Assignment Coversheet – GROUP ASSIGNMENT

Assignment Details:

Assignment Title	**Greenhouse Gas Emissions Data Visualisation**				
Assignment number	**COMP5048 Assignment 2**				
Unit of Study Tutor	**Wanxin Liu**				
Group or Tutorial ID	**CC-07-G01**				
Due Date	**28th May 2024**	Submission Date	**28th May 2024**	Page Count	**8**

Membership

Group Name/Number	CC-07-G01				
Family Name	Given Name (s)	Student Number (SID)	Unikey	Contribution + percentage	Signature
Duan	Xinqi	530810106	xdua0517	20%- Data preprocessing, The whole content of the Task 1.	Xinqi Duan
Wu	Zhengri	540271773	zhwu0901	20% - Data Preprocessing, Task 2 comparison and contribution visualization	Zhengri Wu
Mehta	Rajiv	540771859	rmeh0608	20% - Task 3 – Initial Data Cleaning, PCA, GHG and PCA Grouping dashboard.	Rajiv Mehta
Fu	Ngai Chun	540363470	ngfu0299	20% - Data preprocessing, task 4	Ngai Chun Fu
Xu	Zuoqi	520649200	zuxu2414	20% - Task 2 insight of policies. Task 3 "Grouping based on effectiveness of policies" visualization and report.	Zuoqi Xu

Declaration:

1. I understand that all forms of plagiarism and unauthorised collusion are regarded as academic dishonesty by the university, resulting in penalties including failure of the unit of study and possible disciplinary action.
2. I have completed the **Academic Honesty Education Module** on Canvas.
3. I understand that failure to comply with the Academic Dishonesty and Plagiarism in Coursework Policy can lead to the University commencing proceedings against me for potential student misconduct under Chapter 8 of the ***University of Sydney By-Law 1999*** (as amended).
4. This work is substantially my own, and to the extent that any part of this work is not my own I have indicated that it is not my own by acknowledging the source of that part or those parts of the work.
5. The assessment has not been submitted previously for assessment in this or any other unit, or another institution.
6. I acknowledge that the assessor of this assignment may, for the purpose of assessing this assignment may:
   a. Reproduce this assignment and provide a copy to another member of the school; and/or
   b. Use similarity detection software (which may then retain a copy of the assignment on its database for the purpose of future plagiarism checking).
7. I have retained a duplicate copy of the assignment.

Please type in your group number here to acknowledge this declaration:	CC-07-G01

How would you visualise your data?

COMP5048 Assignment 2

Xinqi Duan
530810106

Zhengri Wu
540271773

Rajiv Mehta
540771859

Ngai Chun Fu
540363470

Zhuoqi Xu
520649200

CC-07-G01
Wanxin Liu

I. Task 1

A. Visualization Overview

According to the data description [1], greenhouse gas (GHG) emissions data from energy generation are used as total greenhouse gas emissions. In this task, three main interactive visualizations were created based on Greenhouse Gas (GHG) emissions from energy: Global GHG Emissions Map, Total Global GHG Emissions, and Top 5 GHG Emitting Countries.

B. Global GHG Emissions Map

Fig. 1. Global GHG Emissions Map

The map displayed in Fig. 1 shows the greenhouse gas emissions of each country in the selected year. Through colors and labels, we can intuitively see the emission levels and relative percentages of each country.

1) Evaluation and Modification: Initially, the color scheme of the map did not consider user limitations such as color blindness. People with color vision deficiencies have difficulty distinguishing colors, and our visualization design should not ignore the needs of this group [2]. After several rounds of user testing, collect feedback and suggestions from users. We chose and reversed the Color Brewer 5-class PIYG color scheme to ensure color-blind safety and print friendliness. The revised scheme better represents greenhouse gas emissions, with low-emission countries shown in green and high-emission countries in pink. Additionally, Added emission and percentage labels to the map to enhance information readability, making it easier for users to observe and compare emissions across different countries.

2) Axes Arrangement: Used geographic coordinates as axes to intuitively show the location and emission distribution of each country.

3) Visual Variables: Used color and size as the main visual variables to highlight the emissions of different countries. Reversed the color scheme so that low-emission countries are shown in green, intuitively indicating environmental friendliness. Green is chosen to represent low greenhouse gas emissions because it evokes energy and vitality [3]. This fits the theme of environmental protection and low emissions.

C. Total Global GHG Emissions

Fig. 2. Total Global GHG Emissions

Fig. 2 shows the total greenhouse gas emissions of all countries globally in the selected year. By calculating the total emissions of all countries in the selected year, we can intuitively see the global emissions for that year.

1) Evaluation and Modification: The initial version of the total emissions view used a simple number to display the total emissions. After several rounds of user testing, collect feedback and suggestions from users. We found that a graphical representation is more effective because simple graphical displays are intuitive and easy to use [4]. Since only a single discrete data point needs to be displayed, and bar charts are one of the most commonly used data visualization methods suitable for discrete data [5], we decided to use a bar chart to represent the total emissions.

2) Axes Arrangement: Used emissions as the columns axis arrangement, making the bar chart horizontally distributed and ensuring the final dashboard layout is neat.

3) Visual Variables: Used a bar chart to represent annual total emissions, making the data display intuitive and concise.

D. Top 5 GHG Emitting Countries

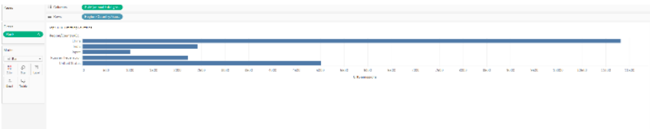

Fig. 3. Top 5 GHG Emitting Countries

Fig. 3 shows the top five countries with the highest greenhouse gas emissions in the selected year. Using the ranking calculation field, dynamically displays the top five emitting countries, helping users quickly identify the largest contributors to emissions.

1) Evaluation and Modification: The initial version of the bar chart was arranged vertically. After several rounds of user testing, collect feedback and suggestions from users. Finally, to maintain uniformity with the dashboard, it was changed to a horizontal arrangement.

2) Axes Arrangement: In the top five countries view, using countries as rows and emissions as columns helps users intuitively see the top greenhouse gas-emitting countries while making the bar chart horizontally aligned. This also keeps the bar charts in the dashboard consistent.

3) Visual Variables: Used a bar chart to represent the emissions of the top five countries because bar charts are easy for visual comparison, showing the differences in emissions among the top five countries [6].

E. Conclusion

Fig. 4. Final Dashboard

The Fig 4 is the final Dashboard. Its visualizations have been carefully designed with the user experience in mind, including colour-blind accessibility and intuitive interaction mechanisms. Overall, the visualizations show that global greenhouse gas emissions are increasing year by year, with China's emissions increasing the most dramatically.

Interaction: Used a slider to select the year, allowing users to explore data from different years dynamically. The slider is suitable for explaining linear time, with the entire timeline visible and easily interactable [7].

II. Task 2

A. CO2 and Methane Emissions Comparison

For this task, the data on Greenhouse Gas (GHG) emissions from energy is used as the total GHG emissions according to the data description [1]. Since the methane proportion in GHG emissions excluding carbon dioxide is approximately 77.75% in 2021 [8], the CH_4 emissions can be calculated from the total GHG emissions. Additionally, the total CO_2 emissions from fuel combustion data are directly used for this visualisation without adding the source from fugitive GHG because the 4% [11] carbon dioxide proportion in fugitive GHG is small and ignorable.

