University of Southern Denmark

Data Visualisation

Global Greenhouse Gas Emissions Dashboard:

Tracking Countries, Sectors, and Corporate Giants

Dashboard Link

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Contents

List of Figures

1 Background and Motivation

Climate change represents the defining challenge of the 21st century, driven primarily by the accumulation of greenhouse gases (GHGs) in the atmosphere. While the scientific consensus on the warming of the planet is clear, the attribution of responsibility remains a complex and politically charged issue. Historically, climate accountability has been framed through the lens of nation-states—tracking emissions by country (e.g., "China vs. USA") or by region (e.g., "Global North vs. Global South").

However, this state-centric view often obscures the role of the actual entities extracting and burning fossil fuels: the corporations. A growing body of research, such as the "Carbon Majors" database, suggests that a small number of investor-owned and state-owned fossil fuel companies are responsible for a vast majority of historical emissions.

Motivation: The primary motivation for this project was to extend beyond the standard "Country Ranking" dashboard. The objective was to develop a tool that enables the triangulation of accountability across three dimensions: geographic, sectoral, and corporate.

Crucially, the assessment of national responsibility is highly sensitive to the metric selected. A country's emissions profile can appear vastly different when viewed through the lens of Total Emissions versus Per Capita, Per GDP, or Total Accumulated historical data. For instance, a nation with high absolute output may rank low on a per-capita basis, or a country with currently low emissions may bear a heavy historical responsibility due to accumulated totals.

Consequently, the overarching aim of this dashboard is to demonstrate how shifting perspectives significantly alters the narrative of responsibility. By juxtaposing these varying metrics, the tool illustrates that there is no single "correct" view of climate accountability. Instead, it provides a comprehensive overview where users can observe these competing stories—historical versus current, national versus corporate—and navigate the data to form their own independent conclusions.

Dashboard Access:
The full visualization tool described in this report can be accessed online at:
https://nicolaslmp.shinyapps.io/Datavisualization/

2 Project Objectives

The overarching objective of this project is to translate complex, high-dimensional climate data into an accessible visual narrative. Rather than presenting a single, static conclusion, the dashboard is designed to allow users to investigate the data through three distinct analytical lenses: geographic distribution, economic sector composition, and corporate responsibility.

By enabling the comparison of these conflicting perspectives, the project aims to answer specific research questions regarding the source and evolution of global greenhouse gas (GHG) emissions.

Geographic Analysis: The Inequality of Nations

The first analytical pillar focuses on the traditional nation-state view, utilizing data from the EDGAR database to interrogate global inequality in emissions.

- **Evolution of Trends:** How have emission trajectories differed between the countries and continents from 1970 to 2023?
- **Metric Sensitivity:** How does the ranking of top emitters change when shifting the metric from Total Absolute Emissions to Emissions Per Capita or Emissions Per GDP?
- **Accumulated Responsibility:** How do historical cumulative emissions compare between established economies and emerging markets?

Sectoral Analysis: The Economic Drivers

Moving beyond national totals, the second objective is to identify the specific economic activities driving climate change within those countries.

- **Sectoral Contribution:** Which specific sectors (e.g. Power Industry, Transport, Agriculture, Buildings) are the primary contributors to a country's total emissions?
- **Composition of Gases:** How does the chemical composition of emissions (CO_2 vs. CH_4 vs. N_2O vs. $F\text{-}Gases$) vary by sector and year within a country?
- **Relative Shares:** How has the relative share of sectors evolved over time? Which are hard-to-abate? Which are easier to electrify?

Corporate Analysis: The "Carbon Majors"

The final and most novel objective is to shift the focus from consumption (countries) to production (companies), utilizing the Carbon Majors database.

- **Corporate Concentration:** What percentage of global industrial emissions can be attributed to the top 174 fossil fuel producers from 1854 to 2023?
- **Top Emitters and Energy Sources:** Who are the top 10 corporate emitters from 1900 to 2023, and what are the primary commodities (e.g., coal, oil, natural gas) driving their emissions?

By addressing these questions, the dashboard aims to provide a tool for "triangulation," allowing the user to construct a holistic view of climate accountability that no single dataset could provide in isolation.

3 Data

To achieve a holistic view of global emissions, the dashboard integrates three distinct high-quality datasets. This integration facilitates the bridging of the analytical gap between "territorial" emissions (attributed to countries) and "production-based" emissions (attributed to corporate entities).

