# Global Greenhouse Gas Emissions: A Comprehensive Visualization Analysis

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**Abstract**

This project develops an interactive visualization platform that analyzes global greenhouse gas emissions, focusing on CO2, methane, and N2O emissions in different countries over time. Greenhouse gas emissions are a critical driver of climate change and understanding them is vital to tackle this global challenge. By combining and analyzing emission data from OurWorldInData.org, our goal is to uncover new insights into how these gases shape our world, while integrating emissions data with carbon tax policies and temperature changes to provide comprehensive insights into climate change patterns and policy effectiveness.

# 1 Introduction

Climate change represents one of humanity's most pressing challenges, with greenhouse gas emissions being the primary driver. Understanding emission patterns and their relationship with policy measures is crucial for informed decision making.

**Background and Existing Work :** Previous visualization attempts, particularly those from OurWorldInData.org, have provided valuable information but are limited in scope. Although they offer comprehensive maps and charts for individual emission types, they lack integrated views that allow simultaneous comparison of different gases, carbon tax policies, and temperature changes. These single-dataset visualizations make it challenging to understand the complex relationships between various environmental factors and their collective impact on climate change.

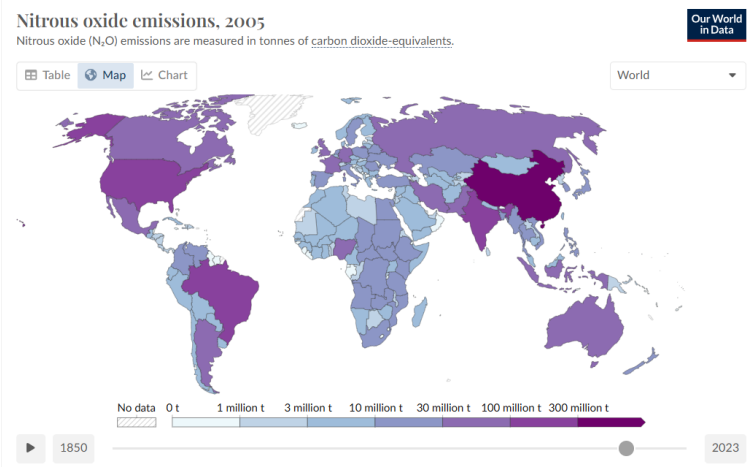


Figure 1: $N_2O$ Emissions (Data from OurWorldInData.org) – Presented as a separate visualization, like overall emissions and other greenhouse gases.

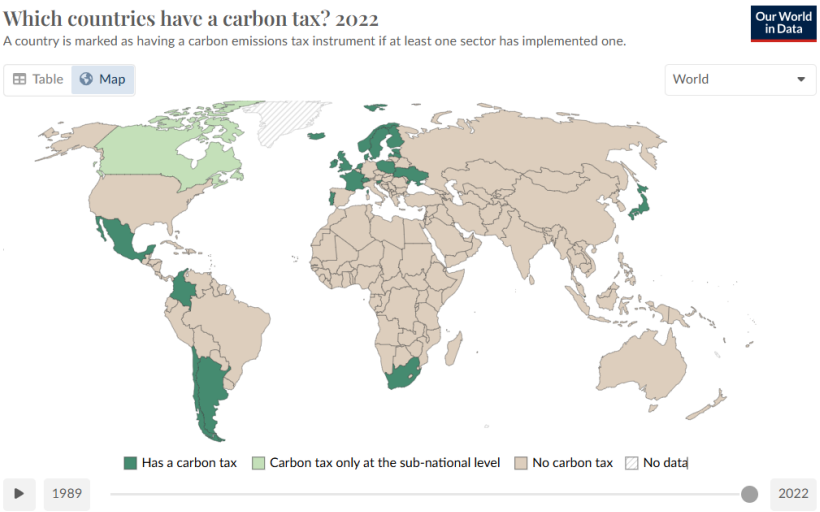


Figure 2: Carbon Tax Status (Data from OurWorldInData.org) – Other metrics like emissions and temperature are available separately.