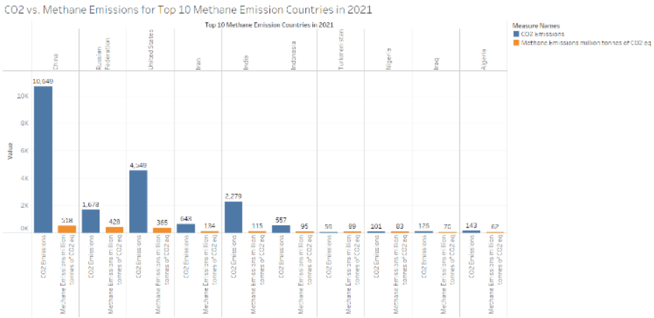

Fig. 5. CO_2 and Methane Emissions Comparison

1) Evaluation and Modification: The multi-series line chart was chosen in the first place to visualise the comparison between CO2 and Methane emissions for the top 10 countries with the highest methane emissions in 2021. Because the line chart can clearly show the change through time, and comparison can be derived from the multiple lines [9]. However, this visualisation is unsuitable according to the analytic inspection because the carbon dioxide emissions data is provided only for 2021. Thus the visualization method is changed to the side-by-side bar chart for emissions comparison in this single year to secure the accuracy of the visualization [10]. The bar chart is optimal for demonstrating the attributes of each category and conveying the comparison among the characteristics with a side-by-side layout. According to the questionnaire results, the bar chart can effectively compare the CO2 and methane emissions for the top 10 countries with the highest methane emissions in 2021 with a clear and direct comparison between the two gas emissions for each country.

2) Axes Arrangements: With a common practice for comparing different categories in the bar chart, the horizontal axis is assigned to the countries variable while the vertical axis shows the specific emission values; and two gas emissions as the sub-category for each country on the verticle axis. This arrangement allows the audience to intuitively compare the gas emissions for each nation through the particular quantity of emissions indicated by the height of the bars, as well as the comparison across the chosen countries.

3) Visual Variables: The bars are set with two colours -- blue for CO2 emissions and orange for methane emissions -- to distinguish between the two types of emissions and highlighted in the legend label. This visual variable can effectively convey categorical information and reduce confusion. The bars' width is consistent to avoid any bias that might arise from varying widths. The volume of emissions is represented by the height of the bars -- with taller bars indicating higher emissions. This direct correlation between height and value makes the data easy to interpret. Each bar is labelled with the exact value of emissions. The direct labels provide precise information without referring to an axis scale thus enhancing the clarity and immediacy of the data presentation.

4) Interaction: Since the visualisation of methane emissions distribution employs the transposed data while the original version is used for the comparison, the data for those steps cannot be connected in Tableau. Thus the only interaction for this step is to highlight the bar when chosen.

The top 10 countries that emitted the highest volume of methane in 2021 displayed in Fig. 5 are China, the Russian Federation, the United States, Iran, India, Indonesia, Turkmenistan, Nigeria, Iraq, and Algeria. The figure is sorted by the methane emissions in 2021. According to the visualization, there is no strong correlation between emitted carbon dioxide and methane, but the countries emitting more CH4 are likely to have a higher emission of CO2 correspondently.

B. Sources of Methane Emissions

From the CO_2 equivalent emission equation [12]:

$$CO_2 \text{ Equivalent Emission} = \Sigma \text{ Emission}_{Gas} * GWP_{Gas} \quad (1)$$

Can derive the methane emissions calculation from CO_2 equivalent emission:

$$\text{Emission}_{CH_4} = CO_2 \text{ Equivalent Emission} * \text{Proportion}_{CH4} / GWP_{CH4} \quad (2)$$

According to the reviewed literature, the methane proportion in GHG released from Fugitive, Coal, Oil, and Gas is 96% [11], 2% [13], 1% [14], and 3.8% [15]. The global warming potential (GWP) is the relative effect of GHG compared to carbon dioxide in terms of its warming of the global climate system and is a function of the time frame considered after the emission of the GHG. Since GWP is changed due to influence factors such as timeframe, location, and measurement, it is identified as the most common number in the reviewed literature with a 100-year timeframe which is 25. After establishing the CH_4 emissions for each source, the total methane emissions for each country can be calculated:

$$\text{Total Methane Emission} = \Sigma \text{ Emission}_{CH4, Source} \quad (3)$$

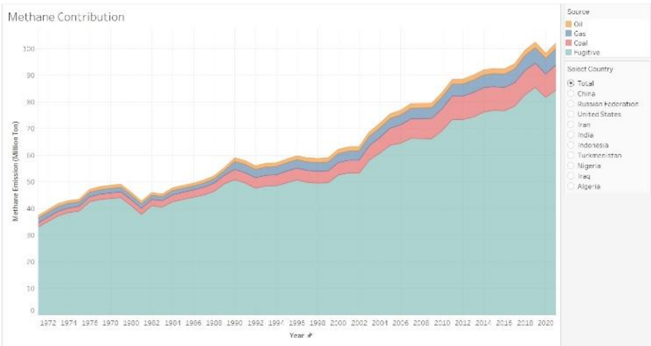

Fig. 6. Total Methane Emissions Contribution for 10 Countries

1) Evaluation and Modification: For investigating the primary methane contributor for those countries as well as the influence of policies and practices, the visualization should have the ability to identify the contribution of each source and the change in trend through time. Thus, the stacked area chart is chosen in compliance with those considerations [16]. The stacked area shows the relative contributions of each source to total emissions with the methane emissions trends over the years. The interview with peers supports the effectiveness of this visualisation with satisfaction in objectives.

2) Axes Arrangements: The year is represented on the horizontal axis, making it intuitive for users to view trends over time. Placing emissions on the vertical axis allows for an intuitive visual assessment of contribution comparison across different sources.

3) Visual Variables: Distinct colours are used to idneify different emission sources including Oil, Coal, Gas, and Fugitive Emissions, and the colour indicators are shown in the legend label. This variable assists in identifying contributions from each source. The stacked area provides a clear visual representation of total emissions while highlighting the contribution of each category. It supports comparison by showing cumulative impacts and individual trends for the contributors.

4) Interactions: The visualisation allows users to filter the displayed data by selecting a specific country from the list. By allowing the user to select different countries, it supports direct comparisons of methane emission profiles and trends across nations. Displaying exact data while hovering over specific points enhances efficiency with the ability to extract detailed information.

According to Fig. 6 and Appendix 1, the primary contributor to methane emission among those countries is fugitive gas. The methane contribution from fugitive emissions is significantly higher than fuel contributors in all of those countries. For fuel combustion sources, the distributions are various across countries. Coal is the most crucial methane contributor from fuel combustion in China, India, and the total data. For the Russian Federation, Iran, Turkmenistan, Nigeria, and Algeria, gas is the most significant fuel contributor. Oil is the primary fuel combustion contributor in Iraq. The methane contribution of fuel combustion in the United States and Indonesia is approximately even.

C. Policy or Practice Factors

There are many policies that may affect the level of methane emissions. For example, fugitive emissions of methane can be reduced by strengthening the management of coal mines and oil and gas fields which is belong to energy policies; Improve livestock management and reduce methane emissions from cattle and sheep by promoting low-emission feeding techniques which is one of Agricultural policies; promoting garbage sorting and reducing the amount of organic waste going to landfills can reduce methane emissions at source which is Waste management. [17] Take China as an example, it committed to its emissions reduction program in the U.S.-China Joint Climate Statement released during the COP26 climate negotiations in 2021, stating that it would implement policies including, but not limited to, those mentioned above. As can be seen from Fig.22 Appendix 1, the growth rate of its methane emissions began to slow down from 2011, and methane emissions decreased significantly from 2014 to 2016, indicating the effectiveness of its policy implementation. [18]

Besides, economic activities and social factors also affect methane emissions. For example, in the United States, see Fig.24 Appendix 1, methane emissions remained stable until 2009, and began to grow at a high rate from 2009, which may be related to the gradual recovery of the economy of the United States after the financial crisis in 2008, and the economic growth has led to an increase in industrial activities and a rise in the demand for energy, which has led to an increase in methane emissions. [19] And in Russia, the collapse of the Soviet Union in 1991, Russia experienced a severe economic recession, and production of industry, agriculture, and livestock decreased dramatically, leading to a decline in methane emissions associated with it (see Fig.23 Appendix 1). And similarly for Iran and Iraq, the large fluctuations (shown in Fig.25 Appendix 1 and Fig.30 Appendix 1) may be related to the fact that it is often in a state of war.