3.1 National and Sectoral Data: EDGAR 2024 GHG

The primary source for national and sectoral analysis is the Emissions Database for Global Atmospheric Research (EDGAR 2024 GHG), provided by the European Commission's Joint Research Centre (JRC).

- **Source:** EDGAR GHG Emissions of all World Countries (2024 Report)
- **Temporal Coverage:** 1970–2023.
- **Granularity:** The dataset provides annual emissions data for every country, broken down by specific economic sectors (e.g., Power Industry, Buildings, Transport, Agriculture) and by gas type.
- **Key Variables:**
  - *Substance:* Carbon Dioxide (CO_2), Methane (CH_4), Nitrous Oxide (N_2O), and F-gases. These were aggregated into a single metric of CO_2 equivalent ($MtCO_2e$) using standard Global Warming Potentials (GWP-100 AR5).
  - *Sectors:* The analysis utilizes IPCC-defined source categories, specifically: Energy (Power Industry, Fuel Exploitation), Industrial Combustion, Industrial Processes, Transport, Agriculture, Buildings, and Waste.
  - *Auxiliary Metrics:* To enable fair comparisons between nations of varying sizes and economic power, the emissions data was supplemented with population and GDP (Purchasing Power Parity) datasets, allowing for the calculation of emissions per capita ($tCO_2e/person$) and per GDP ($tCO_2e/kUSD$).

3.2 Corporate Data: The Carbon Majors Database

To address the objective of corporate accountability, the project utilizes the Carbon Majors Database, maintained by InfluenceMap. Unlike EDGAR, which tracks emissions at the point of combustion (territorial), this dataset tracks emissions at the point of extraction (production).

- **Source:** Carbon Majors Database (InfluenceMap)
- **Temporal Coverage:** 1854–2023
- **Content:** The dataset traces cumulative emissions back to the world's largest industrial producers of oil, natural gas, coal, and cement.
- **Key Variables:**
  - *Parent Entity:* The ultimate owner of the assets (e.g., Saudi Aramco, ExxonMobil, Gazprom).
  - *Entity Type:* Categorization into Investor-owned Companies (publicly traded), State-owned Entities (government-controlled corporations), and Nation States (direct government production). Note: For the corporate analysis, "Nation State" entities were filtered out to strictly isolate corporate responsibility.
  - *Commodity:* The primary fuel source driving the emissions (Oil & NGL, Natural Gas, Coal, Cement).

3.3 Global Baselines: Our World in Data (OWID)

To provide context for the corporate emissions, a baseline of total global emissions was required.

- **Source:** Our World in Data - CO_2 and Greenhouse Gas Emissions
- **Purpose:** This dataset was used exclusively to establish the "Global Total" denominator. This enabled the calculation of the Relative Market Share of the top corporate emitters, answering the research question regarding the concentration of global responsibility.

4 Data Processing

The raw data is not ready for immediate visualization. To ensure reproducibility and maintainability, a modular data processing pipeline was implemented using the R tidyverse ecosystem. The entire workflow is orchestrated by a main control script (`main_dp.R`), which sequentially triggers three specialized sub-scripts.

4.1 Data Transformation Overview

The following table summarizes the structural changes applied to the raw datasets to prepare them for the Shiny dashboard. The primary goal was to standardize column names, shift from "wide" (years as columns) to "long" (years as rows) formats for time-series analysis, and aggregate disparate gas types into a unified metric.

Dataset	Initial Structure (Raw)	Processing Actions	Final Structure (Cleaned)
National	**Wide by Year:** Years (1970–2023) appear as individual columns. **Fragmented Files:** Three separate CSVs for Total Emissions, Per Capita, and Per GDP.	1. **Pivot Longer:** Converted year columns into a single time variable. 2. **Full Join:** Merged the three metric files into one. 3. **Cleaning:** Standardized country naming conventions.	**Unified Long Format:** Columns: Country, Code, Year, Total_Emissions, Per_Capita, Per_GDP.
Sectors	**Long by Substance / Wide by Year:** Each greenhouse gas (CO_2, CH_4, N_2O) occupies a distinct row per sector. Years are spread across multiple columns.	1. **Pivot Wider:** Cast gas substances from rows into separate columns. 2. **Calculation:** Summed gas columns to create CO_2e. 3. **Relative Calc:** Computed % share per sector.	**Sector-Aggregated Long Format:** Columns: Year, Sector, Country, CO2, CH4, N2O, Total_CO2e, Relative_Share.
Companies	**Heterogeneous Entities:** The "Parent Entity" column contains mixed classifications, grouping "Nation States" (e.g., Poland Coal) alongside private corporations.	1. **Filtering:** Removed rows where parent_type == "Nation State". 2. **Left Join:** Added global totals from the OWID dataset to the corporate data.	**Corporate Only:** Columns: Year, Parent_Entity, Commodity, Emissions, World_Total.

