# The Change of Global Temperature Affected by Global Economy

Yuqing Fan [1, *, †], Wu Xia [2, *, †], Linxi Zhang [3, *, †]

[1] Department of Mathematics University College London London, United Kingdom

[2] Department of Biological Science, University of California, Irvine, Irvine, CA, United States

[3] College of Science and Engineering University of Minnesota Twin Cities Minneapolis MN, USA

* Corresponding Author Email: *yuqing.fan.19@ucl.ac.uk, *xiaw3@uci.edu, *zhan5003@umn.edu

†These authors contributed equal

**Abstract.** Global warming is the most serious environmental problem due to rising temperatures. Previous studies showed $CO_2$ is the primary greenhouse gas. $CO_2$ emission is caused by the burning of fossil fuels. Humans pursue industrial growth at the expense of releasing $CO_2$ into the atmosphere. Economic development is represented by Gross Domestic Product (GDP). The growth of $CO_2$ emission increases more and more and does not reach the peak. The global temperature is facing a 2˚C crisis. The global emissions and global economy have a strong indication of relative sensitivity. We found out that countries with higher GDP emit more $CO_2$. Individuals who have higher GDP per capita emit more $CO_2$ to the atmosphere. GDP has a positive correlation with global temperature. Climate change is one of the biggest inequalities around the world. Richer countries caused more damage to global warming, but poor countries suffer more from global warming's damage. GDP per capita has a positive correlation with temperature and $CO_2$ emissions. The development of a country has a trend of increasing $CO_2$ emissions at an early stage and decreasing $CO_2$ emissions at a later stage. Total GDP although cannot positively correlated to $CO_2$ emissions, but multicollinearity tests proved the two variables are related.

**Keywords:** $CO_2$, Global economy, Linear regression analysis.

## 1. Introduction

Because of the release of greenhouse gases (GHG) emissions, the Earth has been experiencing an inevitable change. Undeniably, our Earth is warming up at an unprecedented rate over millennia. Among all GHG releases, $CO_2$ has always been the main contributor. In a study in 2017, $CO_2$ takes up to 3/4 of GHG [1]. Thus, $CO_2$ emissions have always been the focus of climate change study. A study from government, or IPCC, illustrated CO2 emissions caused by human activities are the direct cause of rising temperature (https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement, n.d.). A large number of human activities are fossil fuel burning and industry pollution. The survival of human beings cannot leave fossil fuel. Although the nature of Earth has its own temperature cycle, human beings now are positioning in a temperature-retreat period. Noticeable, rising temperature is causing significant and inevitable effects on the ecosystem if the temperature surpasses 2C. More extreme weather and more frequent natural disasters around the world have alarmed more people to realize the global warming crisis. The more we know about the distribution of global warming, the easier we find the solutions and responsibilities among different countries. In this paper, we investigated the statistical correlation between the global economy and global temperature.

Thoma and Timothy proved evidence of the rising temperature globally since the mid-19 century using six annual global temperature series [1]. They used strong serial correlation to mimic the trend in certain periods of time. They applied a serial-correlation–robust trend test to control the possibility of spurious evidence. They finally confirmed a rise of 0.5°C in the last 100 years. Global warming has caused global economic inequality. Cooler and wealthier countries realized a rising economy, while warmer and poorer countries got a decreased economy [2]. It is a global inequality. The possibility of this rule may reach 90%. Global warming has caused global economic inequality. Cooler and wealthier countries realized a rising economy, while warmer and poorer countries got a decreased economy. It is a global inequality. The possibility of this rule may reach 90%. This article used R programming including local weighted regression. Choiniere and Horowitz analyzed the relationship between worldly GDP and temperature [3]. They proved the correlation is strong and significant. This article used Cobb-Douglas production function to conclude that temperature in fact lowers the physical and human capital.

Marjanovic et al. proved a long-term high significance between GDP and $CO_2$. Non-linear relationship among $CO_2$ per capita, $CO_2$ emission per capita, energy consumption per capita, and GDP per capita [4]. They used an Extreme Learning Machine to predict the $CO_2$ emissions based on GDP. Conventional statistical error indicators forecast accuracy results. Skripnuk and Samylovskaya mentioned that with more energy consumption consumed, more $CO_2$ consumption will be produced, and global warming will be stronger [5]. They used an autoregressive distributed lags (ADL) model and Ljung-Box Q-test. Ping-Yu et al. found that energy consumption negatively influences GDP in the world as a whole and developing countries, but not in developed countries [6]. And there is a unidirectional causality from energy consumption to carbon dioxide emissions both in developing and developed countries. They used a panel cointegration and vector error-correction model. Matthew et al. studied the long-term impact of climate change on economic activity across countries [7]. They found that per-capita real output growth is negatively affected by persistent changes in the temperature above or below its historical norm. They used a stochastic growth model and counterfactual analysis. A positive relationship between carbon dioxide emissions, the most important greenhouse gas (GHG) implicated in global warming, and GDP is shown, examining per capita income and $CO_2$ emissions of 137 countries across 21 years [8]. It also appears that as per capita incomes accelerate across countries emissions increases, for the most part, tend to decelerate. It could be that higher income levels lead to increased demand for environmental protection. Only emissions reduction proposals that assure incomes will not be adversely affected, particularly those of less developed countries (LDCs), will have any possibility of successful implementation. Econometric models of temperature impacts on GDP are increasingly used to inform global warming damage assessments [9]. But theory does not prescribe estimable forms of this relationship. By estimating 800 plausible specifications of the temperature-GDP relationship, we demonstrate that a wide variety of models are statistically indistinguishable in their out-of-sample performance, including models that exclude any temperature effect. This full set of models, however, implies a wide range of climate change impacts by 2100, yielding considerable model uncertainty. The uncertainty is greatest for models that specify effects of temperature on GDP growth that accumulate over time; the 95% confidence interval that accounts for both sampling and model uncertainty across the best-performing models ranges from 84% GDP losses to 359% gains. Models of GDP level effects yield a much narrower distribution of GDP impacts centered around 1–3% losses, consistent with damage functions of major integrated assessment models. Further, models that incorporate lagged temperature effects are indicative of impacts on GDP levels rather than GDP growth. We identify statistically significant marginal effects of temperature on poor country GDP and agricultural production, but not rich country GDP, non-agricultural production, or GDP growth.

Computable general equilibrium (CGE) models are a standard tool for policy analysis and forecasts of economic growth [10]. Unfortunately, due to computational constraints, many CGE models are dimensionally small, aggregating countries into an often-limited set of regions or using assumptions such as static price-level expectations, where next period's price is conditional only on current or past prices. This is a concern for climate change modeling, since the effects of global warming by country, in a fully disaggregated and global trade model, are needed, and the known future effects of global warming should be included in forward-looking forecasts for prices and profitability. This work extends a large dimensional intertemporal CGE trade model to account for the various effects of global warming (e.g., loss in agricultural productivity, sea level rise, and health effects) on Gross Domestic Product (GDP) growth and levels for 139 countries, by decade and over the long term, where producers look forward and adjust price expectations and capital stocks to account for future climate effects. The potential economic gains from complying with the Paris Accord are also estimated, showing that even with a limited set of possible damages from global warming, these gains are substantial. For example, with the comparative case of Representative Concentration Pathway 8.5 (4°C), the global gains from complying with the 2°C target (Representative Concentration Pathway 4.5) are approximately US$17,489 billion per year in the long run (year 2100). The relative damages from not complying to Sub-Saharan Africa, India, and Southeast Asia, across all temperature ranges, are especially severe.

## 2. Methods

The work with the data consisted of two stages: a) data collection for selected variables; b) primary processing of predicted variables in accordance with the requirements of the model. The source of datasets is shown in the Appendix.

**Table 1.** Research Variable

| | Full name | Description |
|---|---|---|
| Global GDP | gross domestic product | describe the economy of a country measured in adjusted U.S. dollar |
| Global GDP per capita | gross domestic product per capita | describe individual behaviors measured in adjusted U.S. dollar |
| Temperature | annual temperature | the positive/negative annual temperatures are compared with 1961-1990 average temperature measured in ˚C |
| $CO_2$ emission | carbon dioxide emission | the measurement of $CO_2$ emission annually in metric tons |

We first got data from NASA climate. We got the $CO_2$ dataset and temperature dataset from NASA. However, the datasets are very big, including unnecessary information. We only need total $CO_2$, $CO_2$ per capita and annual temperature. The file had 2MB of data, so we did data cleaning in R programming first. We threw out unneeded factors such as Population and Country code. We also threw out missing data and duplicative information. We arranged all 235 countries in descending order and chose the top 10 countries to make a bar graph.

We then find datasets about GDP and population from World meter. Their data can update to current years and even predict future data. We had to select the suitable year range in R programming and threw out missing data. All data is downloaded in .csv format.

