

CLIMATE CHANGE PATTERNS: UNDERSTANDING THE VARIABILITY IN THE EARTH'S SURFACE TEMPERATURE AND SPATIAL CORRELATION WITH ECONOMIC INDICATORS

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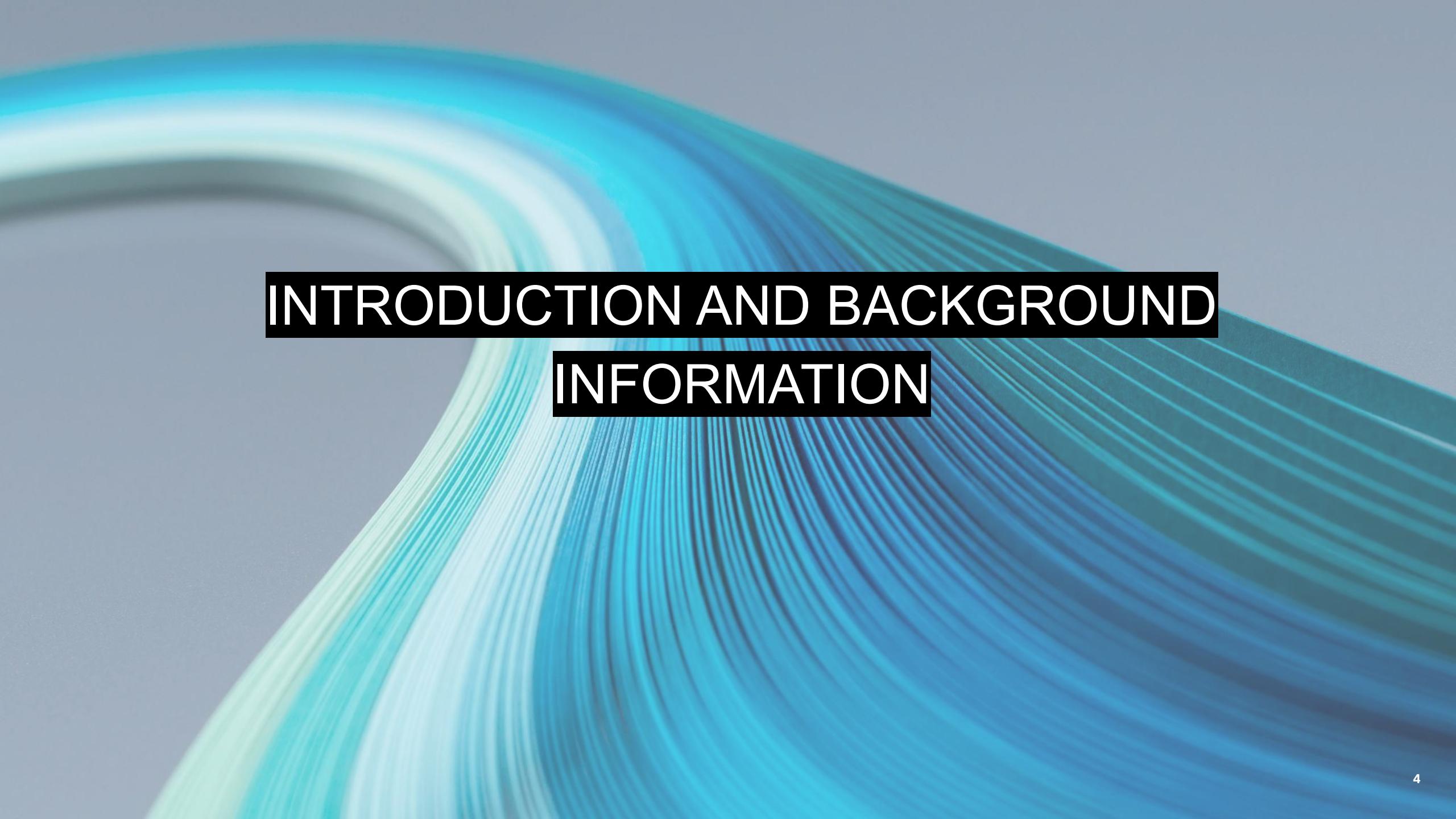
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"Global warming threatens our health, our economy, our natural resources, and our children's future. It is clear we must act."

- Eliot Spitzer



INTRODUCTION AND BACKGROUND INFORMATION

Climate change and Food Production

- The increase in agricultural production in developed countries over the past 50 years is mostly related to increased use of mineral fertilizer, which has also had detrimental consequences on the atmosphere, as higher GHG emissions
- Global greenhouse gas (GHG) emissions from food account for around 26% of all emissions (OWID 2022).
- Energy is responsible for the majority of GHG emissions, whether in the form of power, heat, transportation, or industrial activities incorporated in the food production process
- The combustion of fossil fuels for the production and delivery of food may potentially produce greenhouse gas emissions (Council 2015).

Environmental Science and Pollution Research
<https://doi.org/10.1007/s11356-023-26628-8>

RESEARCH ARTICLE



Influence of access to clean fuels and technology, food production index, consumer price index, and income on greenhouse gas emissions from food system: evidence from developed countries

Gulzara Tariq¹ · Huaping Sun^{1,4} · Imad Ali¹ · Sajjad Ali² · Qasim Shah³

Received: 15 July 2022 / Accepted: 20 March 2023
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$$GHG = a_0 + \delta_1 ACFT + \delta_2 CPI + \delta_3 FPI + \delta_4 GDP \quad (2)$$

Climate change and Economic development

- The economic development is a learning process that generates new products and exporting more complex products.
- Even though industrialization has facilitated economic growth, it has also accelerated energy consumption and carbon emissions (Asane-Otoo, 2015; Liddle & Lung, 2010; Madlener & Sunak, 2011).
- It has been known that carbon emissions originate from different parameters such as energy usage, urbanization processing, exports, production, and economic factors (Dogan et al., 2019; Farhani & Rejeb, 2012; Tarancón & Del Rio, 2007).

Received: 22 July 2020 | Revised: 28 July 2020 | Accepted: 8 August 2020

DOI: 10.1002/sd.2125

RESEARCH ARTICLE



The mitigating effects of economic complexity and renewable energy on carbon emissions in developed countries

Buhari Doğan¹ | Oana M. Driha² | Daniel Balsalobre Lorente³ | Umer Shahzad⁴

Model-1:

$$CO_{2,it} = f(POP_{i,t}^{\beta_1}, GDP_{i,t}^{\beta_2}, REC_{i,t}^{\beta_3}, ECI_{i,t}^{\beta_4}) + \mu_{i,t}$$

$$CO_{2,it} = \beta_0 + \beta_1 POP_{i,t} + \beta_2 GDP_{i,t} + \beta_3 REC_{i,t} + \beta_4 ECI_{i,t} + \mu_{i,t} \quad (1)$$

Model-2:

$$CO_{2,it} = f(POP_{i,t}^{\beta_1}, GDP_{i,t}^{\beta_2}, REC_{i,t}^{\beta_3}, ECI_{i,t}^{\beta_4}, ECI * REC_{i,t}^{\beta_5}) + \mu_{i,t}$$

Problem Statement



- Observing the patterns in average temperature across the world
- Analyzing if there is any spatial association between economic indicators and global warming across the world. **Are all countries equally bearing the burden of climate change?**

Data sources

Global Average Temperature
243 countries

1990-2013

Gross Domestic Product GDP
(\$)
266 countries

1990-2013

Greenhouse Gas emission
(GHG) (MtCO₂e)
231 countries

1990-2013

1990-2013

Consumer Food Price inflation
(%YoY)
182 countries

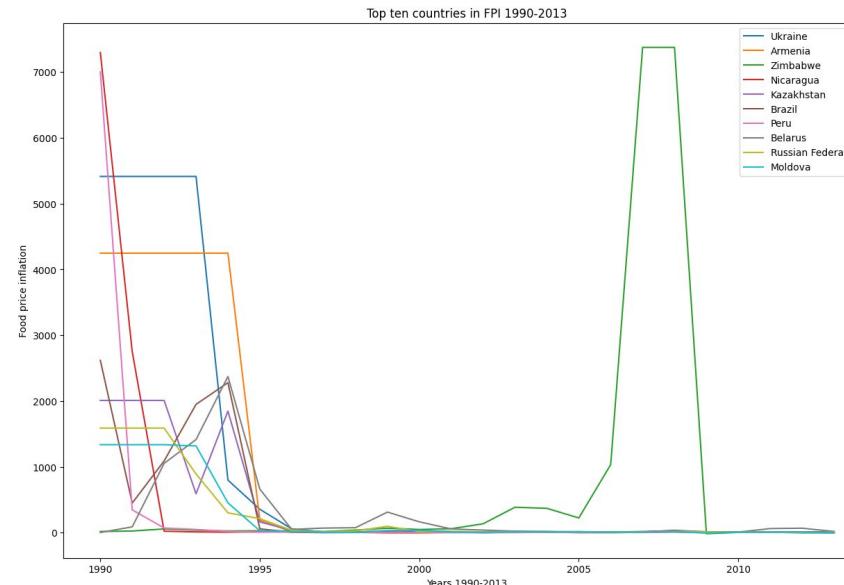
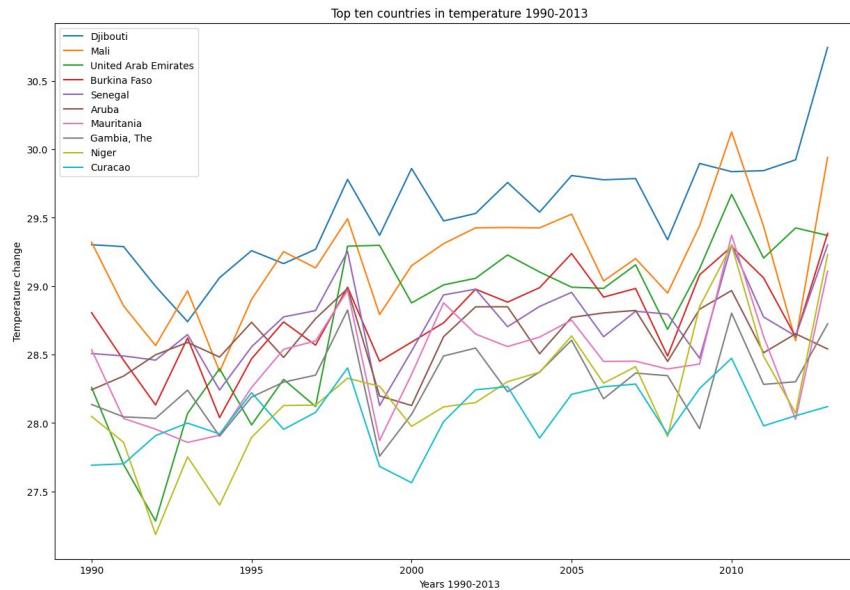
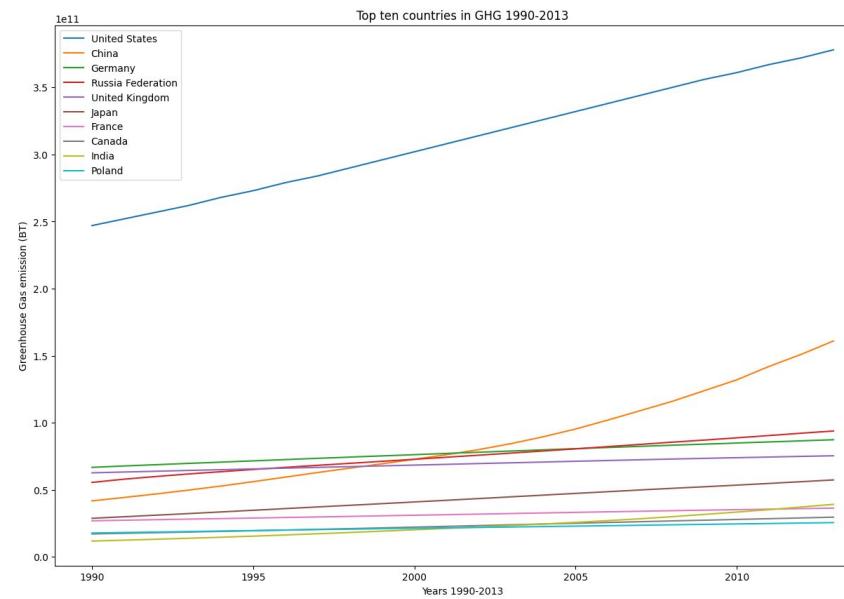
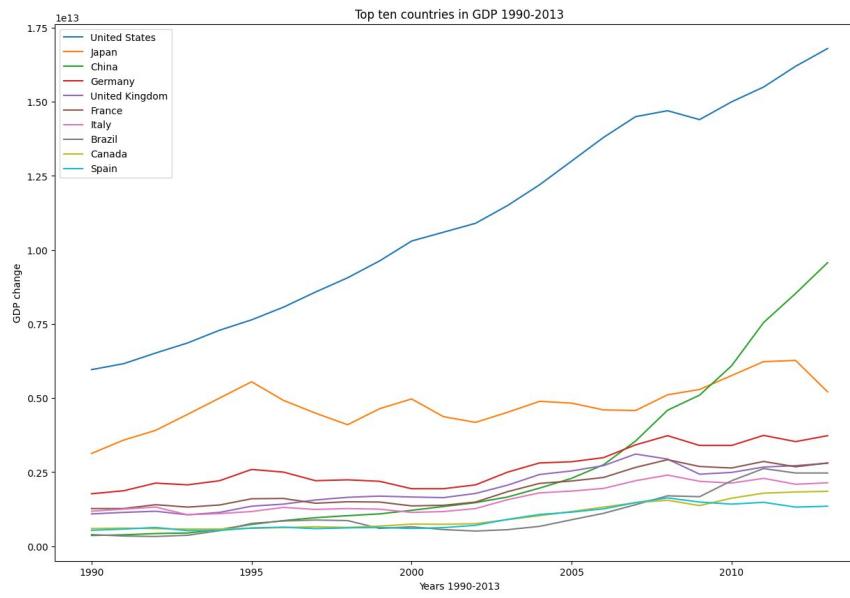
Data Cleaning: 178
countries for GDP, FPI, GHG
and Temperature