4.2 Processing National Trends (data_processing_countries.R)

The first sub-script focused on unifying the fragmented national data. The source data from EDGAR was provided in three separate files: one for absolute emissions, one for per capita emissions, and one for emissions per GDP. Furthermore, these files were in a "wide" format, where years served as column headers. The script first utilized the `pivot_longer` function to reshape each dataset into a "long" format, creating a single year variable essential for time-series plotting. Subsequently, the three datasets were merged into a single dataframe using `full_join` operations. This merged dataset (`GHG_total_gdp_capita.csv`) allows the dashboard to instantly switch between metrics without reloading files.

4.3 Processing Sectoral Composition (data_processing_sectors.R)

The second sub-script addressed the complexity of greenhouse gas composition. A critical step was the aggregation of different pollutants into a single comparable metric: CO_2 equivalent ($MtCO_2e$). The EDGAR dataset aligns with the IPCC Fifth Assessment Report (AR5), utilizing the Global Warming Potential over a 100-year time horizon (GWP-100). This metric accounts for the varying radiative forcing of gases. Mathematically, the total climate impact is calculated by summing the fossil CO_2 with the weighted values of non-CO_2 gases:

$$Total\ CO_2e = CO_2 + CH_{4(GWP100)} + N_2O_{(GWP100)} + F\text{-}gases_{(GWP100)}$$

Implementing this aggregation in R required a specific pivoting strategy. The raw data was structured such that each gas substance appeared as a separate row (long by substance), making row-wise addition impossible. The `pivot_wider` function was utilized to cast these substances from rows into distinct columns. This structural transformation was essential for the mathematical operation: by aligning the gases side-by-side, the calculation could be vectorized, utilizing `rowSums()` to efficiently compute the total CO_2e for every country-sector-year combination.

To enable "shape" visualizations (such as the Stacked Area charts), the script further calculated relative contributions. It grouped the data by country and year to compute the percentage share of each sector relative to the national total. This processed data (`GHG_by_sector_and_country.csv`) serves as the foundation for the Sectoral Analysis page.

4.4 Processing Corporate Entities (data_processing_companies.R)

The final sub-script was designed to isolate corporate responsibility. The raw Carbon Majors dataset mixes "Nation States" (e.g., "Poland Coal" or "Former Soviet Union") with actual corporate entities. To strictly answer the research question regarding corporate control, the script filtered out rows where `parent_type == "Nation State"`. This step was critical to prevent double-counting emissions that were already represented in the country analysis. Furthermore, to enable the "Companies vs. World" comparison, the script loaded an external dataset from Our World in Data (OWID) containing global total emissions. A `left_join` operation was performed to attach the global total to each year of the company data, allowing the dashboard to calculate the market share of the top 174 polluters relative to the entire world.

5 Visualization Methodology

The core utility of the dashboard lies in its ability to triangulate climate responsibility through differing analytical lenses. This section details the visualization strategies employed for the Geographic, Sectoral, Corporate, and AI-driven analyses, describing the visual encodings and interactive elements designed to facilitate data exploration.

5.1 Visual Design and Color Strategy

To ensure a cohesive and accessible user experience, a consistent visual design philosophy was applied across the dashboard.

- **UI Theme:** The dashboard controls and sidebar utilize a specific **"Okabe-Ito Blue"** theme (`#0072B2`). This color was explicitly defined in the CSS styling to highlight active UI elements (such as selected checkboxes and radio buttons) and provide immediate visual feedback on the system status.
- **Colorblind-Safe Palettes:** To ensure inclusivity for users with color vision deficiencies (such as Deuteranopia and Protanopia), scientifically developed palettes from the `khroma` R package were implemented:
  - **Continents/Sectors:** The **Okabe-Ito** palette (8 distinct hues) was used to distinguish categorical variables (Continents like Asia/Europe and Economic Sectors).
  - **Gases:** The **Paul Tol "Bright"** palette was used for the chemical composition clusters.

5.2 Interface and Controls

The analysis is driven by a reactive sidebar control panel (sidebarPanel), which allows users to filter the dataset dynamically.

