Interactive Visualization Report: Understanding Food-Related CO_2 Emissions (1990–2020)

Problem Definition and Motivation of the Visualization

The food system worldwide is a major source of greenhouse gas emissions, with all phases from production to consumption affecting the environment. It is important for policymakers, researchers, students in the field of environmental sciences or sustainability etc., and the general public to have a clear understanding of these emissions in order to make effective decisions regarding sustainability and climate change mitigation. Yet, the sheer complexity and amount of data surrounding food-related CO_2 emissions frequently render it difficult to decipher and analyze efficiently.

The primary objective of this project was to develop an interactive visualization that explains the trends and disparities in food-related CO_2 emissions by nation and over time. By going through the process of transforming complex datasets into intuitive interactive visual representations, the objective was to enable exploration and gaining of insight for users at various levels of expertise using their own customization if needed.

Dataset and Data Abstraction

Dataset

I have used the Agri-food CO_2 Emission Dataset on Kaggle, which gives global food-related CO_2 emissions from 1990 to 2020 for over 200 countries and 31 columns. Key variables are:

- Sources of emissions (e.g., rice cultivation, fires, food packaging, household consumption etc.),
- Population statistics (male, female, total),
- National average temperature (°C),
- Total emission (in kilotonnes), where 1 kiloton equals 1,000 metric tonnes of CO_2 released into the atmosphere.
- Derived fields such as Emissions_Per_Capita and sectoral emissions summed up.

Data Processing

- Missing values in emission columns were substituted with 0 by validating on total_emission.
- Sector types were defined by dividing 22 columns into: Agricultural, Processing, Transport, and Domestic emissions.

- Per capita emissions were calculated using total population.
- Data was pivoted for treemaps and used in both wide and long formats via replicated data sources in Tableau.

Task Abstraction

In the context of Munzner's Nested Model (2014), task abstraction involves transforming high-level user goals into tangible, observable, and actionable low-level tasks that the visualization must enable. For this work, the high-level goal is to enable users, primarily students, researchers, and educators in sustainability studies and environmental science to understand global food-related CO_2 emissions' trends, sources, and disparities over time. Such users are not likely to possess technical data analysis functionality, and thus the tasks were rendered intuitive, visually driven, and exploratory.

Following Brehmer and Munzner's (2013) multi-level typology of abstract visualization tasks, I structured the task analysis by considering the "why", "how", and "what" of user goals. Below is a breakdown of high-level goals into specific tasks supported by the system:

T1: Identify top emitting countries in a particular year, both in terms of total emissions and per capita emissions. This activity is for the sake of determining geographical hotspots of emissions and their relative impact.

T2: Compare changes in emissions over time between two or more countries. This allows for temporal comparison and highlights longitudinal trends.

T3: Contrast which sectors (e.g., processing, household, agriculture) are the prime sources of emissions in each country and year. This allows users to compare the structure of emissions by category.

T4: Examine whether there is any relationship between temperature changes and the amount of emissions over time or across countries. This is especially useful for users studying climate impacts.

T5: Quantify the inequality of emissions by dividing per capita rates by population sizes, which indicates fairness or unfair burden.

T6: Observe the total emissions evolve globally and nationally over time using animation, which supports serendipitous detection of emission spikes, dives, and anomalies.

Each of these tasks corresponds to a primitive analysis function: filtering, comparing, correlating, summarizing, or identifying (Brehmer & Munzner, 2013). They provided a foundation for deciding how the data would be visualized and interacted with.

Design Rationale of the Visual Representation and Interaction

The visual encoding and interaction design rationale was dictated immediately by the above-described tasks and nature of the dataset. As Munzner (2014) mentions, effective visualization design entails a mapping among data attributes, user tasks, and suitable visual encodings. Below, each major visualization element is discussed in terms of the tasks it supports.

To answer T1, a choropleth map was used to show country-level emissions. Map color coding is proportional to per capita or total CO_2 emissions, with higher values being shown by darker colors. This geospatial visualization exploits the human geospatial intuition to visually identify regions of high emissions with ease (Heer & Shneiderman, 2012). Hover tooltips also provide secondary information like exact kiloton values, allowing overview and detail-on-demand.

For T2, a multi-line chart can facilitate comparing emission trends of different countries over the years 1990–2020. Time is along the x-axis, and total emissions are on the y-axis. A single color represents each country. A filter panel facilitates the selection of a single or multiple countries. Both "lookup" and "compare" tasks are facilitated by this design as well as best practices for visualizing time series (Munzner, 2014). Interactivity allows users to investigate specific circumstances, such as whether emissions rose more quickly in developing or developed nations.

In order to attain T3, a stacked bar chart as well as treemap were used, displaying emissions by aggregated sectors: Agricultural, Processing, Transport, and Household in the stacked bar charts and distribution of all types of emissions present in the dataset in each country over the years. Color intervals along the bar represent each sector's and emissions share. This encoding does a good job of representing totals and proportions, helping users compare sectoral and emissions categories impact per year and nation. Users can toggle between years or countries through filter controls. Stacking layout or the distribution provides a visual differentiation on whether specific countries are dominated by one industry or possess more diversified patterns.

To investigate T5, a bubble plot was created whose x-axis is population, y-axis is per capita emissions, and size is total emissions. This encoding has maximum differences: i.e., low population but high emissions or high population with low per capita emissions. This makes it straightforward for users to consider equity in environmental burden, a topic given high priority in Poore and Nemecek's (2018) research into food system pressures.

Lastly, T6 was addressed with an animated bubble chart and a treemap built using Tableau's Pages feature, where users are able to flip through each year to observe the way global emissions evolved. Although Tableau's dashboard does not have live Pages animation natively, a hack using sliders or jumping to an independent animated worksheet allows temporal storytelling. Animation, when properly done, enhances user engagement and facilitates exploratory learning (Heer & Shneiderman, 2012).