III. TASK 3

A. *Grouping countries by the effectiveness of policies*

We begin by grouping countries based on the effectiveness of GHG governance. We judge the effectiveness of a country's GHG governance by the change in the value of “CO2 emissions/GDP using exchange rates” from 1971 to 2021, i.e., if the overall trend of the values in the observed years is decreasing, it is defined as effective governance; if the overall trend of the values in the observed years is increasing, it is defined as non-effective governance; in addition, if the values fluctuate significantly in the observed years, which is difficult to define whether the overall trend is increasing or decreasing, then it is assigned to the "fluctuating" group.

1) *Axes arrangement and visual variables used:*

To observe the trend, we plot a line chart that show the change in CO2/GDP values by year for each country. Here, "year" are ordered and set as the X-axis, "CO2/GDP" is continuous data and set as the Y-axis. Countries are nominal data, which represented by the visual variable color hue, then different countries can observe in a single chart.

2) *Interaction applied:*

After plotting the line graphs, we divided the countries with a decreasing overall trend into one group, the countries with an increasing overall trend into one group, and the remaining countries with no significant trend in CO2 GDP values in the observed years into one group and plotted each of the three groups of countries in three-line charts. The three different groups "increase", "decrease", and "fluctuation" are created as an interaction so that the user can see which countries are in a specific group and how they are trending after choosing the group.

As mentioned above, we use the attribute CO2/GDP here as a criterion to judge the effectiveness of a country's governance of GHG. The reason is that it is only accurate to judge the change of GHG emissions in a country by combining social and economic indicators, rather than simply judging by greenhouse gas emissions. For example, China's CO2/GDP has been decreasing year by year, but the total GHG emissions continue to rise, which may be due to China's population growth as well as the development of its society, but the decrease in CO2/GDP indicates that China has been effective in its policies to reduce GHG emissions.

In addition to the CO2/GDP attribute, we also wanted to see how each group of countries performed under other attributes, so we added an interaction so that after users select a group, they can filter to see how that group of countries performed on other attributes. Some countries that fall on the CO2/GDP may rise on other attributes. This interaction gives us a more complete picture of these countries.

3) *Evaluations and Modifications of Visualization*

The final idea of the visualization is mentioned above, but at the beginning of the design, we wanted users to have a clear view of the changes in GHG emissions for each country, so we created a filter that could select countries. In addition, we initially used the slope to determine whether the overall trend in each country was up or down, and we kept the slope line in the form of dashed lines to give users an intuitive sense of the classification. The initial visualization is shown in Fig.7.

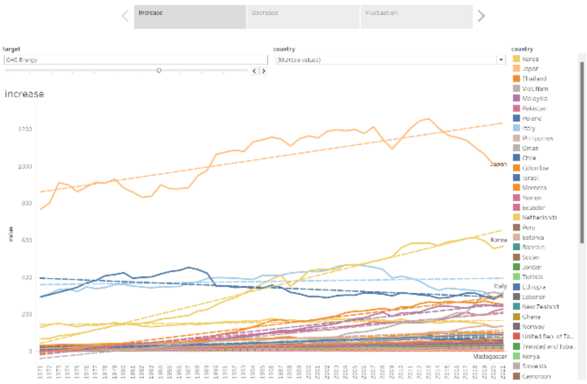

Fig. 7. Initial visualization

The first evaluation method we used here is analytic inspection. According to week 6 lecture, we know that this can be used early in the design phases. We do a cognitive walkthrough, analyze the task and think about how we want the user to use the visualization. First, the user should click on the grouping options "increase", "decrease", "fluctuation" at the top of the dashboard to see what countries are in the group and how they are trending, then the user can filter to other attributes to see how the group of countries performs against the other attributes, and finally the user should be able to select one of the countries in the group to see the change in its value over the years individually. We work through these steps, for example, as shown in the Fig.9., the user looks at the "increase" group, i.e., countries with invalid policies, and then the user selects one of the countries in the group in order to see the trend for that country individually, but the filter doesn't prevent the user from selecting countries outside of the group, and the visualization can't be back to the previous grouping status after the user selects a country, making the user confusing. In addition, during testing we found that filtering the 12 attributes in the form shown is very inconvenient because we can't tell what the next attribute is, and the user may have to click on the filter many times to find the attribute he wants to see.

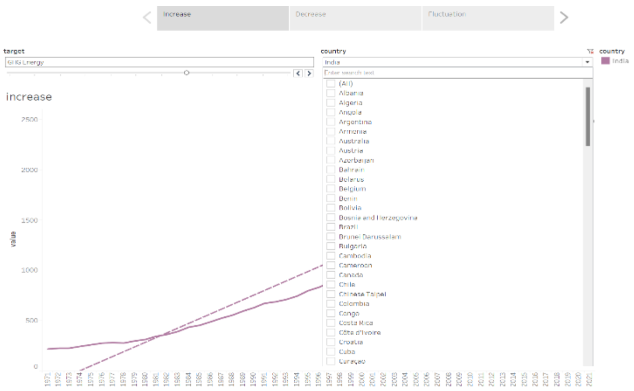

Fig. 8. Initial visualization

With this evaluation, we realized that the main task of task3 is grouping and that looking at trends for a particular country in isolation was not necessary, so we eliminated the filtering for country. And the style of filtering attributes was replaced. The improved visualization is shown in Fig. 9.

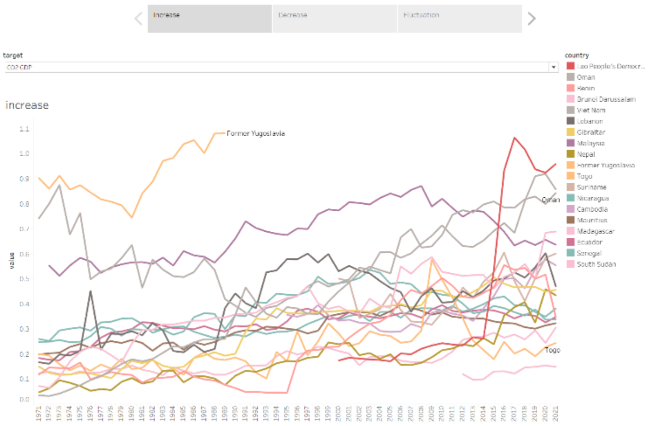

Fig. 9. Final visualization – "Increase" group

As seen in Fig. 9, the other change is we removed the slope lines. This is what we have done after the second evaluation we made. The second evaluation method we used here is interview. We used structured interviews to confirm if our visualization has weakness or not. We first create some pre-defined set of questions and choose our peers but not those who have taken this unit as interviewees. Some of the pre-defined questions are "Can you see the difference between the "increase", "decrease" and "fluctuation"?", "Do you recognize this grouping method?", "Are you interested in seeing detailed trends for specific countries?". During the interview, we first briefly introduce the background of the visualization, then give them some time to explore the dashboard individually and see if they are confused somewhere, and then lead them with the pre-defined questions and these may change according to their response. Through this, we have found that many people are confused about what the dotted line is. So, the final visualization is shown as Fig.9 and Fig. 26 and Fig. 27 in Appendix 2.

B. *The Socio-Economic Relationship with Countries Emissions*

1) *Visualisation Techniques*

A standard principal component analysis was performed on the data to apply dimension reduction on the data to help identify groupings between countries. The model first standardised the features and fitted the data into the 'Sklearn' library. After testing, different component levels, it was found that fitting 2 components gave the best spread in the data and was therefore, used for future analysis. Fig.34 Appendix 2. This PCA data was then extracted for analysis.

This then led to the choice of visualisation being scatter plots, where the independent variables along the x-axis would be the types of emissions, which was then compared to the Total Emissions for GHG or Total Energy Supply for CO2. Thanks to the dimension reduction and data transformation, it also meant that the data could be grouped by also country and year, where each factor could interactively play through the years to see changes, while also being able to remove or add countries to see smaller groups.

