Does Economic Growth Increase CO_2 Emissions?

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DATA 375 – Statistical Computing

An Analysis of Global GDP and Environmental Impact

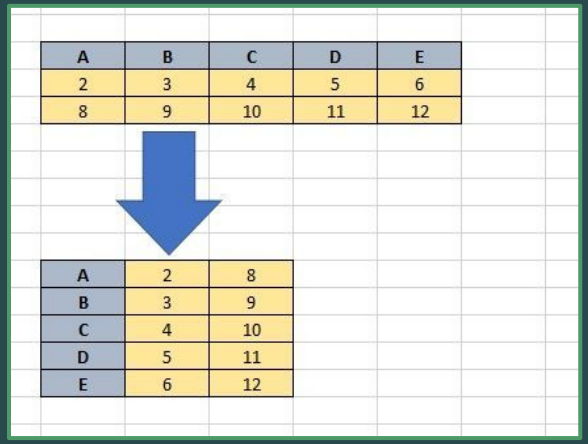
Background

- Economic growth often leads to more industrial activity and energy use, which can increase CO_2 emissions
- Some countries are now growing without raising emissions, this is called “decoupling”
- This project explores whether global economic growth still drives emissions using world data from 1990 to 2023
- Focus: Global GDP and territorial CO_2 emissions by country and year

Data & Cleaning

gdp	co2_emissions
total GDP in current US dollars	**territorial CO_2 emissions ($MtCO_2$)**
Source: World Bank	Source: Our World in Data

- Both datasets had yearly, country-level data from 1990 to 2023
- Reshaped into long format with columns: country, year, gdp, co2_emissions
- Dropped countries with large amounts of missing data
- Final dataset was fully cleaned, with no NAs remaining



Long Format data

Summary of the Data

GDP:

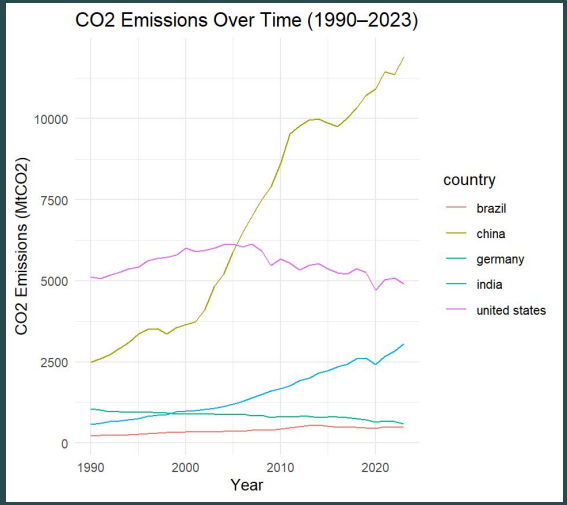
- Min: $9.54 million Max: $106 trillion
- Mean: $712 billion Median: $15.98 billion
- Highly skewed — large economies raise the average

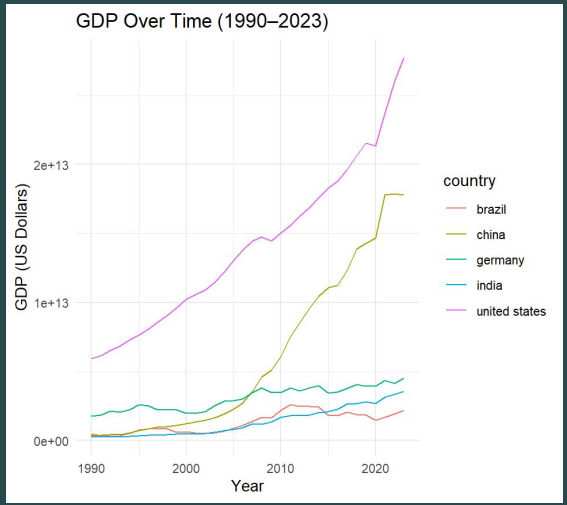
CO_2 Emissions:

- Min: 0.00366 $MtCO_2$ Max: 37,792 $MtCO_2$
- Mean: 356 $MtCO_2$ Median: 8.69 $MtCO_2$
- Also highly skewed — dominated by China, USA, etc