- Inputs: Users can select a specific Country via a dropdown menu and customize the view by toggling specific Sectors on or off using a checkbox group.
- Context: To aid interpretation, the page also includes a "Sector Definitions" panel explaining the IPCC categories and a "Research Questions" panel guiding the user's inquiry.
- View Toggle: A radio button allows the user to switch the secondary visualization between two distinct modes: "Relative (%)" (Line Chart) and "Relative Stacked(%)" (Area Chart)

5.3 Global Analysis: Continents and Countries

The first analytical tab provides a high-level overview of emission trends from 1970 to 2023. The associated graph, "How have emissions evolved over time?", is designed to compare macro-regional trends with specific national trajectories.

- **Visualization Type:** A Multi-Line Time Series Chart.
- **Visual Channels:**
  - **Position (y-axis):** Encodes the magnitude of the selected metric (e.g., $MtCO_2e$).
  - **Color:** Each continent is assigned a fixed hue from the **Paul Tol "Bright"** scheme (e.g., Europe=Blue, Asia=Red) to ensure consistent identification across the user session.
- **Hierarchy of Focus:** To distinguish between the two levels of data (Continents vs. Countries), a distinct line style strategy was employed:
  - **Continents:** Rendered with **thick, solid lines** and larger markers. These serve as the visual anchor.

– **Countries:** Rendered with **thinner, dashed lines**. Their color matches their parent continent (e.g., France appears as a dashed blue line, matching Europe), allowing users to visually correlate a nation with its regional context.

- **Metric Flexibility:** Users can toggle between Total Emissions, Per Capita, Per GDP, and Accumulated Emissions to observe how ranking order shifts (e.g., Asia leads in Total, but is overtaken by Oceania/Americas in Per Capita).

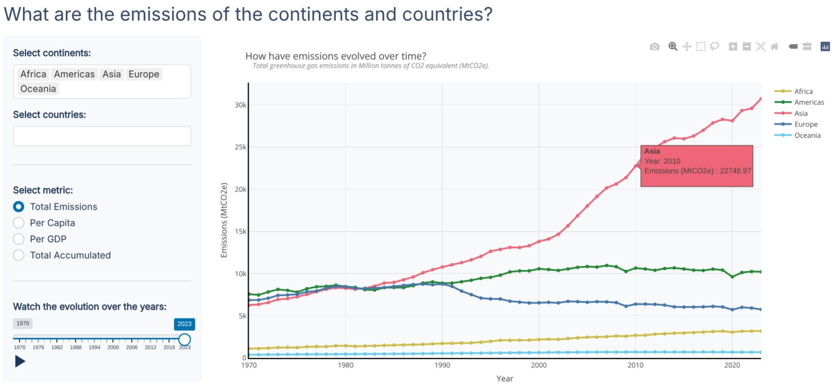

Figure 1: Line chart regions

5.4 Geographic Analysis: The Interactive Map

To enable spatial exploration of emissions intensity, an interactive Choropleth Map was implemented using the `Leaflet` library.

- **Visual Channels:** The specific metric value is encoded using **color saturation** on a sequential scale.

- **Color Strategy:** A "Value-Linked" scientific heat scale was crafted, progressing from a light, neutral yellow (`#ffffcc`) for low emissions to a deeply saturated dark red (`#b10026`) for the highest emitters. This intuitive "heat" metaphor allows users to instantly identify hotspots.

- **Interactivity:** Users can hover over any country to trigger a tooltip displaying its name, the selected year, and the precise value of the chosen metric.

Figure 2: Interactive Heat Map

5.5 Sectoral Analysis

The Sectoral Analysis page allows users to decompose a country's emissions profile into specific source categories. Four distinct visualization layers were coordinated to explore this data.

Absolute Trends: The Line Chart

The primary visual element is a **Line Chart** tracking the absolute emissions ($MtCO_2e$) of selected sectors over time (1970–2023).

- **Visual Channels:** The chart relies on position on the y-axis to encode emission magnitude and color hue (Okabe-Ito) to distinguish between sector categories. Markers are added to the lines to emphasize individual data points.
- **Rationale:** This chart type was selected because it maps two continuous variables simultaneously: time and emission quantity. The linear geometry allows the eye to easily track gradients and rates of change.
- **Interactivity:** A tooltip interaction is implemented for precise retrieval (Sector, Year, Value).

Chemical Composition: The Linked Donut Chart

Positioned alongside the time series is a Donut Chart, which breaks down the specific greenhouse gases constituting the sector's emissions.