Originally, the visualisation would only the user to access a specific year, though, what we found was it was important to allow the user to see changes over different periods of time and watch how they moved comparatively year to year. This meant that implementing year as an action play button was an improvement on the overall dashboard. Additionally, a zoom slider was also added to look and identify smaller groupings of countries.

2) *How did Emissions relate to Socio-Economic*

Starting with 1971, during this time, U.S.A was a clear outlier in the energy consumption and emissions. This was probably due to their involvement in the Vietnam war ending 1975 [20]. Excluding U.S.A, the grouping from other countries becomes clearer. When looking at scatterplots of each factor as seen in Fig.10, (clearer pictures shown in Fig.31 Appendix 2, Fig.32 Appendix 2, Fig.33 Appendix 2, Fig.34 Appendix2) during 1971, countries such as Germany and China were leading the way in amount of energy emissions with Japan and United Kingdom (UK) not trailing far behind. When looking further into the individual factors, Germany and the China heavily relied on coal as their main energy source while Japan and the UK had a mixture of all emission sources except for where all four of the countries had very little fugitive emissions.

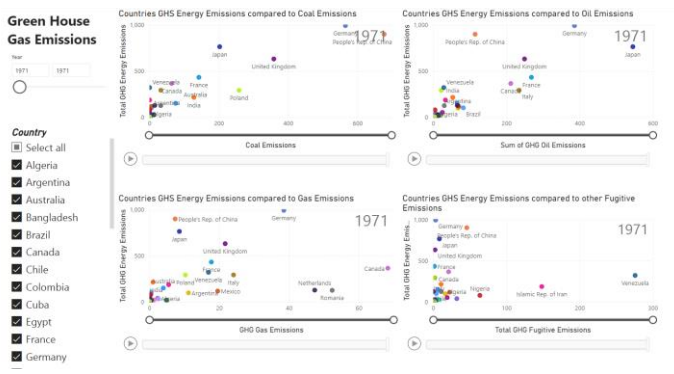

Fig. 10. GHG Emissions in 1971

Looking at the GDP for these countries, from 1970, these countries ranked in the top 10 of highest GDPs, with U.S.A ranking 1st, Germany 3rd behind the USSR, Japan 4th and China in 8th [21]. Though the ranking for China in 1970 might be low comparatively, China's growth in 1971 had raised by 7.1% indicating the country was investing resources into its manufacturing and exports as inflows from international capital and trade increased [22][23].

This is then furthered by looking at the carbon dioxide emissions of each country relative to their GDP ranking. Fig.33 in Appendix 2 indicates that the those with a smaller GDP Purchasing power tend to have the same CO2 TES as those with highly ranked GDP PPPs.

Fast forward to 2021, countries such as China might be producing more emissions in GHG and Carbon Dioxide, when looking relative to their GDP and Population size, countries with a lower population such as Australia are still producing the relative same amount of carbon dioxide. This could be related to the change in ethical views from countries in the west as the push for a net zero carbon emissions and a sudden upshift from China in the early 2000s as they became the manufacturing leaders of the world. The extremities of China's growth compared to the other leading GDP countries can be seen in Figure 11.

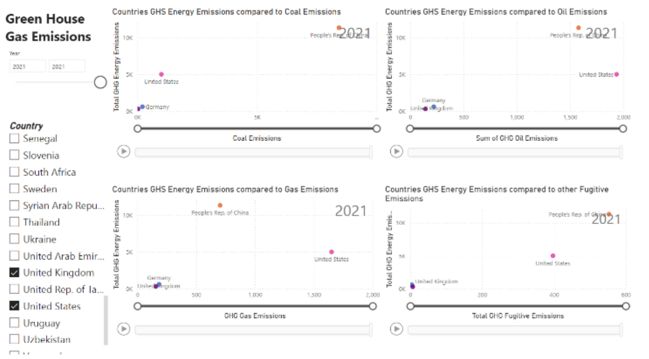

Fig. 11. 2021 GHG Emissions of highest GDP in 1971

IV. TASK 4

Fig. 12. shows the top five countries with the highest greenhouse gas emissions in the 2021, with filtered the top 5 countries in the data.

A. *Top five countries with the highest emissions in 2021*

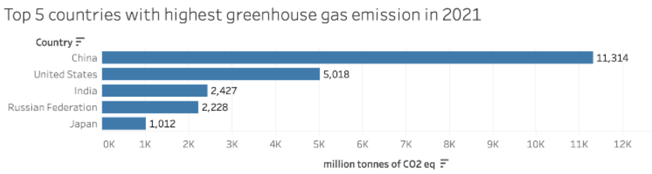

Fig. 12. Top five countries with the highest emissions in 2021

1) Evaluation and Modification: For the Fig. 12., The initial version of this bar chart was arranged based on data order. As we want to include more information in the bar chart, we arranged it with order and label each bar to let audience know clearly the value of each bar in the bar chart so they can make comparison easily among those 5 countries. After performing the questionnaire, the participants are more satisfied with the version that the bar chart is ordered with labels.

2) Axes Arrangement: To observed the top 5 countries with the highest emission in 2021, we are using the greenhouse gas emissions as the x-axis, while the y-axis is the country name, it can let audience to understand the difference between different countries more clearly.

3) Visual Variables: Using a bar chart to represent the emissions of the top five countries because bar charts are easy for visual comparison, showing the differences in emissions among the top five countries [6].

According to the Fig. 12., the top 5 countries having the highest greenhouse gas emissions is China, United States, India, Russian Federation and Japan. We can observe that China has the highest greenhouse gas released in the world and the United States is the second.

B. *Year with the minimum emissions for United States*

From the Fig. 12., we chose the United States to make further investigation. To find the year of minimum emission in United States, we pre-processed the cleaned data, converted the greenhouse gas fugitive emissions to million tonnes CO2 equivalent, select all the United States data and merge it into an excel file according to the year attribute.

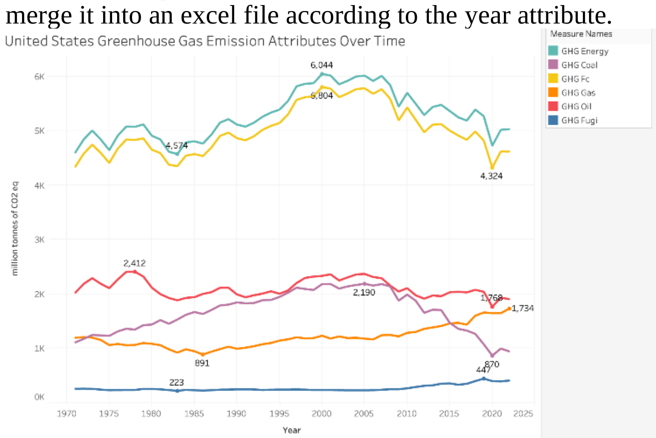

Fig. 13. Greenhouse gas emission attributes in United States over time

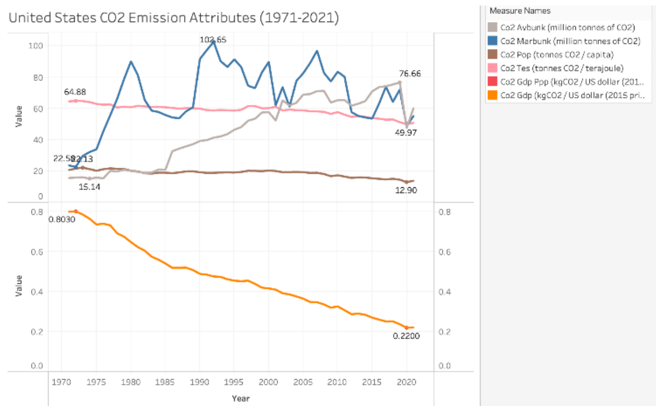

Fig. 14. CO2 emission attributes in United States overtime

1) Evaluation and Modification: Since the 12 attributes can be classified into greenhouse gas and CO2 emissions attributes, and the values of the two types of values is significantly different. Therefore, we separated the attributes into 2 visualisations. Since the value of CO2 GDP and CO2 GDP PPP is between 0 to 1, we visualise them on a different scale to better describe their trend in Fig. 13. After performing an interview, it is suggested that labels of highest and lowest value in the line can be added to better visualises the slightly difference between two years.

