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CO_2 emission heat map of Gulf Cooperation Council region using Python for Geographic Information Systems

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Abstract. As part of the efforts to ensure a place in the global competitive landscape, Oman is aligning itself with sustainable development through diversified economic measures. To address the United Nations thirteenth Sustainable Development Goal (SDG) which is climate action, the stakeholders of Oman need to understand the carbon dioxide (CO_2) emissions and compare the amount of CO_2 with the emissions in neighbouring Gulf Cooperation Council (GCC) countries such as United Arab Emirates (UAE), Bahrain, Qatar, Kuwait, and Kingdom of Saudi Arabia (KSA). In this research, an attempt is being made to collect the CO_2 emission for all these countries and show them on a web map using python programming language. The data ranging from year 1964 to 2021 is collected from CO_2 and Greenhouse Gas Emissions in Comma Separated Values (csv) format. For each country, an approximate location for Capital in terms of Latitude and Longitude is taken from google maps. Using folium library of python, these locations and CO_2 emission for a particular year is plotted on google map Application Programming Interface (API). The findings reveal that Oman's CO_2 emissions from fossil fuels and industry in 2022 year is 72 million tonnes which is relatively lower when compared to those of smaller GCC countries such as Qatar (101 million tonnes) and the UAE (244 million tonnes). Nonetheless, a gradual upward trend of 12 million tonnes of CO_2 emissions has been observed in Oman between the years 2019 to 2022. The python program provides an easy way to visualise the CO_2 emission heatmap without the need of any proprietary software or program.

Keywords: CO_2, Folium, Oman, Python, SDG

1. Introduction

With the cities in GCC region becoming increasingly populous, urban transportation is now a major source of carbon emissions and environmental damage [1]. Given the challenges posed by urban transportation related carbon emissions, the main research question of this study is how these emissions can be easily displayed and visualized using the power of python programming language for GIS. The aim of this research is to study the CO_2 emission data available for GCC region countries such as Oman, Qatar, Bahrain, Saudi Arabic, Kuwait, and UAE and try to show the amount of emission year wise for each country on a web map using Folium python library for GIS. This research is highly relevant to the current global challenges of climate change and urban development. The findings of this study can help policymakers, urban planners, and environmentalists in the GCC region to better understand the growing emissions of CO_2. The stakeholders can visualize the emissions in the form of a heat map, which can help them to identify the countries that are emitting the most CO_2 relative to their size and area. Heat mapping, from a GIS perspective, is a method of showing the geographic clustering of a phenomenon. Sometimes also referred to as hot spot mapping, heat maps show locations of higher densities of geographic entities (although hot spot analysis tends to be used to show statistically significant patterns [3]. Heatmaps were generated for rapid detection of landslide using open-access satellite radar data in Google Earth Engine to assess the damage and save lives [4]. Open-source technologies like Python have many GIS code libraries such as Folium that now provide robust alternatives to desktop GIS in a variety of use-scenarios [5] like one used in this research.

2. Methodology

2.1 Program Development Environment

The program development environment is based on Google Colaboratory (Colab) which is an interactive environment hosted on web that allows researchers to write and execute python code without the need of any configuration or download of any Interactive Development Environment (IDE). Colab notebooks allow to combine executable code and rich text in a single document, along with images, HTML, LaTeX and more. Colab notebooks are stored in Google Drive account and can be easily shared with co-workers or friends, allowing them to comment on your notebooks or even edit them [6]. In this work, google colab is used to run and execute the code written in python for displaying **CO_2** emission heatmap.

2.2 Folium Python Library

Folium builds on the data wrangling strengths of the Python ecosystem and the mapping strengths of the Leaflet.js library. Manipulate your data in Python, then visualize the data in a Leaflet map via Folium. Folium makes data visualization easy that’s been manipulated in Python on an interactive leaflet map. This folium library enables both the binding of data to a map for choropleth visualizations as well as passing rich vector/raster/HTML visualizations as markers on the map. The folium library has several built-in tiles sets from OpenStreetMap, Mapbox, and Stamen, and supports custom tile sets. Folium supports both Image, Video, GeoJSON and TopoJSON overlays and has several vectors layers-built in. [7].

2.3 Pandas Python Library

Pandas is a Python package that provides fast, flexible, and expressive data structures designed to make working with "relational" or "labeled" data both easy and intuitive. This library aims to be the fundamental high-level building block for doing practical, real world data analysis in Python. Additionally, Pandas has the broader goal of becoming the most powerful and flexible open-source data analysis / manipulation tool available in any language [8].