- **Visual Channels:** This visualization uses arc length to encode proportion and color (Paul Tol Bright) to differentiate the gas types.
- **Rationale:** The donut chart was chosen to represent the part-to-whole relationship of the gas composition for a single point in time.
- **Interactivity:** This chart is dynamically linked to the main line chart. When a user hovers over a specific year on the line chart, the Donut Chart automatically updates to reflect the chemical composition for that specific year and sector.

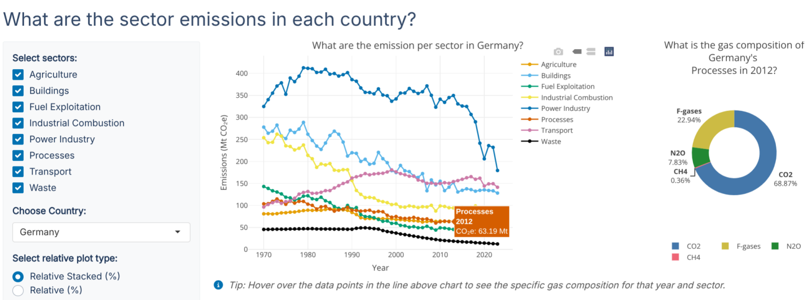

Figure 3: Sectors absolute emissions line chart and donut chart

Relative Evolution: The Percentage Line Chart

Accessible via the "Relative (%)" toggle, this Line Chart displays the relative share of each sector (0–100%) over the timeline without stacking.

- **Visual Channels:** Similar to the absolute chart, this utilizes position on a vertical scale to represent percentage contribution and color (Okabe-Ito) for sector identification.
- **Rationale:** By not stacking the values, users can easily read specific percentage values and identify crossover points (e.g., when the Transport sector overtakes the Power Industry in relative importance).
- **Interactivity:** The hover interaction provides comprehensive details for the specific data point: Sector, Year, Share (%), and the absolute emission value (M tCO2 e).

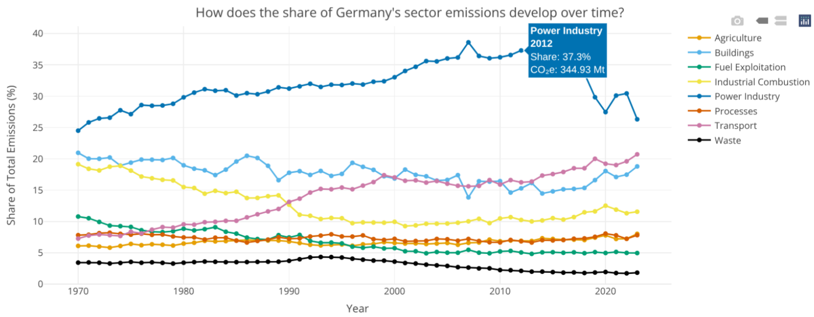

Figure 4: Sector emissions line chart relative

Relative Composition: The Stacked Area Chart

Accessible via the "Relative Stacked (%)" toggle, this Stacked Area Chart visualizes the cumulative composition of the economy (summing to 100%).

- **Visual Channels:** This plot uses area size to represent the volume of the share and color (Okabe-Ito) to differentiate sectors.
- **Rationale:** This visualization is essential for understanding the "energy mix" or "economic structure" of a country. Unlike the line chart, the stacked area emphasizes the whole; it allows users to see how the expansion of one sector (e.g., Energy) naturally compresses the relative share of others, highlighting which sectors are dominant at specific historical moments.
- **Interactivity:** Consistent with the other charts, hovering over an area segment displays the Sector, Year, Share (%), and absolute value (M tCO2 e).

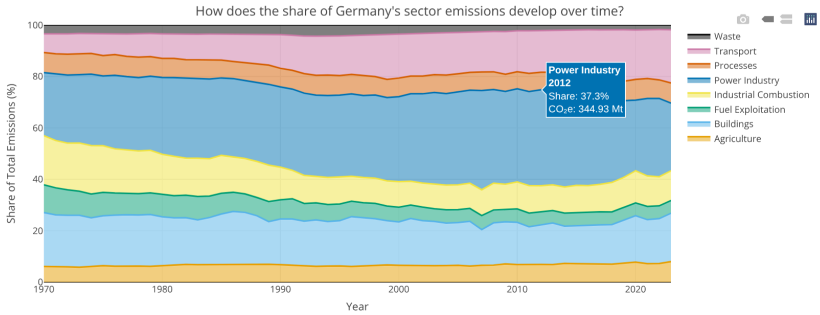

Figure 5: Sector emissions line chart relative stacked

5.6 Corporate Analysis

The final analytical dimension shifts the focus from the demand side (countries) to the supply side (corporations).

