has demonstrated a more consistent downward trend, whereas the US has experienced fluctuations.



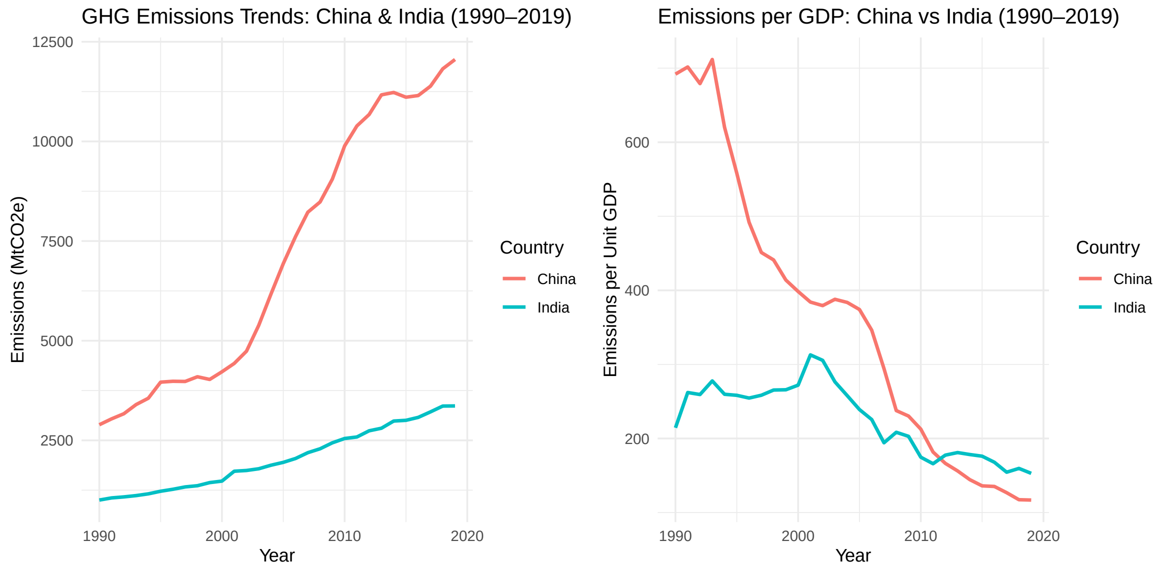
The European Union has steadily reduced emissions since the 1990s, largely due to strict climate policies, the transition to renewable energy sources, and the implementation of carbon pricing mechanisms. The United States, in contrast, saw emissions rise in the 1990s and early 2000s, followed by a decline after 2008. The US reduction in emissions can be attributed to a shift from coal to natural gas, improvements in energy efficiency, and the expansion of renewable energy. However, periodic increases indicate that the country still faces challenges in fully transitioning to a low-carbon economy.

The key takeaway from this analysis is that the EU has been more successful in decoupling economic growth from emissions, whereas the US, despite progress, continues to show variability in its emissions trends. This suggests that long-term policy stability and regulatory frameworks play a crucial role in emissions reduction efforts.

GHG Emissions Trends: China & India

China and India, as two of the fastest-growing economies, have shown significant increases in emissions over the years. However, the magnitude and pace of their emissions growth differ due to varying levels of industrialization and energy dependency.

Emissions per unit of GDP serve as an indicator of how efficiently a country produces economic output while managing carbon emissions. In both China and India, emissions per GDP have shown a downward trend over the past three decades, indicating improvements in energy efficiency and industrial modernization.



China's emissions have surged dramatically since 2000, reflecting its rapid industrialization, urban expansion, and reliance on coal as the primary energy source. The country's economic boom, driven by manufacturing and large-scale infrastructure projects, has made it the world's largest emitter of GHGs. India, while also experiencing economic growth, has shown a more gradual increase in emissions. Unlike China, India has relied more on hydro and renewable energy sources, contributing to a slower emissions growth rate.