Then, we use data from R package maps to draw the world map. However, there are some structural errors when we try to merge the map data with GDP per capita data. For example, the country name for America is USA in map data whereas it is represented by America in GDP per capita data. We then downloaded another map data from tapiquen-sig.jimdofree.com, which best matches the GDP per capita data, and then combined them together using the common country name variable.

Linear regression is a linear approach to analyze the relationship between response variable and predictor variables. It focuses on the conditional distribution of the response variable given the values of predictors.

We used simple regression and multiple regression tests by using the lm. beta R package. The simple regression model assumes a linear relationship, $Y=\alpha+\beta X+\varepsilon$, between a response variable Y and a single predictor variable X, with the regression coefficient $\beta$ and the error term $\varepsilon$. A positive coefficient means a positive relationship between outcome variable and predictor variable. Multiple regression uses several predictor variables to predict the outcome of a response variable.

## 3. Results

We first analyzed the global average temperature variation trend from 1880 to 2020. The data was collected by land-ocean surface temperature by GHCN–Monthly (GHCNm). The baseline was 1961-1990 average temperature. The red color represented temperatures higher than baseline. The blue color indicated temperatures cooler than baseline. The global temperature increased from -0.4˚C to 1˚C. Fig. 1 proved the world was getting warmer and warmer. After the 21st century, 19 hottest years have happened. The years 2020 and 2016 were the hottest years ever since 1880. The surface of the Earth continues to warm up, and we are facing a severe climate change problem.

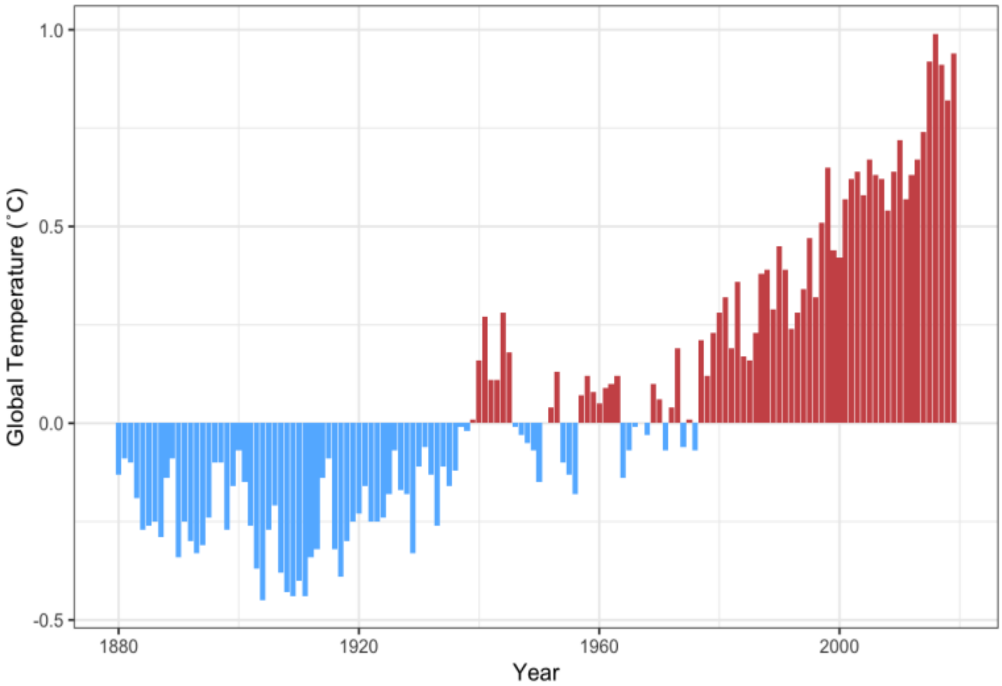



**Figure 1.** Average global Temperature Anomaly. Global average land-sea temperature (˚C) anomaly relative to the 1961-1990 average temperature.

We tried to analyze the temperature change that varies around the world. The abnormal temperature dataset was published by the Met Office Hadley Centre in the U.K. At a global level, northern hemisphere, southern hemisphere, tropics, and global temperature changes were compared. Black line was the median of temperature. Gray color areas provided upper and lower bounds of 95% confidence interval. y=0 was highlighted. The baseline was 1961-1990. The global temperature increased from -0.4˚C to 0.8˚C. The northern hemisphere increased from -0.5˚C to 1.2˚C because more countries aggregated in the northern hemisphere. Southern hemisphere changed from -0.7˚C to 0.5˚C. In the tropics, the temperature changed from -0.5˚C to 0.5˚C, because more green plants helped absorb $CO_2$ and less developed countries existed in the tropic areas.

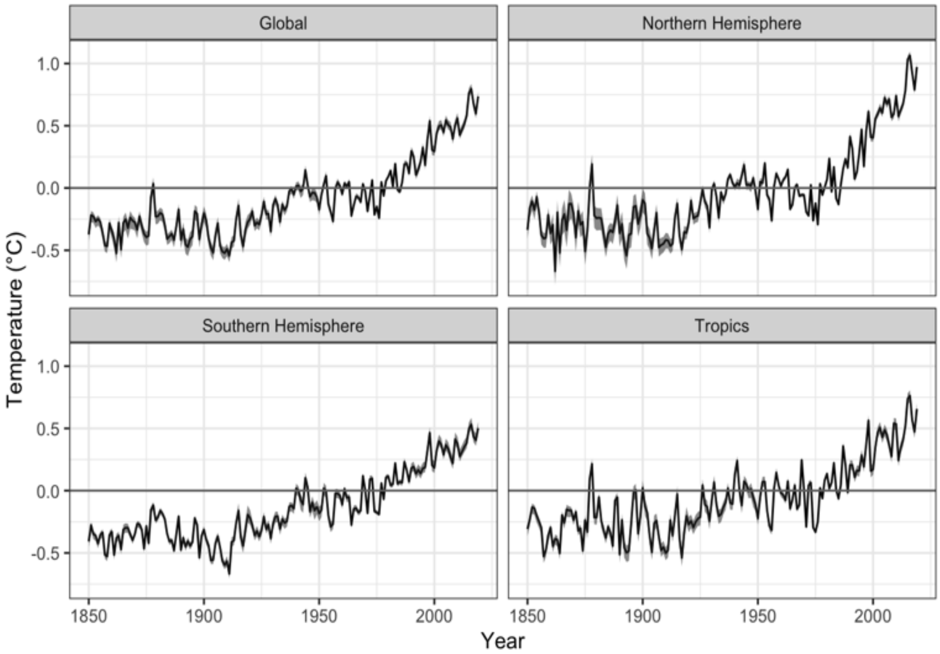



**Figure 2.** Northern Hemisphere, Southern Hemisphere, Tropics, and Global. Global average land-sea temperature (˚C) anomaly relative to the 1961-1990 average temperature.

*Source: Hadley Centre (HadCRUT4)*

*Note: The red black line represents the median average temperature change, and the grey lines represent the upper and lower 95% confidence intervals.*

Fig. 2 showed $CO_2$ concentration through the years 1850-2000. The graph begins after the Industrial Revolution in 1850 with a $CO_2$ concentration of 280 ppm. After 1960, the rate of $CO_2$ conc. has boosted faster than ever since more and more countries entered industrial societies. The rate of $CO_2$ concentration in the atmosphere is still increasing and not reaching its peak.

Fig 3 indicated the use of energy releasing $CO_2$ through the years in 1990-2018. The graph listed the top three carbon sources: coal (solid), natural gas (gas), and oil (liquid). At a global level, coal is the dominant emissions as solid fuel. Coal and oil dominated the $CO_2$ emissions in million tons. After entering the 21st century, $CO_2$ emissions increased and coal increased more. Today, coal and oil still dominate, while natural gas production and other energy sources, i.e., cement and flaring remain little contribution. Through time, the energy pattern has been diverse.

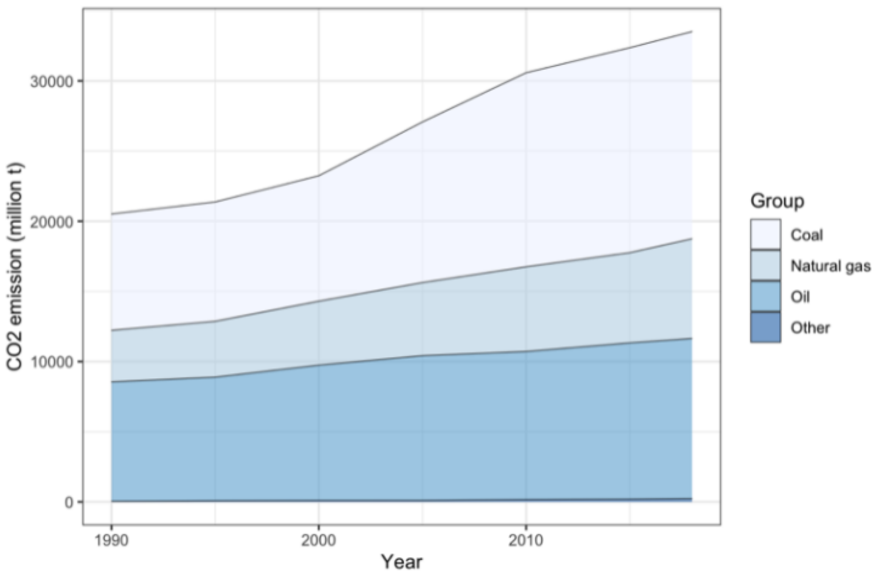



**Figure 3.** The energy used for releasing $CO_2$. The burning of coal, oil and natural gas all lead to increasing $CO_2$ emissions (million t).