Briefly, visual design was tightly integrated with task analysis following best practices for encoding, layout, and interaction design. Global filters were employed across charts to promote consistency and coordinate multi-viewing. Color palettes were made eye catchy and visible, and were kept the same across charts to reduce cognitive load even though because of the data pattern color-blind palette was not accessible. Textual feedback such as chart titles and explanatory text boxes were given to help novice users understand the data context. This design evolution process illustrates how theory and user response can be applied to real-world visualization problems to create an interactive system that is both efficient and accessible I think.

Iterative Design Process

The development of this interactive visualisation was an iterative, structured design process derived from user-centric philosophy and mediated by Munzner's Nested Model (2014). Experience, experimentation, and refinement led each development step, from sketching the basic concepts right the way through to the production of a horizontally scrolling dashboard, in the constant exchange between task analysis, visual encoding, and testing with users.

The project began with the creation of a first working prototype, as documented in Project Report 2. In this version, I produced a number of charts to represent different facets of the dataset, such as a choropleth map of country-level emissions, a line chart for trend analysis, and a stacked bar chart for sectoral breakdown. But the layout of this initial dashboard was vertical with all the charts stacked upon one another. This design, as noted in the report, led to issues of visual clutter, inefficient use of space, and disorientation moving from one visualization to another.

By peer review during group discussions and self-assessment, the design seemed to discourage storytelling and user engagement. I experimented with layout sketches and drew inspiration from observed best practices of public Tableau dashboards, such as the "Historical Crime Levels of New York City" and the "Olympics Throughout the Years" dashboards. Drawing inspiration from these, I shifted to a horizontal layout so users can scroll left-to-right across themed sections. This revision was a key design milestone, improving clarity as well as use experience.

Other improvements were influenced by the user study, wherein three target users (an environmental science student, a food science researcher, and an agricultural researcher) tested the second prototype and provided feedback regarding assigned tasks and interviews. The study uncovered numerous significant usability problems:

1. **Filter Inconsistency:** The year and country filters were individually embedded in each of the charts, which gave a feeling of disorganization and redundant interaction. Following this feedback, I added global filters in all the charts using Tableau's "Apply to Worksheets" feature, which gave a consistent and seamless experience.
2. **Chart Readability:** Axis labels and legends were hard to read for some participants. I improved this by refining axis titles, including unit annotations (e.g., kilotonnes for emissions), and ensuring consistency of labeling across views.
3. **Color Palette and Accessibility:** A color-blind friendly palette was suggested by participant P1.Even though I could not use colour-blind-palette I used even colour palette to reduce cognitive load, which offers improved accessibility.
4. **Multi-Country Comparison:** The first version of the line chart was single-country viewing only. Based on P2's feedback, I enabled multi-select interaction so that users can see and compare multiple countries' emissions trends simultaneously.
5. **Reset and Navigation:** P3 indicated the need for a "Reset Filters" button. While Tableau lacks a dedicated reset button, I worked around this limitation by designing filter panels that are easy and straightforward to toggle.

These modifications were made consistently within the final dashboard, here. Relative to the old version, still accessible here, the end product contains numerous improvements:

- A scrollable left-right layout supports a storytelling pattern following the steps in the food system and actions on the part of users.
- Individual sections within the charts are encased within white wrappers for better readability, using consistent margins and spacing.
- Tooltips were supplemented with context-relevant metrics and notes, supporting users of all proficiency levels.
- Some new visualizations such as the inequality bubble chart and sector treemap were added in response to the feedback of Project Report 2 and further effort on task abstraction.

Along the way, I re-examined the mapping of user tasks to visual encodings, making sure each design element was helping with intended insights. This continuous reflecting and revising along with user testing by hand, ensured the dashboard evolved into an integrated and interactive visualization environment.

In practice, therefore, the iterative process was not linear but circular, reflecting the nested nature of Munzner's design model. By cycling through data abstraction, encoding decisions, and user feedback, I was able to progressively enhance the readability, usability, and user experience of the dashboard. This process also confirmed the importance of empirical user feedback, as emphasized in Lam et al. (2012), and demonstrated the advantage of iterative refinement in developing effective visual analysis tools.

Lessons Learned

During this visualization project, I cultivated a deep respect for the layered and iterative process of good visual design. Of all the things that I have learned, maybe the most useful was that good visualization is less about translating data into charts than about matching up those visual forms with real user needs and cognitive patterns. Initially, I was fixated on completeness, trying to show everything about the data at once but through peer review and testing with users, I learned the value of clarity, storytelling, and guided exploration. Simplifying the design from a cluttered vertical scroll to a horizontally arranged narrative demonstrated to me how crucial layout, space, and flow are to the user experience. I realized from Heer and Shneiderman's (2012) study the importance of interactive dynamics filters, tooltips, and linked views as an instrument for functionality as well as for engagement and insight generation.

The second key lesson was how design decisions must evolve based on user input. I came to appreciate accepting criticism not as a barrier but as a means to improve. The user study highlighted usability issues that I was not aware of, such as inconsistent filters and inaccessible color schemes, and their correction made the dashboard much improved. I also became more comfortable using visualization techniques to the structure of the dataset such as pivoting a dataset for treemaps or adding calculated fields to grow per capita numbers. Overall, this exercise helped me learn to view visualization not only as a type of aesthetics but as a thinking and communication process one that takes empathy, iteration, and awareness of both data and design considerations.

Reference

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Tableau Dashboard Link

Final Dashboard Link
Initial Dashboard Link