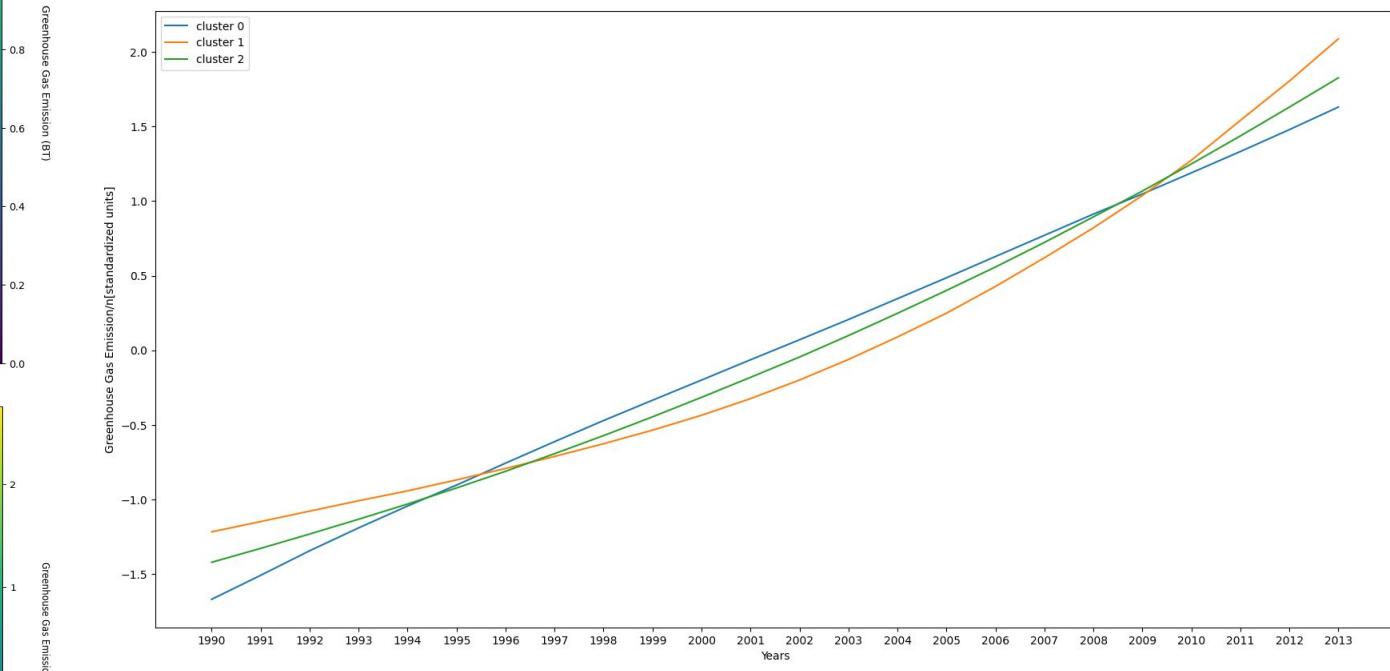
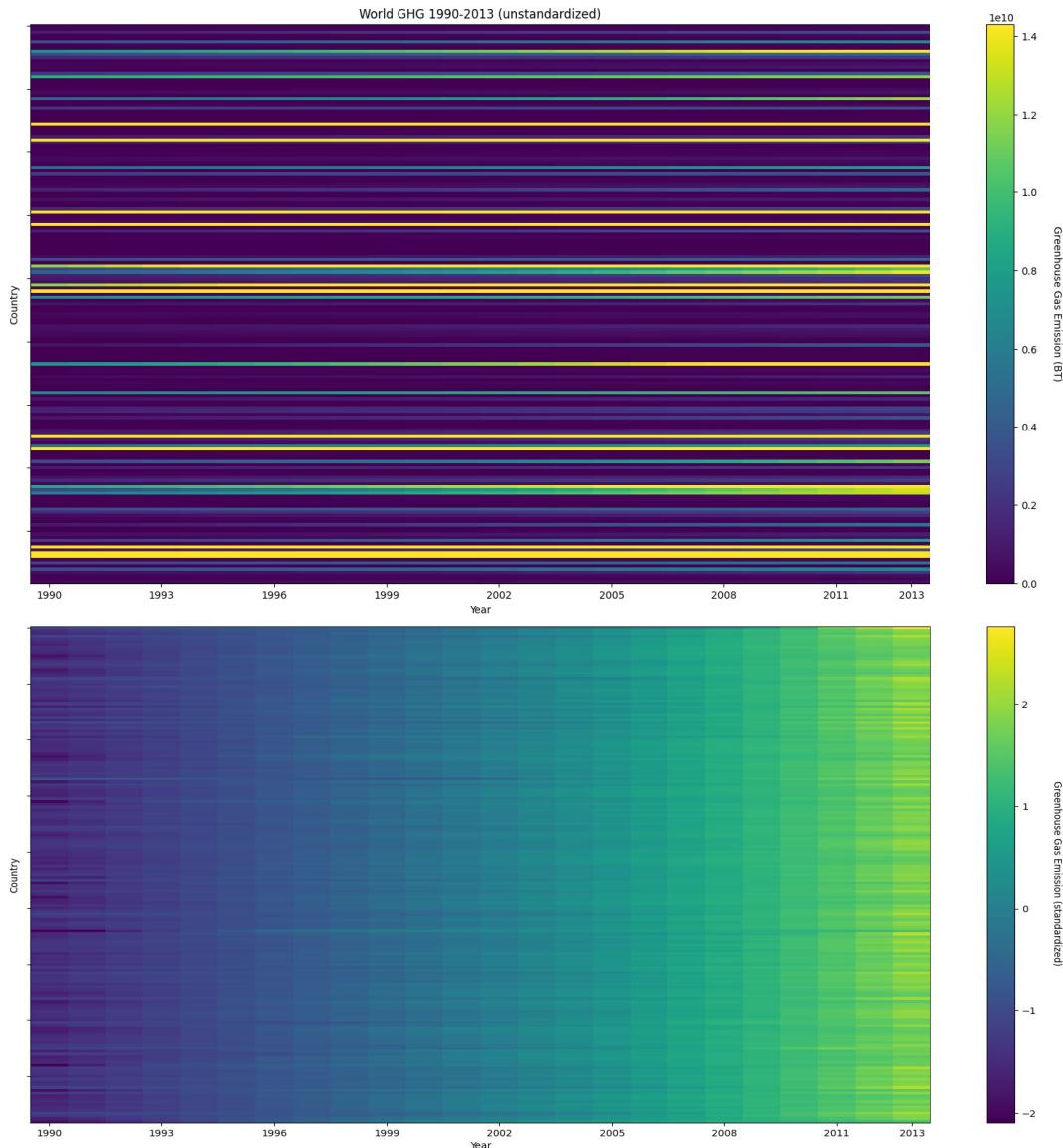