Fig 4 analyzed GDP per capita around the world. The top 10 countries and economic communities are all the most developed countries. Developed countries and richer people emit more $CO_2$.

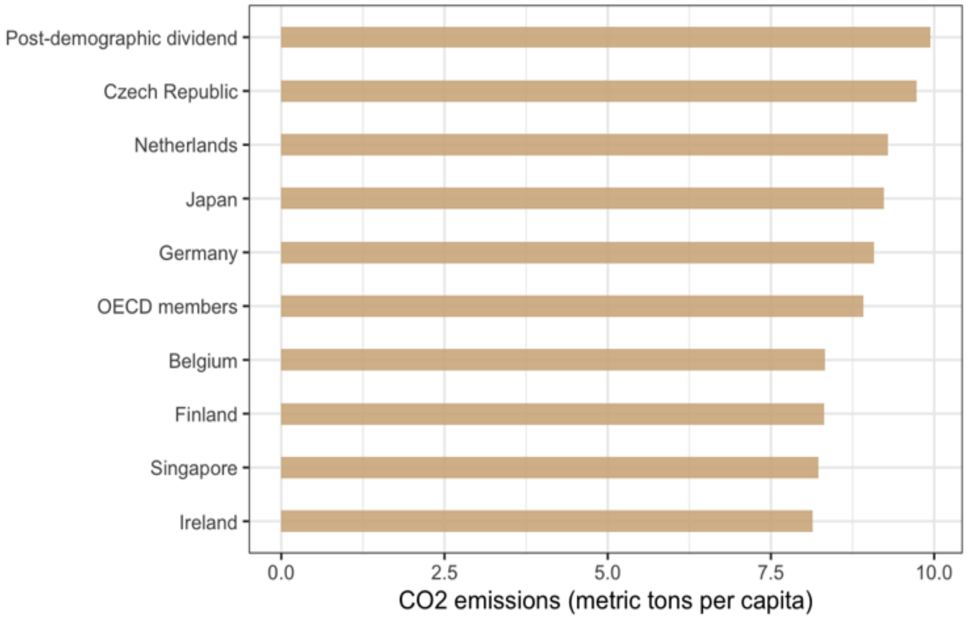



**Figure 4.** Top 10 countries or economic communities releasing the most $CO_2$ per capita in 2016. Developed countries release more $CO_2$ per capita (metric tons).

Fig 5 analyzed the annual $CO_2$ emissions divided by world regions. Until around 1950, the global $CO_2$ emissions were led by Europe and U.S. For example, over 90% of $CO_2$ emissions were emitted by Europe or the U.S. Until 1950, they still took up over 85% of global emissions. However, in recent decades, the situation has changed. Other countries and world regions catched up and overpassed. Asian countries, especially China, India, and Russia, had a significant increase in global $CO_2$ emissions. Europe and the U.S., on the contrary, took up almost 1/3 of the global $CO_2$ emission. In this figure (Fig. 6), $CO_2$ emissions were calculated by annual production, not including traded goods, and measured in tonnes based on territorial division.

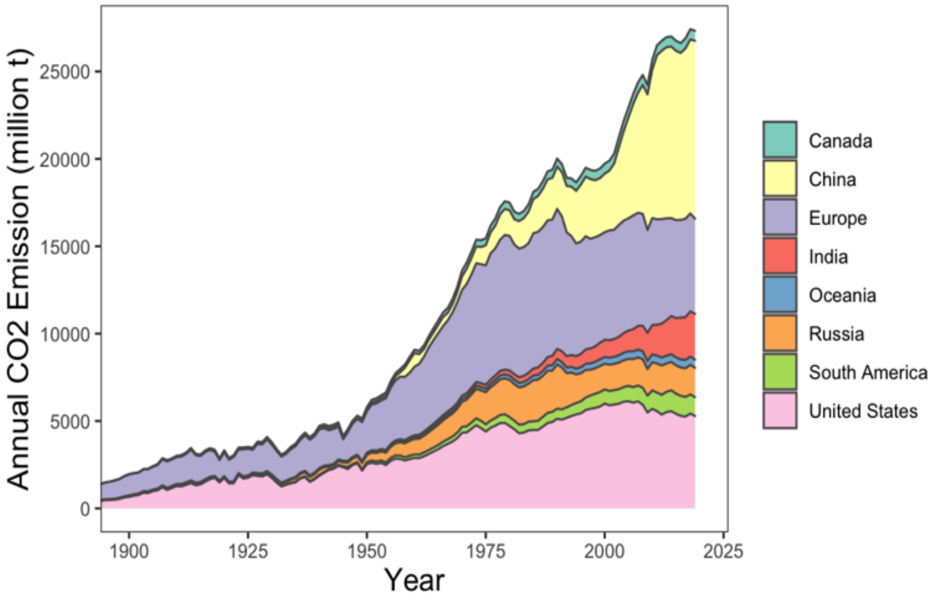



**Figure 5.** Annual total $CO_2$ emissions, by world region. Top countries and world regions are included. Global emissions have not yet peaked. Europe and the U.S. emitted 90% of $CO_2$ emissions before around 1980. China, Russia and India took the top place in recent years.

*Source: Global Carbon Budget - Global Carbon Project (2020)*

GDP in the world increased fast. GDP per capita describes individual behaviors. GDP per capita=GDP/Population. Fig 6 is a choropleth map of GDP per capita in 2016. Europe, North America, and Australia had higher GDP per capita. South America, Asia, and Africa had lower GDP per capita. This was corresponding to economic development. Europe and the U.S. began industrial revolution earlier than other countries.

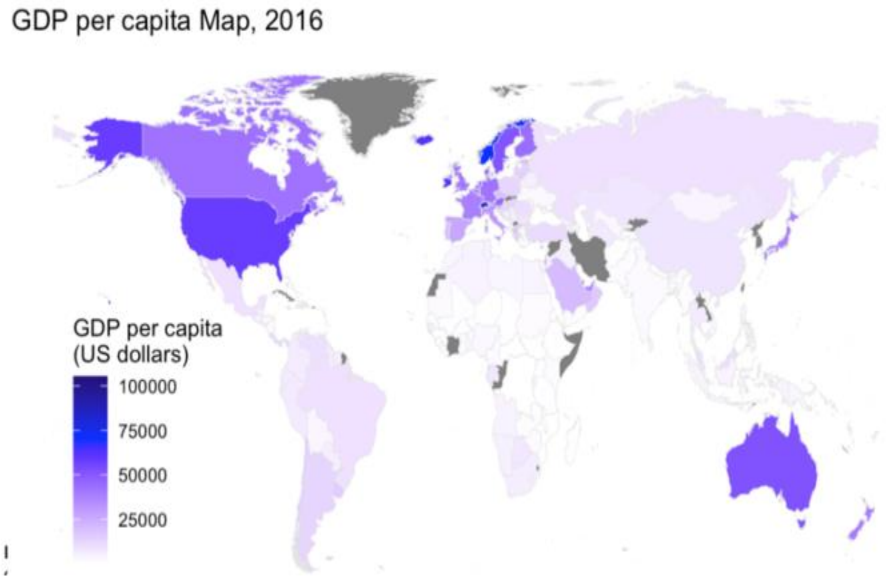



**Figure 6.** GDP per capita choropleth map in 2016. The map describes Western Europe, North America and Australia as the countries with the highest GDP per capita (in U.S. dollars). Grey colour represents missing data.

Fig 7 showed the top ten countries in 2016 GDP per capita measurement. Developed countries, such as Luxembourg, Switzerland, Norway, took the lead.