The primary driver of China's emissions increase is its high reliance on coal-powered electricity and export-driven industrial production. In contrast, India's emissions trajectory suggests a more diversified energy mix and a growing emphasis on renewable energy expansion. The key takeaway here is that while both nations are on a high-emission trajectory, India is progressing at a slower rate, potentially offering a greater opportunity for early climate mitigation interventions.

China, despite having the highest total emissions, has made significant progress in reducing its emissions intensity. This trend is largely driven by technological advancements, shifts towards cleaner energy, and government-led emissions reduction initiatives. India has also reduced emissions per unit of GDP, but at a more gradual pace, reflecting its ongoing industrial expansion and evolving energy policies.

The declining emissions intensity in both countries suggests that economic growth does not necessarily have to be tied to increased emissions. While China's rapid decline indicates a more aggressive transition towards efficiency, India's slower yet consistent improvements highlight the growing role of renewables and energy-efficient technologies in shaping the future of emissions management.

The Impact of Climate Policies

Given the strong connection between economic growth and emissions, international climate agreements have sought to mitigate emissions by setting reduction targets and encouraging greener energy transitions. Two of the most significant agreements in recent decades are the Kyoto Protocol (1997) and the Paris Agreement (2015). The effectiveness of these agreements can be evaluated by comparing emissions levels before and after their implementation.

Policy	Before	After
Kyoto Protocol	163.9541	215.4787
Paris Agreement	194.9743	245.9037

The data reveals that neither agreement has resulted in an absolute reduction in global emissions. Following the Kyoto Protocol, average emissions increased from 163.96 $MtCO_2e$ before 1997 to 215.48 $MtCO_2e$ afterward, suggesting that the agreement did not lead to meaningful reductions. This could be attributed to the lack of participation from major emitters such as the United States, as well as the fact that some countries were not required to meet binding emissions targets.

Similarly, after the Paris Agreement in 2015, emissions continued to rise, increasing from an average of 194.97 $MtCO_2e$ before the agreement to 245.90 $MtCO_2e$ afterward. While the Paris Agreement set ambitious targets, it relies on voluntary national commitments rather than legally binding enforcement, making it difficult to ensure compliance.

Overall, climate agreements have raised awareness and encouraged emission reduction efforts, but their effectiveness has been limited by enforcement challenges, economic constraints, and the continued dominance of fossil fuels. Stronger policies, economic incentives, and technological advancements will be necessary to achieve significant reductions in global emissions. Without binding international commitments and greater accountability, emissions are likely to continue rising despite policy efforts.

Summary and Discussion

Summary Analysis

This project examined global greenhouse gas emissions from 1990 to 2019, with a particular focus on the relationship between emissions, economic development, and population growth. By integrating emissions data with GDP and population statistics, we revealed how industrial expansion and demographic trends have influenced the trajectory of global emissions.Between 1990 and 2019, total global GHG emissions increased from approximately 33,000 $MtCO_2e$ to about 50,000 $MtCO_2e$, showing a sharp and consistent upward trend. This rise was especially steep after the year 2000, a period that aligned with China's industrial expansion and integration into the global economy. In 2000, China emitted just over 4,000 $MtCO_2e$, but by 2019, this number had surpassed 12,000 $MtCO_2e$, tripling in less than two decades. India also saw emissions grow steadily, from under 1,000 $MtCO_2e$ in 1990 to about 3,000 $MtCO_2e$ by 2019. On the economic front, global GDP also experienced significant growth. Total world GDP increased from about $44 trillion in 1990 to over $124 trillion by 2019 (in current US dollars). Much of this growth was driven by developing economies.

Despite leading the world in total emissions, China made substantial progress in reducing emissions intensity. In 1990, China emitted around 700 $MtCO_2e$ per unit of GDP, but by 2019, this number had dropped to under 150 $MtCO_2e$ per unit GDP, a decline of nearly 80%. India showed similar but slower progress, reducing emissions intensity from about 240 to 180 $MtCO_2e$ per unit GDP over the same period. These changes suggest that both countries became significantly more efficient in how they generate economic output relative to emissions.