Analysis

Quick look at trend in top ten countries

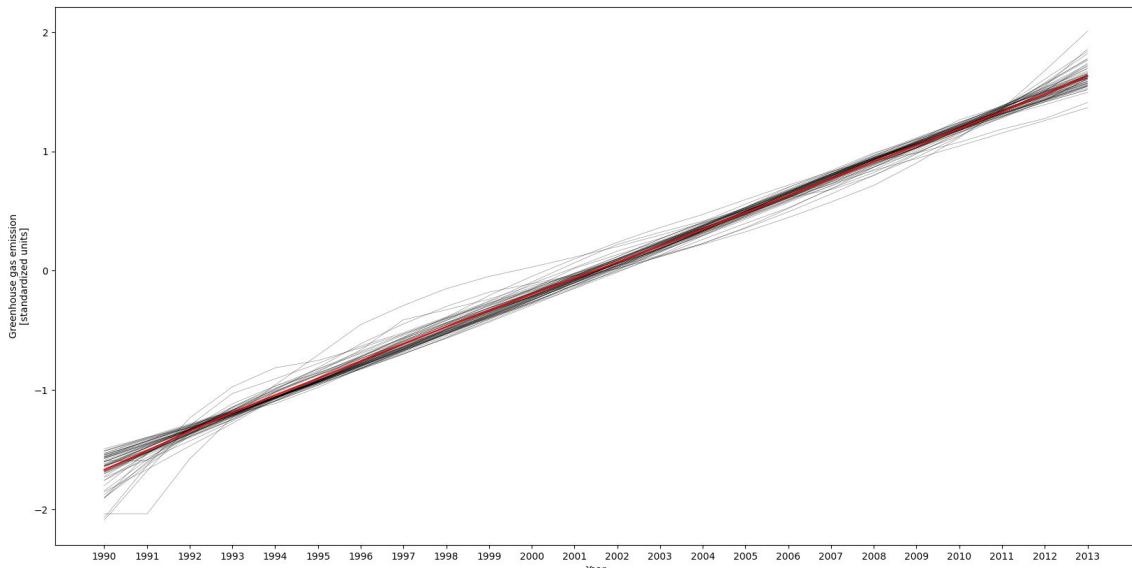


Clustering Greenhouse Gas Emission

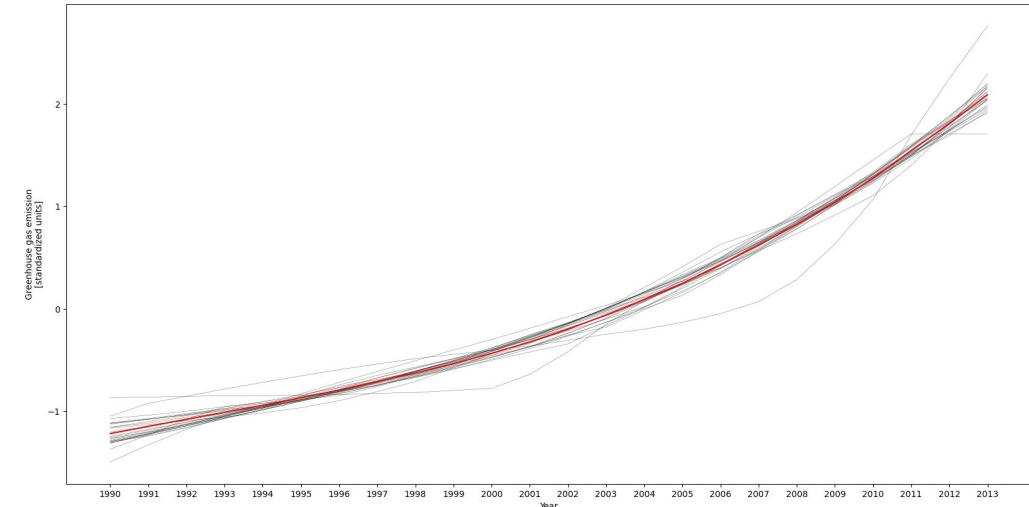


Clustering Greenhouse Gas Emission

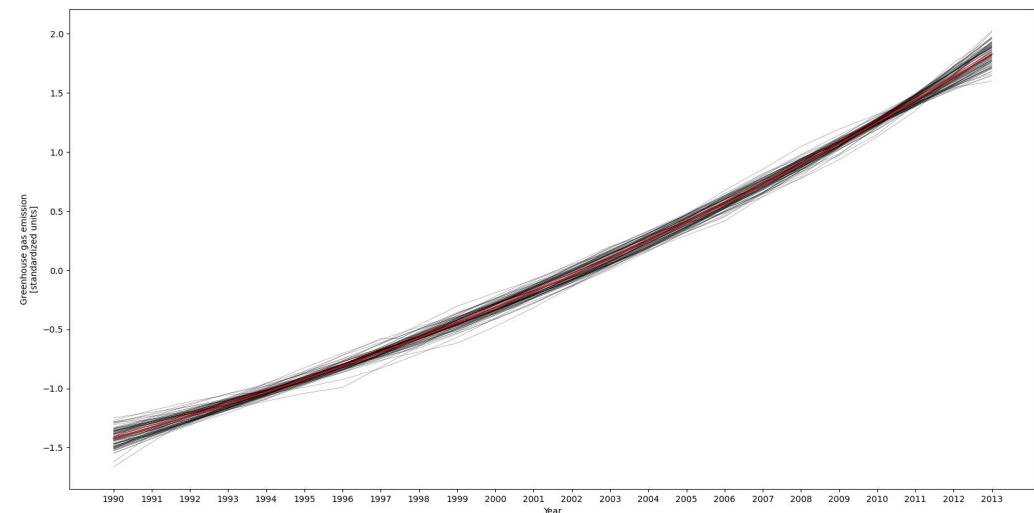
#Cluster 0, including 59 countries



#Cluster1, including 26 countries

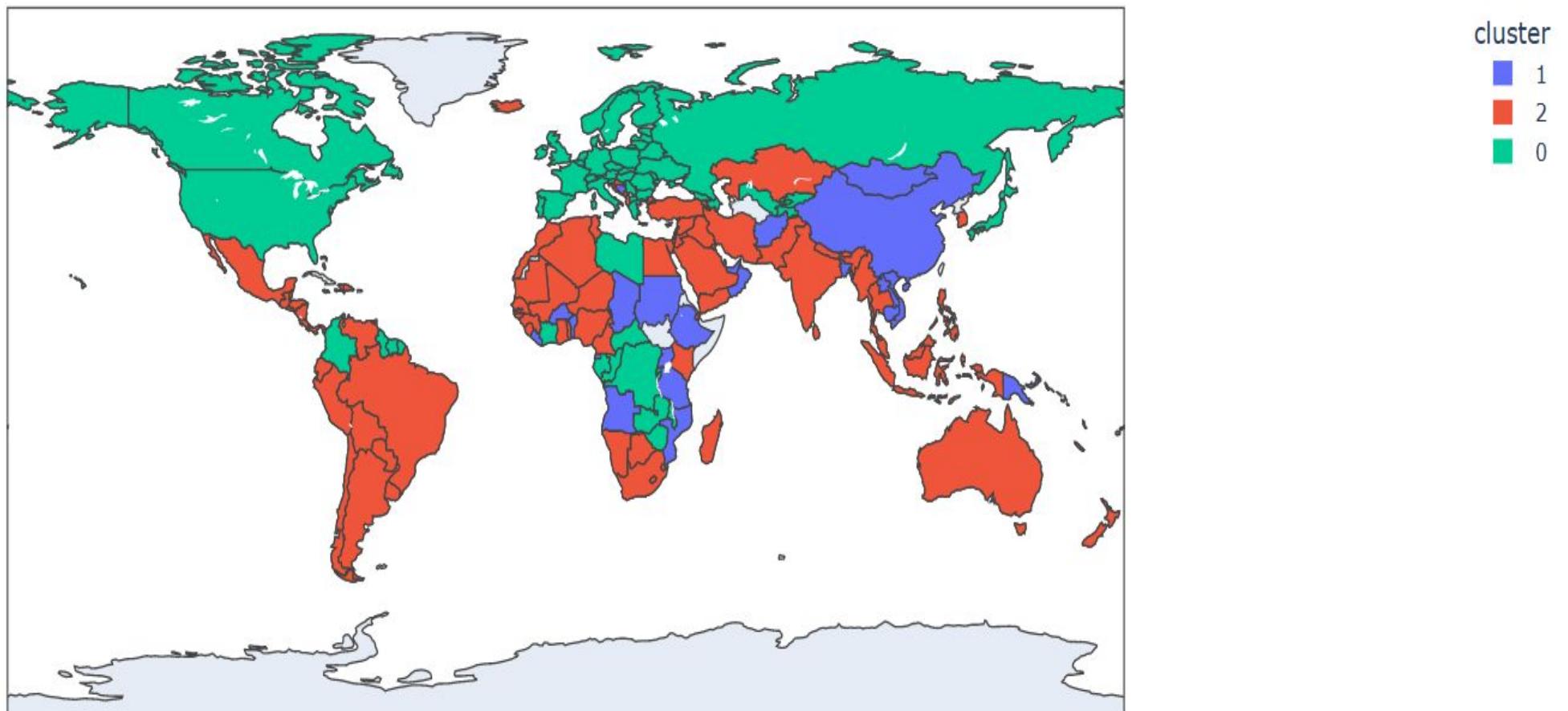


#Cluster 2, including 93 countries

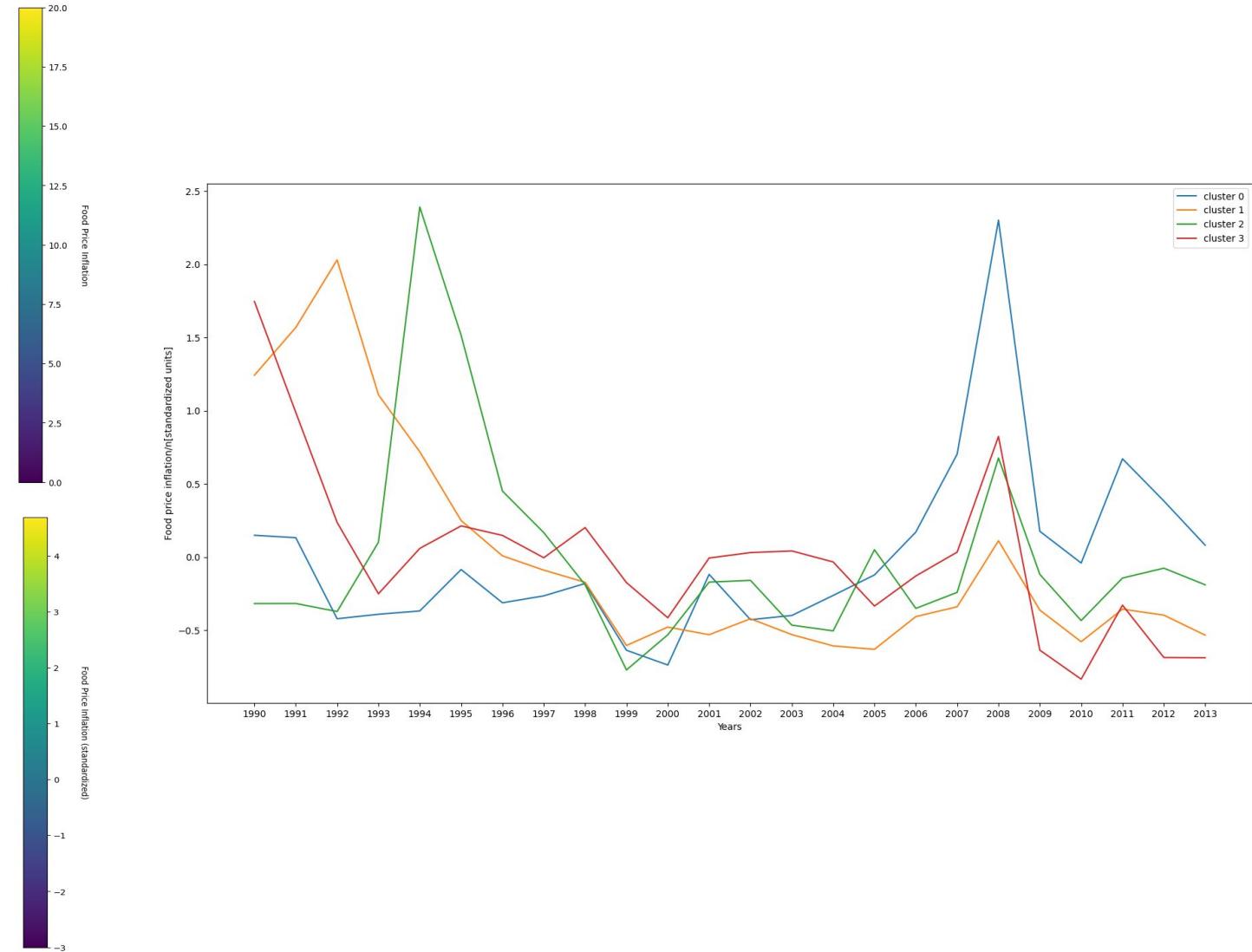
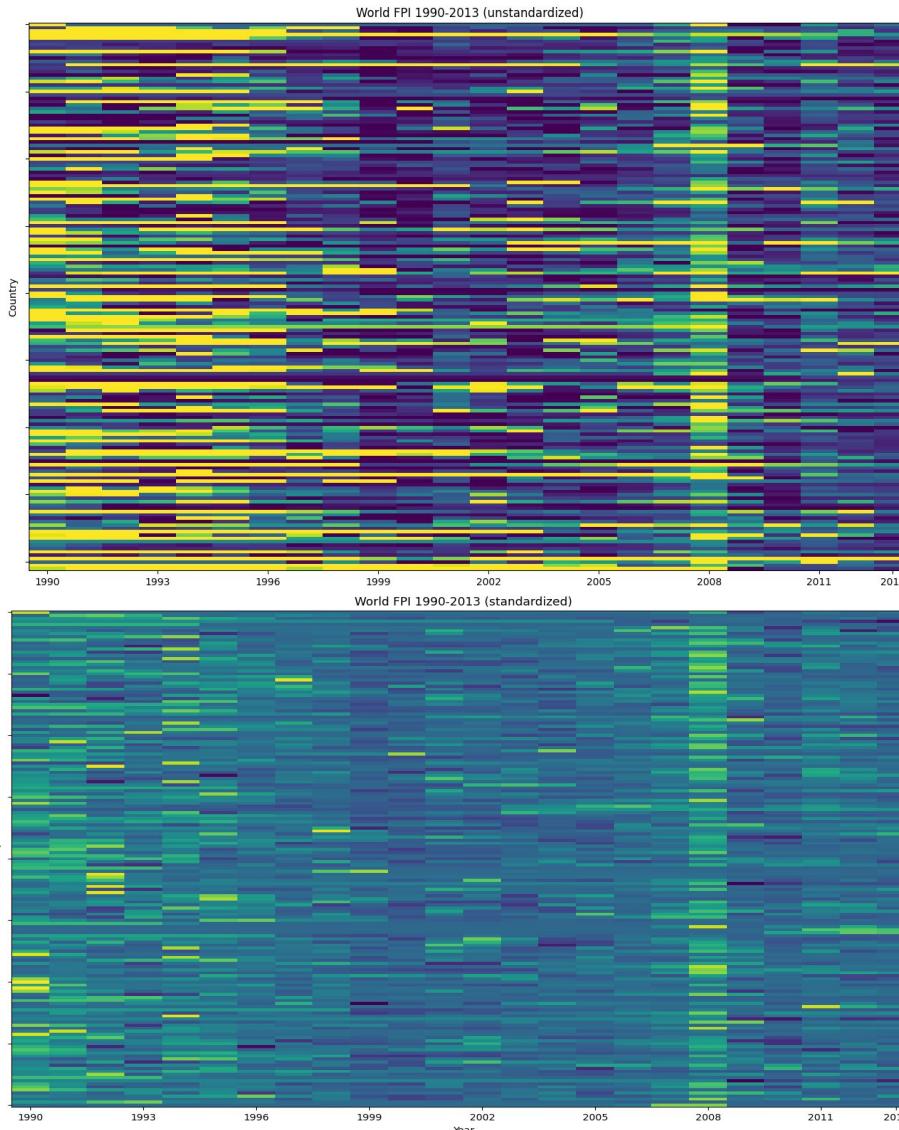