Global Context: Companies vs. The World

To validate the significance of the corporate data, a Multi-Line Time Series Chart was implemented to compare two specific aggregates from 1854 to 2023: the Global Total Emissions and the emissions of the 174 most emitting companies.

- **Visual Channels:** The chart uses position (y-axis) for magnitude and color to distinguish the entities.
- **Color Strategy:** A deliberate "Focus vs. Context" color strategy was employed:
  - Top Emitting Companies: Rendered in the primary Okabe-Ito Blue(#0072B2) to visually link them to the UI control elements and designate them as the primary subject of analysis.
  - World Total: Rendered in a neutral Paul Tol Grey (#BBBBBB) to serve as the background context or denominator.
- **Rationale:** A multi-line chart is the most effective method for direct comparison of magnitudes over a long temporal range. By plotting both aggregates on the same axes, the visualization allows for an immediate visual assessment of the gap between global totals and corporate-controlled production.
- **Interactivity:** When hovering over the "Companies" line, the tooltip does not merely show the absolute value (M tCO2 e) but also dynamically calculates and displays the Share of World (%) for that specific year, allowing users to verify the degree of market concentration.

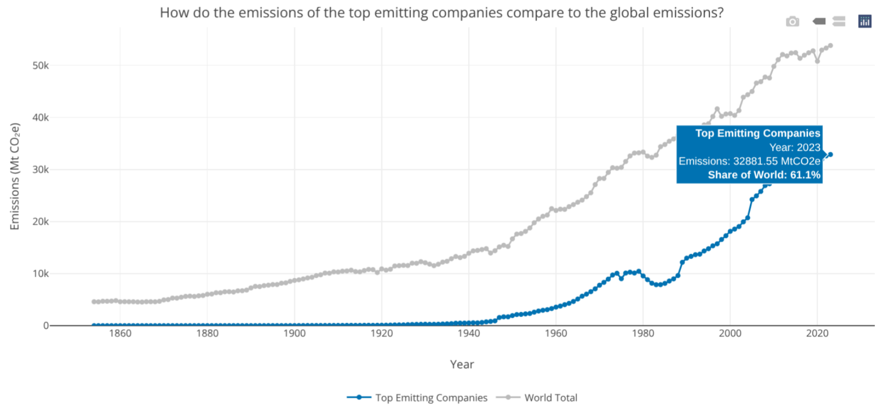

Figure 6: Top 174 emitting companies in relation to global emissions

Top Corporate Emitters: The Animated Bar Chart Race

To visualize the changing fortunes of the world's largest polluters over a century, an animated **Bar Chart Race** was developed.

- **Visual Channels:**
  - **Length:** Encodes cumulative total emissions.
  - **Vertical Position:** Encodes rank.
  - **Color:** Encodes the primary commodity resource (Coal=Grey, Oil=Dark Blue, Gas=Light Blue).
- **Rationale:** A static chart cannot convey the *"story of rise and fall"* that characterizes the fossil fuel era (e.g., the rise of state-owned entities like Saudi Aramco in the late 20th century).