2.4 Data Used

The data for this work is taken from an article that was first published in May 2017 and last revised in August 2020 called CO_2 and Greenhouse Gas Emissions. The data was created to address how emissions are changing in each country and is your country making progress on reducing emissions? A database is available for CO_2 and Greenhouse Gas Emissions for the entire world [2]. The data is available in the form of Country’s annual CO_2 emissions. For this work, the data for GCC Countries is used ranging from the year 1964 to 2021. The annual CO_2 emissions is considered in million tonnes (year 2021) as shown in following table1. For plotting the location on web map, geographic coordinates in degree decimals of Latitude and Longitude are considered for capital region of each country in GCC [9]. The geographical area information is taken from GCC Wikipedia [10].

Table 1. *Sample Data (2021) used in this work*

country	population	CO_2 (Million Tonnes)	Lat (Degree Decimals)	Long (Degree Decimals)	Geographical Area (Sq. Km)
Bahrain	1463266	39.016	26.2154	50.5832	786.5
Kuwait	4250111	106.134	29.3697	47.9783	17,818
Oman	4520474	80.991	23.6139	58.5922	309,500
Qatar	2688239	95.667	25.2747	51.5245	11,581
Saudi Arabia	35950396	672.38	24.6905	46.7096	2,149,690
UAE	9365149	204.087	24.4648	54.3618	83,600

2.5 Python Program Code

A python code is written as follows using folium and pandas library and executed using google colab notebook. The program can be found at https://colab.research.google.com/drive/1tea1LPrlys1ZmfzcwzJkpod-1YcTfJfU?usp=sharing
This code is completely written by Amol Ganesh Deshmukh, Geomatics Lecturer in Military Technological College, Oman.

```
!pip install pandas
!pip install folium
import folium
from folium import plugins
import pandas as pd
from google.colab import files
import io
# Create a folium map centered at a specific location
map_location = folium.Map(location=[26,52.75], zoom_start=6)
# Add a Google Maps layer as an overlay
api_key = 'AIzaSyCLA76azA5hSdwsZDdAz2dzCrkG-tgVzXE'
google_tiles = 'https://mt1.google.com/vt/lyrs=m&x={x}&y={y}&z={z}&s=Ga'
#google_tiles = 'https://mt1.google.com/vt/lyrs=y&x={x}&y={y}&z={z}'
google_layer = folium.TileLayer(tiles=google_tiles, attr='Google', name='Google Maps',
overlay=True)
map_location.add_child(google_layer)
year  = int(input("Enter the year. Range :1964-2021  "))
data= pd.read_excel('/content/GCC_CO2.xlsx')
heatmap_data = []
for idx in data.index:
        if data['year'][idx] == year:
        radius = data['CO2'][idx] *100
        heatmap_data.append([data['Latitude'][idx], data['Longitude'][idx], radius])
#print(heatmap_data)
# Create a heatmap layer and add the layer to the map
heatmap= plugins.HeatMap(heatmap_data)
map_location.add_child(heatmap)
# Add layer control to switch between base layers
```

```
folium.LayerControl().add_to(map_location)
map_location
```

2.6 Step by Step explanation of Python Program Code

!pip install pandas: This line starts with an exclamation mark (!). In Jupyter Notebook or a similar interactive environment, this is used to run shell commands from within the notebook.
pip is a package manager for Python, used to install and manage Python packages (libraries).
install is the command telling pip to install a package.
pandas is the name of the package you want to install. In this case, you're installing the "pandas" library, which is a powerful data manipulation and analysis library for Python.

!pip install folium: This line is similar to the first line, but for installing a different Python package. Folium is the name of the package you want to install. This is a Python library used for creating interactive maps.

import folium: This line imports the `folium` library, which is used for creating interactive maps in Python. Importing folium allows you to create and customize maps with various features and layers.

from folium import plugins: This line imports the `plugins` module from the `folium` library. The `plugins` module provides additional functionality and plugins for creating interactive maps with Folium.

import pandas as pd: This line imports the `pandas` library and assigns the alias `pd`. Using an alias like `pd` is a common convention when working with `pandas`. `pandas` is a powerful data manipulation and analysis library for Python.

from google.colab import files: This line imports the `files` module from the `google.colab` package. `google.colab` is typically used in Google Colab notebooks, a cloud-based Python development environment. The `files` module provides functions for interacting with files in a Colab environment, such as uploading and downloading files.

import io: This line imports the `io` module, which is part of Python's standard library. The `io` module provides tools for working with input and output operations, such as reading and writing data to streams and buffers.

Create a Folium Map: `map_location= folium.Map(location=[26, 52.75], zoom_start=6)`:
This line creates a Folium map centered at latitude 26 and longitude 52.75 with an initial zoom level of 6. This sets the initial view of the map.

