Analysis regarding CO2, precipitation and temperature affection on soil conditions

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1. Introduction

Soil is a crucial component of the environment. As climate change garners increasing attention, it is essential to investigate how soil conditions are affected by these changes. In this report, we conducted a data science project to study soil conditions in relation to recent temperature trends, greenhouse gas emissions, and precipitation patterns.

In this report, we have raised five questions and answered them.

1. How has the global CO2 emission changed over the years?
2. How has the temperature changed in Germany over the years?
3. How has the precipitation changed in Germany over the years?
4. How has soil condition changed in Germany over the years?
5. How does the global CO2 emission, temperature change and precipitation affect the soil condition?

2. Used Data

We used seven open data sources in this project, including CO2 emission data, regional temperature data, regional precipitation data, soil condition data, soil station data, Germany geography data, and Germany postal data. All of these sources are free to use and redistribute. The first five sources are licensed under CC BY 4.0, and the sixth and seventh are under the Open Database License. An overview can be found in Table 2.1.

1. **CO2 Gas Emission** - Contains over 64 columns, recording global CO2 emissions from 1850 to 2022. The relevant columns for this project are CO2 emission, year, and CO2 emission growth rate.

Datasource	License	File type
CO2 Gas Emission	CC BY 4.0	CSV
Regional temperature	CC BY 4.0	CSV Directory
Regional precipitation	CC BY 4.0	CSV Directory
Soil condition	CC BY 4.0	CSV Directory
Soil Station	CC BY 4.0	CSV
Germany Geography	ODbL	SHP
Germany postcode	ODbL	CSV

Table 2.1: Data source Overview

2. **Regional Temperature** - Consists of monthly mean temperatures (in Celsius) across different federal states from January 1881 to January 2024.

3. **Regional Precipitation** - Includes monthly mean precipitation records in federal states from January 1881 to January 2024.

4. **Soil Condition Data** - Contains data from January 1991 to December 2023 from over 400 soil stations. This dataset includes more than 40 columns, covering soil moisture, soil temperature, and more. The important columns needing are **Summe von VPGH** (potential evaporation over gras), **Mittel von TS05** (mean daily soil temperature in 5 cm depth) and **Mittel von BFGL02_AG** (soil moisture up at 11-19 cm depth).

5. **Soil Station Positions** - Provides the locations of soil stations in Datasource 4.

6. **Germany Geography Data** - Contains postcodes of various cities and counties, along with their geometric information (in WGS84 polygon format).

7. **Germany Postal Data** - Includes city names, city postcodes, and their corresponding federal states.

In the data pipeline, we identified common years and months among Datasources 2, 3, and 4, and selected only the relevant rows. Additionally, we merged soil condition data with station data to consolidate all necessary columns into a single compact dataframe. Similarly, Datasources 6 and 7 were joined based on postal codes to integrate their respective information.

Further, all German umlaut letters in cells and headers were replaced with their English counterparts for convenience. Before loading, all datasets underwent cleaning by removing empty rows. Datasources 1, 2, 3, 4, and the combined 4 and 5 were loaded into an SQLite file and saved as CO2, temperature, precipitation, and soil datasets, respectively. Datasources 6 and 7 were saved as a GeoJSON file to ensure compatibility with geometric data.