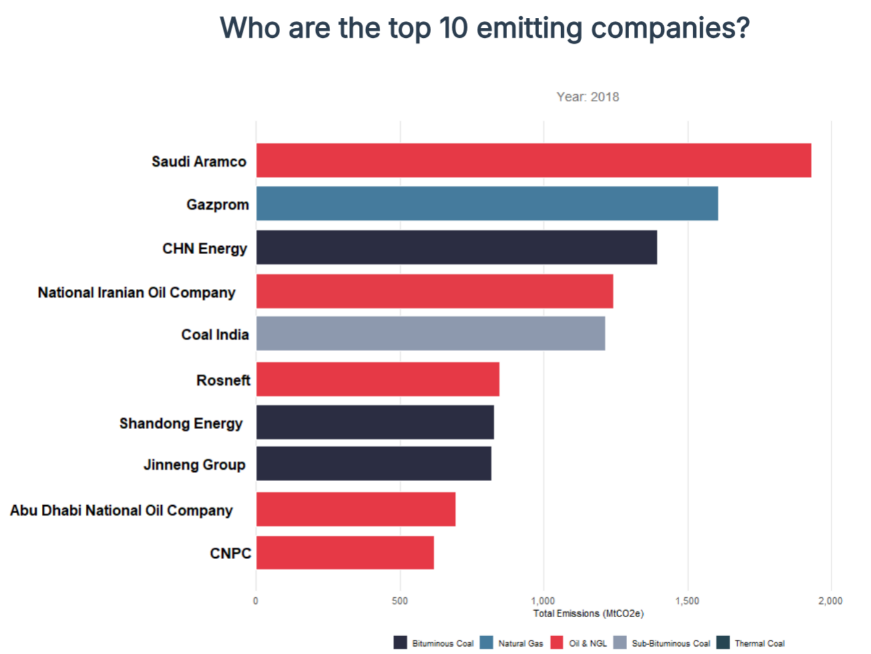

Figure 7: Top 10 Companies Bar Chart (Animated)

5.7 AI Analysis: The Sector Fingerprint

To provide a novel, data-driven perspective on economic structures, an “AI Analysis” page was introduced, featuring a comparative **Radar Chart** (Spider Plot).

5.7.1 Overview and Concept

This visualization conceptualizes a country’s emission profile as a unique “fingerprint” or “DNA”.

- **Visual Channels:** Radial axes represent the 8 major economic sectors; the shape connects the percentage share of each sector in the national total.
- **Interactivity:** Users can overlay multiple shapes (e.g., USA vs. China vs. World) to instantly perceive structural differences that are invisible in simple bar charts.

5.7.2 AI-Assisted Production Methodology

This advanced visualization module was produced with the assistance of the AI coding platform **Google Gemini**.

- **Platform:** Google Gemini. `ggplot2`) was generated through an iterative dialogue with the AI model.
- **Prompts Strategy:** Key prompts included:
    1. *"Generate a R Shiny module using Plotly's 'scatterpolar' trace to visualize a multivariate dataset."*
    2. *"Implement logic to dynamically normalize sector emissions as percentage shares for selected countries."*

5.7.3 Research Question Addressed

This specific graph was designed to answer the following research question:

> **"Do nations with similar total emission levels share the same underlying economic structure?"**

The visualization reveals the answer is often **no**. By comparing the "shapes" of high-emitting nations, the dashboard demonstrates distinct structural realities (e.g., China's "Industrial Diamond" shape vs. the USA's "Transport-Heavy" shape), implying that decarbonization strategies must be tailored to these fingerprints.

Figure 8: AI Radar Chart

6 Story and Results: The Triangulation of Responsibility

By utilizing the dashboard to navigate the three analytical dimensions—Geography, Sectors, and Corporations—we can reconstruct the complex story of climate accountability. The visualizations reveal that the answer to "Who is responsible?" differs fundamentally depending on the lens applied.

6.1 Geographic Insights: The Great Divergence

The **Global Analysis** tab immediately highlighted the stark inequality inherent in the climate crisis.

- **The Metric Inversion:** When viewing *Total Absolute Emissions*, the narrative is dominated by the rapid rise of Asia. China currently stands as the world's undisputed largest emitter, with a trajectory that has spiked dramatically since 2000. However, toggling the dashboard to *Emissions Per Capita* instantly inverts this hierarchy. In this view, major developed nations (such as the USA, Canada, and Australia) and petrostates (Qatar, UAE) remain far ahead of the global average, while China drops significantly in the rankings. This visually confirms that while emerging economies produce more in aggregate, the individual carbon footprint in the West remains disproportionately high.

- **The Weight of History:** The *Total Accumulated* metric on the Map page provided perhaps the most critical insight. While current emission maps highlight the Global South, the accumulated history (1970–2023) shifts the heat map back towards the North Atlantic. The visualization clearly demonstrates that the United States and the EU-27 bear the heaviest historical "carbon debt," having utilized the atmosphere's capacity for over a century before other nations industrialised.

6.2 Sectoral Insights: The Engines of Growth

The **Sectoral Analysis** decomposed these national totals, revealing the economic engines driving the trends.

- **The Power Prerogative:** Across almost all major economies, the *Power Industry* (Electricity & Heat) was visible as the dominant driver of emissions, correlating strongly with the "Coal" commodity in the corporate analysis.

- **Chemical Signatures:** The *Chemical Composition* donut chart revealed distinct sector identities. While the Energy and Transport sectors are dominated by CO_2, the Agriculture sector displays a completely unique profile, composed largely of Methane (CH_4) and Nitrous Oxide (N_2O). This insight is crucial for policy, illustrating that decarbonizing the food system requires tackling different gases than the energy transition.