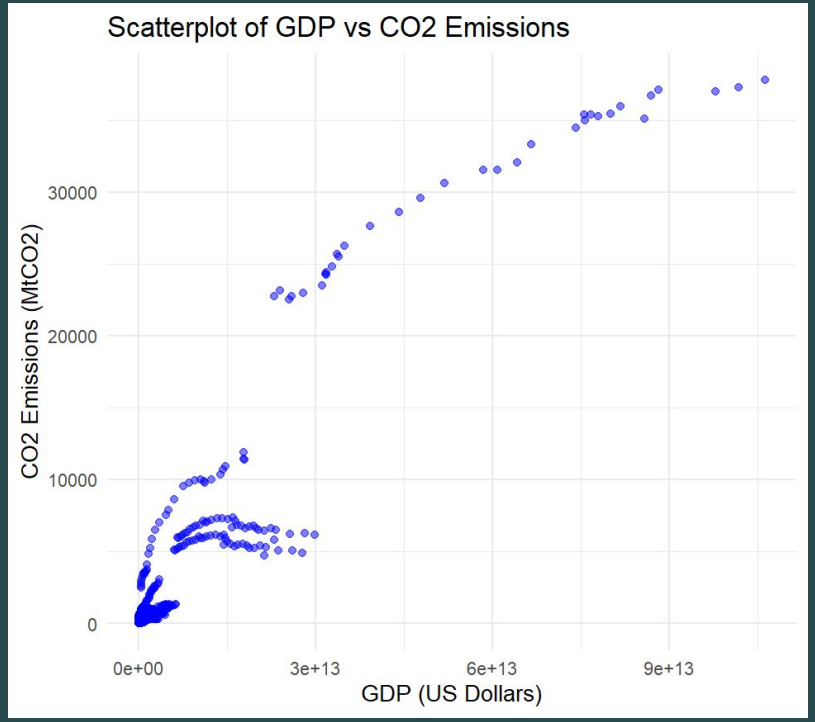
GDP & CO_2 Trends Over Time

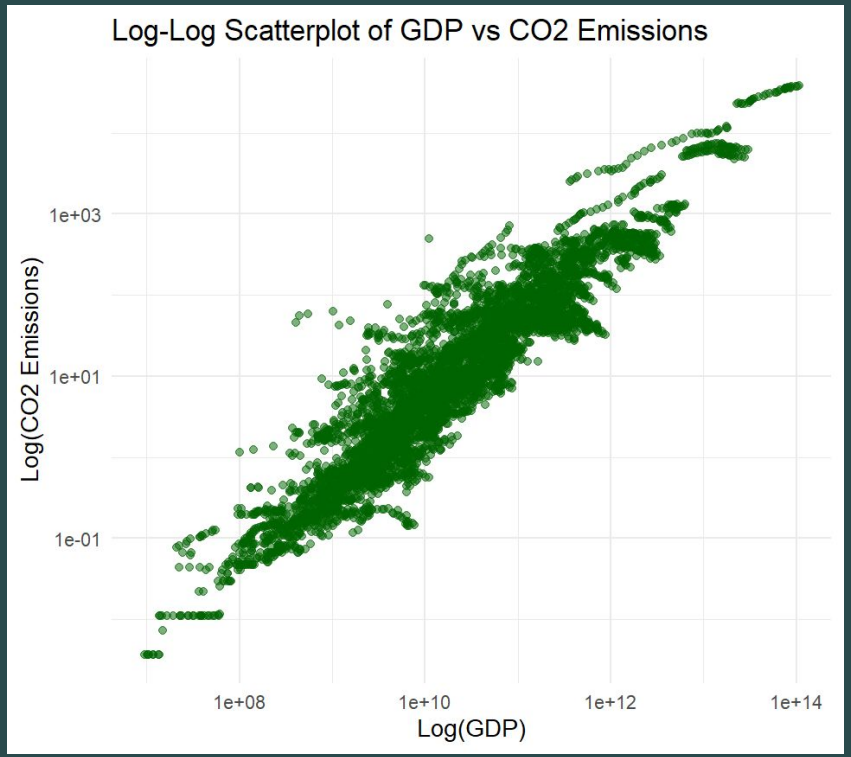
- China's GDP and CO_2 emissions grew rapidly after 2000
- The U.S. shows steady GDP growth but declining emissions since ~2008
- India's trends are consistently rising in both variables
- Germany and Brazil have stable or slightly declining emissions
- Some countries like Germany may be **decoupling** growth from emissions





Scatterplots of GDP vs CO_2





- Raw scatter: wide spread, hard to interpret
- Log–log scale: clear linear pattern
- Log transformation improves visibility and model fit

Model: Simple Linear Regression

```
Call:
lm(formula = co2_emissions ~ gdp, data = df)

Residuals:
     Min       1Q   Median       3Q      Max
-11588.8    -27.7    -24.9    -18.3  12045.6

Coefficients:
             Estimate Std. Error t value Pr(>|t|)
(Intercept) 2.486e+01  9.926e+00   2.504   0.0123 *
gdp         4.649e-10  1.951e-12 238.234   <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 757.2 on 5934 degrees of freedom
Multiple R-squared:  0.9053,    Adjusted R-squared:  0.9053
F-statistic: 5.676e+04 on 1 and 5934 DF,  p-value: < 2.2e-16
```

- Fitted model:

  CO_2 Emissions ~ GDP
- R^2 = 0.905: GDP explains ~90.5% of variation in emissions.
- Slope is positive and highly significant (p < 2e-16)

- ❖ Confirms strong relationship between economic growth and emissions
- ❖ Will explore log-log model to improve fit and handle skew

What's Next?

Monte Carlo Simulation:
Simulate different GDP growth scenarios (e.g., +5%, +10%) to predict their impact on future CO_2 emissions using the regression model.

Log-Log Regression:
Apply $\log(CO_2) \sim \log(GDP)$ to better model the multiplicative relationship and reduce skewness seen in the raw data.

Bootstrapping:
Resample the dataset to estimate the variability of the regression slope and better understand model uncertainty.

Regional Analysis:
Split the data by continent or income group (e.g., high-income vs. low-income countries) to compare how the GDP–CO_2 relationship varies across groups.

GitHub Repository

- ❑ All datasets, cleaning scripts, plots, and documentation are publicly available
- ❑ Organised into folders: /data/, /scripts/, /plots/, /docs/

🔗 **github.com/sushanthvk02/gdp-co2-emissions**

Thank You