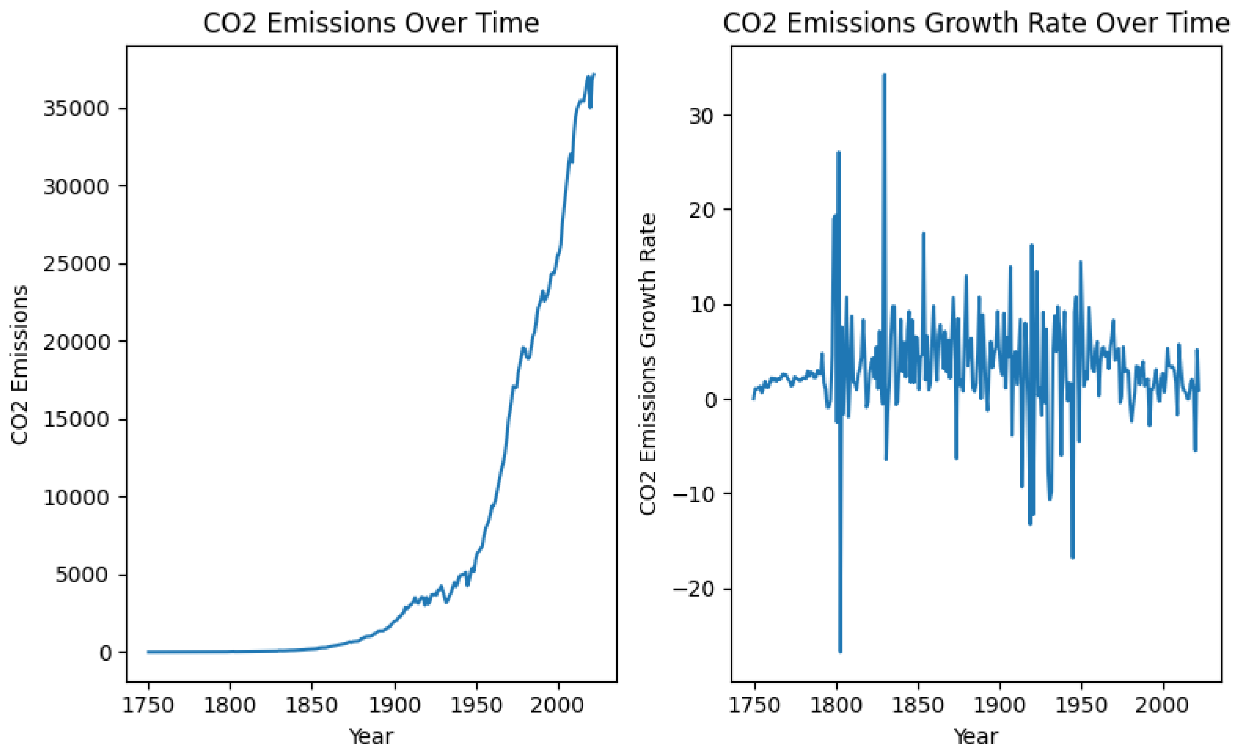

Figure 3.1: CO2 emission over time

3. Analysis

In this section, we analyse the processed data and give exact answers to questions raised.

1. How has the global CO2 emission changed over the years?

The global CO2 emission increase drastically since recorded. It has increased up to 3900 times, from 9.3 million tonnes to 37149.7 million tonnes, with an average annual increase of 14.6 times. Figure 3.1 shows the Emission curve.

2. How has the temperature changed in Germany over the years?

We joined the temperature data with Germany's geographic data via the Bundesland column. Our analysis revealed a significant increase in temperatures across Germany. The largest national temperature difference observed was approximately 2.4 degrees Celsius, with temperatures rising from 7.2°C in 1996 to 10.6°C in 2023. Figure 3.2 illustrates the temperature changes in geographical form at four-year intervals. From Figure 3.2, it is evident that there has been a substantial temperature increase, as there are no longer any blue regions in recent years.

3. How has the precipitation changed in Germany over the years?

We joined the precipitation data with Germany's geographic data via the Bundesland column. Our analysis did not yield a clear conclusion about whether precipitation levels are increasing or decreasing. However, from a national average perspective, the most significant