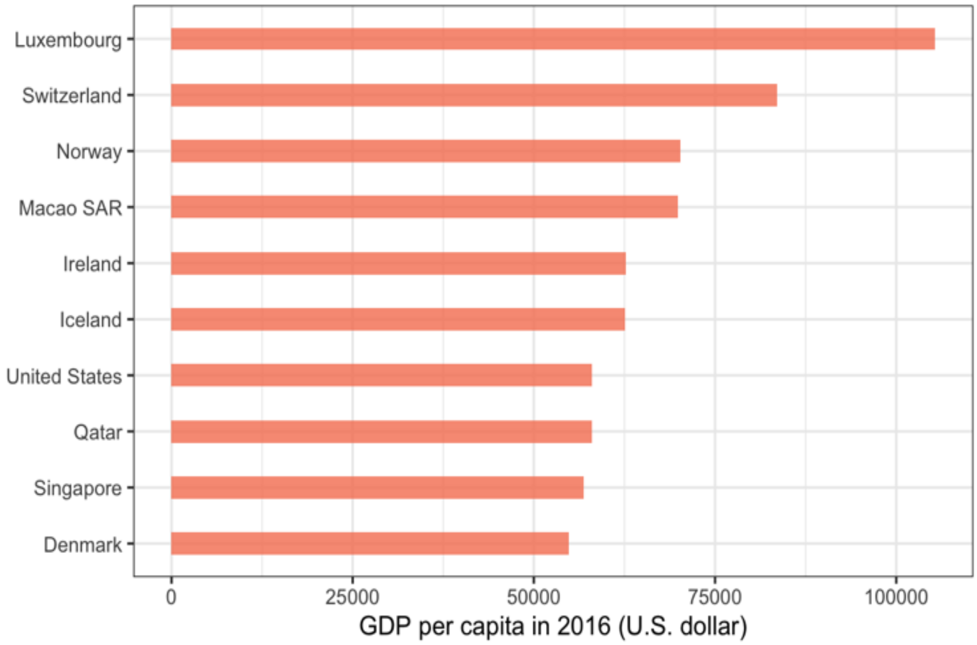
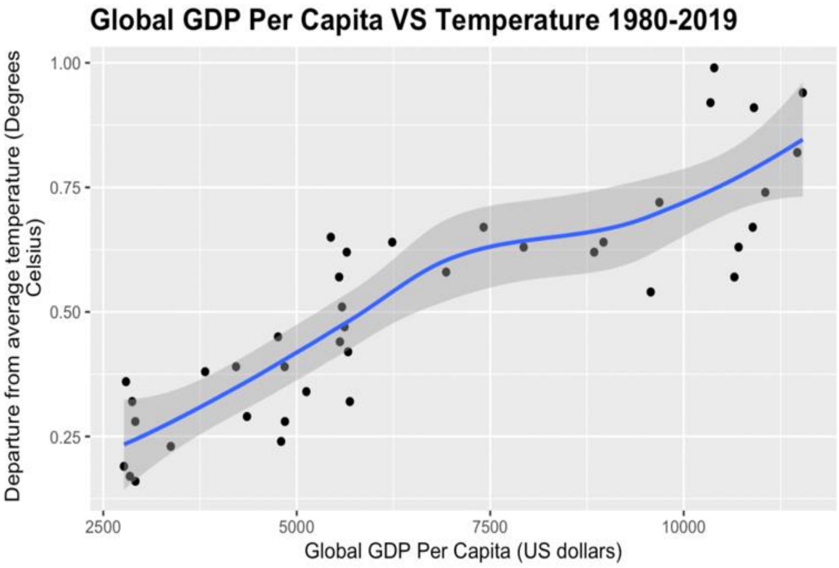



**Figure 7.** Top 10 Countries by GDP per Capita in 2016. European Countries took the lead.

A simple linear regression (Fig. 9) was calculated to predict temperature based on global GDP per capita. A significant regression equation was found ($F(1, 38) = 119$, $p<0.000$, with an $R2$ of 0.75. Global temperature is equal to 0.07763 + 6.626e-05 (GDP), where GDP is measured in adjusted U.S.

dollars. Temperature of measurement increased by 0.00007 degrees for each 1 unit increase in Global GDP Per Capita.




```
Call:
lm(formula = Temp ~ GDP, data = temp_GDP)

Residuals:
      Min        1Q    Median        3Q       Max 
-0.213663 -0.076537 -0.002693  0.071037  0.223608 

Coefficients:
             Estimate Standardized Std. Error t value Pr(>|t|)    
(Intercept) 7.763e-02    0.000e+00  4.398e-02   1.765   0.0856 .  
GDP         6.626e-05    8.706e-01  6.074e-06  10.909 2.88e-13 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.1111 on 38 degrees of freedom
Multiple R-squared:  0.758,	Adjusted R-squared:  0.7516 
F-statistic:   119 on 1 and 38 DF,  p-value: 2.879e-13
```

**Figure 8.** Relationship between global GDP per capita and global temperature with a loss smoother and standard error bar (left). Simple linear regression analysis of the data (right). Positive correlation is confirmed ($p < 0.001$).

*Note:* $b = 0.00007$ $(SE = 0.000006)$, $\beta = 0.87$, $R^2 = 0.75$

A simple linear regression (Fig. 9) was calculated to predict temperature based on global CO2 emissions. A significant regression equation was found ($F (1, 5) =44.23$, $p<0.001$, with an R2 of 0.89. Global temperature is equal to -0.299 + 3.479e-05 ($CO_2$), where $CO_2$ is measured in parts per million. Temperature of measurement increased by 0.000035 degrees for each 1 unit increase in $CO_2$ emissions.

```
Call:
lm(formula = Temp ~ CO2, data = temp_GDP_CO2)

Residuals:
       1        2        3        4        5        6        7
 0.03533  0.02552 -0.08946  0.02710 -0.04483  0.09314 -0.04679

Coefficients:
              Estimate Standardized Std. Error t value Pr(>|t|)
(Intercept) -2.990e-01    0.000e+00  1.433e-01  -2.086  0.09136 .
CO2          3.479e-05    9.479e-01  5.231e-06   6.650  0.00116 **
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.06857 on 5 degrees of freedom
Multiple R-squared:  0.8984,    Adjusted R-squared:  0.8781
F-statistic: 44.23 on 1 and 5 DF,  p-value: 0.001159
```

**Figure 9.** Simple regression test for $CO_2$ emissions as predictor and global temperature as response variable. Positive correlation is confirmed ($p < 0.001$).

*Note: b = 0.000035 (SE = 0.000005), β = 0.95,* $R^2 = 0.88$

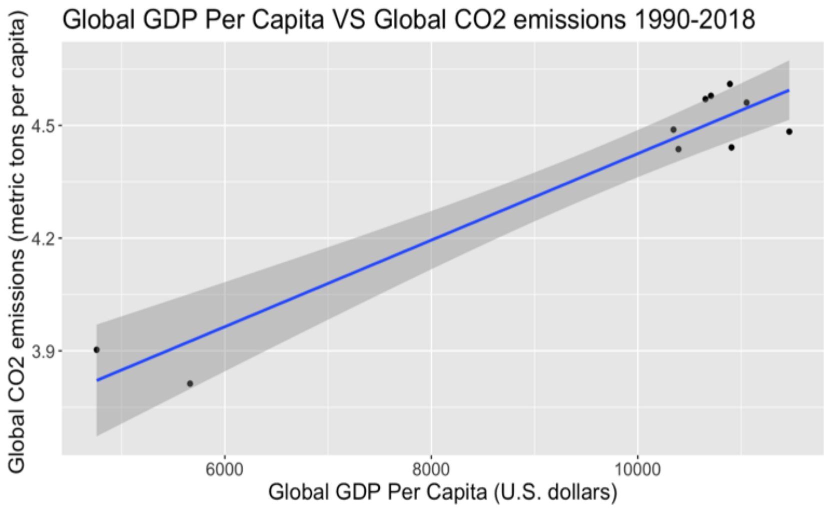
A multiple linear regression (Fig. 10) was calculated to predict temperature based on global GDP and global $CO_2$ emissions together. A significant regression equation was found (F (2, 4) =17.69, p=0.01, with an R2 of 0.89. Global temperature is equal to -0.3088 - 1.81e-06 (GDP) + 3.567e-05 ($CO_2$), where GDP is measured in adjusted U.S. dollars and $CO_2$ is measured in parts per million. Temperature of measurement increased by 1.81e-06 degrees for each 1 unit increase in GDP and 3.567e-05 degrees for each 1 unit increase in $CO_2$.

```
Call:
lm(formula = Temp ~ GDP + CO2, data = temp_GDP_CO2)

Residuals:
       1        2        3        4        5        6        7
 0.03545  0.02643 -0.09012  0.02620 -0.04473  0.09285 -0.04607

Coefficients:
              Estimate Standardized Std. Error t value Pr(>|t|)
(Intercept) -3.088e-01    0.000e+00  4.804e-01  -0.643    0.555
GDP         -1.810e-06   -2.444e-02  8.428e-05  -0.021    0.984
CO2          3.567e-05    9.721e-01  4.176e-05   0.854    0.441

Residual standard error: 0.07666 on 4 degrees of freedom
Multiple R-squared:  0.8984,    Adjusted R-squared:  0.8477
F-statistic: 17.69 on 2 and 4 DF,  p-value: 0.01031
```

**Figure 10.** Multiple regression test for $CO_2$ emissions and GDP per capita as predictors, and global temperature as response variable ($p < 0.01$).