Add a Google Maps Layer: `api_key= 'AIzaSyCLA76azA5hSdwsZDdAz2dzCrkG-tgVzXE'`
This variable stores a Google Maps API key.
`google_tiles= 'https://mt1.google.com/vt/lyrs=m&x={x}&y={y}&z={z}&s=Ga'`:
This URL template is used to fetch Google Maps tiles. This URL uses the provided API key to access the map tiles.
`google_layer= folium.TileLayer(tiles=google_tiles, attr='Google', name='Google Maps', overlay=True)`:
This line creates a Tile Layer using the Google Maps URL template. The layer is given the name 'Google Maps' and is set as an overlay on the map.
`map_location.add_child(google_layer)`
This adds the Google Maps layer to the Folium map.

User Input for Year: This line prompts the user to enter a year, which is then converted to an integer and stored in the `year` variable.
`year = int(input("Enter the year. Range: 1964-2021 "))`:
Read Data from Excel File
data= pd.read_excel('/content/GCC_CO2.xlsx')`:
This line reads data from an Excel file located at '/content/GCC_CO2.xlsx' and stores the values in a pandas Data Frame called `data`.

Create Heatmap Data: `heatmap_data` is initialized as an empty list.
A loop iterates through the rows of the `data` Data Frame. For each row, it checks if the 'year' column matches the user-entered year. If the year value matches, then the code calculates a radius value based on the 'CO_2' column and appends a list containing latitude, longitude, and radius to the `heatmap_data` list.

Create a Heatmap Layer: `heatmap= plugins.HeatMap(heatmap_data)`
This line creates a heatmap layer using the data collected in the previous step.

Add Heatmap Layer to Map: This adds the heatmap layer to the Folium map, displaying the heatmap based on the data for the selected year.
`map_location.add_child(heatmap)`

Overall, this code creates an interactive map that displays a heatmap of CO_2 data for a user-selected year, with Google Maps as an overlay. The heatmap's intensity is based on CO_2 values from the Excel file.

3. Results

The following figures which are the output of the python program shows the heatmap showing CO_2 emission for different years of GCC countries.