2) Axes Arrangement: For Fig. 13., multiple line chart is used to visualise the greenhouse gas released in different sector of the United States over the time. The vertical axis represents the value of greenhouse gas emissions, and the horizontal axis represents the time series. For Fig. 14., there are 2 multiple line chart inside the figure, the vertical axis represents the value of attributes, and the horizontal axis represented the time series. Since the scale of CO2 GDP and CO2 GDP PPP is different from other values, we divided it and create another multiple line chart for better visualisation, with sharing the same horizontal time series. In the Fig. 14., the red and orange lines, which represent the CO2 emissions divided by GDP using exchange rate and purchasing power parities, are fully overlapped, because the exchange rate and purchasing power parities are all using the United States as the standard, therefore, the 2 attributes have the same value over the years and plot the same line.

3) Visual Variables: The multiple line chart used in Fig. 13. and Fig. 14. can let the audience compare the trend of different attributes and the multiple line chart can display more information than normal line chart, in this case, we would like to visualise twelve attributes and let the audience understand the trend of those attributes from 1971 to 2021, the chart can illustrate more information at the same space with comparison differences attributes. We can observe the trend of different attributes and their contribution to the greenhouse gas emissions from energy attribute from the Fig. 13. Also, we labelled the highest and lowest point of the line, make it easier for the audience to understand the peak and lowest point of the attribute.

After considering the trends and values of those attributes for the years, we decided that 1983 is the year of minimum emission for the United States. We found that 1983 has the lowest greenhouse gas emission of energy, which means that the total emission of greenhouse gases, including CO2 will be low, and the attribute greenhouse gas emission of energy is a summarise of all other greenhouse gas related attributes, we are choosing 1983 as the year that United States have the lowest emissions of greenhouse gases.

C. Step-by-step plan transitioning to lower emission

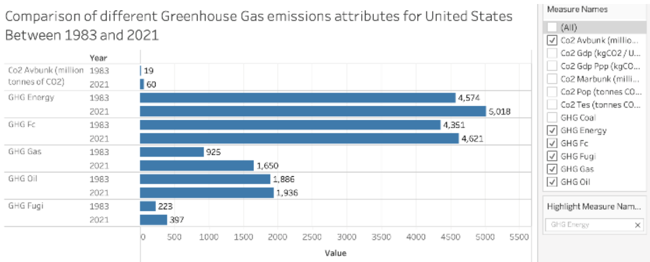

Fig. 15. Comparison of different attributes for United States between 1983 and 2021

1) Evaluation and Modification: In Fig. 15., we are only interested in attributes that increase in 2021. Since those attributes are rising, we would like to learn from past experience and plan for the transition in the United States. Therefore, we are focus on the attributes that increased in 2021, we found that only fugitive emission, international aviation emissions, and fuel combustion for gas and oil have an increase in value between 1983 and 2021. We label the values of each bars add clear information to the visualisation. The interviewee is satisfied with the interactive design that allows them to select different attributes for analysis and the highlight design.

2) Axes Arrangement: In Fig. 15., the year attribute and the 12 attributes is the x-axis, while the y-axis represents the values of those attributes.

3) Visual Variables: According to Fig. 15., the data is visualised by focusing on the difference between 1983 and 2021 The multiple bar chart with label displays the difference of values between the two years for different attributes. It can effectively illustrate relationships between the attributes and the years for comparison, which helps to tell the difference.

4) Interactive design: The interactive visualisation with filter can let the audience to select the different attributes for comparison the difference in 1983 and 2021, and the block can let the audience select a particular attribute they want to highlight.

According to Fig. 15., we noticed that the emission of greenhouse gases for international flight have a significant increase, the CO2 emission in international aviation increased from 19 million tons of CO2 to 60 million tons. One of the reasons is increasing number of passengers, from 1990s to 2021s, the passenger and freight demand increasing rapidly (except for 2020 due to covid), although the energy intensity for each passenger has decreased, the CO2 emission each year still increasing steadily in the world [23]. For transitioning the emission of international flight to lower emission, development, and deployment of low-CO2 fuels, such as hydrogen and biofuel is a method to lower greenhouse gas emission [24]. With smoother air traffic management and lower cruise speed, reducing weight, boosting aircraft lift-to-drag ratios, and improving engine efficiency can result in reduced energy intensity, which can save more energy during the flight [24]. Other than the technology sector, the US government can help to push the model shifting for the aircrafts to lower the emission [24].

The greenhouse gas emissions from energy, it is a composite of the fuel combustion and fugitive emissions. For the fugitive emissions in United States, fugitive emissions are found in oil and gas supply chain [25] and urban area [26]. Facility-scale measurements of oil, natural gas and methane such as BU method and TD measurements can be used to detect the emission [25]. After the issue is detected, then the issue can be fixed easily. For the fuel combustion greenhouse gas emissions, the population of United States increased from 230 million to 336 million [27]. Since the population of United States significantly increased the energy demand has increased. In Fig. 16., the tonnes of CO2 per capita have a reducing trend, therefore it is normal for rising of energy consumption. Although the government is hard to reduce energy demand, but they could promote the renewable energy, the federal legislation can set up law to encourage people to use renewable energy by providing benefits to support the renewable energy technology [28].

Overall, there are many measurements that can be taken to reduce greenhouse gas emissions step by step. The methods mentioned above can help reduce the greenhouse gas emissions attributes increased in 2021.

REFERENCES

[1] International Energy Agency, "Database documentation," Greenhouse Gas Emissions from Energy 2023 Edition, 2023.

[2] B. Jenny and N.V. Kelso, "Color design for the color vision impaired," Cartographic perspectives, vol. 58, pp. 61-67, 2007.

[3] W.U. Xingxing and H. OUYANG. "Research on the Application of Color in the Design of Environmental Protection Posters," Forest Chemicals Review, pp. 309-319, 2022.

[4] D.A. Keim, M.C. Hao, U. Dayal, and M. Hsu, "Pixel bar charts: a visualization technique for very large multi-attribute data sets," Information Visualization, vol. 1(1), pp. 20-34, 2002.

[5] M. Khan and S.S. Khan, "Data and information visualization methods, and interactive mechanisms: A survey," International Journal of Computer Applications, vol. 34(1), pp. 1-14, 2011.

[6] C. Xiong, V. Setlur, B. Bach., E. Koh, K. Lin, and S. Franconeri, "Visual arrangements of bar charts influence comparisons in viewer takeaways," IEEE Transactions on Visualization and Computer Graphics, vol. 28(1), pp. 955-965, 2021.

[7] M.J. Kraak, R. Edsall, and A.M. MacEachern, "Cartographic Animation and Legends for Temporal Maps: Exploration and or Interaction," Proceedings of the 18th International Cartographic Conference, vol. 1, pp253-261, June 1997.

[8] H. Ritchie, P. Rosado, and M. Roser, "Greenhouse gas emissions," Our World in Data, June 2020.

[9] J. Lal, A. Mitkari, M. Bhosale, and D. Doermann, "LineFormer: Line Chart Data Extraction Using Instance Segmentation," in Document Analysis and Recognition - ICDAR 2023, G.A. Fink, R. Jain, K. Kise, and R. Zanibbi, Eds, Lecture Notes in Computer Science, vol. 14191, Springer, Cham, August 2023. https://doi.org/10.1007/978-3-031-41734-4_24

[10] E. Oktay, "Different Types of Bar Charts and Use Cases," The Information Lab Nederland, January 2022.