Our comparison of developed and developing nations revealed stark contrasts. Developed countries such as the United States and European Union members have maintained or reduced their emissions. For example, the United States' emissions remained relatively flat from the mid-2000s, hovering around 6,000 $MtCO_2e$, and showed a slight decline after 2008. In contrast, emissions from developing countries have increased significantly. This is especially clear in our analysis of aggregated emissions, where developing countries surpassed developed ones in total GHG emissions around 2007, driven primarily by industrial growth in Asia.

Although international agreements like the Kyoto Protocol (1997) and Paris Agreement (2015) were implemented during this period, global average emissions continued to rise. After the Kyoto Protocol, average emissions increased from 163.95 $MtCO_2e$ to over 215.47 $MtCO_2e$, and after the Paris Agreement, from 194.97 $MtCO_2e$ to more than 245.90 $MtCO_2e$. These trends highlight the difficulty of translating international commitments into substantial emission reductions, especially when agreements lack enforcement or global buy-in.

In essence, while many countries have made progress in emissions efficiency, total global emissions have continued to climb. High-emitting nations like China and India are becoming more carbon-efficient, but their total output continues to rise due to economic and population growth. Developed nations have stabilized or slightly reduced emissions, but they must continue to lead in innovation and support. Equally important is the need for equity: vulnerable nations facing climate threats need both financial and technological support to adapt.

Limitations of the Analysis

One of the primary limitations of this study is the absence of post-2019 emissions data. The dataset, sourced from Climate Watch, only includes data up to 2019, which restricts the ability to analyze more recent trends in greenhouse gas emissions. Since 2019, several significant global events, including the COVID-19 pandemic, have had profound effects on industrial activity, transportation, and energy consumption, all of which are key drivers of emissions. Without updated data, it is difficult to determine whether the pre-2019 trends identified in this study have continued, reversed, or changed due to new policies, economic disruptions, or technological advancements. This gap in the dataset limits the ability to assess the effectiveness of recent climate policies and mitigation strategies, making it necessary for future research to incorporate post-2019 data for a more comprehensive analysis.

Another key limitation is the challenge of distinguishing correlation from causation in emissions trends. While the analysis identifies statistical relationships between emissions reductions and economic indicators such as GDP growth, policy changes, and energy transitions, it does not establish direct causal links between specific policies and changes in emissions. Many factors influence emissions trends, including global economic conditions, advancements in renewable energy technologies, and variations in industrial activity. Without more detailed policy-level data and controlled study designs, it is difficult to determine the precise impact of individual policies on emissions reductions. Future research could address this limitation by employing more sophisticated econometric models, conducting case studies on specific policy interventions, or utilizing natural experiments to isolate policy effects.

These limitations highlight the need for continued data collection and methodological advancements to improve understanding of emissions trends and their underlying causes. Incorporating post-2019 data would provide a clearer picture of how emissions have evolved in response to recent global developments, while more robust analytical techniques could help establish clearer causal relationships between policy measures and emissions outcomes. Addressing these gaps would enable more effective policymaking and contribute to the broader effort of mitigating climate change.