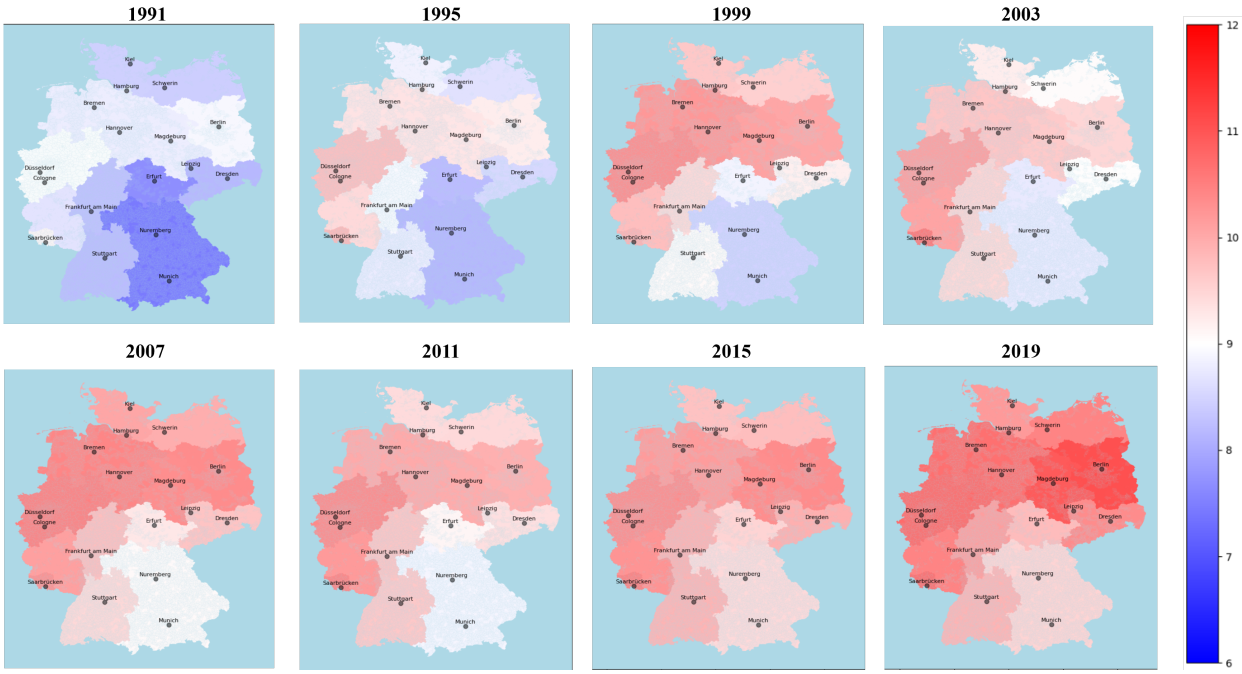

Figure 3.2: Temperature over time in Germany

change was nearly double. In 2002, the national average precipitation was 84mm, while in 2018, it was 48.8mm. Most federal states experienced minimal changes in precipitation, although Bayern appears to be drier than before. Figure 3.3 illustrates the precipitation changes in geographical form at four-year intervals.

4. How has the soil condition changed over the years in Germany? For this study, we selected three representative columns: soil temperature, soil moisture, and soil evaporation. We grouped the soil condition data by year and calculated the averages. This data was then joined with geographical data. Our analysis revealed a rapid increase in soil evaporation, as shown in Figure 3.4. In 2019, soil evaporation in Brandenburg and Sachsen-Anhalt increased significantly as the climate became hotter. A similar sharp increase was observed in soil temperature, as shown in Figure 3.5. In contrast, soil moisture appeared to correlate closely with precipitation, showing only slight changes. Figure 3.6 presents three snapshots of soil moisture.

5. How does the global CO2 emission, temperature change and precipitation affect the soil condition? We joined these data sets via the year column and computed the confusion matrix. Figure 3.7 presents the confusion matrix. From this matrix, we observed that CO2 levels, temperature, soil evaporation, and soil temperature negatively impact soil moisture, while precipitation has a positive effect. Additionally, CO2 levels and temperature significantly increase soil temperature, whereas precipitation decreases it. Soil evaporation is moderately correlated with CO2 levels and temperature but is strongly negatively correlated with precipitation.