*Note: b1 =* -1.81e-06 *(SE1 = 8.428e-05), β1 = -2.444e-02, b2 = 3.567e-05 (SE2 = 4.176e-05), β2 = 9.721e-01,* $R^2 = 0.89$

A simple linear regression (Fig. 11) was calculated to predict global $CO_2$ emissions based on global GDP per capita. A significant regression equation was found (F (1, 8) =93.7, p<0.000, with an R2 of 0.92. Global $CO_2$ emissions are equal to 3.273 + 2.15e4 (GDP), where GDP is measured in adjusted U.S. dollars. $CO_2$ emissions of measurement increased by 2.15e4 parts per million for each 1 unit increase in global GDP per capita.




```
Call:
lm(formula = CO2 ~ GDP, data = CO2_GDP)

Residuals:
     Min       1Q   Median       3Q      Max 
-0.11283 -0.07447  0.01926  0.07162  0.08260 

Coefficients:
             Estimate Standardized Std. Error t value Pr(>|t|)    
(Intercept) 3.2732835    0.0000000  0.1183317   27.66 3.15e-09 ***
GDP         0.0001152    0.9598637  0.0000119    9.68 1.08e-05 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.08528 on 8 degrees of freedom
Multiple R-squared:  0.9213,	Adjusted R-squared:  0.9115 
F-statistic:  93.7 on 1 and 8 DF,  p-value: 1.082e-05
```

**Figure 11.** Relationship between global GDP per capita and global temperature. Linear regression model is used. Positive correlation is confirmed ($p < 0.001$).

*Note:* $b = 0.0001$ $(SE = 0.00001)$, $\beta = 0.96$, $R^2 = 0.92$

A simple linear regression (Fig. 12) was calculated to predict log (global $CO_2$ emissions) based on log (global GDP per capita). A significant regression equation was found ($F (1, 163) = 1040$, $p<0.000$, with an R2 of 0.86. Log (global $CO_2$ emissions) are equal to -10.22+1.187(GDP per capita), where log (GDP per capita) is measured in adjusted U.S. dollars. Log ($CO_2$ emissions) of measurement increased by 1.187 parts per million for each 1 unit increase in log (global GDP per capita).

```
Call:
lm(formula = log(Annual.CO2.emissions..per.capita.) ~ log(GDP.per.capita), 
    data = df11)

Residuals:
     Min       1Q   Median       3Q      Max 
-2.01767 -0.32554 -0.04654  0.28596  1.55082 

Coefficients:
                     Estimate Standardized Std. Error t value Pr(>|t|)    
(Intercept)         -10.22282      0.00000    0.34184  -29.91   <2e-16 ***
log(GDP.per.capita)   1.18699      0.92977    0.03681   32.24   <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.5658 on 163 degrees of freedom
  (135 observations deleted due to missingness)
Multiple R-squared:  0.8645,	Adjusted R-squared:  0.8636 
F-statistic:  1040 on 1 and 163 DF,  p-value: < 2.2e-16
```

**Figure 12.** Positive relationship between log(GDP per capita in dollar) and log(Annual $CO_2$ emission per capita in t) for most of the countries in 2015 ($p < 0.001$). Log is used to strengthen the correlation.

*Note: b = 1.2 (SE=0.04),* $\beta = 0.93$*,* $R^2 = 0.86$

A simple linear regression (Fig. 13) was calculated to predict China CO2 emissions based on China GDP per capita. A significant regression equation was found (F (1, 79) = 2458, p<0.000, with an R2 of 0.96. China CO2 emissions are equal to -3.481e-02 + 6.06e-04 (China GDP per capita), where China GDP per capita is measured in adjusted U.S. dollars. China CO2 emissions of measurement increased by 6.06e-04 parts per million for each 1 unit increase in China GDP per capita.

```
Call:
lm(formula = Annual.CO2.emissions..per.capita. ~ GDP.per.capita,
    data = df121)

Residuals:
    Min      1Q  Median      3Q     Max
-0.9304 -0.3384  0.1283  0.2737  0.6615

Coefficients:
                 Estimate Standardized Std. Error t value Pr(>|t|)
(Intercept)    -3.481e-02    0.000e+00  5.986e-02  -0.581    0.563
GDP.per.capita  6.060e-04    9.843e-01  1.222e-05  49.575   <2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.3784 on 79 degrees of freedom
  (205 observations deleted due to missingness)
Multiple R-squared:  0.9689,    Adjusted R-squared:  0.9685
F-statistic:  2458 on 1 and 79 DF,  p-value: < 2.2e-16
```

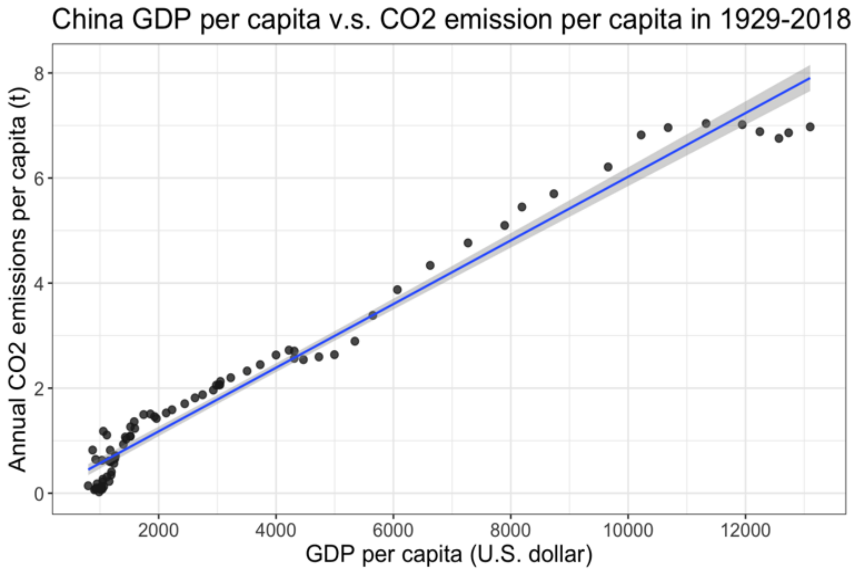



**Figure 13.** GDP per capita v.s. $CO_2$ emission per capita in developing countries, China. Linear regression models were applied (*right).* Simple regression was applied in analysis. Positive correlation is confirmed in China (p < 0.001).

*Note: b=0.0006 (SE=0.00001),* $\beta = 0.98$*,* $R^2=0.97$

A simple linear regression (Fig. 14) was calculated to predict India $CO_2$ emissions based on India GDP per capita. A significant regression equation was found (F (1, 134) = 3049, p<0.000, with an R2 of 0.95. India $CO_2$ emissions are equal to -0.2173+3.549e-04 (India GDP per capita), where India GDP per capita is measured in adjusted U.S. dollars. India $CO_2$ emissions of measurement increased by 3.549e-04 parts per million for each 1 unit increase in India GDP per capita.

```
Call:
lm(formula = Annual.CO2.emissions..per.capita. ~ GDP.per.capita,
    data = df123)

Residuals:
     Min       1Q   Median       3Q      Max
-0.28258 -0.07485 -0.02965  0.07690  0.18828

Coefficients:
                 Estimate Standardized Std. Error t value Pr(>|t|)
(Intercept)    -2.173e-01    0.000e+00  1.355e-02  -16.03   <2e-16 ***
GDP.per.capita  3.549e-04    9.787e-01  6.427e-06   55.22   <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.09361 on 134 degrees of freedom
  (124 observations deleted due to missingness)
Multiple R-squared:  0.9579,    Adjusted R-squared:  0.9576
F-statistic:  3049 on 1 and 134 DF,  p-value: < 2.2e-16
```