Future Research Directions

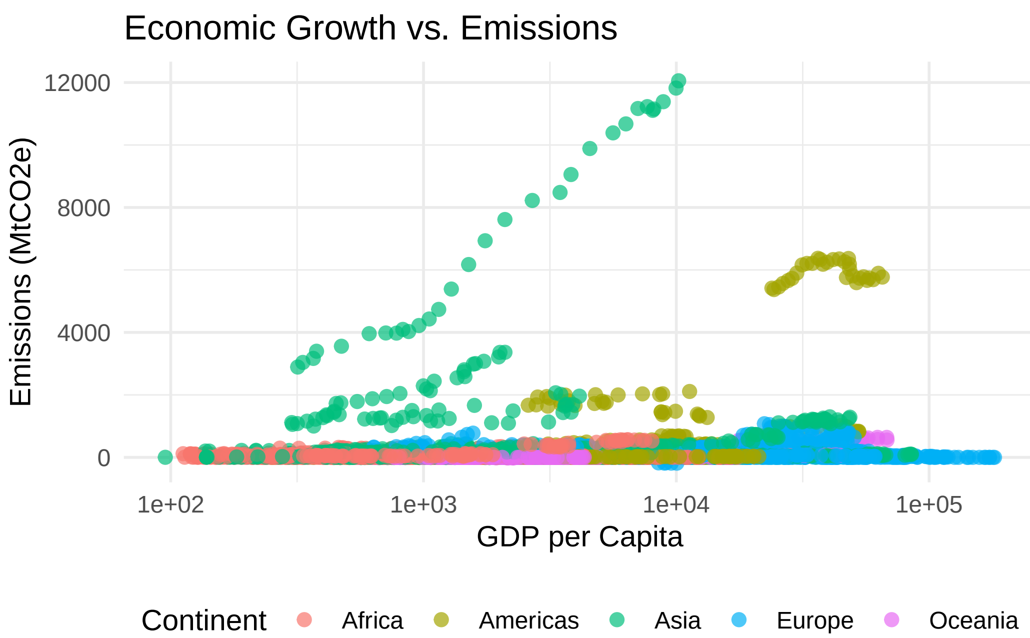
A key priority for future research is extending the analysis to include emissions data beyond 2019. The current dataset limits insights into recent trends, making it difficult to evaluate the impact of global events such as the COVID-19 pandemic, advancements in renewable energy, and evolving climate policies. Incorporating post-2019 data would provide a more up-to-date understanding of emissions patterns and allow researchers to assess whether previously observed trends have continued or shifted. This extended analysis could help identify the long-term effects of economic disruptions and policy interventions, offering valuable insights for future climate action. Additionally, with many countries setting net-zero targets for 2050 or earlier, tracking emissions trends in the most recent years would provide a clearer picture of global progress toward these goals.

Another critical area for future research is examining the interplay between emissions, GDP, and human development indices (HDIs). While economic growth has historically been linked to rising emissions, the relationship is not always straightforward, as factors such as energy efficiency improvements, policy measures, and technological advancements can decouple growth from emissions. By analyzing the connections between emissions, GDP, and HDI, researchers can better understand how economic development influences environmental sustainability. This approach could also shed light on the trade-offs and synergies between economic growth and emissions reduction strategies, particularly in developing nations where both economic expansion and sustainability goals must be balanced. A deeper investigation into this relationship could inform policies that promote sustainable development without compromising economic prosperity or human well-being.

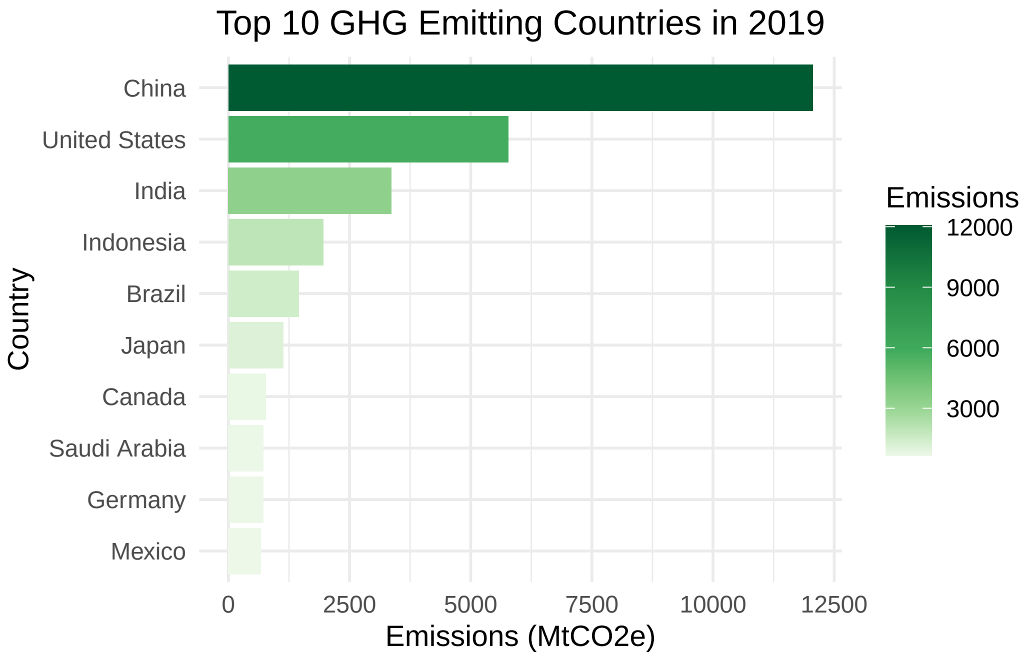
Addressing these research directions would significantly enhance our understanding of global emissions trends and their socioeconomic drivers. Expanding the dataset to include post-2019 emissions and integrating economic and human development indicators into the analysis would provide a more comprehensive picture of the factors shaping global climate change. These efforts would not only contribute to academic research but also support policymakers in designing more effective climate strategies that align with both environmental and economic objectives.