**Project Motivation :** The need for a more comprehensive visualization platform stems from several key factors: Current visualizations often present data in isolation, making it difficult to identify correlations between different types of emissions. Existing tools rarely integrate policy measures (like carbon tax) with emission data. Temperature change data is typically displayed separately from emission sources. Most platforms lack interactive features that would allow users to explore relationships between different variables.

**Objectives :** Our project aims to address these limitations through:

1. Creating comprehensive, interactive visualizations that combine multiple greenhouse gas emissions (CO2, methane, and N2O).
2. Analyzing the relationship between emissions and carbon tax policies to evaluate policy effectiveness.
3. Enabling user-friendly exploration of emission trends across different gases and regions.
4. Integrating temporal and regional data to provide an engaging and educational experience.

By combining multiple datasets and implementing interactive visualization techniques, our objective is to create a platform that not only presents the data clearly but also allows users to explore and understand the complex relationships

between different types of emissions, their geographic distribution and their evolution over time.

# 2 Methodology

## 2.1 Dataset

Our analysis utilizes comprehensive greenhouse gas emissions datasets from OurWorldInData.org, including:

1. Overall annual greenhouse gas emissions
2. Gas-specific emissions (CO2, CH4, N2O)
3. Carbon tax status
4. Temperature change data

### Common Columns

| **Column** | **Data Type** |
|---|---|
| Entity (Country) | object |
| Code (Country Code) | object |
| Year | int64 |

Table 1: Common Columns Across Datasets

### Unique Columns by Dataset

| **Dataset** | **Column (Data Type)** |
|---|---|
| Overall annual greenhouse gas emissions | Annual Overall Emissions (float64) |
| Gas-specific emissions (CO2, CH4, N2O) | N2O Emissions (Annual, float64)<br>Methane Emissions (Annual, float64)<br>CO2 Emissions (Annual, float64) |
| Carbon tax status | Tax Status (object) |
| Temperature change data | Change in Temperature (float64) |

Table 2: Unique Columns for Each Dataset

The datasets were collected through direct CSV downloads from OurWorldInData.org using pandas' read_csv function. This ensures a direct access to regularly updated datasets.

## 2.2 Pre-processing

The data transformation process involved the following steps:

1. Integration of individual gas type emissions and overall annual emission datasets into a unified structure.

2. Transformation into tidy format for analysis efficiency.

3. Implementation of temporal filtering post-1950 due to data reliability.

4. Transforming the tidy data format to Hybrid format (Tidy + Wide) for satisfying the needs of - plotting a map via plotly dash (Tidy format) and visualization aids like tooltips (Wide Format).

## 2.3 Process

Plotly Dash was chosen for this project for several key advantages - Interactive Visualization: Dash enables creation of interactive web applications with dynamic maps and charts without requiring separate frontend/backend development. Python Integration: Allows seamless integration with pandas dataframes and other Python data analysis tools. Real-time Updates: Supports callback functions for real-time data updates and user interactions.

Plotly dash operates through four stages : App setup, App layout, Callbacks and App deployment.

**App setup :** The setup creates a foundation for building an interactive emissions visualization dashboard where users can explore and analyze global emissions data through maps and other visual components.

**App Layout :** The app layout in Plotly Dash defines the structure and organization of the web application's interface through the following key functions. It is like designing a HTML page of a website. The layout serves as the blueprint for how users will interact with the emissions data visualization, ensuring a logical flow and intuitive user experience.
Layout of this project consists of : Side Menu components, Main Visualization area with its interactive feature and their respective styles.

The side menu consists of Category (Emissions, Carbon Tax, Temperature change), Gas Type (Overall, CO2, N20 and CH4 - only visible when Emissions from Category is chosen), Projection type (Robinson, Mollweide).

Main Visualization area consists of a Choropleth map along with an interactive year slider. The choropleth map can also be analyzed by hovering onto countries

where a dynamic tooltip pops up with relevant information for the choice of selection from side menu.

Styling of the entire plot : The entire styling of the final plot is set in Layout stage. This project employs Responsive design with percentage-based values when needed.

**Callbacks :** Callbacks are the core interactive components of a Plotly Dash application that enable dynamic updates and user interactions - Connect user inputs to application outputs. Enable real-time updates of visualizations and content. Handle data filtering and processing based on user selections. Functions included here are :

1. Update Figure Function : Handles map visualization updates based on user selections, processes emissions data filtering and aggregation, creates color-coded choropleth maps with custom scales, manages different display modes (Emissions, Carbon Tax, Temperature).