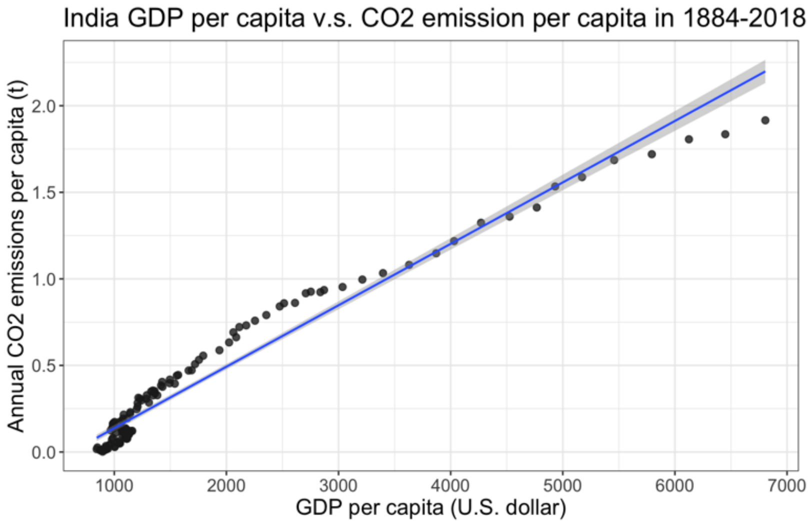
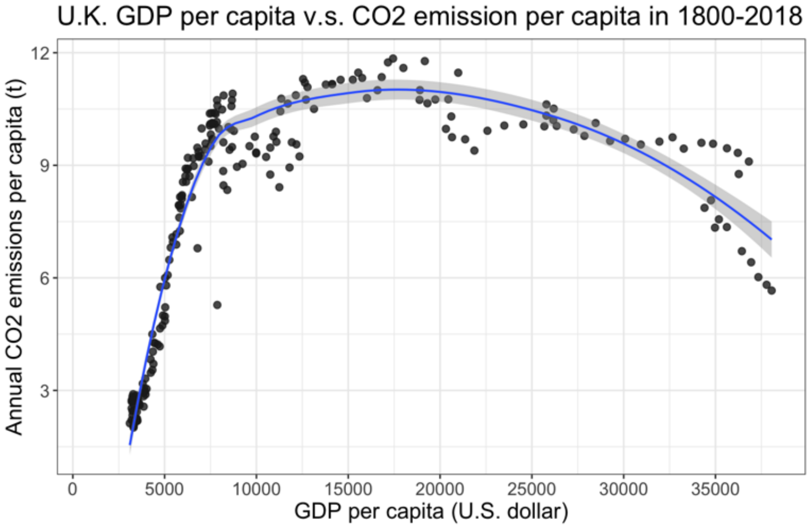



**Figure 14.** GDP per capita v.s. $CO_2$ emission per capita in developing countries, India. Linear regression models were applied (right). Simple regression was applied in analysis. Positive correlation is confirmed in India ($p < 0.001$).

*Note: b=0.0004 (SE=0.000006), β= 0.98,* $R^2$*=0.96*

A simple linear regression (Fig. 16) was calculated to predict U.K. CO2 emissions based on the U.K. GDP per capita. A significant regression equation was found (F (1, 217) = 56.8, p<0.000, with an R2 of 0.20. U.K. $CO_2$ emissions are equal to 5.951 + 1.451e-04 (U.K. GDP per capita), where the U.K. GDP per capita is measured in adjusted U.S. dollars. U.K. $CO_2$ emissions of measurement increased by 1.451e-04 parts per million for each 1 unit increase in the U.K. GDP per capita.

A multiple linear regression (Fig. 16) was calculated to predict U.K. $CO_2$ emissions based on the U.K. GDP per capita. A significant regression equation was found (F (2, 216) = 294.7, p<0.000, with an R2 of 0.73. U.K. CO2 emissions are equal to 0.773+1.106e-03 (U.K. GDP per capita) - 2.605e-08 (U.K. GDP per capita)2, where U.K. GDP per capita is measured in adjusted U.S. dollars. U.K. $CO_2$ emissions of measurement increased by 1.106e-03 parts per million for each 1 unit increase in the U.K. GDP per capita and -2.605e-08 parts per million for each 1 unit increase in the square of the U.K. GDP per capita.




```
Call:
lm(formula = Annual.CO2.emissions..per.capita. ~ GDP.per.capita,
    data = df124)

Residuals:
    Min      1Q  Median      3Q     Max
-5.8118 -2.9812  0.8154  2.4180  3.7178

Coefficients:
                Estimate Standardized Std. Error t value Pr(>|t|)
(Intercept)    5.951e+00    0.000e+00  2.930e-01  20.313  < 2e-16 ***
GDP.per.capita 1.451e-04    4.555e-01  1.925e-05   7.537 1.29e-12 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 2.783 on 217 degrees of freedom
  (574 observations deleted due to missingness)
Multiple R-squared:  0.2075,	Adjusted R-squared:  0.2038
F-statistic:  56.8 on 1 and 217 DF,  p-value: 1.293e-12
```

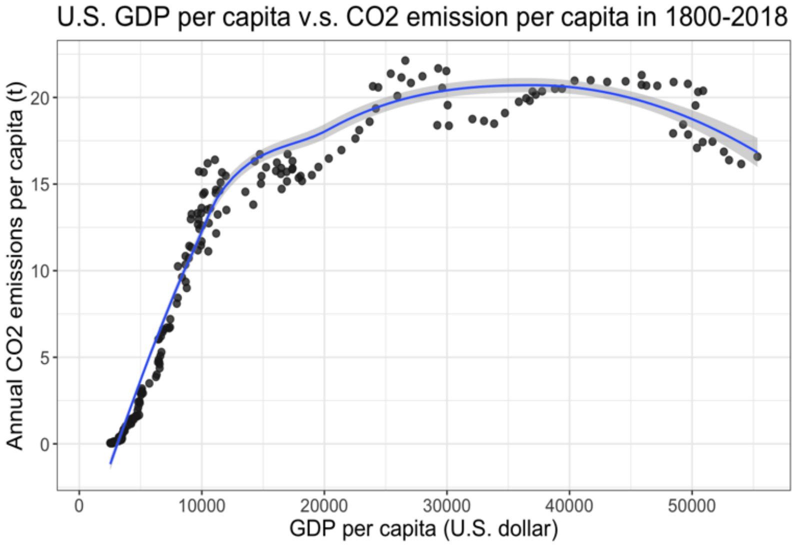
```
Call:
lm(formula = Annual.CO2.emissions..per.capita. ~ GDP.per.capita +
    gdpsqr, data = df124)

Residuals:
   Min     1Q Median     3Q    Max
-3.107 -1.479 -0.122  1.575  2.920

Coefficients:
                 Estimate Standardized Std. Error t value Pr(>|t|)
(Intercept)     7.730e-01    0.000e+00  3.044e-01   2.539   0.0118 *
GDP.per.capita  1.106e-03    3.471e+00  4.808e-05  22.999   <2e-16 ***
gdpsqr         -2.605e-08   -3.102e+00  1.268e-09 -20.549   <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 1.623 on 216 degrees of freedom
  (574 observations deleted due to missingness)
Multiple R-squared:  0.7318,	Adjusted R-squared:  0.7293
F-statistic: 294.7 on 2 and 216 DF,  p-value: < 2.2e-16
```

**Figure 15**. GDP per capita v.s. $CO_2$ emission per capita in developed countries, U.K. Linear regression models were applied. Simple regression (above) and multiple regression (below) of $GDP^2$ was applied in analysis. Correlation is confirmed in the U.K. ($p < 0.001$).

*Note: b=0.0006 (SE=0.00002), $\beta$ = 0.46, $R^2$ of GDP=0.21 (above), $R^2$ of $GDP^2$=0.73 (below)*

A simple linear regression (Fig. 17) was calculated to predict the U.S. CO2 emissions based on the U.S. GDP per capita. A significant regression equation was found (F (1, 217) = 412.7, p<0.000, with an R2 of 0.65. U.S. CO2 emissions are equal to 3.302+4.316e-04 (U.S. GDP per capita), where the U.S. GDP per capita is measured in adjusted U.S. dollars. U.S. $CO_2$ emissions of measurement increased by 4.316e-04 parts per million for each 1 unit increase in the U.S. GDP per capita.

A multiple linear regression (Fig. 16) was calculated to predict U.S. CO2 emissions based on the U.S. GDP per capita. A significant regression equation was found (F (2, 216) = 1548, p<0.000, with an R2 of 0.793. U.S. $CO_2$ emissions are equal to -3.21+1.503e-03 (U.S. GDP per capita)-2.167e-08 (U.S. GDP per capita) where U.S. GDP per capita is measured in adjusted U.S. dollars. U.S. $CO_2$ emissions of measurement increased by 1.503e-03 parts per million for each 1 unit increase in the U.S. GDP per capita and -2.167e-08 parts per million for each 1 unit increase in the square of the U.S. GDP per capita.