Appendix: Extra Graphs

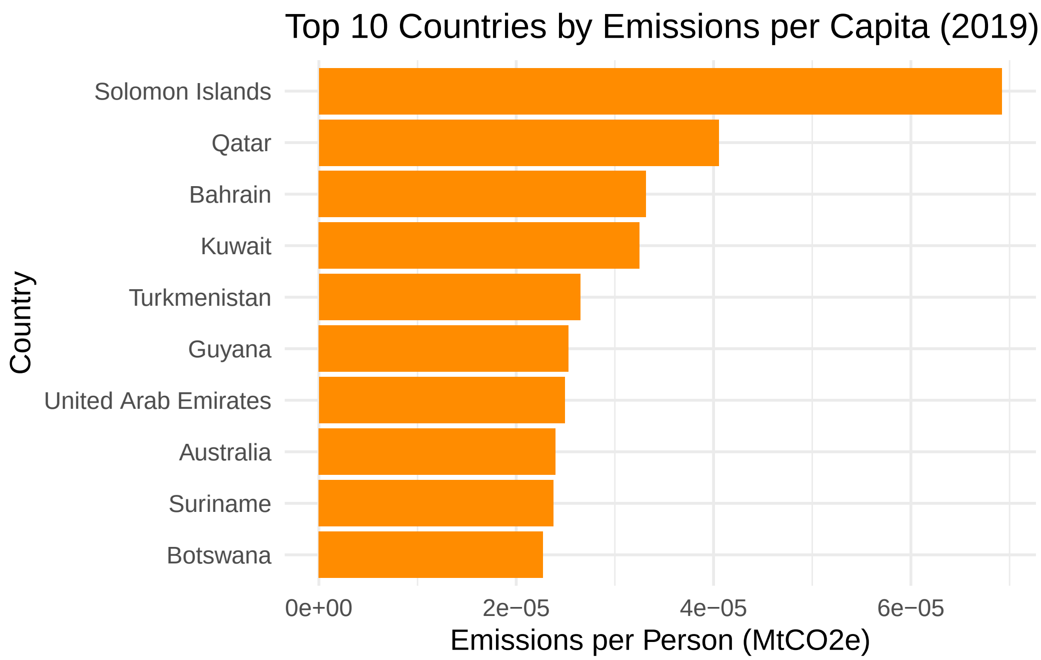
GDP per Capita vs. Emissions



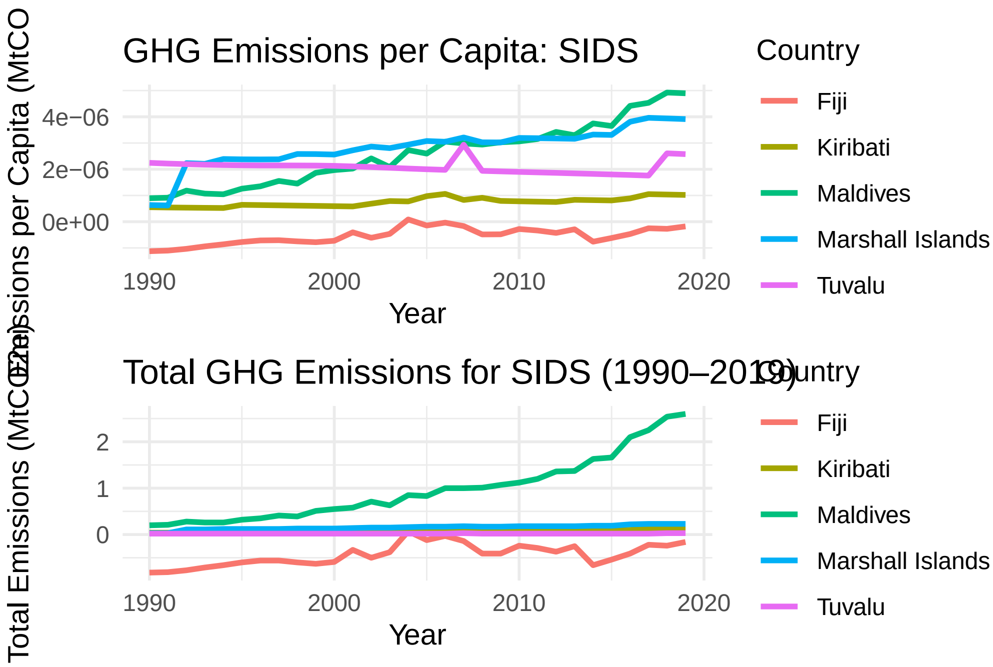
Top 10 GHG Emitters (by Country)



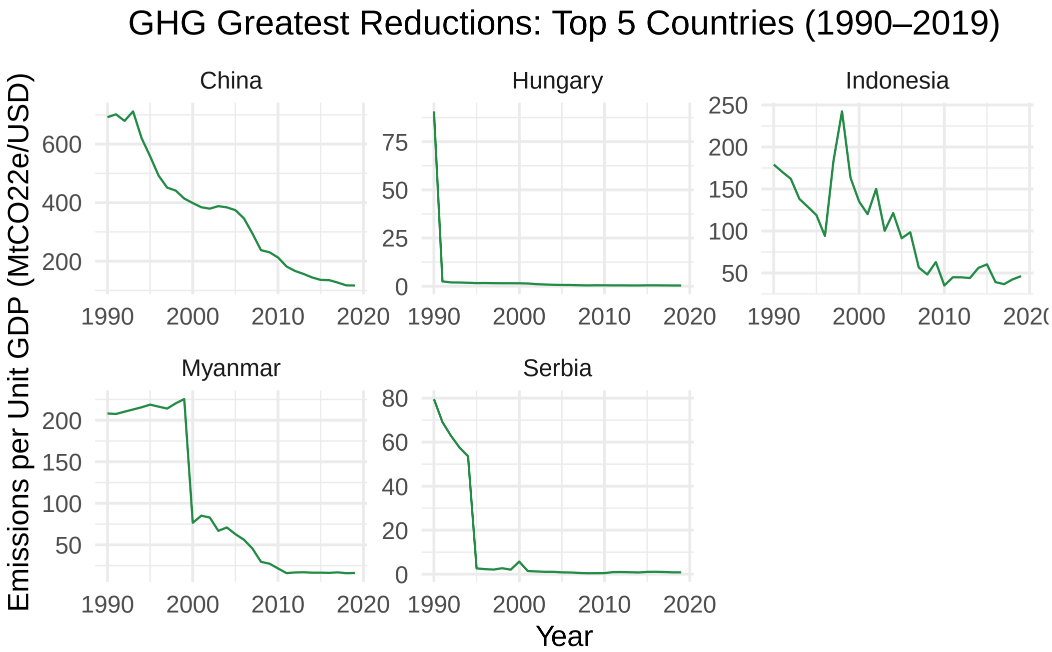
Emissions per Capita



Emissions per Capita and Total GHG Emissions: Small Island Developing States



Emissions Reduction (GHG per unit of GDP)



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