2. Toggle Emissions Options : Controls visibility of UI components based on display mode, manages gas type selection options, toggles between different slider controls.

3. Collapsible menu toggle Function

4. Checklist and Message Handler : Manages gas type selection logic, handles validation messages, controls user interface feedback.

**App deployment :** This stage handles two key functions: Browser launch and Server execution.

## 2.4 Visualization Evolution

### Failed Approaches

- Static matplotlib visualizations proved inadequate for temporal data representation.

- Basic line plots couldn't effectively show geographical distribution.

- Multiple separate visualizations hindered understanding relationships between gas types.

**Successful Methods** Choropleth maps emerged as the optimal solution for geographical representation.

- Interactive elements enabled effective temporal exploration.
- Color-coded visualization schemes differentiated between emission types.
- Integrated tooltips provided detailed country-specific information.

The final implementation uses Plotly Dash to create an interactive web application that combines these successful approaches into a cohesive visualization platform.

**Color scheme selections :** The process of selecting appropriate color schemes was crucial for data clarity and accessibility.

- Emissions Category : Implemented a sequential color palette ranging from deep blue to pastel yellow - Cividis.
- Carbon Tax Status : Utilized distinct colors to represent different policy states.
- Temperature change : Employed the 'Inferno_r' continuous color scale for temperature visualization, providing an intuitive representation of temperature variations.

These carefully selected color schemes, combined with choropleth maps, interactive elements, and integrated tooltips, created a cohesive and effective visualization platform using Plotly Dash.

# 3 Results

Our interactive visualization platform successfully demonstrates global greenhouse gas emission patterns through three distinct views: Emissions, Carbon Tax Status, and Temperature Change.

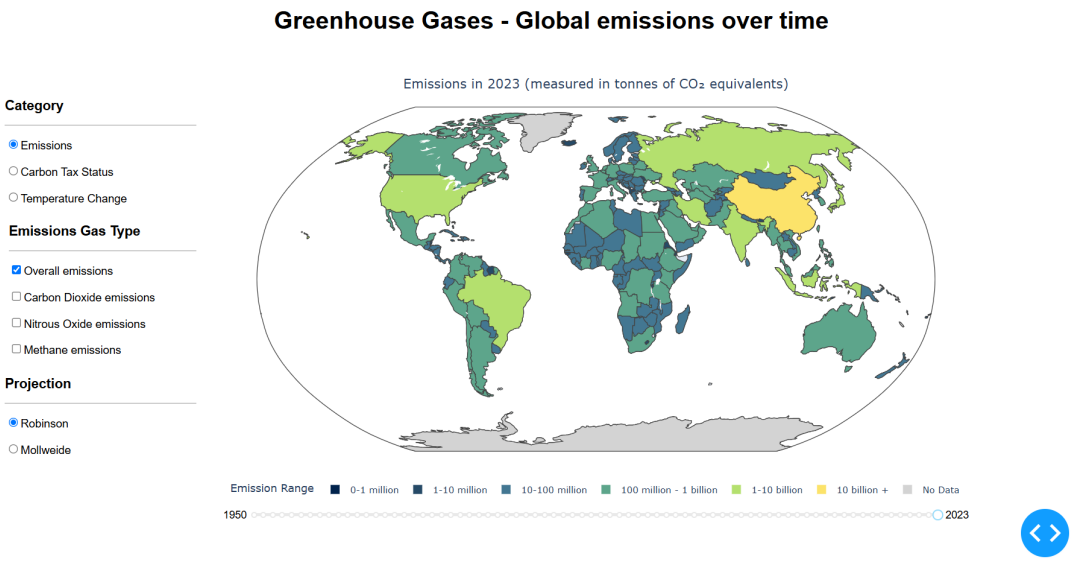


Figure 3: Final Output: Emissions as default selection.