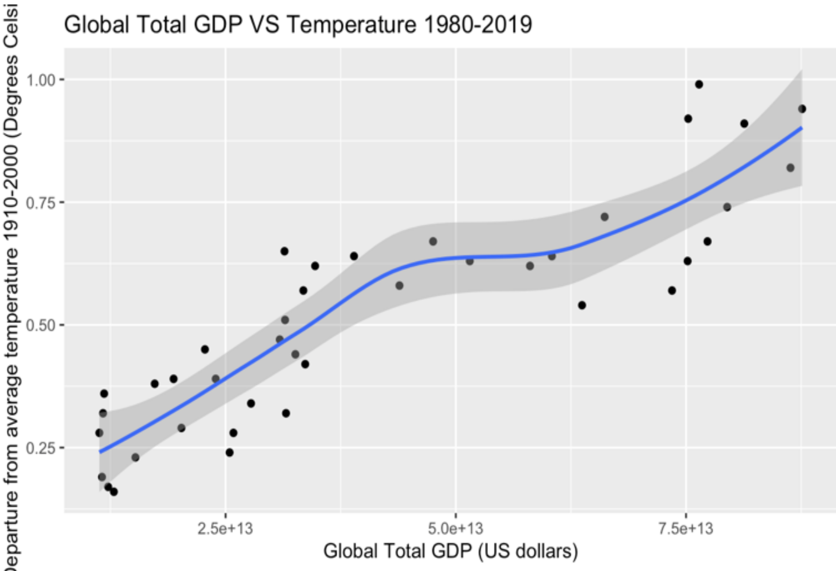

```
Call:
lm(formula = Annual.CO2.emissions..per.capita. ~ GDP.per.capita,
    data = df122)

Residuals:
     Min       1Q   Median       3Q      Max
-10.5992  -4.3279  -0.8974   4.5728   8.3802

Coefficients:
                Estimate Standardized Std. Error t value Pr(>|t|)
(Intercept)    3.302e+00    0.000e+00  4.466e-01   7.394 3.07e-12 ***
GDP.per.capita 4.316e-04    8.096e-01  2.124e-05  20.316  < 2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 4.627 on 217 degrees of freedom
  (42 observations deleted due to missingness)
Multiple R-squared:  0.6554,	Adjusted R-squared:  0.6538
F-statistic: 412.7 on 1 and 217 DF,  p-value: < 2.2e-16
```

```
Call:
lm(formula = Annual.CO2.emissions..per.capita. ~ GDP.per.capita +
    gdpsqr, data = df122)

Residuals:
    Min      1Q  Median      3Q     Max
-4.3666 -1.2527 -0.6285  0.8763  6.3211

Coefficients:
                Estimate Standardized Std. Error t value Pr(>|t|)
(Intercept)    -3.213e+00    0.000e+00 2.895e-01  -11.10   <2e-16 ***
GDP.per.capita  1.503e-03    2.820e+00 3.643e-05   41.27   <2e-16 ***
gdpsqr         -2.167e-08   -2.079e+00 7.123e-10  -30.42   <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 2.017 on 216 degrees of freedom
  (42 observations deleted due to missingness)
Multiple R-squared:  0.9348,	Adjusted R-squared:  0.9342
F-statistic:  1548 on 2 and 216 DF,  p-value: < 2.2e-16
```

**Figure 16.** GDP per capita v.s. $CO_2$ emission per capita in developed countries, U.S. Linear regression models were applied. Simple regression *(above)* and multiple regression *(below)* of $GDP^2$ was applied in analysis. Correlation is confirmed in the U.S. ($p < 0.001$).

*Note:* $b=0.0004$ $(SE=0.00002)$, $\beta= 0.81$, $R^2$ *of GDP*$=0.66$ *(E)*, $R^2$*of* $GDP^2=0.93$ *(F)*

A multiple linear regression (*Fig. 17*) was calculated to predict temperature based on the global total GDP and GDP per capita. A non-significant regression equation was found ($F(2, 37) = 70.31$, $p<0.000$, with an R2 of 0.79.




```
Call:
lm(formula = Temperture ~ WorldGDP, data = dat)

Residuals:
      Min        1Q    Median        3Q       Max
-0.197116 -0.080976  0.006625  0.075078  0.214366

Coefficients:
             Estimate Standardized Std. Error t value Pr(>|t|)
(Intercept) 1.883e-01    0.000e+00  3.304e-02   5.699 1.47e-06 ***
WorldGDP    7.878e-15    8.826e-01  6.808e-16  11.571 5.08e-14 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.1062 on 38 degrees of freedom
Multiple R-squared:  0.7789,    Adjusted R-squared:  0.7731
F-statistic: 133.9 on 1 and 38 DF,  p-value: 5.083e-14
```

**Figure 17.** Relationship between global total GDP (in U.S. dollars) and temperature from average temperature in 1910-2000 (˚C). Loess regression model was used. Positive correlation was confirmed ($p < 0.001$).

*Note: b=0.0001 (SE=0.001), β = 0.88,* $R^2=0.78$

A simple linear regression (Fig. 17) was calculated to predict temperature based on the Global total GDP. A significant regression equation was found (F (1, 38) =133.9, p<0.000, with an R2 of 0.77. Temperature is equal to 0.188+7.878e-15 (total GDP), where the total GDP is measured in adjusted U.S. dollars. Temperature of measurement increased by 7.878e-15 parts per million for each 1 unit increase in total GDP.

## 4. Discussion

Humans released a great amount of $CO_2$ to the atmosphere (Fig. 4) of the Earth after the Industrial Revolution (Fig. 3). Many major developed countries finished the Industrial revolution after 1850. Industry released a great amount of CO2, so the $CO_2$ conc. increased greatly from that period of time.

Previous studies showed $CO_2$ conc. increases 48% than pre-industrial time (NASA). This change rate was much greater than natural changes by nature. As we well into 1960, the rate of $CO_2$ conc. has boosted faster than ever since more and more countries entered industrial societies. A warning sign was that the rise of $CO_2$ conc was still not at its peak. The leaders of most countries realized the existing damages and underlying crisis for human beings. Thus, in 2015, 195 countries agreed to reduce carbon emissions and set a zero-increase target in the Paris Accord. However, as we can tell in Fig. 3 the rate of $CO_2$ increased at the same speed. The effect of the Paris Accord was weak. We also found out Covid-19 in 2020 didn't slow down the increasing rate of $CO_2$. The $CO_2$ conc. has increased to a new record level. We need more powerful agreement and stronger crisis awareness to gather all human beings together and protect the environment.

Human activities increased the $CO_2$, a heat-trapping green-house gas, in the Earth's atmosphere. By burning fossil fuels, deforestation, and natural activities of volcanic eruptions, the level of $CO_2$ concentration increased in the atmosphere. Carbon dioxide ($CO_2$) is a natural gas fixed via photosynthesis. However, in recent years, human emissions of fossil fuel combustion and biomass burning caused abnormal increases in atmospheric $CO_2$. Other industrial processes and land use also contribute to the current $CO_2$ increase. $CO_2$ is the main cause of rising temperature in the atmosphere. The increasing amount and level of CO2 of a country are the indicator of greenhouse gas (Oliver & Peters, 2017). Greenhouse gases include $CO_2$, $CH_4$, $N_2O$, $O_3$, and water vapor. $CO_2$ increase is caused by anthropogenic activities. The forms of $CO_2$ include solid, liquid, and gas fuels/flaring. The rising of $CO_2$ will affect the radiative balance in the atmosphere of the Earth. By increasing the absorbance of heat-carrying long-wavelength infrared rays, $CO_2$ holds the heat inside of the planet which causes atmosphere temperature to increase. The $CO_2$ emissions are the key reference gas in our climate change analysis.

The $CO_2$ release came from fossil fuel and industrial production. We analyzed the top three $CO_2$ sources: coal, oil, and natural gas (Fig. 4). At a global level, we saw coal as the dominant emission source as solid fuel. From the 18th century, coal-fired power emerged for industry use in Europe and the U.S. Until the 20th century, we started to see the growth of oil and natural gas. Today, coal and oil still dominate, while natural gas production and other energy sources, i.e., cement and flaring remain little contribution. The figure 4 showed an energy pattern: solid fuel in early industrialization turned into liquid or gas fuel. As time went, the energy pattern has been diverse. Even in some developing areas like Latin America, coal consumption was still small in the early stage. But in Asia, solid carbon emission still dominated the contribution compared to other areas.

GDP is the best economic indicator. GDP can describe the economy of a country straightforwardly. GDP in the world increased fast. We were four times richer than people in 1980. Prosperity was a recent achievement compared to our ancestors. GDP is a measure of the total production of an economy. It is the monetary value of all goods and services. GDP per capita is calculated by GDP / Population. It can measure the prosperity of individuals in a country. Through inflation-adjusted GDP measured in U.S. dollars, we can know the country's history and development level. By GDP per capita, we can understand the behavior of each person.

In figure 5 and 6, we analyzed the total annual $CO_2$ emissions and $CO_2$ emissions per capita divided by world regions. People in developed countries release more $CO_2$ to the air compared to people in other countries. Richer people made more contributions to the climate change situation (Fig. 5). By comparing annual $CO_2$ emissions among all 235 countries in the world, we found that until around 1950, the global $CO_2$ emissions were led by Europe and U.S. For example, over 90% of $CO_2$ emissions were emitted by Europe or the U.S. Until 1950, they still took up over 85% of global emissions. However, in recent decades, the situation has changed. Other countries and world regions catched up and overpassed. Asian countries, especially China, India, and Russia, had a significant increase in global $CO_2$ emissions. Europe and the U.S., on the contrary, took up almost 1/3 of the global $CO_2$ emission. In this figure (Fig. 6), $CO_2$ emissions were calculated by annual production, not including traded goods, and measured in tonnes based on territorial division.