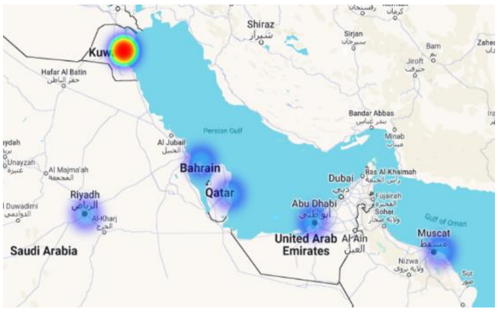


Figure 1. CO_2 emission heatmap for year 1964

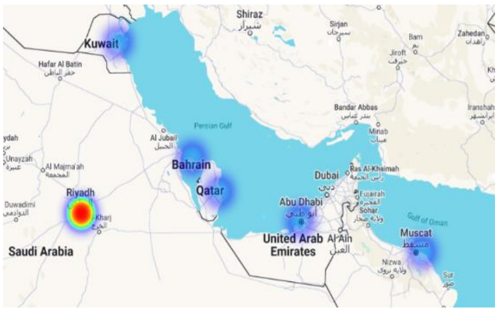


Figure 2. CO_2 emission heatmap for year 1974

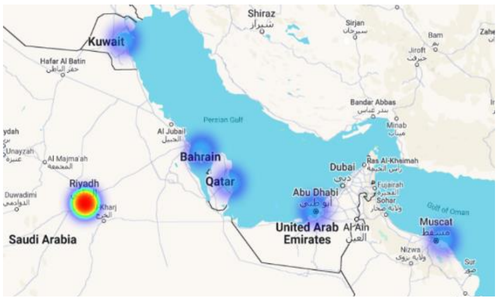


Figure 3. CO_2 emission heatmap for year 1984

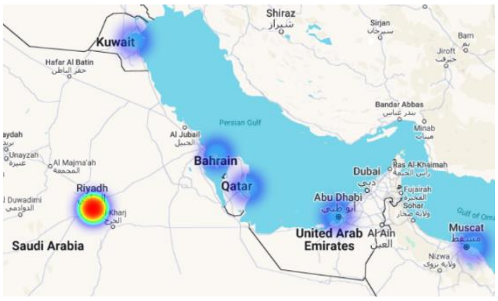


Figure 4. CO_2 emission heatmap for year 1994

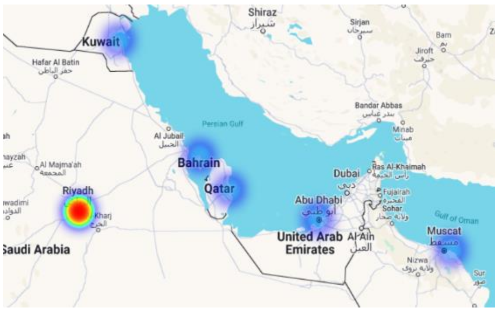


Figure 5. CO_2 emission heatmap for year 2004

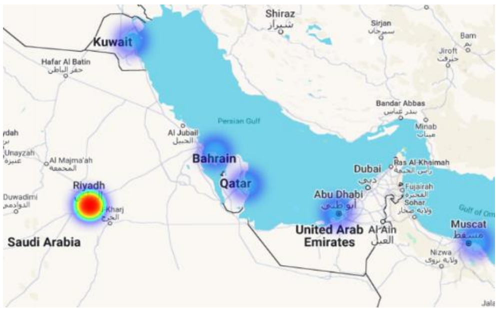
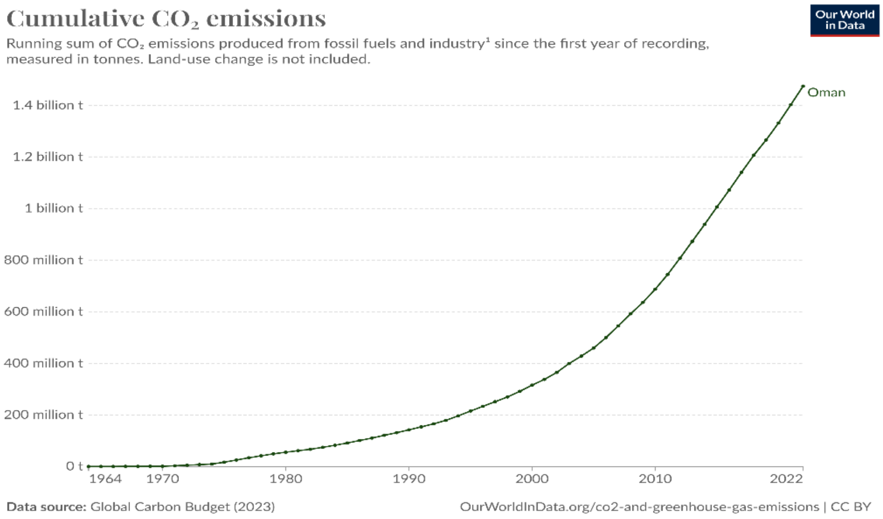


Figure 6. CO_2 emission heatmap for year 2014

From the above 6 figures, it is seen that CO_2 emission was maximum in 1964 for Kuwait but thereafter it increased significantly in Saudi Arabia. This can be attributed to Saudi Arabi's large geographic area, population and increased tourism in the last few decades as compared to other GCC region.

As far Oman is concerned, a rapid increase in the annual CO_2 emission is observed in last 10 years as depicted in the following chart [2].


Cumulative CO_2 emissions

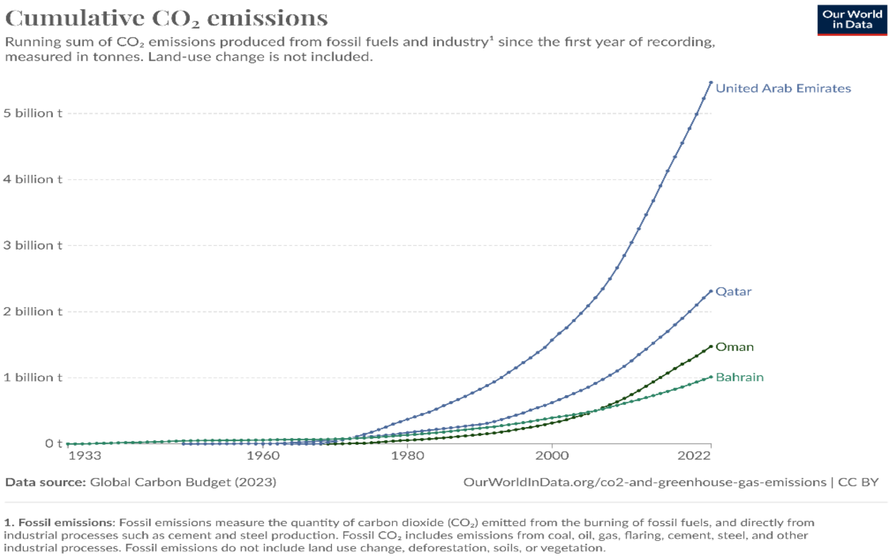
Running sum of CO_2 emissions produced from fossil fuels and industry[1] since the first year of recording, measured in tonnes. Land-use change is not included.