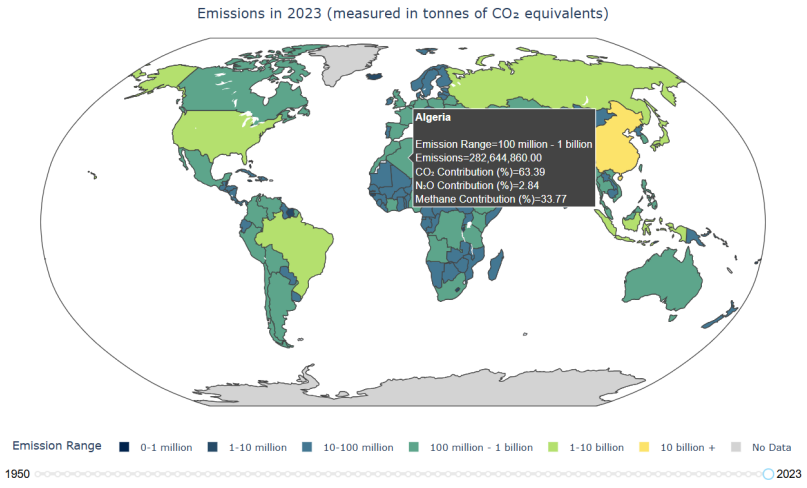


Figure 4: ToolTip Information.

The emissions view reveals several key **insights**:

– Countries show varying patterns of greenhouse gas contributions.

– Carbon dioxide (CO2) is indeed a major contributor to overall greenhouse gas emissions. Methane (CH4) is typically the next highest contributor after CO2, and this pattern is consistent with global data.

– Developed nations typically show higher CO2 emissions.

– Agricultural regions display elevated methane and N2O levels.

The ability to view multiple gases simultaneously enables direct comparison of emission profiles.

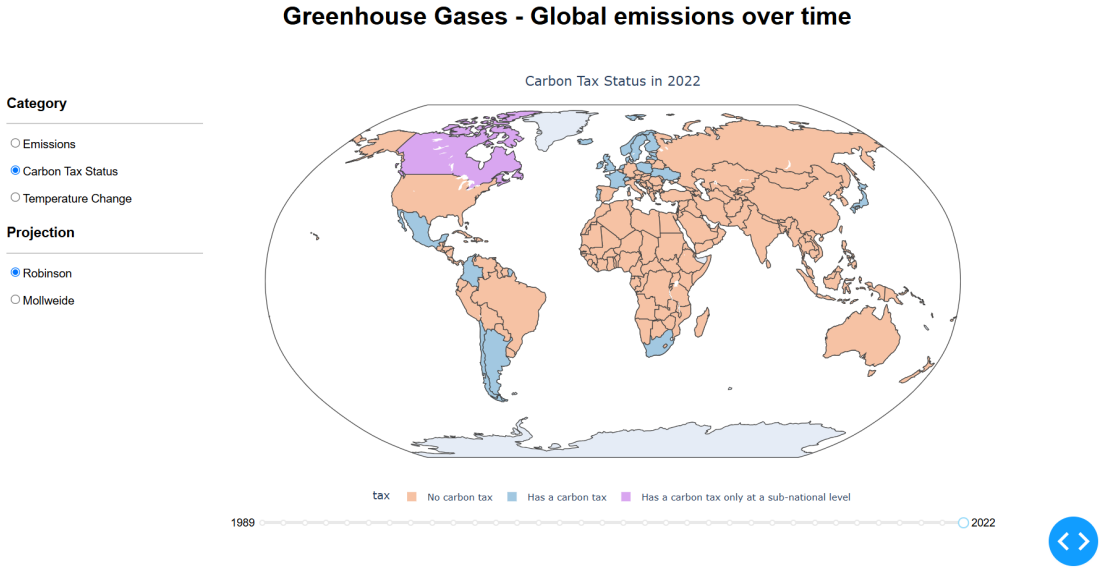


Figure 5: Carbon-tax status.

The carbon tax visualization demonstrates:

– Carbon tax policies have seen a growing adoption over time.

– There are significant regional variations in the approaches to implementation.

– A clear correlation exists between the implementation of carbon tax policies and reduced emission levels.

– Despite the growing adoption, most countries still lack carbon tax policies as of 2022.

– The earliest adoption of these policies began in 1990, with Finland and Poland being the first countries to implement them.

– A notable observation is that Australia introduced carbon tax policies in 2012 but discontinued them in 2015.