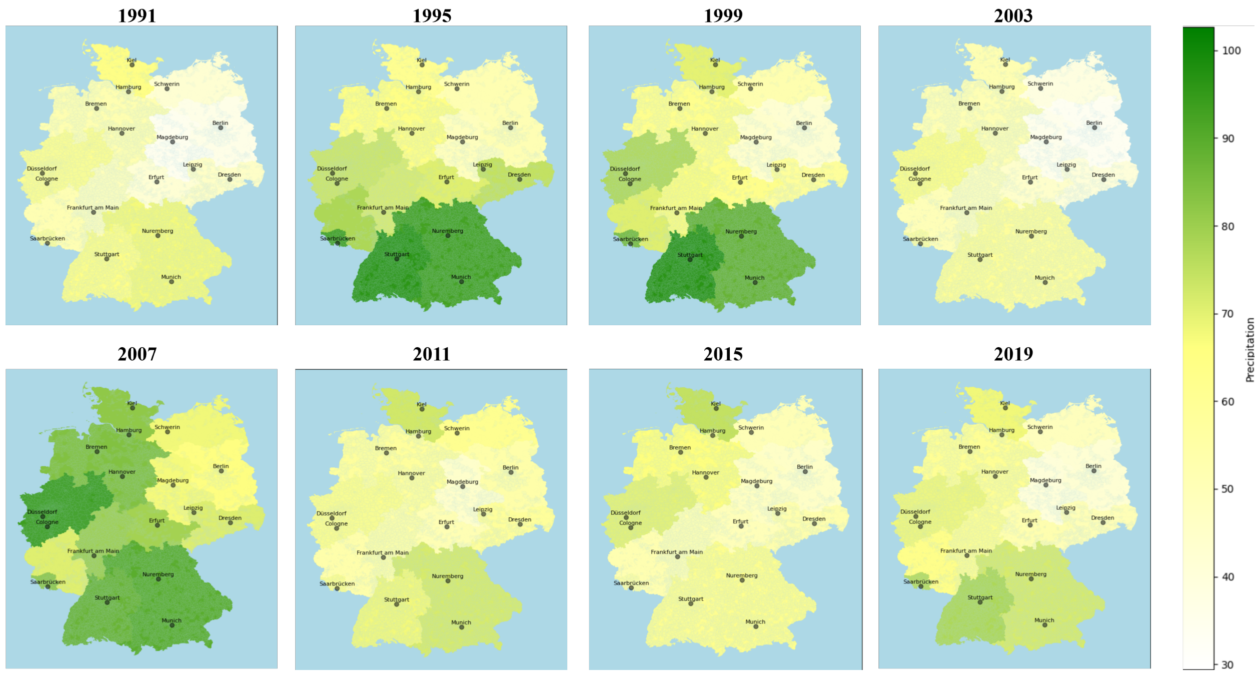

Figure 3.3: Precipitation over time in Germany

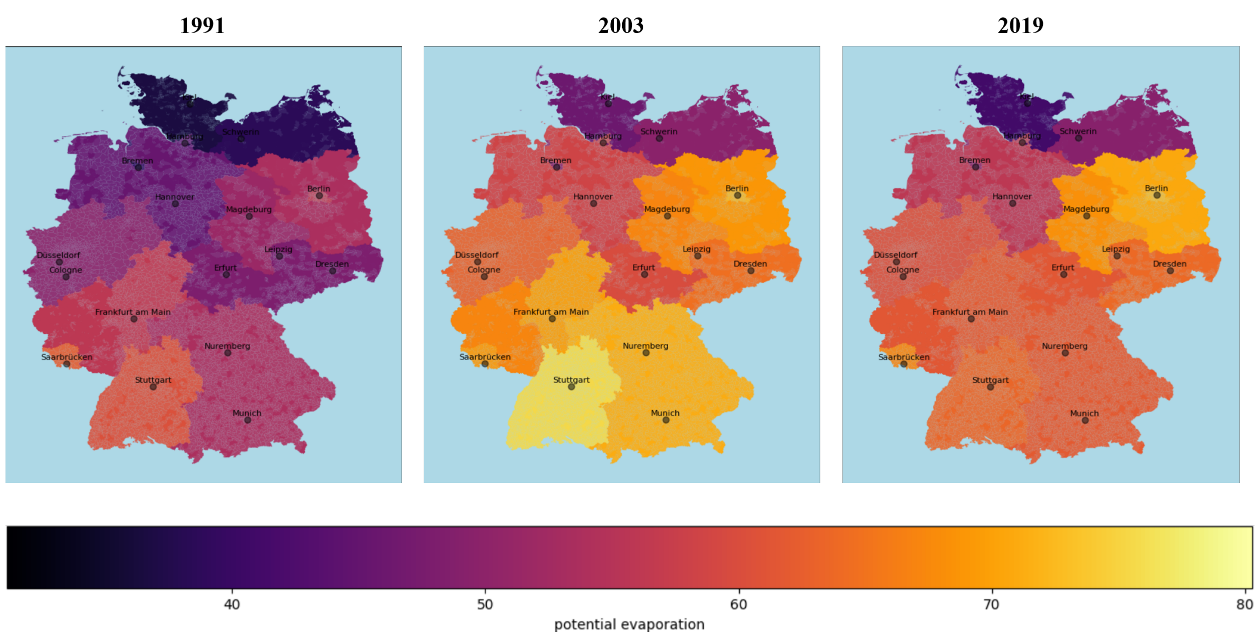

Figure 3.4: Potential Evaporation over grass in Germany

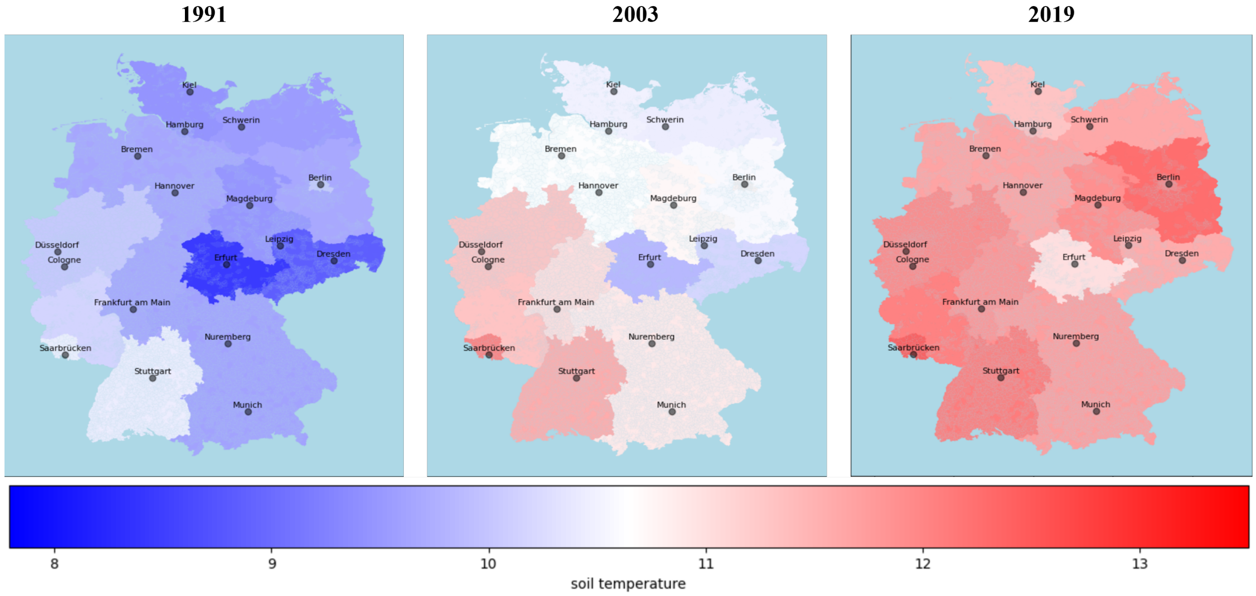

Figure 3.5: Soil Temperature

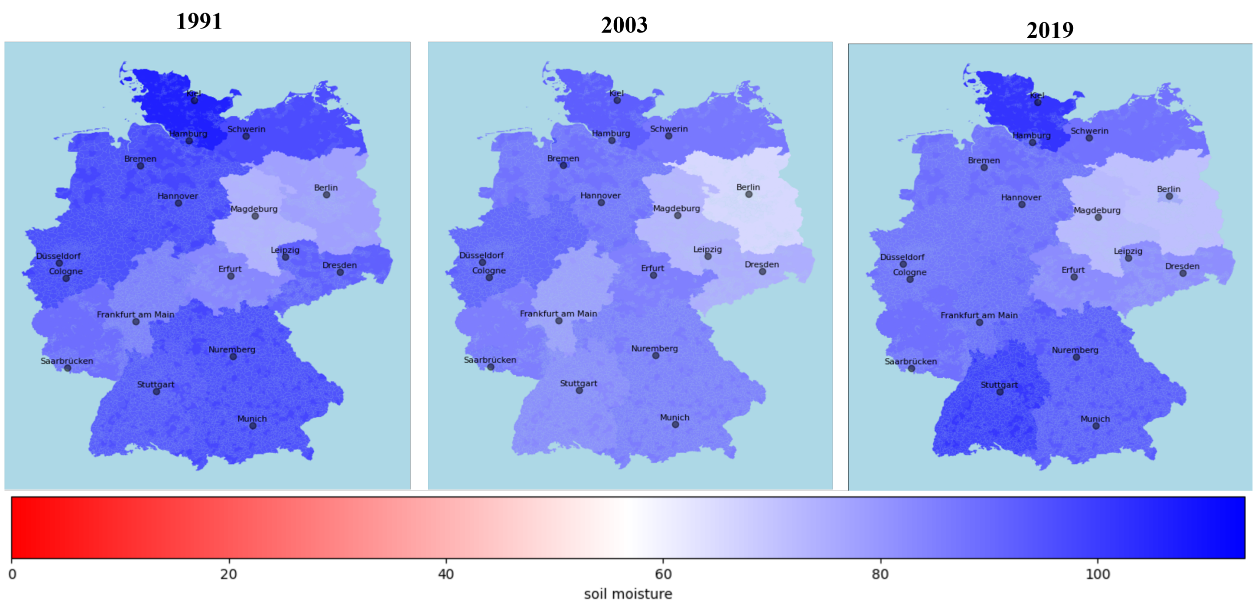

Figure 3.6: Soil Moisture

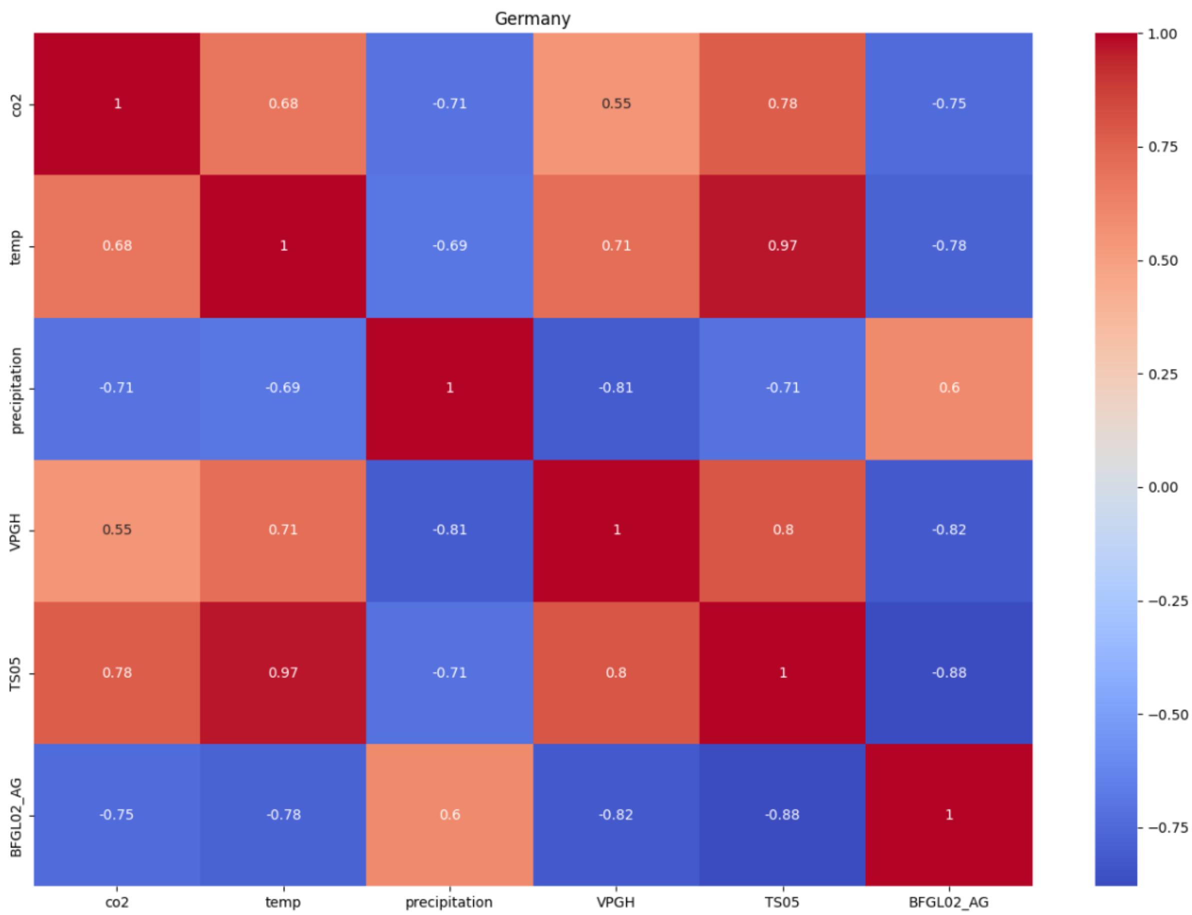

Figure 3.7: Confusion matrix of all federal state data

4. Conclusion

In this report, we raised several questions and used analysis to answer them. All five questions have been addressed with solid answers.

However, there is a bias regarding the coefficient analysis (Question 5). We combined data from all federal states for this analysis, which is not scientifically rigorous. Different federal states have distinct geographical characteristics, such as terrain, altitude, and monsoon patterns. Therefore, each federal state should be analyzed separately.

Furthermore, the correlation analysis alone is insufficient to fully represent real natural states. Natural disasters or human activities might cause deviations in the collected data or reinforce natural changes. Numerous other natural and human factors need to be considered to answer these questions scientifically. By addressing these aspects, we can better understand and mitigate the impacts of climate change on soil health, ensuring sustainable soil development.