- **Structural Transitions:** The *Stacked Area Chart* revealed the "de-industrialization" of Western economies, showing a relative shrinking of the "Industrial Combustion" wedge in the UK and USA over time, replaced by a stubborn "Transport" wedge that has proven harder to abate.

6.3 Corporate Insights: The Rise of the State

The **Corporate Analysis** provided the most novel perspective, shifting blame from the consumer to the producer.

- **Extreme Concentration:** The *Companies vs. World* line chart confirmed a staggering degree of concentration. A mere 174 entities are visually shown to track a massive percentage of total global industrial emissions. This validates the hypothesis that climate action could be highly effective if targeted at the supply chain of these specific producers.

- **The Geopolitical Shift:** The *Bar Chart Race* told a compelling story of geopolitical power. The animation begins with the dominance of private Western capital (Standard Oil, UK Coal) in the early 20th century. However, as the animation progresses into the 1970s and 80s, we observe a massive structural shift: the rise of State-Owned Entities. By 2023, the top of the race is dominated not just by ExxonMobil or Chevron, but by giants like Saudi Aramco, Gazprom, and China Coal. This finding challenges the narrative that pressure on Western stock markets alone can solve the crisis.

6.4 AI Insights: Economic DNA

The *Sector Fingerprint* (Radar Chart) successfully clustered economies into recognizable "types" without human labeling.

- **The Manufacturer:** China's shape is heavily skewed towards the top-right axes (Power & Industry), reflecting its role as the "factory of the world."

- **The Consumer:** The USA's shape extends deeply into the "Transport" axis, reflecting a high-mobility, car-centric infrastructure.

- **The Developing Producer:** Many developing nations displayed shapes skewed towards “Agriculture” and “Land Use,” illustrating a fundamentally different relationship with emissions than the industrialized North.

7 Conclusion and Discussion

7.1 Summary of Achievements

The objective of this project was to move beyond the traditional, state-centric view of climate change and provide a multi-dimensional tool for accountability. By developing the *Global Greenhouse Gas Emissions Dashboard*, we successfully integrated three distinct datasets to triangulate responsibility across Geography, Economic Sectors, and Corporate Entities.

We achieved a highly interactive application that allows users to:

1. **Invert the Narrative:** Instantly toggling between total and per-capita metrics to challenge assumptions about national liability.
2. **Visualize the Supply Side:** revealing the immense concentration of emissions within a small group of 174 corporate entities.
3. **Profile Economies:** Using novel visualizations like the Radar Chart to “fingerprint” the economic structure of nations.

7.2 Methodology and Tools

The project was built entirely within the R ecosystem, demonstrating the power of reproducible code for complex data visualization.

- **Data Processing:** The `tidyverse` suite was essential for cleaning, pivoting, and merging the heterogeneous EDGAR and Carbon Majors datasets.
- **Interactivity:** We utilized `shiny` as the application framework, coupled with `plotly` and `leaflet` to provide client-side interactivity (tooltips, zooming) that makes dense data explorable.
- **Visual Design:** We strictly adhered to colorblind-safe palettes (Okabe-Ito, Paul Tol) to ensure the scientific accessibility of the results.

7.3 Challenges Encountered

The triangulation of these datasets presented significant technical hurdles:

- **Data Heterogeneity:** Merging the EDGAR (Country) and Carbon Majors (Corporate) datasets was not straightforward.
- **Animated Graphics:** Creating the *Bar Chart Race* for the top companies was technically demanding. We found that rendering animations on-the-fly in Shiny using `gganimate` was too slow. The solution (pre-rendering the GIF) solved the performance issue but required significant workarounds.
- **Complex Metrics:** Calculating the "Accumulated Emissions" required implementing grouped cumulative sums across thousands of country-year combinations.

7.4 Future Course Improvements

To further enhance the learning outcomes of this course, we suggest:

- **Complex Animations:** We recommend adding a module specifically dedicated to creating complex animated graphics. While we successfully implemented the Bar Chart Race, learning how to optimize these frame-by-frame animations for web performance was a significant self-taught hurdle.

Finally, we would like to express our sincere gratitude to the professor for her excellent teaching. The clear explanation of visualization principles and the hands-on approach with R/Shiny were instrumental in helping us realize this project.

In conclusion, this project demonstrates that data visualization is not merely about making "charts," but about building tools that allow users to navigate complexity and form their own, data-driven conclusions about the most pressing crisis of our time.