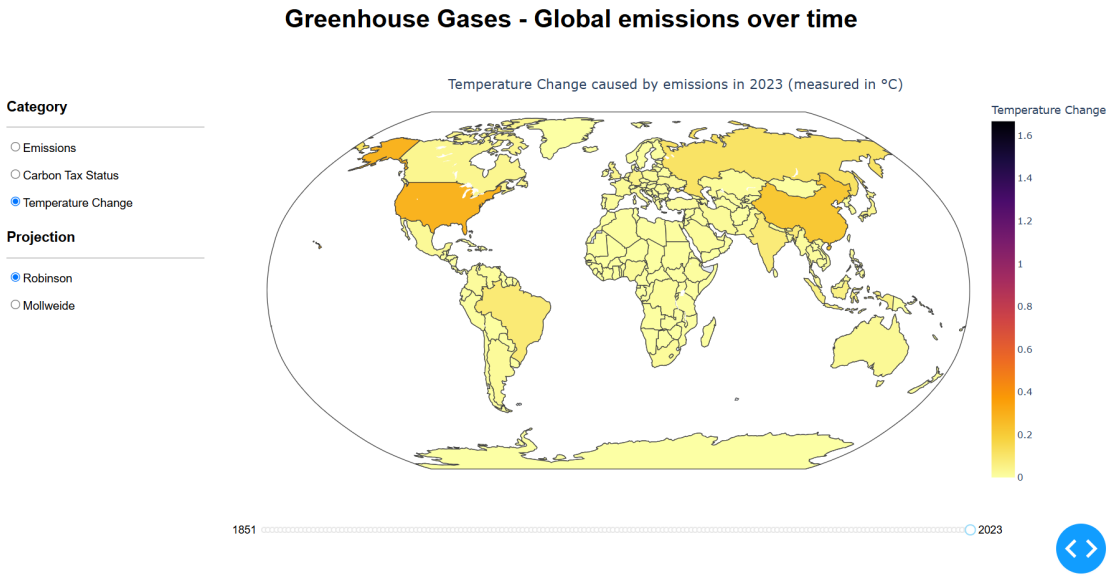


Figure 6: Contribution of Greenhouse gases to Temperature.

Temperature change visualization reveals:

- There is a direct relationship between emission levels and temperature increases.
- Regional variations significantly impact temperature changes.
- Historical progression shows a clear trend of increasing temperatures over time.
- North America, excluding the USA, has observed the highest change in temperature across years.
- In recent years, this is followed by Russia and Asia, excluding China.

**Key Findings** The integration of these three perspectives provides valuable insights into: The relationship between policy implementation and emission levels. Regional variations in greenhouse gas compositions. Temporal trends in global emission patterns. The effectiveness of carbon tax policies in emission reduction. These results demonstrate the power of interactive visualization in understanding complex environmental data and supporting informed policy decisions.

# 4 Conclusion

This project successfully achieved its primary objectives by: Creating a comprehensive visualization platform for global emissions data. Enabling multi-dimensional analysis of greenhouse gases. Providing insights into policy effectiveness through carbon tax visualization. Demonstrating the relationship between emissions and temperature changes.

**Key Takeaways :** The development of this interactive visualization platform has provided valuable insights into both technical implementation and data analysis aspects of environmental data visualization.

Technical achievements include : Successfully implemented a complex interactive visualization system using Plotly Dash. Developed efficient data preprocessing methods for handling multiple datasets. Created an intuitive user interface that balances functionality with accessibility. Mastered callback implementations for dynamic data updates.

Analytical achievements include : Discovered clear patterns in regional emission distributions. Identified correlations between carbon tax implementation and emission levels. Understood the varying contributions of different greenhouse gases across regions. Recognized the importance of temporal analysis in understanding emission trends.

**Future work :** Enhanced Data Integration by incorporating additional environmental indicators and including economic and industrial data for correlation analysis.

Analytical Expansions by including sector-specific emission breakdowns. Adding comparative analysis tools for country-to-country evaluation. Integrating policy effectiveness metrics and developing scenario modeling capabilities for policy impact assessment.

These future directions would further enhance the platform's utility as a tool for environmental policy analysis and decision-making.

## References


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