[11] Y.A. Alhamadani, M.H. Hassim, R.T.L. Ng, and M. Hurme, "The estimation of fugitive gas emissions from hydrogen production by natural gas steam reforming," International Journal of Hydrogen Energy, vol. 42 (14), pp. 9342-9351, April 2017. https://doi.org/10.1016/j.ijhydene.2016.07.274

[12] T.V. Ramachandra, H.A. Bharath, G. Kulkarni, and S.S. Han, "Municipal solid waste: Generation, composition and GHG emissions in Bangalore, India," Renewable and Sustainable Energy Reviews, vol. 82 (1), pp. 1122-1136, February 2018. https://doi.org/10.1016/j.rser.2017.09.085

[13] T.M.L. Wigley, "Coal to gas: the influence of methane leakage," Climatic Change, vol. 108, pp. 601–608, August 2011. https://doi.org/10.1007/s10584-011-0217-3

[14] D.T. Allen, Q. Chen, and J.B. Dunn, "Consistent Metrics Needed for Quantifying Methane Emissions from Upstream Oil and Gas Operations," Environ. Sci. Technol. Lett, vol. 8 (4), pp. 345-349, January 2021. https://doi.org/10.1021/acs.estlett.0c00907

[15] R.W. Howarth, "A bridge to nowhere: methane emissions and the greenhouse gas footprint of natural gas," Energy Science & Engineering, vol.2 (2), pp. 47-60, May 2014. https://doi.org/10.1002/ese3.35

[16] M. Yi, "A Complete Guide to Area Charts," Atlassian, n.d.

[17] J. Gorski, D. Kenyon, B. Israël, and M. Kniewasser, "Policy Approaches for Reducing Methane Emissions," November 2018.

[18] L. Friedman, "What Happened at COP26 on Wednesday: China and U.S. Say They'll 'Enhance' Climate Ambition," The New York Times, 10 November 2021.

[19] F. J. Dresen, "The Piratization of Russia: Russian Reform Goes Awry," Wilson Center, n.d.

[20] N.C. Crawford, "Pentagon fuel use, climate change, and the costs of war," Costs of War, November 2019.

[21] F. R. B. Mathisen, "Mapped: The world's largest economies, sized by GDP (1970-2020)," Visual Capitalist, April 2022.

[22] Database.earth, "Annual GDP (gross domestic product) by country in 1971 (World Map)," n.d.

[23] S. Kobayashi, J. Baobo, and J. Sano, "The 'Three Reforms' in China: Progress and Outlook," Japan Research Institute Periodical RIM, vol. 45, September 1999.

[24] H. Ritchie, "What share of global CO_2 emissions come from aviation?" OurWorldInData.org, April 2024.

[25] M. Sharmina, et al., "Decarbonising the critical sectors of aviation, shipping, road freight and industry to limit warming to 1.5–2°C," Climate Policy, vol. 21(4), pp. 455–474, October 2020. https://doi.org/10.1080/14693062.2020.1831430.

[26] A.A. Ramón, et al., "Assessment of methane emissions from the U.S. oil and gas supply chain," Science, vol. 361(6398), pp. 186-188, June 2018. https://doi.org/10.1126/science.aar7204

[27] G. Plant, E.A. Kort, C. Floerchinger, A. Gvakharia, I. Vimont, and C. Sweeney, "Large fugitive methane emissions from urban centers along the U.S. East Coast," Geophysical Research Letters, vol. 46 (14), pp. 8500–8507, July 2019. https://doi.org/10.1029/2019GL082635

[28] Macrotrends, "U.S. Population 1950-2024", n.d.

[29] K.L. Donald, "A critical assessment of renewable energy usage in the USA", Energy Policy, vol. 31(4), pp. 353-367, March 2003. https://doi.org/10.1016/S0301-4215(02)00069-1