Clustering Greenhouse Gas Emission

Categorizing countries Based on Greenhouse gas emission 1990-2013

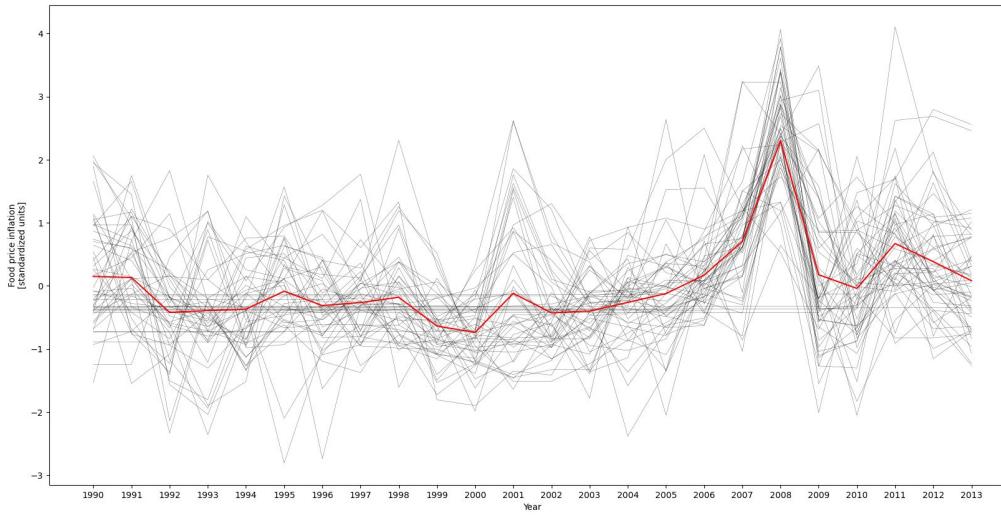


Clustering Food Price Inflation

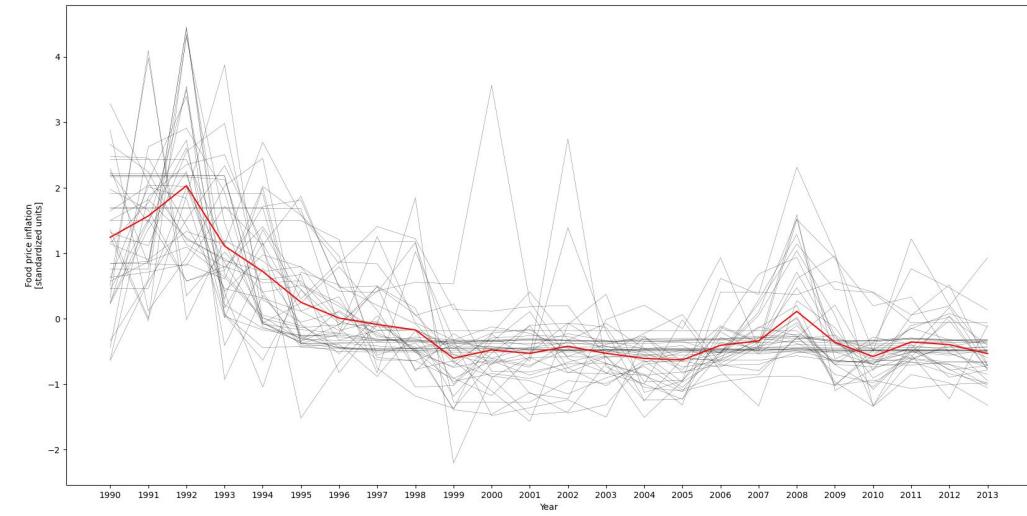


Clustering Food Price Inflation

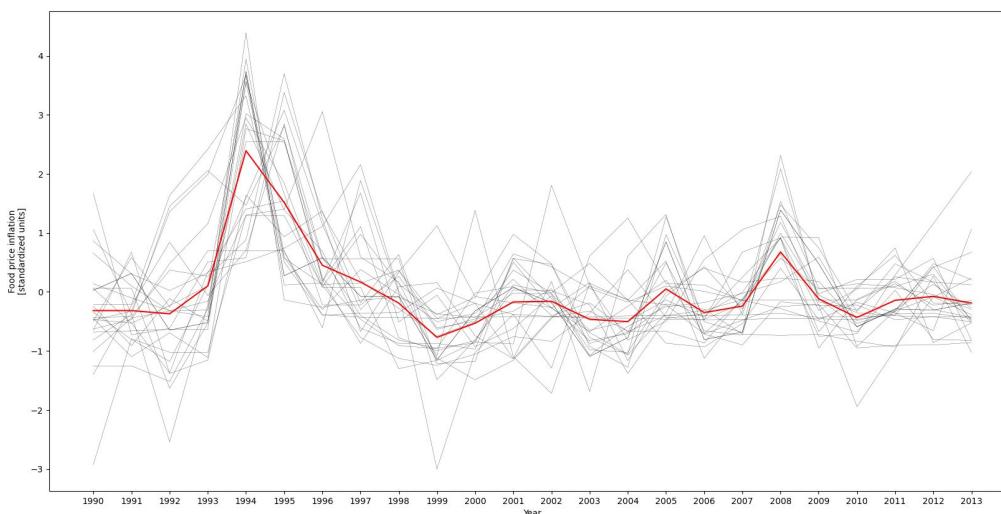
#Cluster 0, including 55 countries



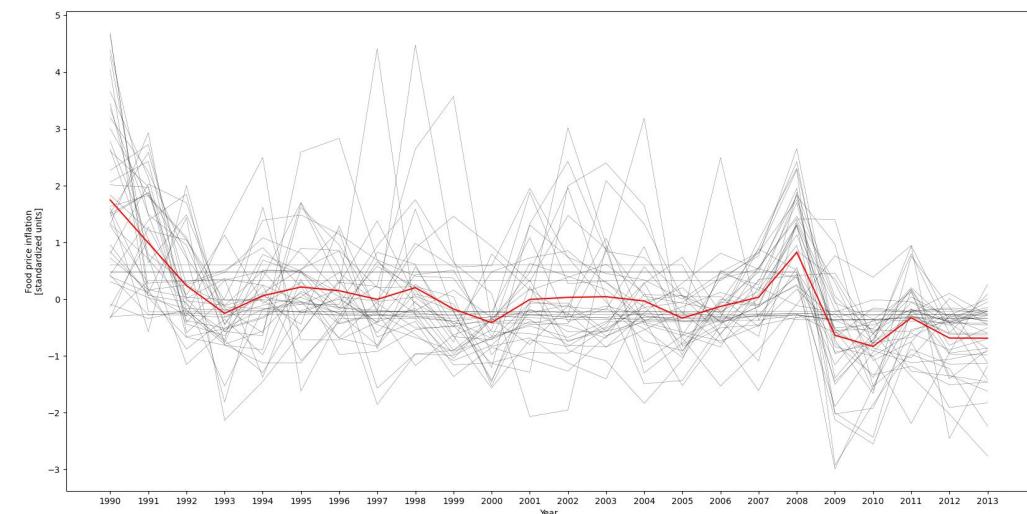
#Cluster 1, including 43 countries



#Cluster 2, including 25 countries

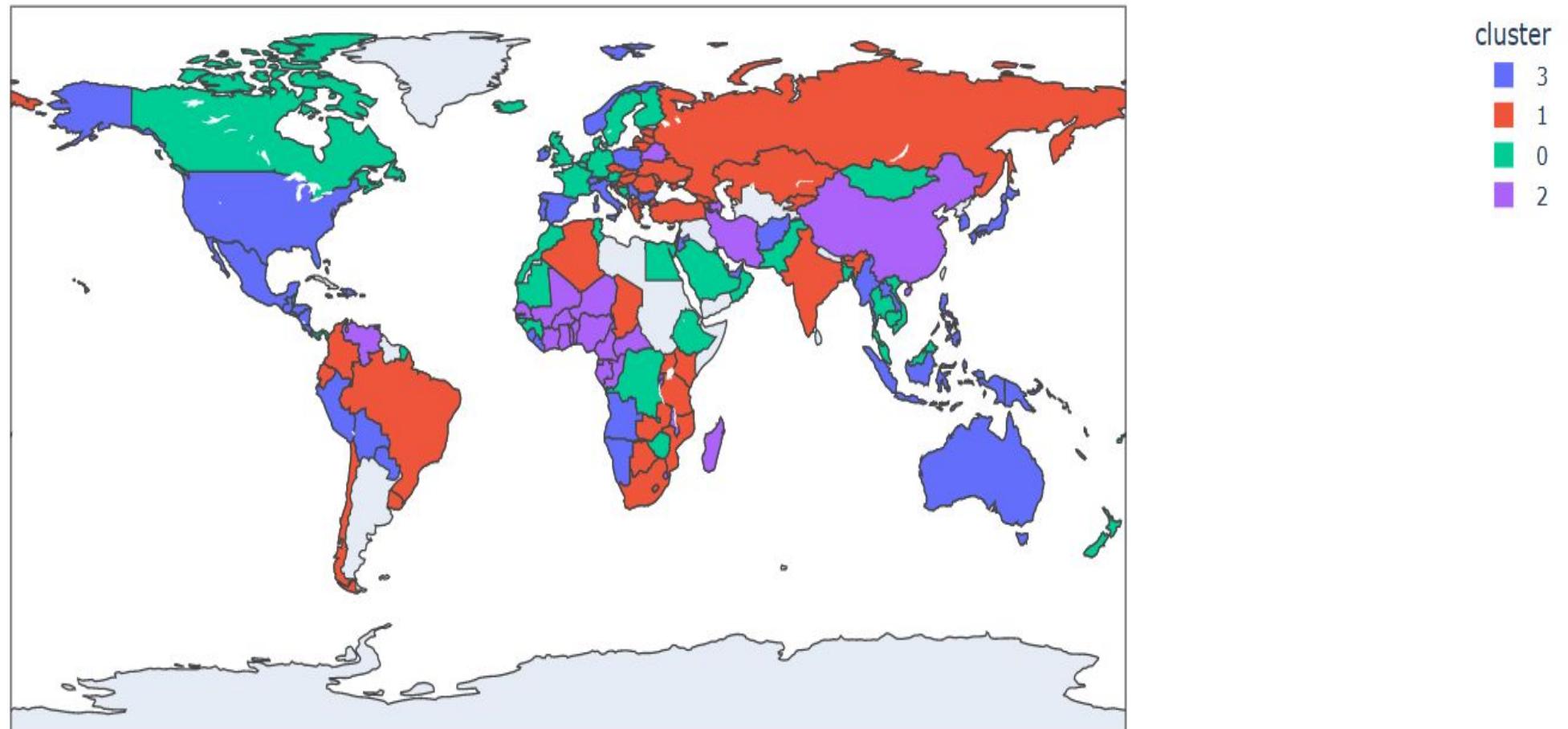


#Cluster 3, including 42 countries



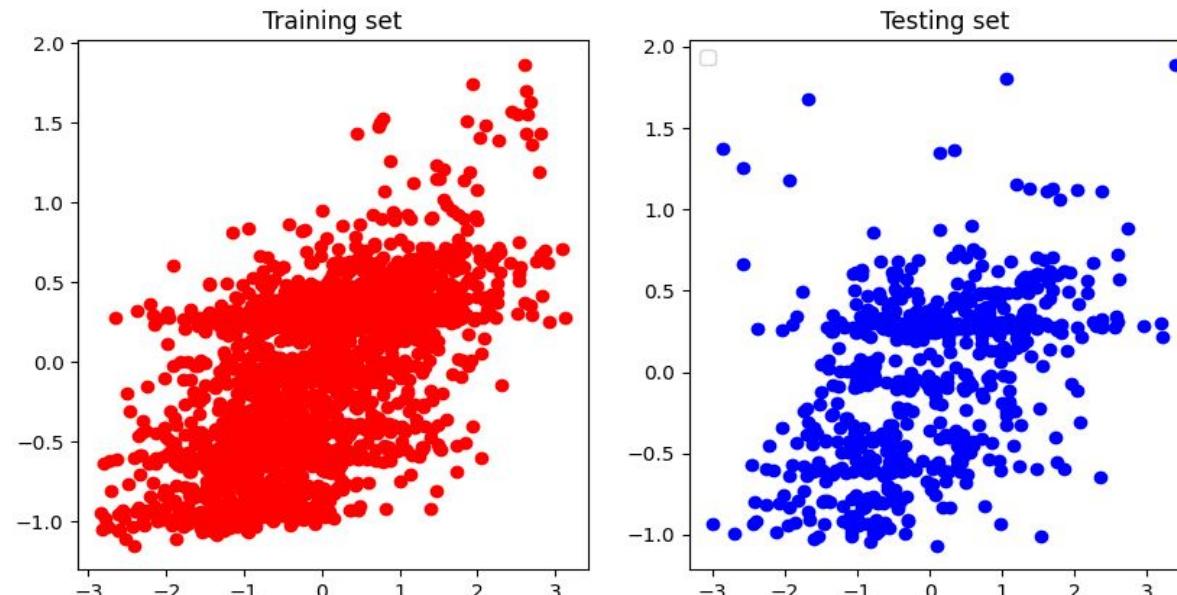
Clustering Food Price Inflation

Categorizing countries Based on Food Price inflation 1990-2013



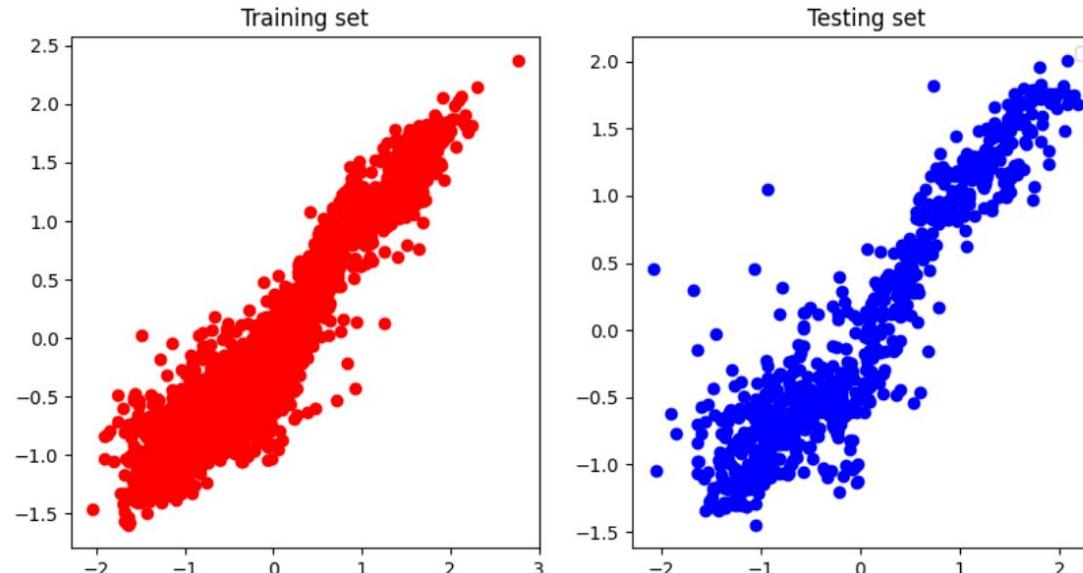
Decision Tree and Random Forest (Temperature as target)

Models	Training set (RSqr)	Testing set (RSqr)	MSE	RMSE
Decision Tree Regressor	29.6%	13.3%	0.95	0.97
Random Forest Regressor	32.94%	18.9%	0.89	0.94



Decision Tree and Random Forest (Greenhouse Gas Emission as target)

Models	Training set (RSqr)	Testing set (RSqr)	MSE	RMSE
Decision Tree Regressor	90.8%	81.4%	1.19	1.09
Random Forest Regressor	91.8%	85.06%	0.14	0.38



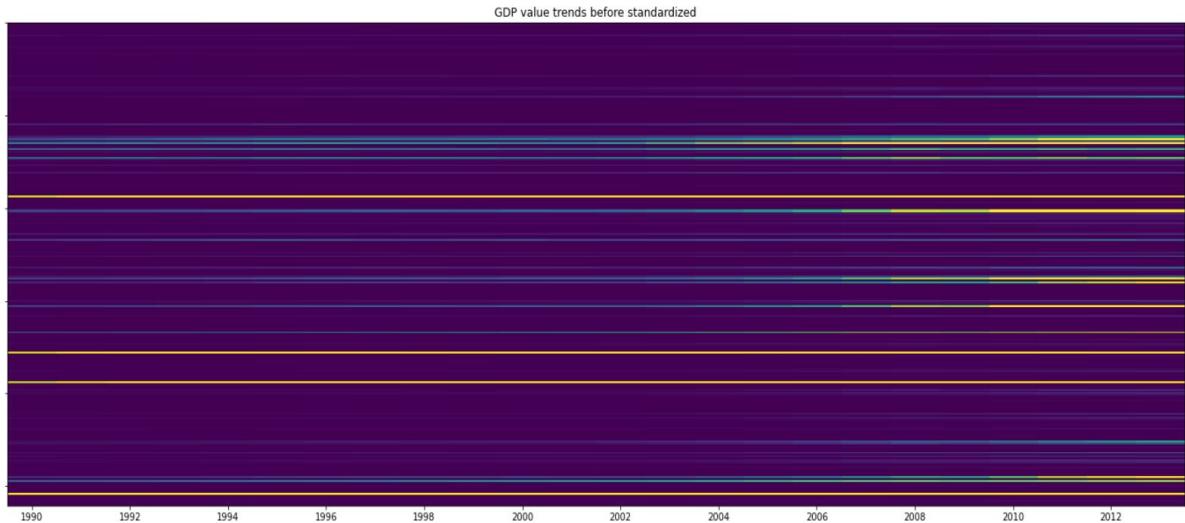
Decision Tree and Random Forest (Cross validation)

Ten-fold cross validation	Decision tree (Temperature)	Random forest (Temperature)	Decision tree (GHG)	Random forest (GHG)
Fold 1	23.51%	30.01%	87.48%	88.80%
Fold 2	18.26%	20.32%	83.70%	85.40%
Fold 3	16.17%	22.57%	83.77%	86.63%
Fold 4	15.89%	23.46%	85.81%	87.32%
Fold 5	23.91%	26.62%	87.98%	90.59%
Fold 6	17.09%	20.85%	87.83%	89.32%
Fold 7	24.84%	27.54%	85.78%	87.07%
Fold 8	20.07%	27.56%	86.33%	89.09%
Fold 9	18.93%	28.55%	86.06%	88.24%
Fold 10	29.46%	27.13%	85.73%	87.56%

Machine learning Models on GDP dataset

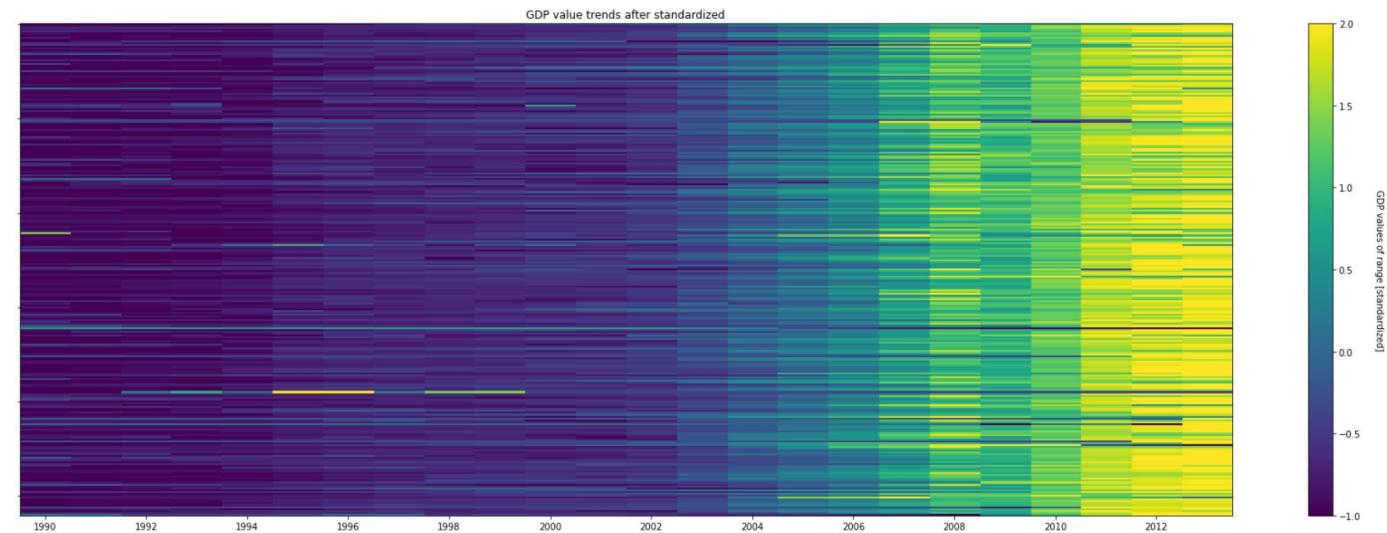
- The GDP data was Standardized and we will use this standardize data for cluster analysis to observe the similar GDP patterns in different countries
- We used k means algorithm to find the clusters.
- The number of Clusters can be chosen using “elbow method” and in this case we choose three clusters.
- We used regression models to fit and predict the data
- MSE and R² values are calculated to evaluate the performance of models

non- Standardized vs Standardized GDP data

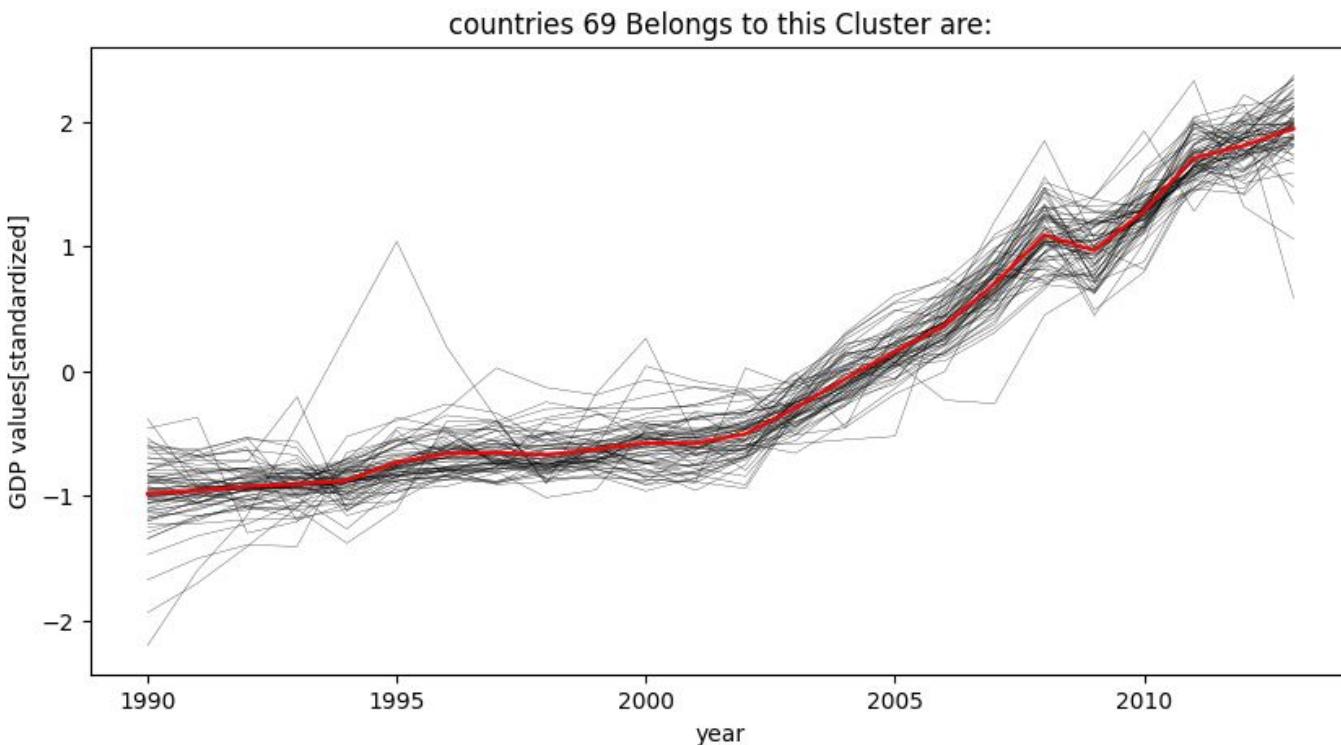


- Heat map of GDP values before standardizing the data

- We can clearly see a trend as all countries' GDP values have been increasing rapidly after 2004, it may be due to advancements in technology, population growth, and an increase in productivity due to demand and It can also be due to changes in government policies.