If we compare every region with their economy in the past, we will find every world region is richer than before. But not every country developed the same. Unequal development caused serious inequality in the world. Europe, North America, and Australia had higher GDP per capita. South America, Asia, and Africa had lower GDP per capita (Fig. 7). This was corresponding to economic development. Europe and the U.S. began industrial revolution earlier than other countries.

Economic growth is a good thing. We all hope we can live better lives. But we need to reduce the human impact on the environment. Like the saying from Mariana Mazzucato: “economic growth has not only a rate but also a direction” (Mazzucato, 2017). We have other better options than polluting industries such as improved technology, alternatives to meat, and enhanced solar energy. We are at a point to take action and choose a direction. Economic growth is not the top priority anymore. It is one of the methods to achieve other goals. With a better economy, more chances are obtained. A good economy could offer people a suitable lifestyle. A low-carbon and green lifestyle could be the best choice for people. GDP per capita describes the behaviors of individuals based on the freedom of choice. Thus, it is very important to trace the GDP per capita around the world.

It is time to figure out how the GDP per capita relates to global warming. First of all, we drew a scatter plot to see the relationship between Global GDP per capita and Global temperature (Fig. 9). Then we used a simple regression model to fit the data. From Figure 9, there is a roughly positive linear relationship between Global GDP per capita and Global temperature from the year 1980 to 2019. The simple regression analysis, b=0.00007, indicates that for each 1 unit increase in Global GDP Per Capita, Global Temperature increases by 0.00007 degrees. And beta =0.87 means that for each 1 standard deviation increase in Global GDP Per Capita, Global Temperature increases by 0.87 standard deviations. R2=0.75 represents that Global GDP Per Capita accounts for 75% of the variance in Global Temperature. Global GDP Per Capita significantly predicts Global Temperature since p-value < 0.001.

Then, we analyzed the relationship between $CO_2$ emission and Global temperature in figure 10. Similar simple regression results were seen for the relationship between $CO_2$ emission and Global temperature. $CO_2$ emission significantly predicts temperature since the p-value is less than significance level. From the results of two simple regression tests, both Global GDP Per Capita and $CO_2$ emission are significant variables in predicting Global temperature. Next, we considered multiple regression analysis with Global GDP Per Capita and $CO_2$ emission together as predictor variables, Global Temperature as the response variable.

The relation between Global GDP per capita and Global $CO_2$ emission per capita was positive linear from 1990 to 2018 (Fig. 12). From the simple regression analysis, the p-value is less than 0.001. The relationship between the two variables was highly significant. With 1 unit of GDP per capita increased, $CO_2$ emission per capita increased 0.0001. And beta = 0.96 illustrated that $CO_2$ emission increased by 0.96 standard deviations if GDP per capita would increase by 1 standard deviation. And the R2 =0.92 represented that Global GDP Per Capita accounted for 92% of the variance in Global $CO_2$ Emission per capita.

Figure 13 illustrates the relation between GDP per capita and $CO_2$ emission per capita for each county in 2015. To show stronger relation, the GDP per capita and $CO_2$ per capita were calculated with log. P value was smaller than 0.001, which means the relation between log (GDP per capita in dollar) and log (Annual $CO_2$ emission per capita in t) was significant. With 1 unit of log (GDP per capita) increases, log ($CO_2$ emission per capita) increased 1.2. Beta = 0.93 illustrated that log ($CO_2$ emission per capita in t) increased by 0.93 standard deviations if log (GDP per capita) would increase by 1 standard deviation. And the R2 =0.86 represents that log (GDP Per Capita) accounted for 86% of the variance in log ($CO_2$ Emission per capita in t).

The counties were divided into developing countries and developed countries. And the relation between country GDP per capita and annual $CO_2$ emission per capita was evaluated. From figure 14 and figure 15, developing countries' conditions were shown by using China and India as examples. In the China linear regressions analysis, the simple regression results for China (Fig. 14). b=0.0006 means when GDP per capita increased 1-unit, annual $CO_2$ emission per capita would increase 0.0006. When GDP per capita increased 1 standard deviation, annual $CO_2$ emission per capita would increase 0.98 standard deviation. P value was small enough to say the relation was sever significant. And R2=0.97 represents GDP Per Capita accounted for 97% of the variance in $CO_2$ emission per capita. The India linear regressions analysis illustrated the simple regression analysis results for India (Fig. 15). Compared with China’s data, the results were very similar. GDP per capita increased 1-unit, annual $CO_2$ emission per capita would increase 0.0004. GDP per capita increased 1 standard deviation, annual $CO_2$ emission per capita would increase 0.98 standard deviation. R2=0.96 represents GDP Per Capita accounted for 96% of the variance in $CO_2$ emission per capita.

In figure 16 and figure 17, developed countries' conditions from 1800 to 2018 were shown by using the United States and the United Kingdom as examples. For the developed countries, the relations were no longer linear. The relations were still significant since the p value < 0.001. From simple regression analysis, both R2 show the level decrease of GDP Per Capita accounting for the variance in $CO_2$ emission per capita. To increase the accuracy of the statistical analysis, multiple regression analysis was used. GDP per capita and square of GDP per capita were used together to evaluate $CO_2$ emission. Multiple regression analysis for the United Kingdom, with 1 unit of GDP per capita increased, $CO_2$ emission per capita would increase 0.001. With 1 unit of (GDP per capita)2 increased; $CO_2$ emission per capita would decrease 0.00000003. With both GDP per capita and its square, $CO_2$ emission per capita can be explained by 73%. The level of explanation for CO2 emission was also increased a lot with multiple regression analysis for the United States. Now, 93% of $CO_2$ emission could be explained by GDP per capita and its square.

It is the analysis on the relationship between global total GDP and temperature change. First, we can see the simple regression between them is roughly linear, very similar to the regression between global GDP per capita and temperature change. Second, for the bottom right, it is the simple regression test on the relationship between global total GDP and temperature change, we can see that p-value is very small, and we can say that global total GDP is a significant variable on predicting global temperature change. Thirdly, the left summary is on the multivariable regression test when we put global GDP per capita and global total GDP together to predict temperature change, the result is not the same as the simple regression test, p-values for both variables cannot support the significance on all confidence levels. We think the reason is because of multicollinearity, if we put the variables together as prediction variables, they will affect each other.

Lastly, we did a variable selection test on multiple variable regression test to see if we really want to drop the variable or not, the method is backward elimination. The result tells us that we should not drop either of them because of lower AIC value, so that is also supporting our multicollinearity hypothesis.

The whole world is facing a global warming crisis. Now, the world is on the pathway of 1˚C. The warming rate is still increasing. G20 countries are putting efforts to slow down the carbon emissions before 1.5˚C. If the global temperature breaks 1.5˚C, the environmental damage will be irreversible. We don’t need to have ecology despair since humans will get together to not pass the 1.5˚C threshold. A lower price on renewable energy could help the world find a potential pathway to balance development and environmental protection. With more and more research and analysis being applied, people will be more aware of climate change and more possible to speed up finding a solution to solve this ecology problem.

We have to face the inequality of global warming, a contentious consensus of climate change. Developed countries contributed more $CO_2$ to the atmosphere. But people in developing countries, especially women and old people in poverty, suffer more from global warming. When the global temperature increases, the higher temperature causes more damage to developing countries since agriculture takes more proportion in those countries. Although China and the U.S. are the two top $CO_2$ countries, Europe and the U.S. accumulated more carbon pollution from 1850. Those developed countries should shoulder more obligations. But currently, we got more pledges than actions.

## 5. Conclusion

The world needs more attention on climate change more than ever. Under this situation, we made this project to analyze the history, causes, outcomes, contribution of $CO_2$, relationship with the economy. Our results supported our hypothesis. Global warming began after the Industrial Revolution and speeded up after 1960. The solid carbon release dominated, and liquid / gas carbon release speeded up greatly. Increasing $CO_2$ caused the sea-level rise and more coral bleachings. The U.S. and Europe had a long history of $CO_2$ emissions. Developed countries emitted more $CO_2$ per capita. Developing countries like China, Russia, and India have caught up and released $CO_2$ in recent years. In the development of a country, $CO_2$ emission levels will increase greatly in the early stages. The rate of $CO_2$ emission then will decrease at a later stage. We found strong indications of relative sensitivity between global emissions and the economy. GDP per capita has a positive correlation with increasing temperature. GDP per capita is positively correlated with $CO_2$ emission. Total GDP is positively correlated with $CO_2$ emission. Overall, the global economy has a positive correlation with global warming. Total GDP and GDP per capita and $CO_2$ emission are significant variables in predicting global temperature change. Our simple regression tests support the hypothesis with $p < 0.001$. Although terms are no longer significant in multiple regression tests for total GDP and $CO_2$ emissions, we kept the relationship due to the multicollinearity AIC test.

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# Appendix

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