APPENDIX 1

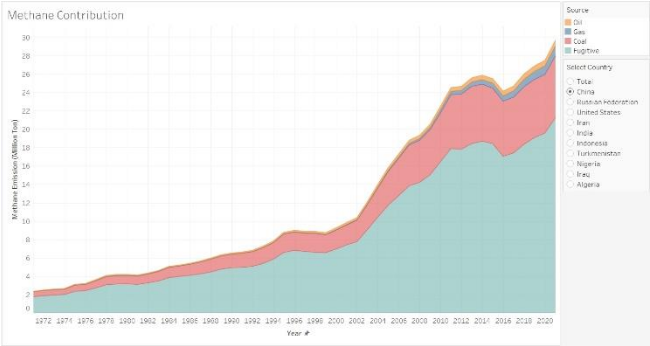

Fig. 16. Methane Emissions Contribution in China

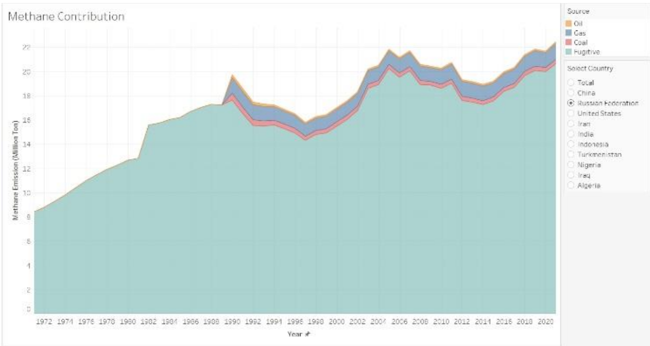

Fig. 17. Methane Emissions Contribution in Russian Federation

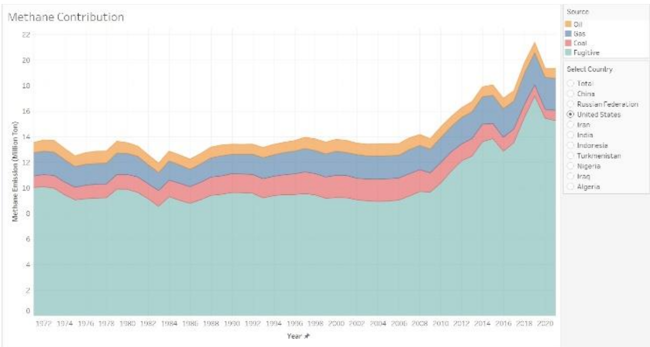

Fig. 18. Methane Emissions Contribution in United States

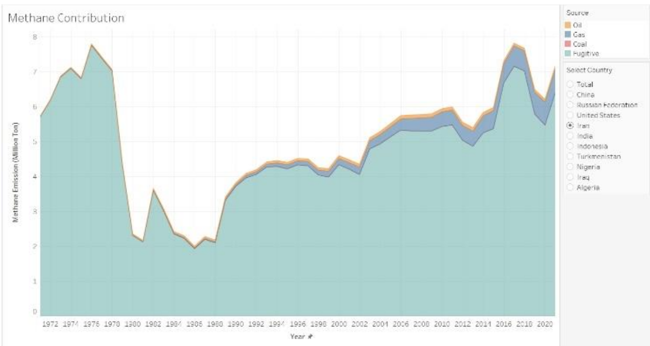

Fig. 19. Methane Emissions Contribution in Iran

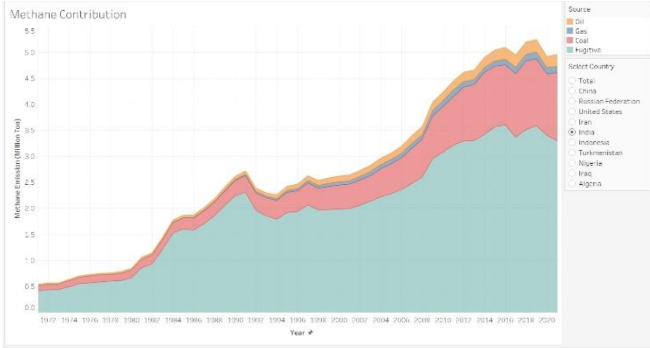

Fig. 20. Methane Emissions Contribution in India

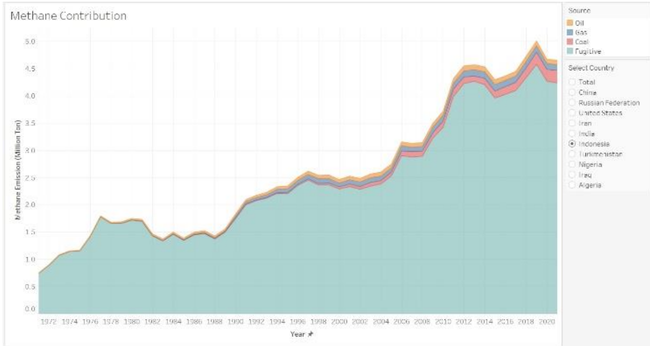

Fig. 21. Methane Emissions Contribution in Indonesia

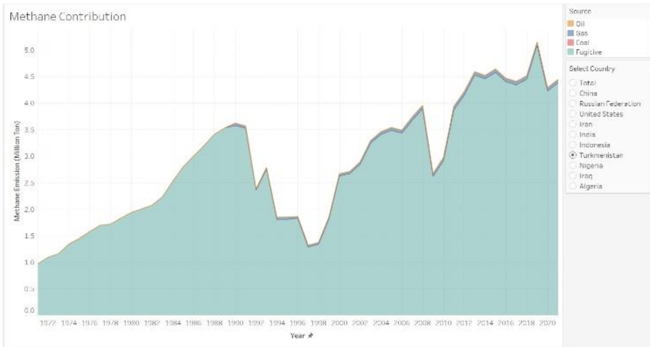

Fig. 22. Methane Emissions Contribution in Turkmenistan

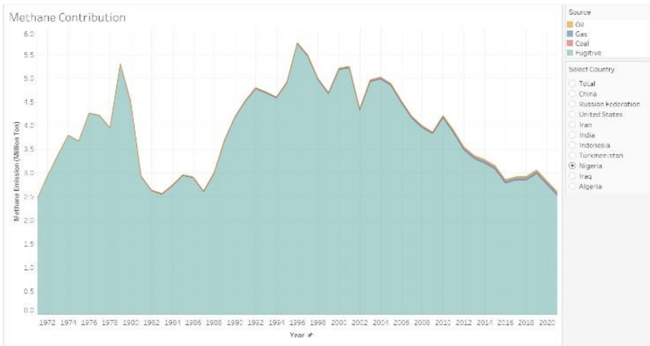

Fig. 23. Methane Emissions Contribution in Nigeria

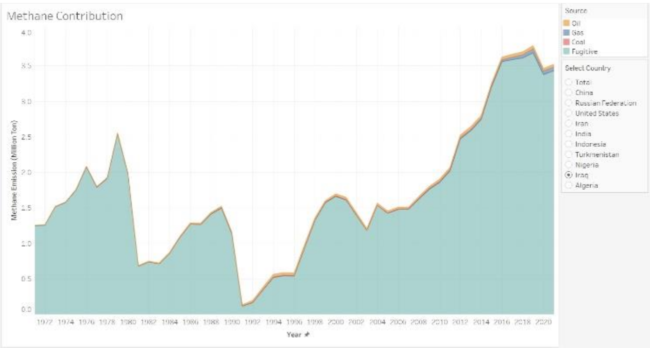

Fig. 24. Methane Emissions Contribution in Iraq

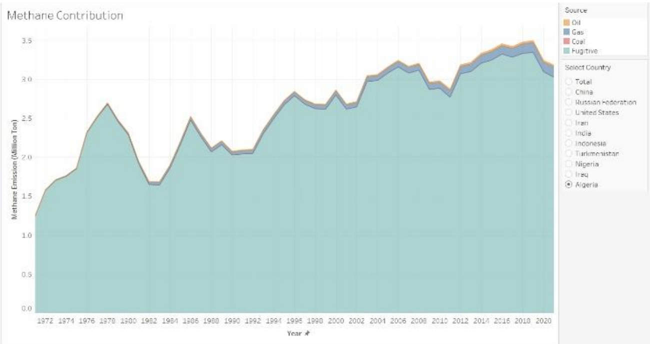

Fig. 25. Methane Emissions Contribution in Algeria

APPENDIX 2

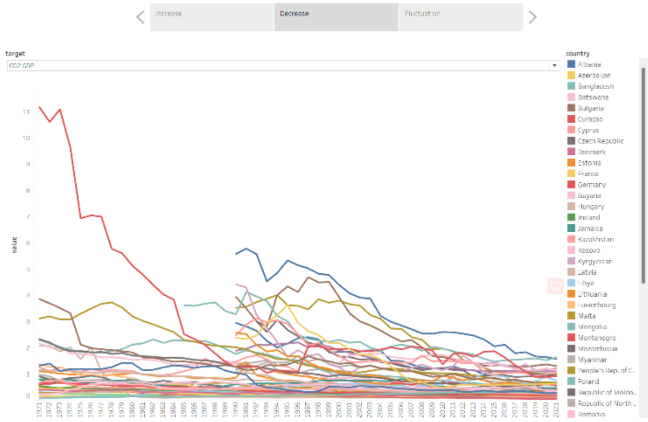

Fig. 26. Final visualization – "Decrease" group

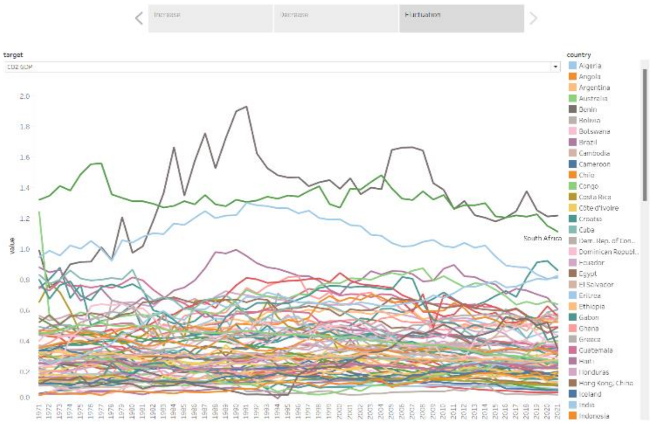

Fig. 27. Final visualization – "Fluctuation" group