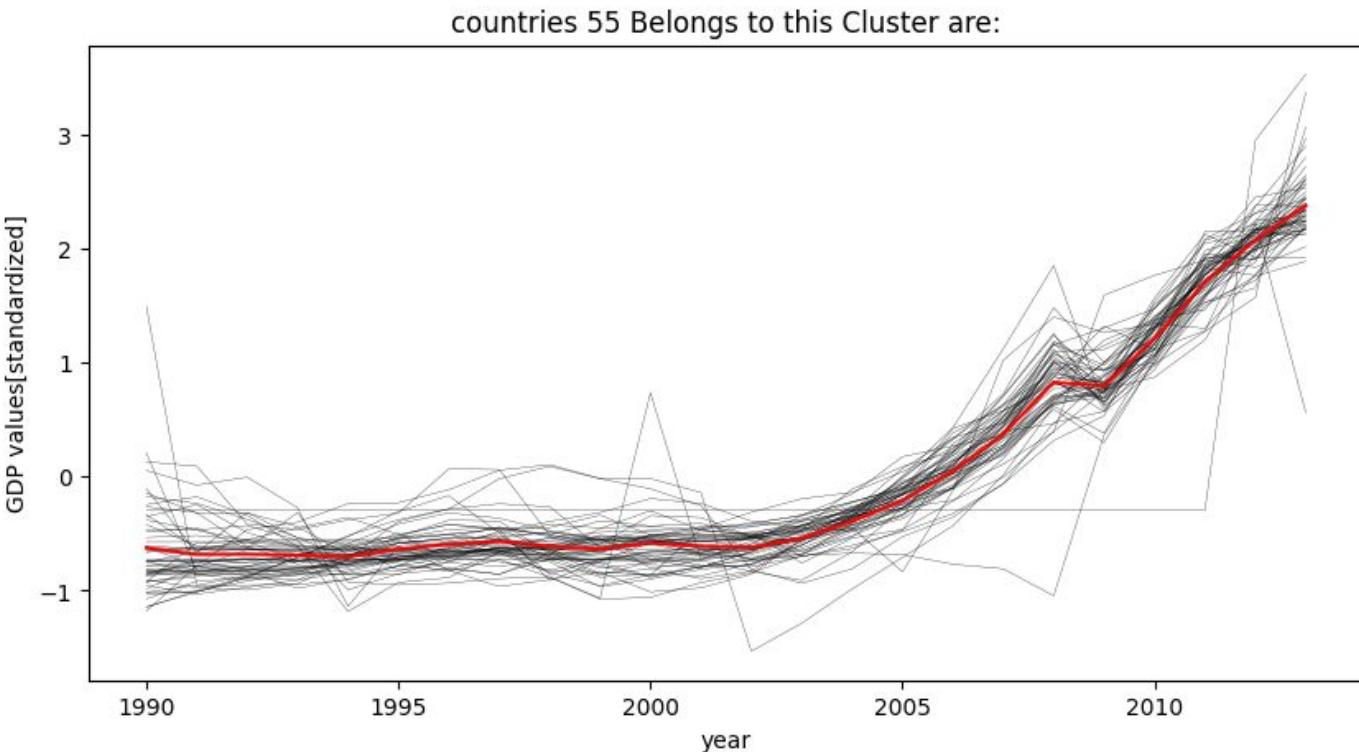


GDP Clustering



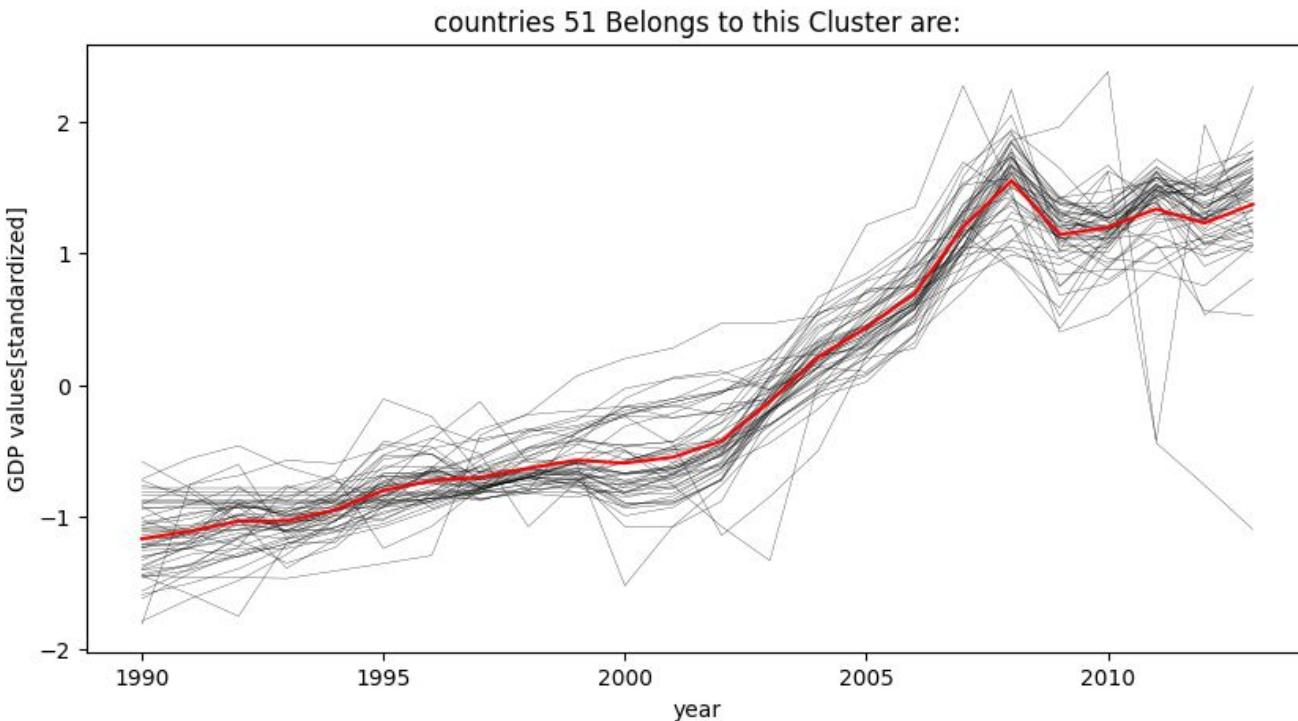
- There are 69 countries out of 175 countries belong to this cluster 0.
- Some countries in this cluster such as bahrain,kuwait,saudi arabia and the united arab emirates(UAE) are oil producing countries with high dependence on oil for their economics.
- Some countries like bangladesh ,cambodia, Benin,mall.. etc have similar levels of economic development and also which are among poorest countries in the world belong to this cluster.
- some countries like India, canada, japan, norway, switzerland and united arab emirates are among world richest countries belong to this cluster.

GDP Clustering



- There are 55 countries out of 175 countries belong to this cluster I.
- Some countries like brazil, columbia and peru..etc are known for it natural resources and have significant exports of commodities such as gas and minerals
- Some countries like afghanistan, Burundi, liberia, Niger.. etc which are among poorest countries in the world belong to this cluster.
- Some countries like china, australia, qatar and israel..etc are among richest countries in the world belong to this cluster.

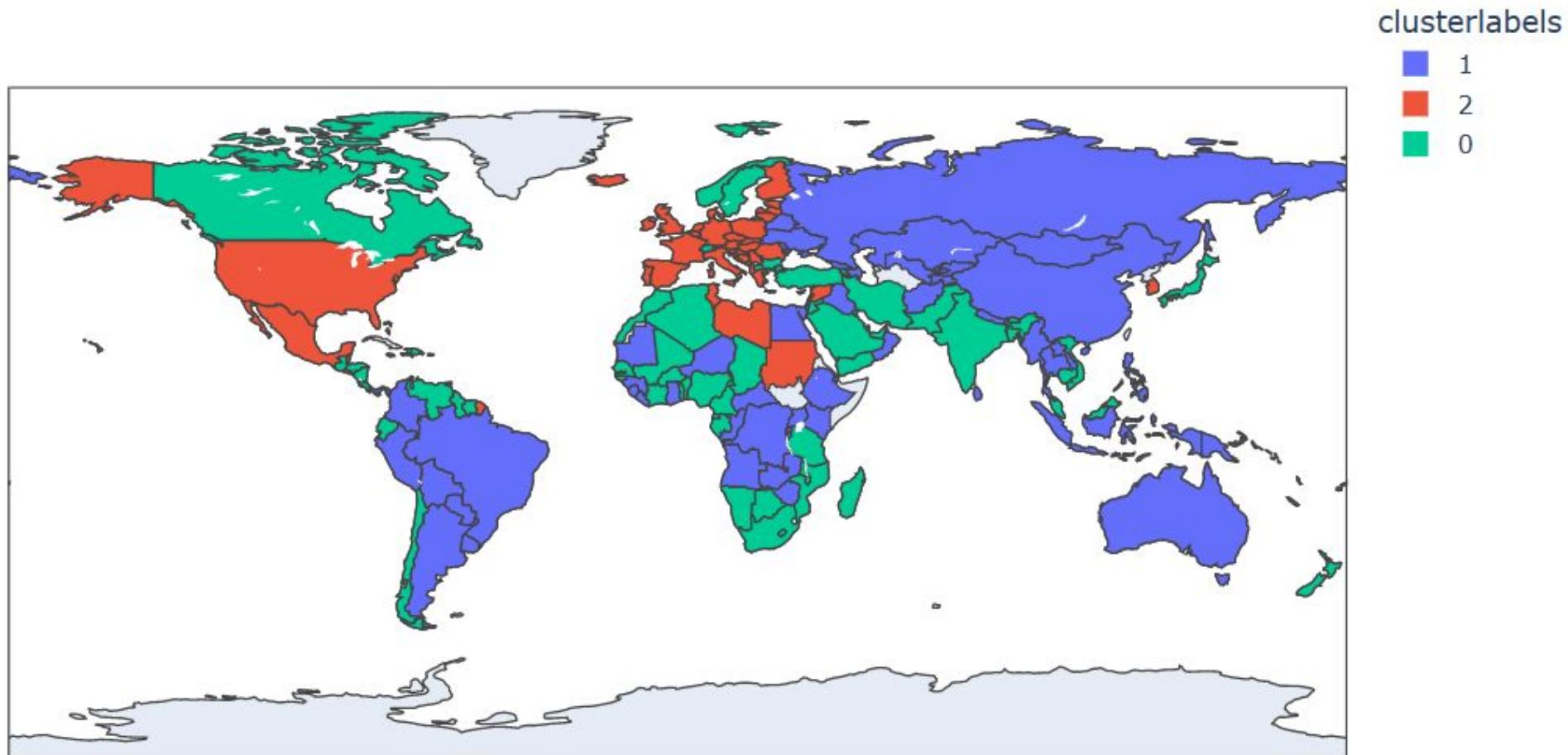
GDP Clustering



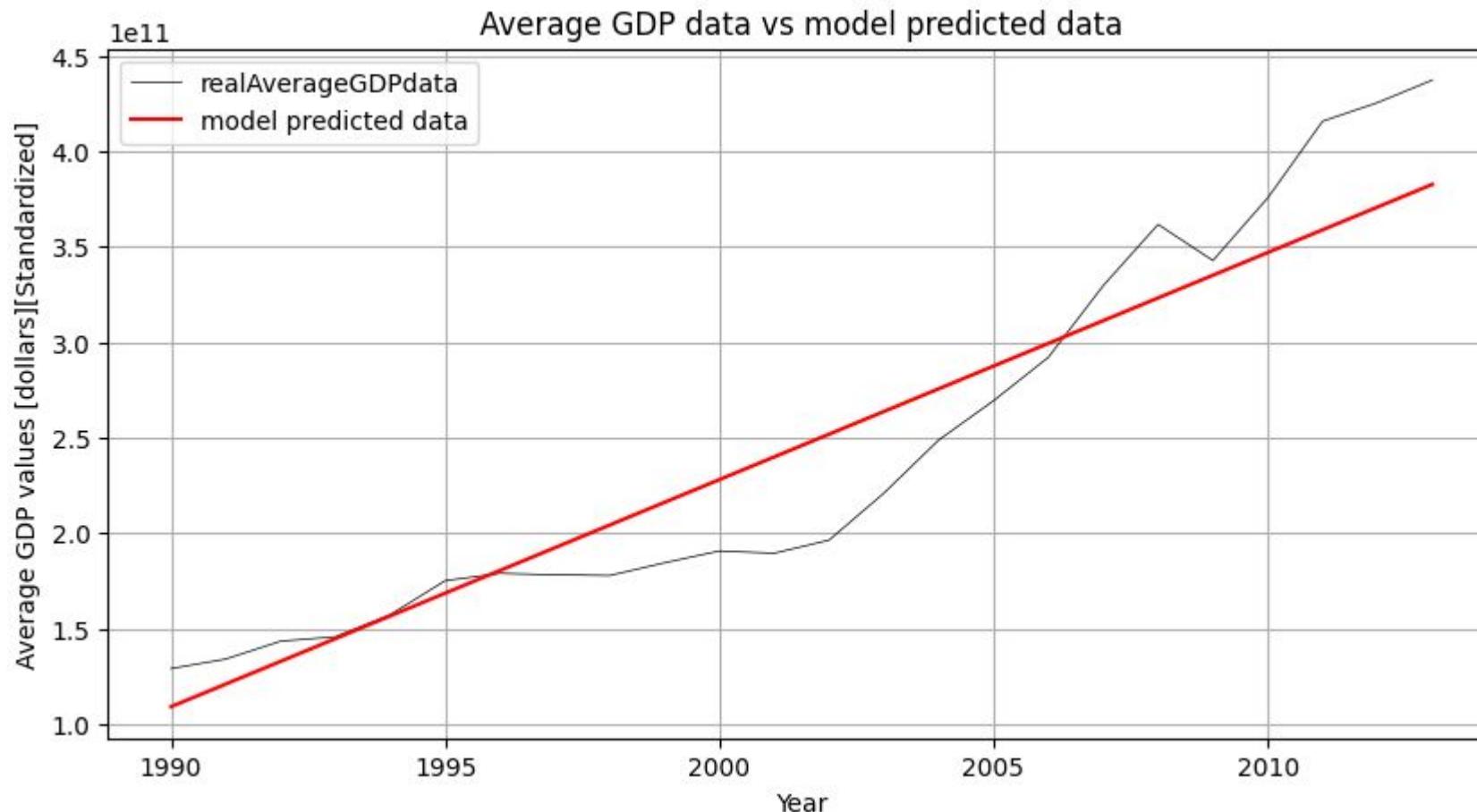
- There are 51 countries out of 175 countries belong to this cluster 2.
- The majority of countries belong to this cluster 2 are located in european region.
- Some countries like Austria, Belgium, Denmark, estonia, Finland, ireland, iceland, italy, netherlands and united kingdom..etc are belong to the same cluster
- “united states” which was highest in GDP belongs to this cluster.