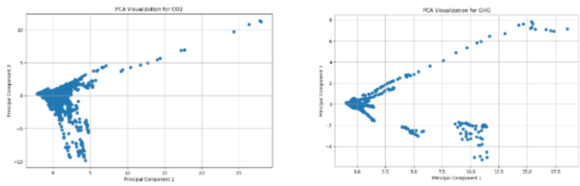

Fig. 28. Spread from PCA at 2 components

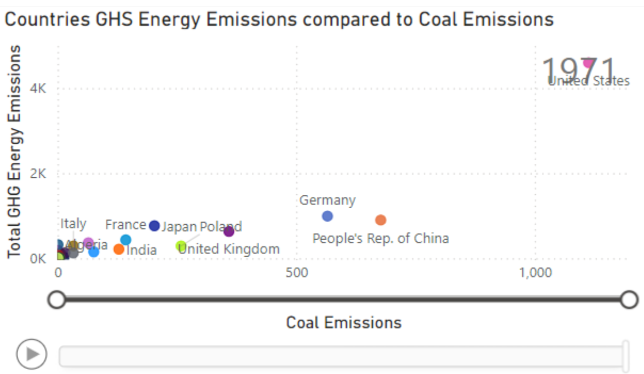

Fig. 29. 1971: Total GHG Emissions vs Coal Emissions

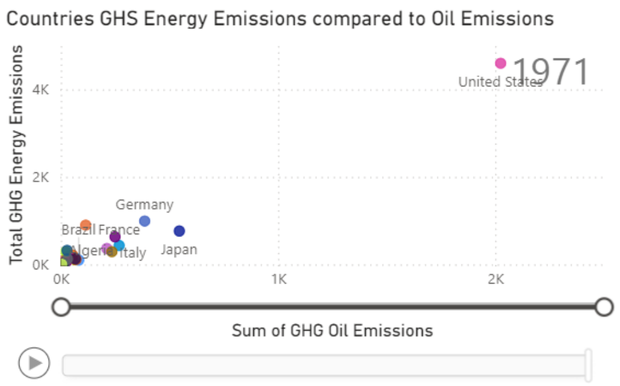

Fig. 30. 1971: Total GHG Emissions vs Oil Emissions

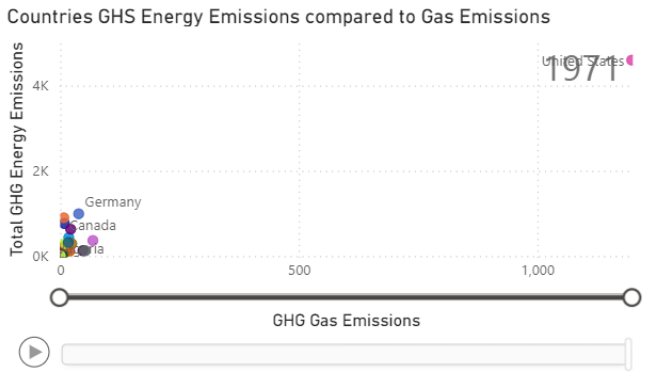

Fig. 31. 1971: Total GHG Emissions vs Gas Emissions

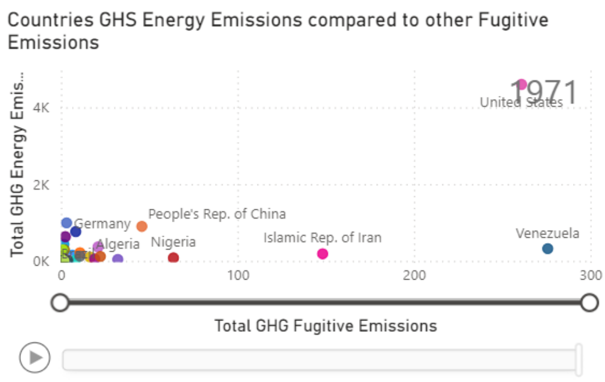

Fig. 32. 1971: Total GHG Emissions vs Other Fugitive Emissions

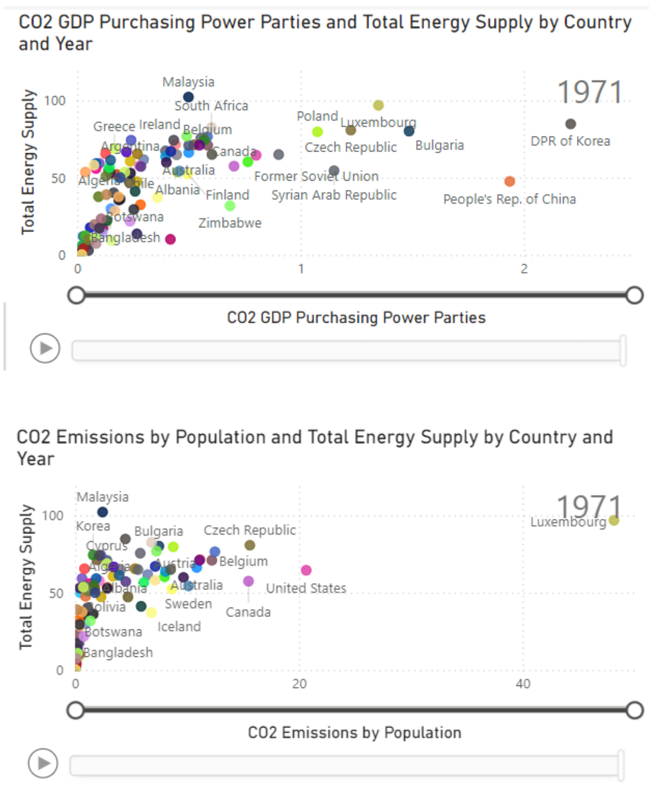

Fig. 33. Total Energy Supply by GDP PPP and Population in 1971

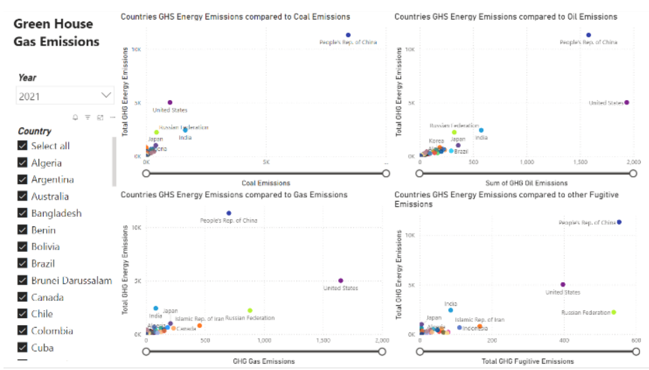

Fig. 34. 2021 Greenhouse Gas Emissions Dashboard

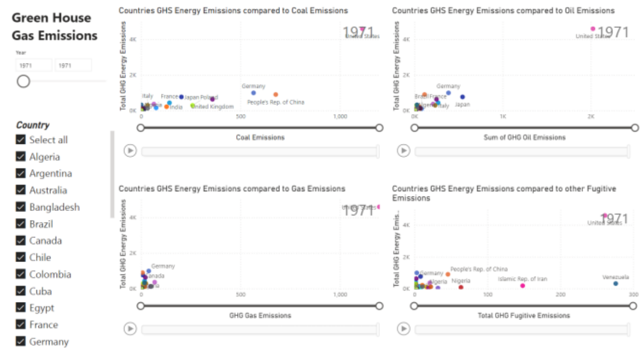

Fig. 35. 1971 Carbon Dioxide Emissions Dashboard

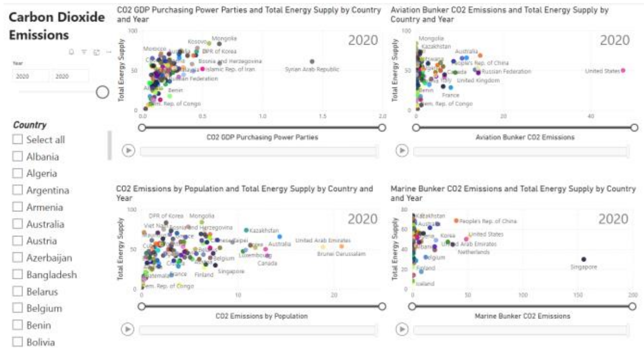

Fig. 36. 2020 Carbon Dioxide Emission Dashboard

APPENDIX 3

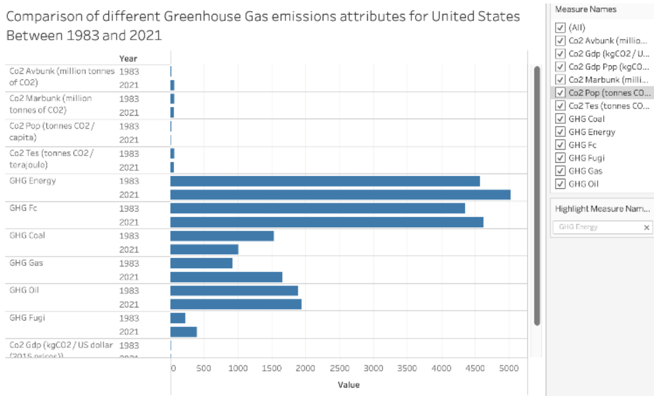

Fig. 37. Comparison of different attributes for United States between 1983 and 2021 - filter

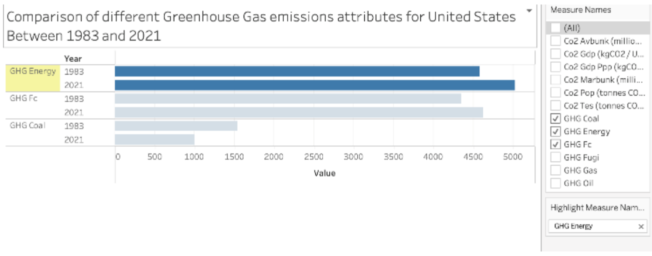

Fig. 38. Comparison of different attributes for United States between 1983 and 2021 - highlight