GDP Clustering

GDP with cluster labels

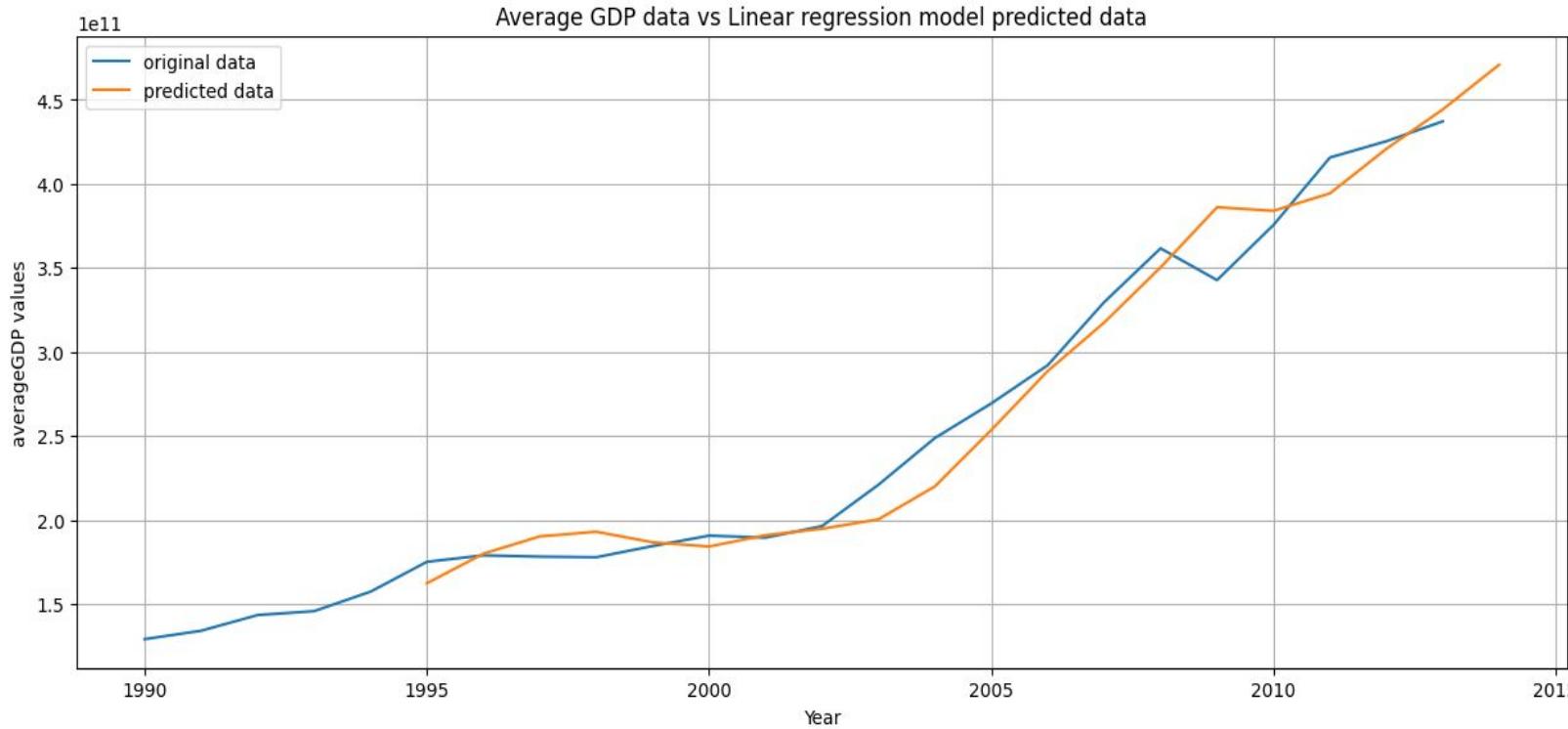


LINEAR REGRESSION MODEL



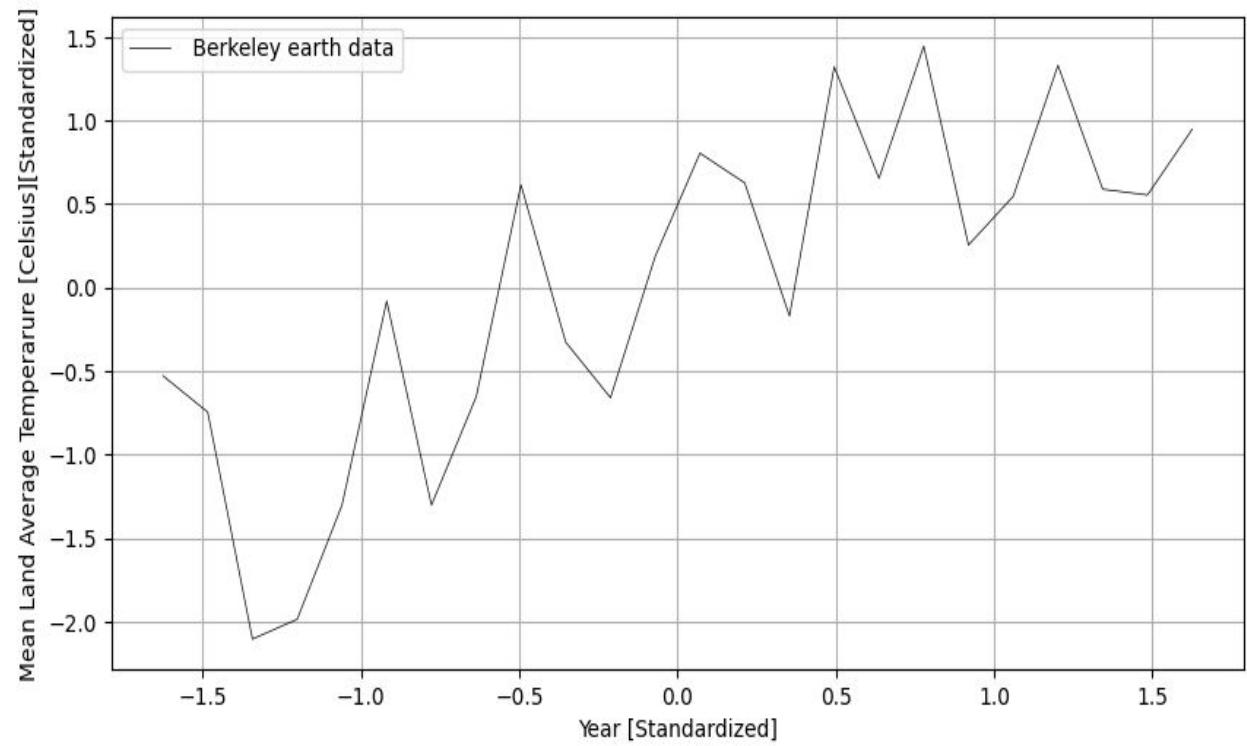
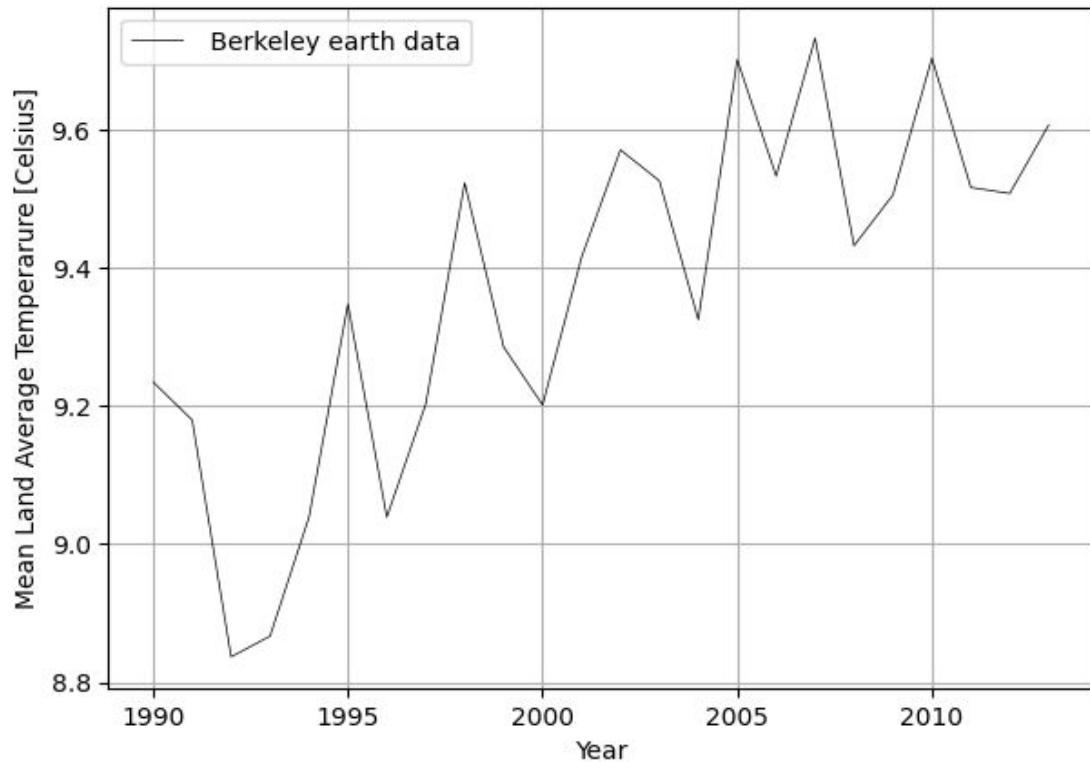
- We fit the model with total Years as features and total GDP values as target values and we predict the GDP values for all the years.
- By Using this model we got R Square value of 0.9

LINEAR REGRESSION MODEL



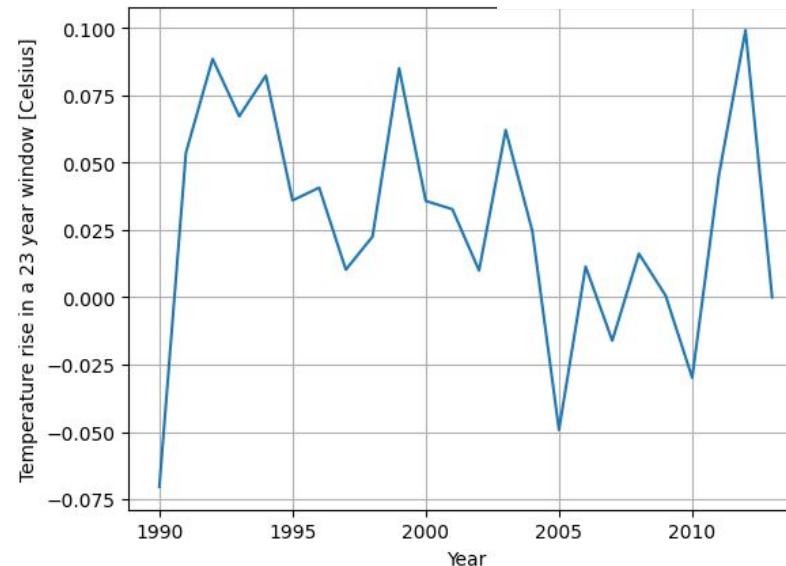
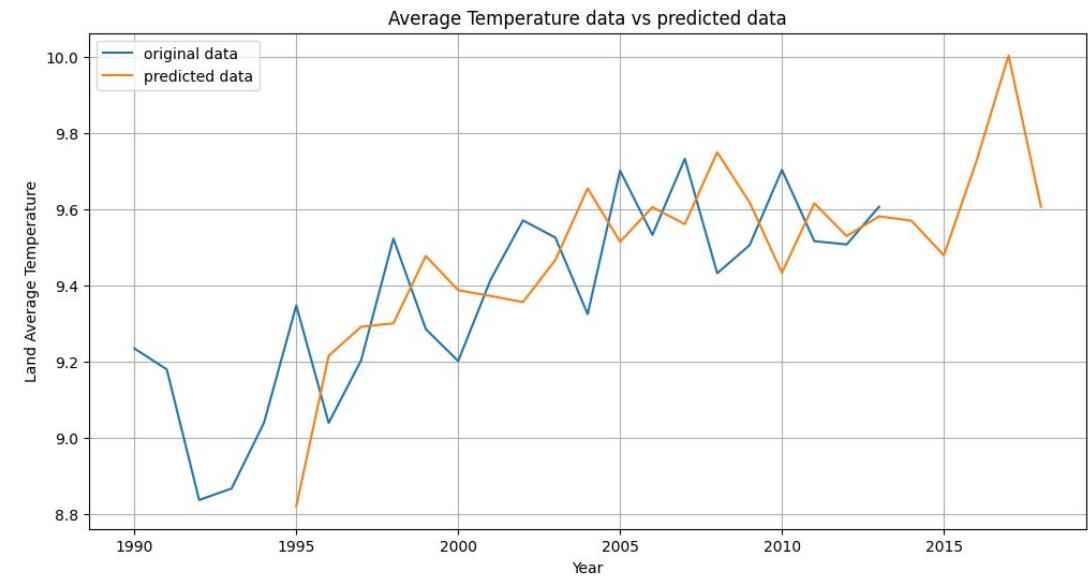
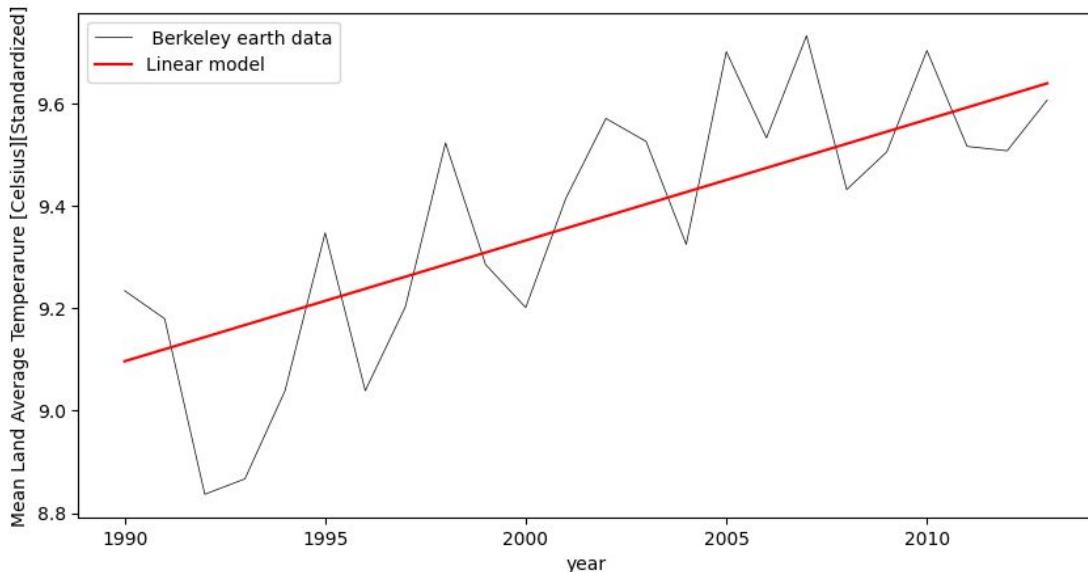
- We Fit the linear regression model with five years GDP data and predict the next year GDP data.
- Features are five years and targets are five years GDP data and we train the machine learning model with this data to predict next year GDP value.(ex :Train 1991 to 1995 years average GDP data and predict 1996 GDP value)
- By Using the Linear Regression model we got R Square value of 0.97.

Analysis- Global Average Temperature

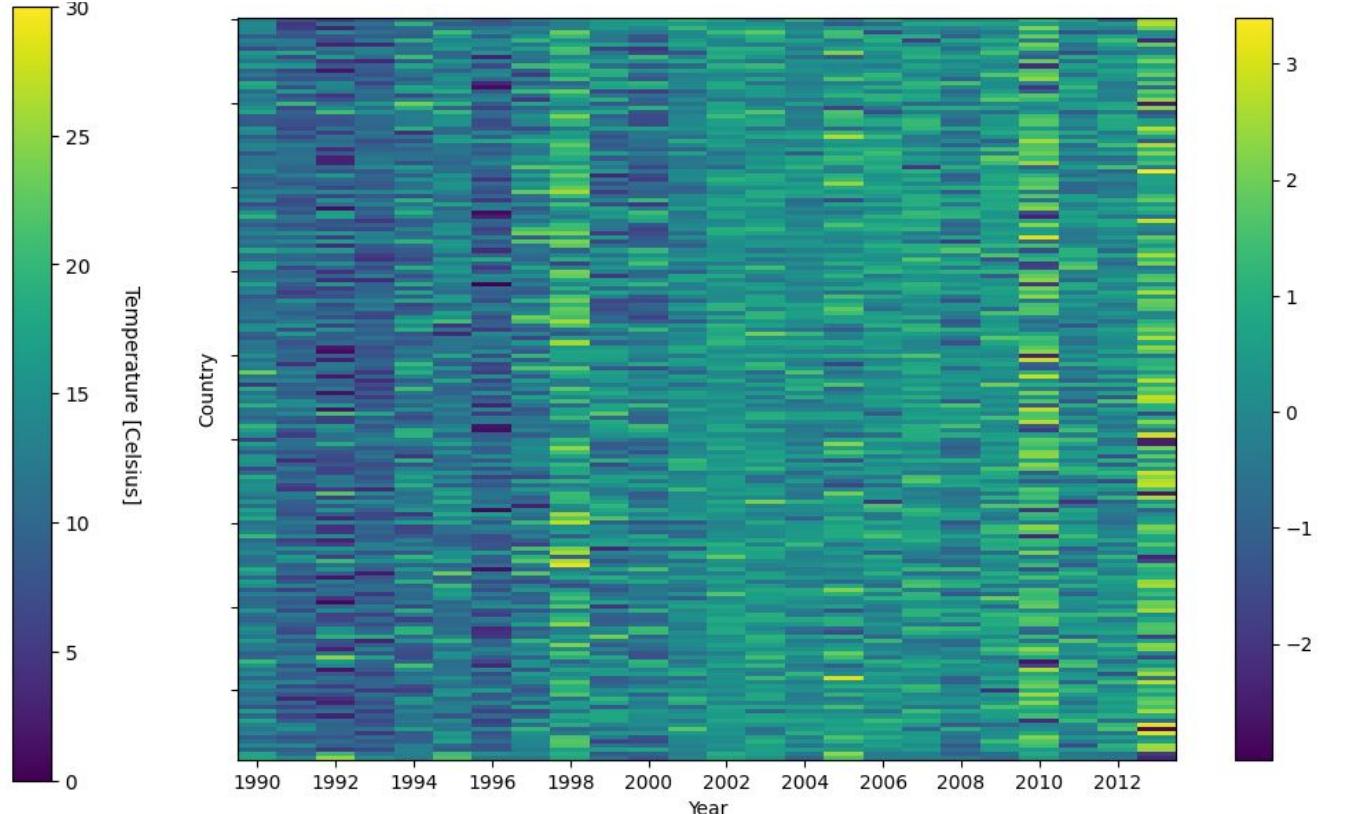
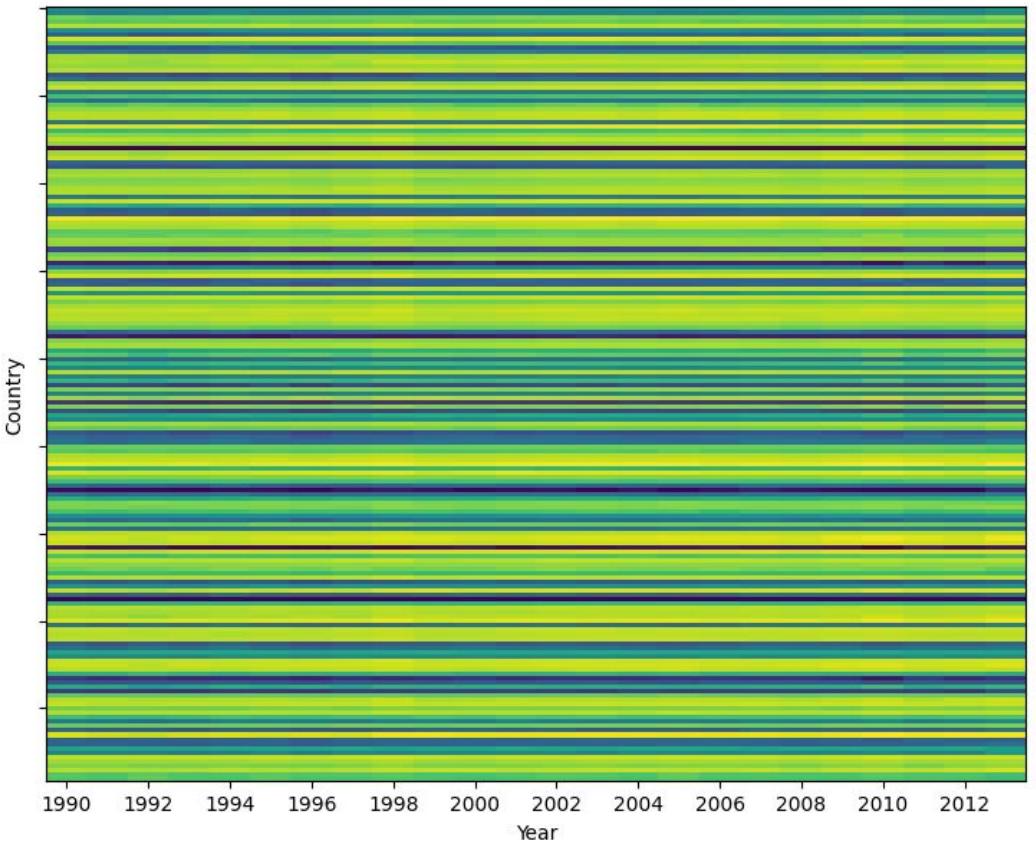


The rise in average world land temperature is approximately 1.5 degrees C in the past 250 years, and about 0.9 degrees in the past 50 years. (Berkeley Earth , 2019)

Analysis- Global Average Temperature



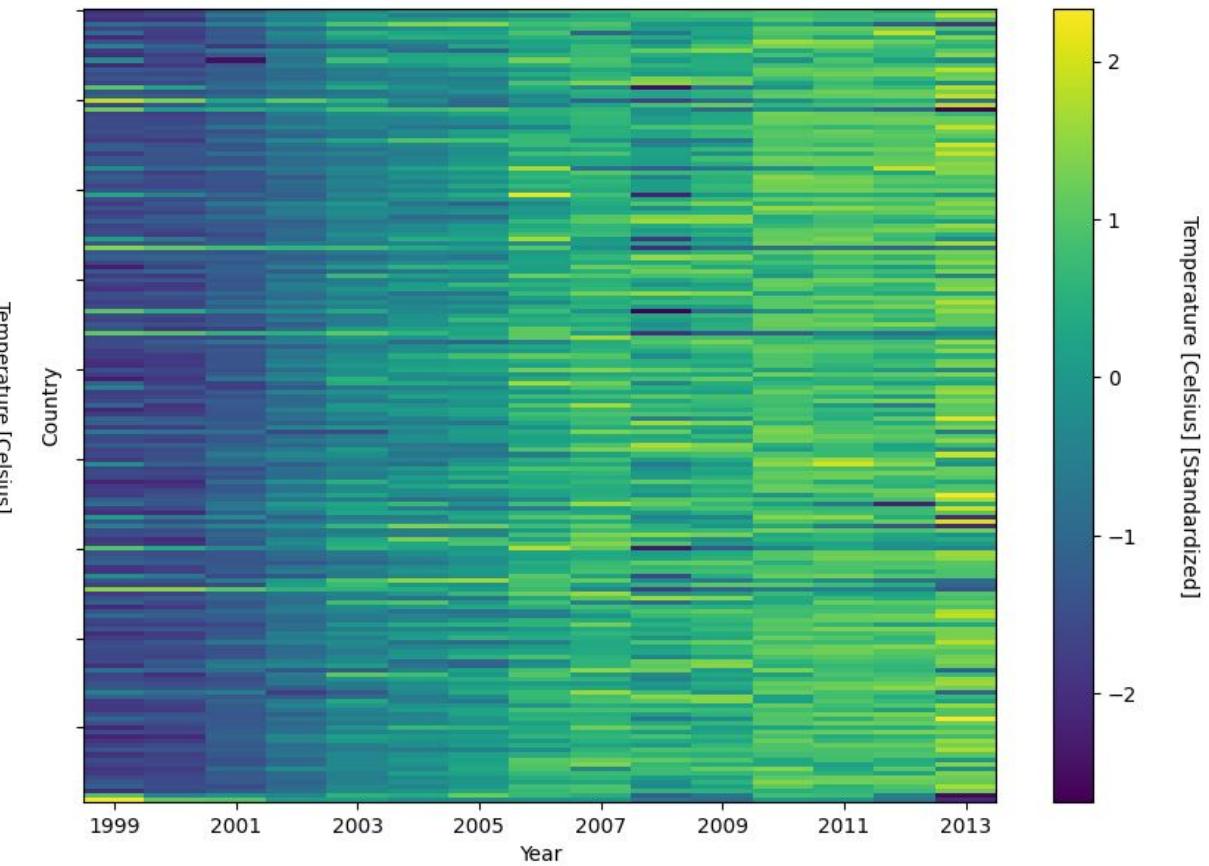
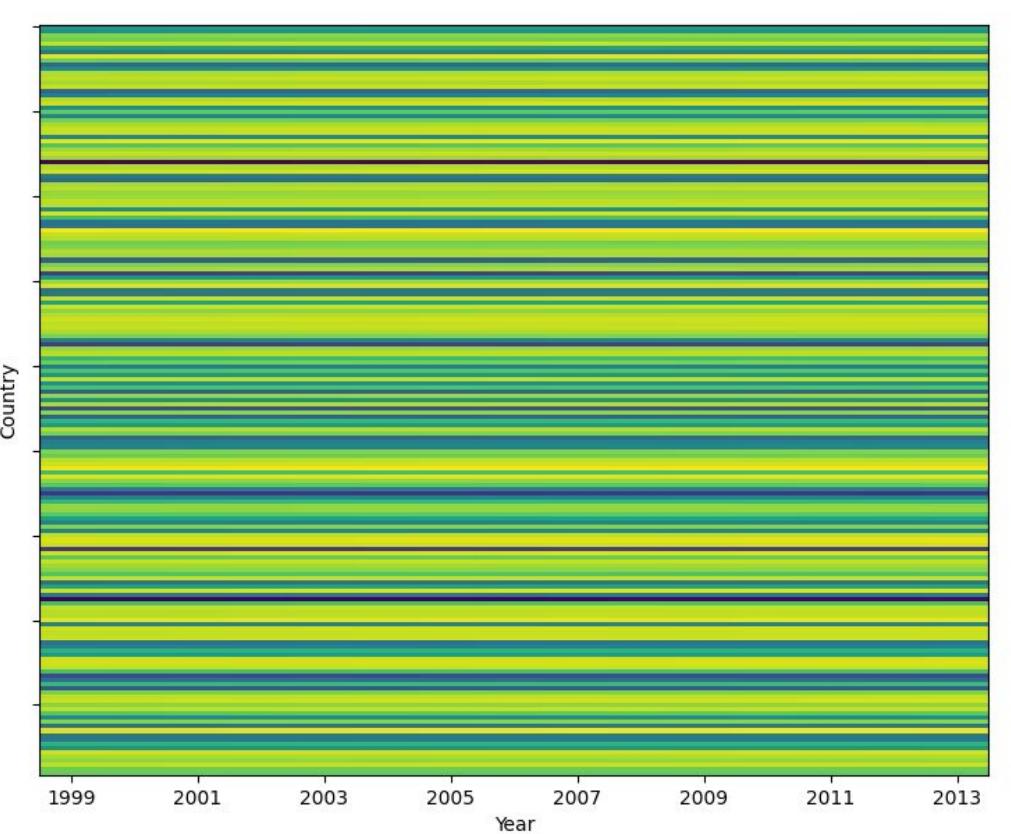
Heatmap- Global Temperature



Temperature [Celsius] [Standardized]

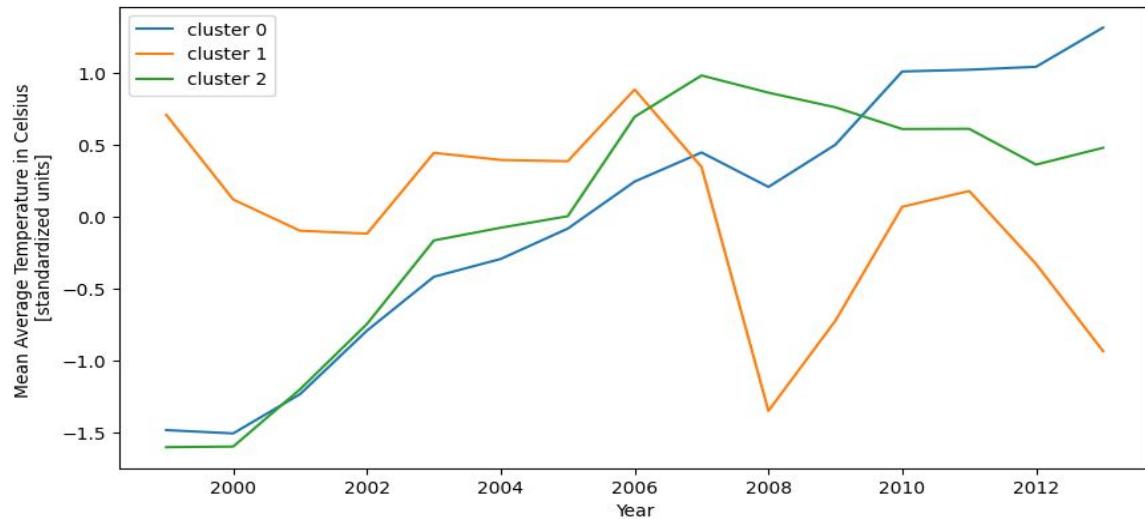
Heatmap- Global Temperature

A moving average with a window of 10 years was applied to the temperature dataset. Moving averages help to smooth out the noise and random fluctuations in a time series, revealing underlying trends and patterns.

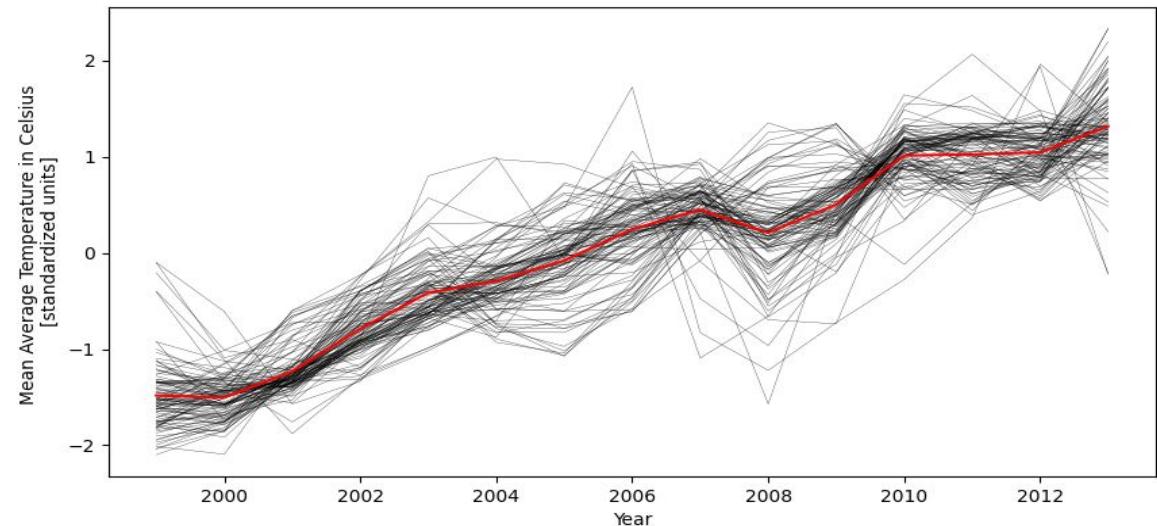


Cluster analysis Global Temperature

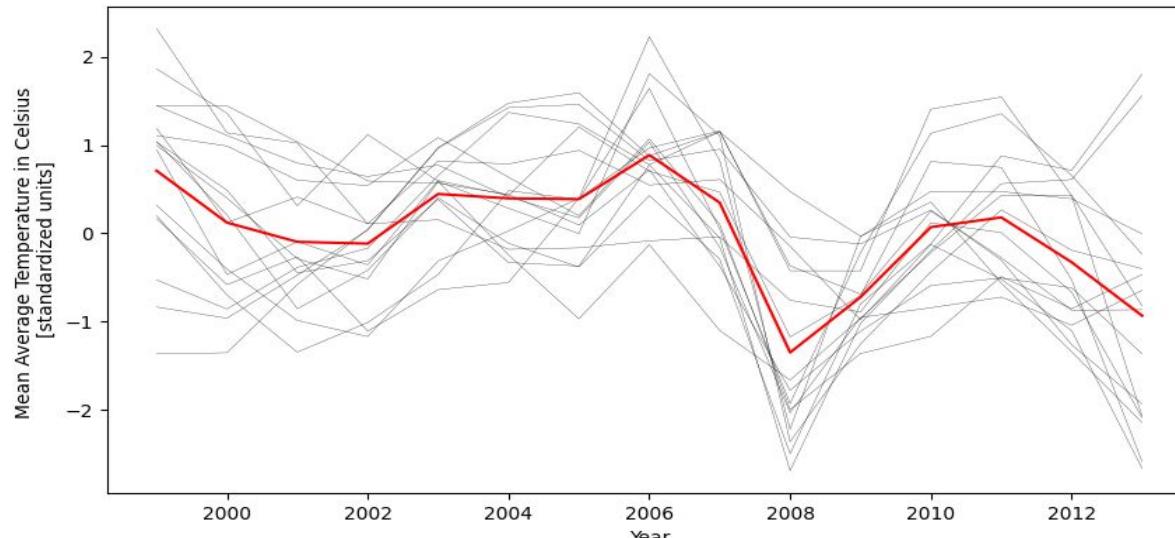
Cluster centers



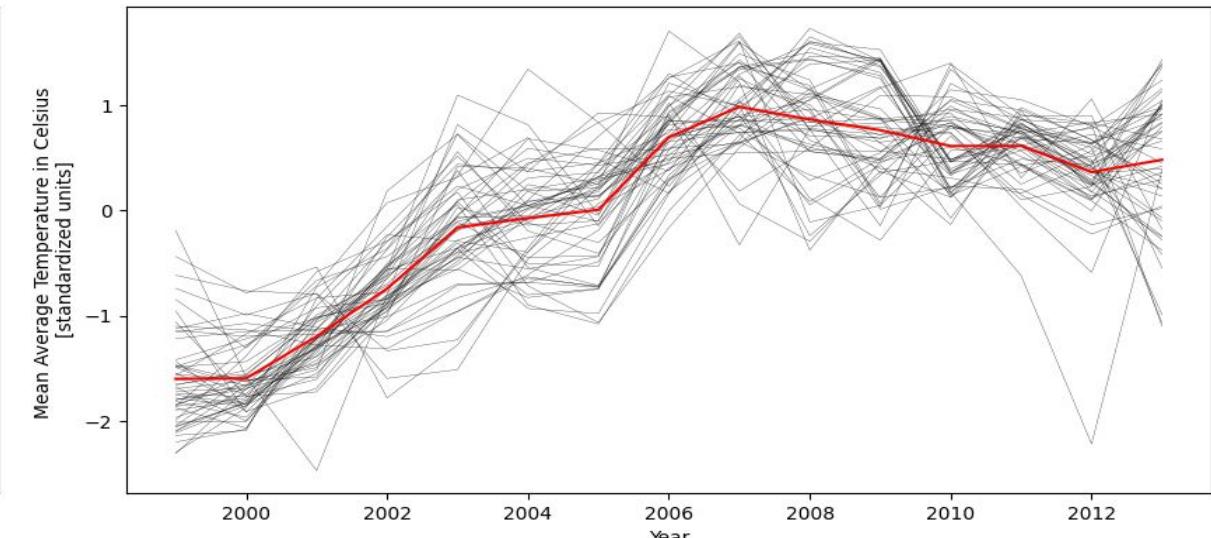
Number of countries in Cluster 0 is 108



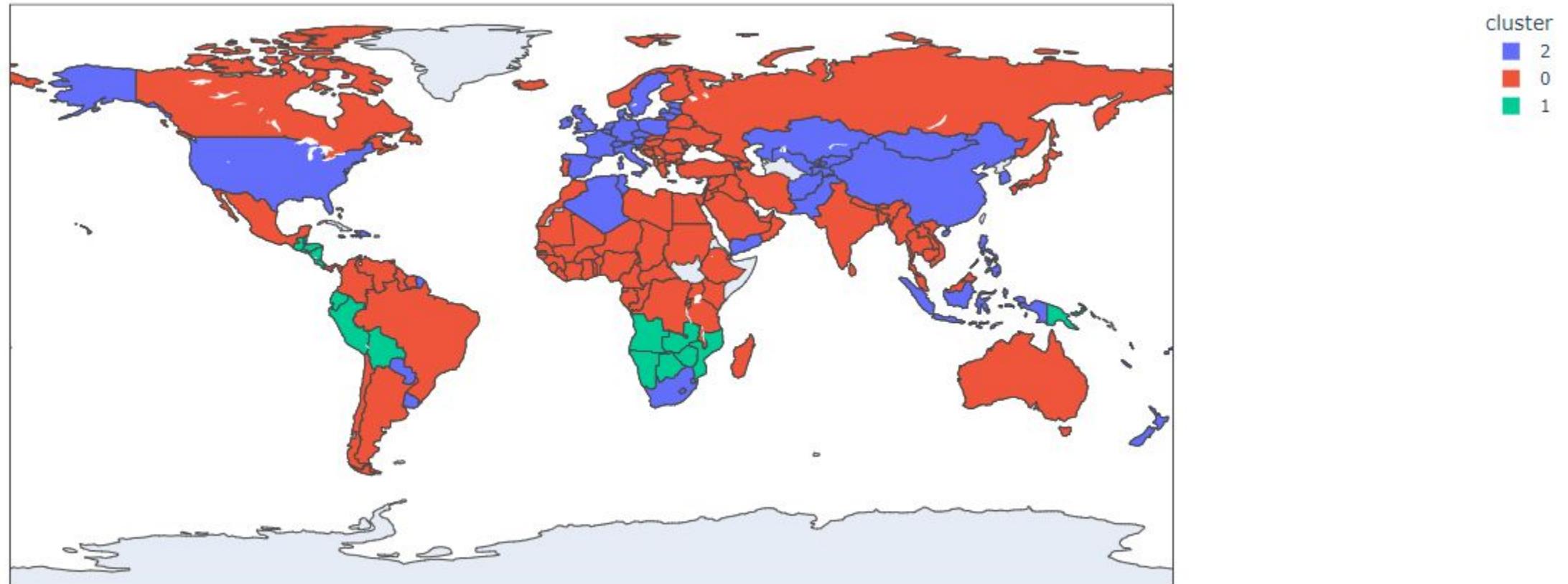
Number of countries in Cluster 1 is 16



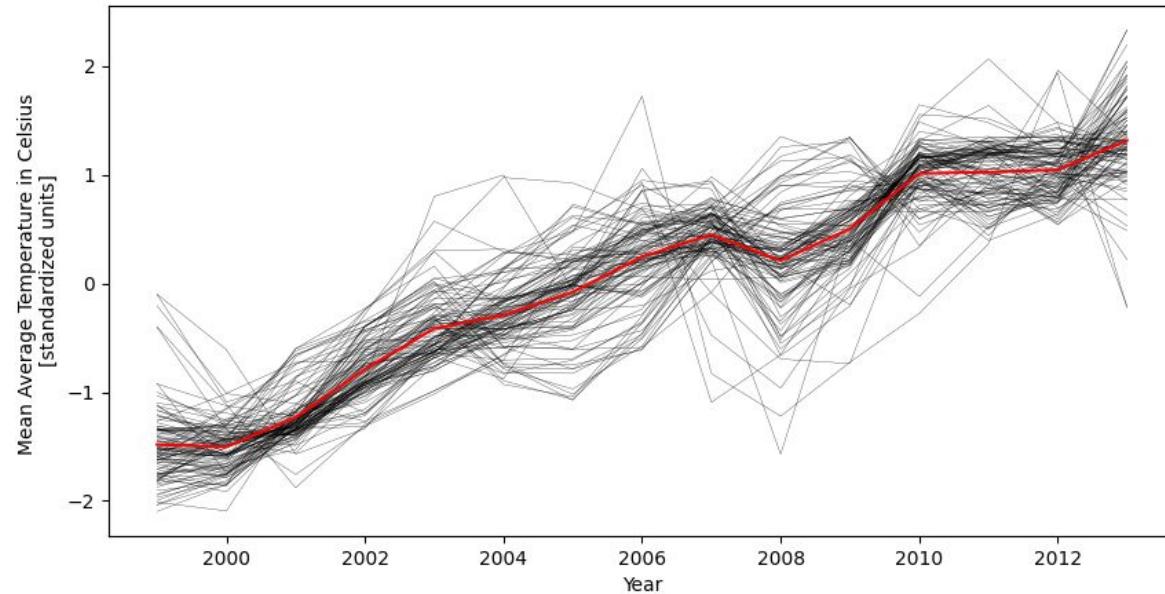
Number of countries in Cluster 2 is 53



Cluster analysis Global Temperature



Number of countries in Cluster 0 is 108



Countries :

- Brazil, Canada, India, Russian Federation
- Comoros, Dominica, Grenada, Guinea-Bissau, São Tomé and Príncipe, Vanuatu, Cabo Verde, Bhutan

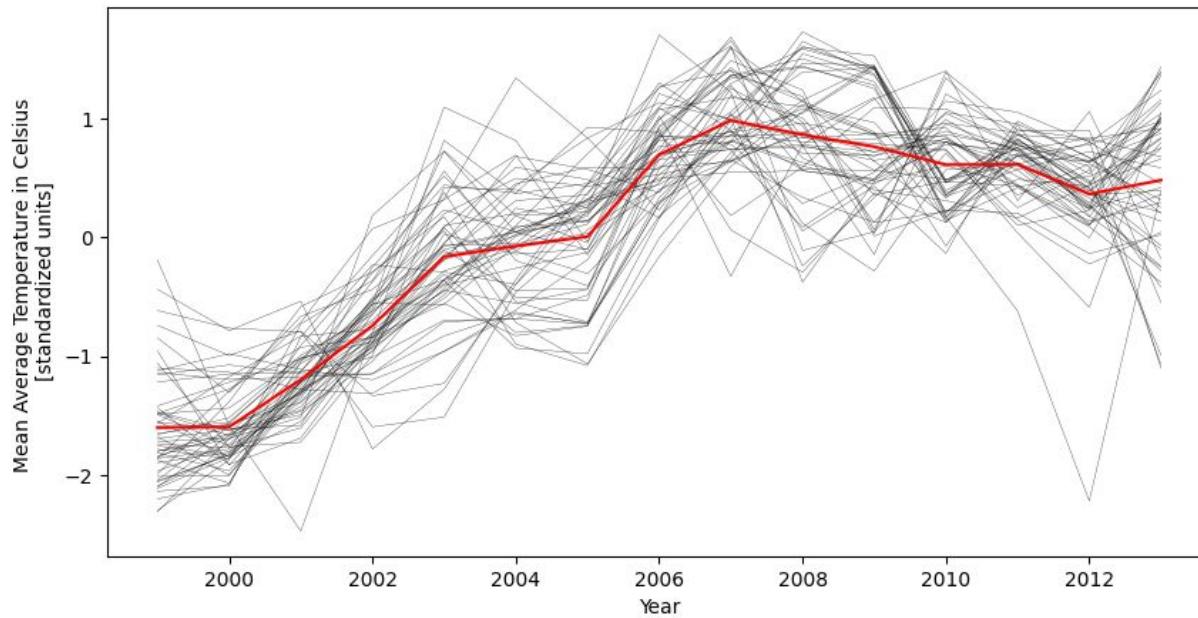
■ : Top 10 GDP + GHG

■ : Top 10 GHG

■ : Bottom 10 GDP + GHG

■ : Bottom 10 GHG

Number of countries in Cluster 2 is 53



■ : Top 10 GDP + GHG

■ : Top 10 GHG

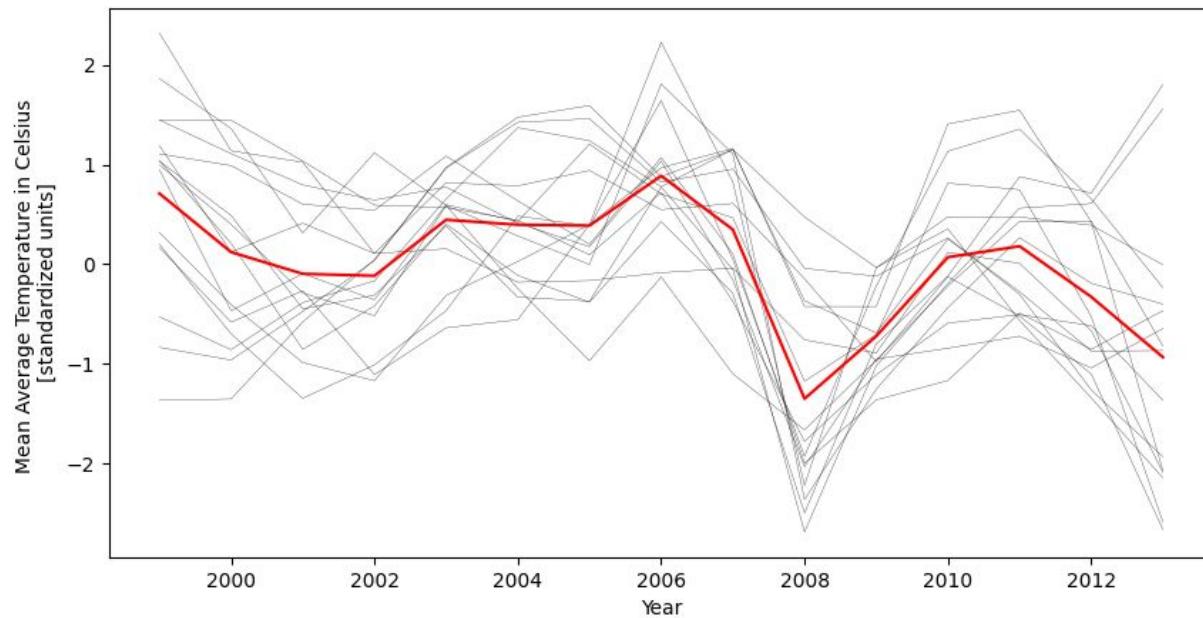
■ : Bottom 10 GDP + GHG

■ : Bottom 10 GHG

Countries :

- China, France, Germany, Italy, United Kingdom, United States, Spain, Poland
- Samoa, Swaziland, Tonga

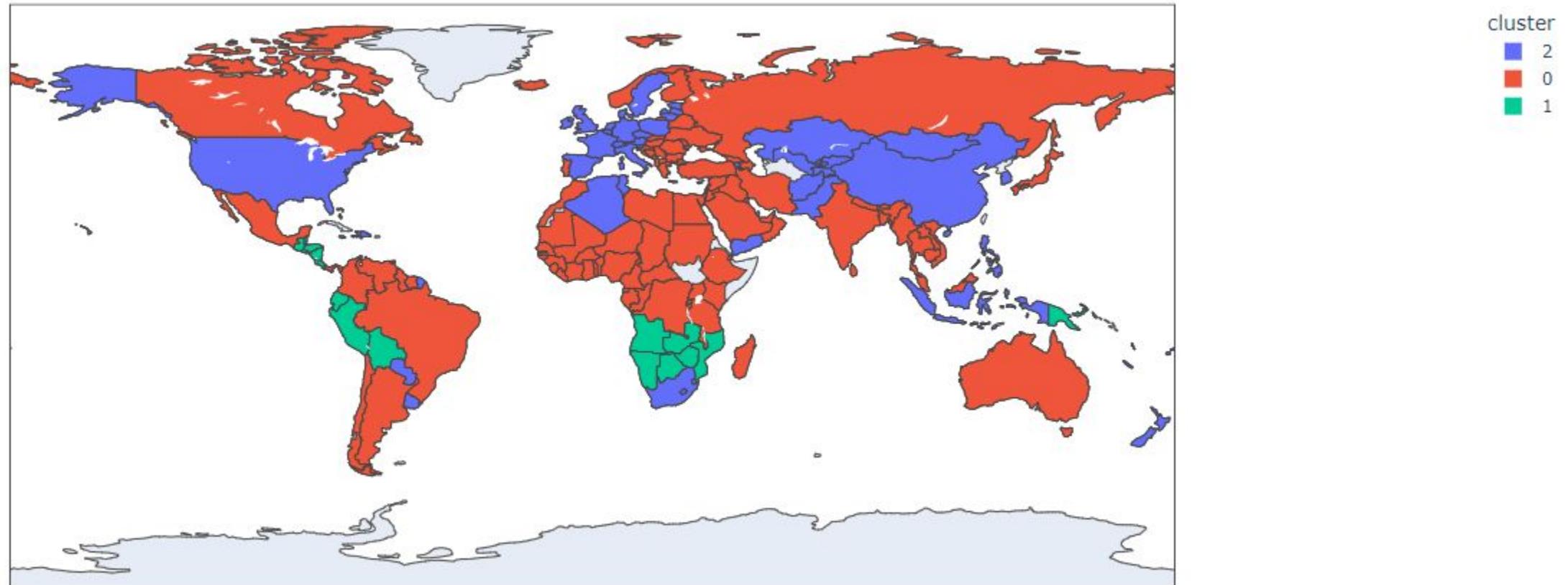
Number of countries in Cluster 1 is 16



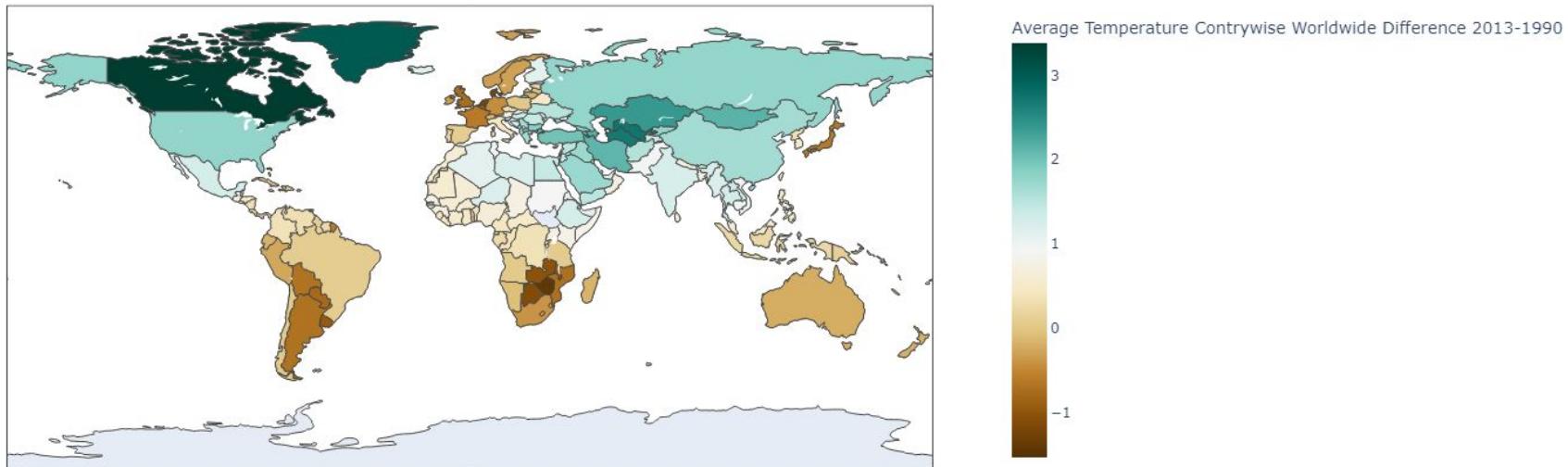
Countries :

Angola,Belize,Bolivia,Botswana,Costa Rica,Ecuador,El
Salvador,Guatemala,Honduras,Mozambique,Namibia,
Nicaragua,Papua New Guinea,Peru,Zambia,Zimbabwe

Cluster analysis Global Temperature



Difference in Mean Average Temperature (2013-1990)



- The Arctic region, which includes the North Pole and surrounding areas, is experiencing more rapid warming than other parts of the world. This phenomenon is known as Arctic amplification.
- According to data from the National Oceanic and Atmospheric Administration (NOAA), the Arctic region has been warming at a rate of about twice the global average over the past few decades.
- The consequences of this rapid warming in the Arctic are significant, including melting sea ice, rising sea levels, and changes in weather patterns around the globe.

Clustering global temperature dataset

- The clustering analysis of the temperature dataset reveals a discernible pattern where certain countries experience a consistent temperature increase, while only a few observe a temperature decrease.
- The detailed analysis of each cluster highlights that climate change affects countries unequally. Specifically, some countries with low greenhouse gas emissions and GDP experience a substantial temperature rise. Conversely, some countries with high greenhouse gas emissions and GDP observe a temperature increase but not to the same degree.

Discussion and conclusion

- **While all countries are affected by climate change to some extent, the impacts are not equally distributed**, and some countries are more vulnerable than others. Additionally, responsibility for causing climate change is not equally distributed, with developed countries historically contributing more than developing countries, although this is changing as developing countries increase their emissions.
- The **Paris Agreement**, adopted at the 21st Conference of the Parties (COP21) in 2015, is a landmark international agreement on climate change. It aims to strengthen the global response to climate change.
- It sets a framework for countries to **submit national climate pledges**, and to regularly report on their progress towards meeting those pledges. The agreement also includes provisions for **financial and technological support to developing countries**, and for countries to work together to address the impacts of climate change.
- The Paris Agreement has been ratified by 191 countries, and is widely regarded as a major step forward in global efforts to combat climate change.
-

THANK YOU