Data source: Global Carbon Budget (2023) OurWorldInData.org/co2-and-greenhouse-gas-emissions | CC BY

[1] **Fossil emissions:** Fossil emissions measure the quantity of carbon dioxide (CO_2) emitted from the burning of fossil fuels, and directly from industrial processes such as cement and steel production. Fossil CO_2 includes emissions from coal, oil, gas, flaring, cement, steel, and other industrial processes. Fossil emissions do not include land use change, deforestation, soils, or vegetation.

Figure 7. Cumulative CO_2 emissions of Oman

When the annual CO_2 emission of Oman is compared with UAE, Qatar and Bahrain, which are smaller countries in terms of area, it is observed that Oman's CO_2 emission is on lesser side as depicted in the following chart [2].



Cumulative CO_2 emissions

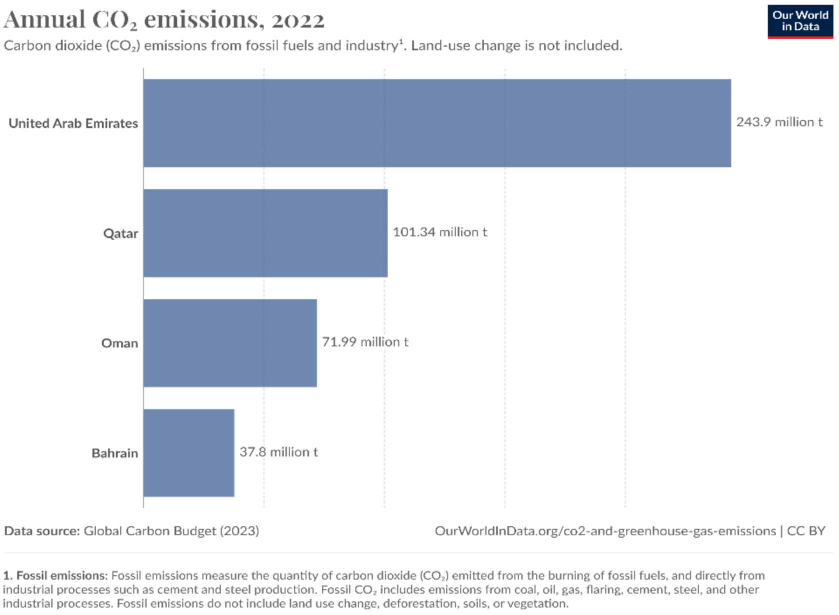
Running sum of CO_2 emissions produced from fossil fuels and industry[1] since the first year of recording, measured in tonnes. Land-use change is not included.

Data source: Global Carbon Budget (2023) OurWorldInData.org/co2-and-greenhouse-gas-emissions | CC BY

1. Fossil emissions: Fossil emissions measure the quantity of carbon dioxide (CO_2) emitted from the burning of fossil fuels, and directly from industrial processes such as cement and steel production. Fossil CO_2 includes emissions from coal, oil, gas, flaring, cement, steel, and other industrial processes. Fossil emissions do not include land use change, deforestation, soils, or vegetation.

Figure 8. Cumulative CO_2 emissions of Oman, Qatar, UAE and Bahrain

Following bar chart shows annual CO_2 emission for Oman, UAE, Qatar and Bahrain in year 2022. Saudi Arabia is not selected as it is big in terms of both population and size as compared to Oman [2].



Annual CO_2 emissions, 2022

Carbon dioxide (CO_2) emissions from fossil fuels and industry[1]. Land-use change is not included.

Data source: Global Carbon Budget (2023) OurWorldInData.org/co2-and-greenhouse-gas-emissions | CC BY

1. Fossil emissions: Fossil emissions measure the quantity of carbon dioxide (CO_2) emitted from the burning of fossil fuels, and directly from industrial processes such as cement and steel production. Fossil CO_2 includes emissions from coal, oil, gas, flaring, cement, steel, and other industrial processes. Fossil emissions do not include land use change, deforestation, soils, or vegetation.

Figure 9. Annual CO_2 emissions 2022 for Oman, Qatar, UAE and Bahrain

4. Discussion

This work is beneficial to some of the major organisations in Oman who are addressing the United Nation’s Sustainable Development Goals (SDGs) 2030 initiative. Major stakeholders in Oman such as Ministry of Environment can track the Wilayat which produces most CO_2, the National Centre for Statistics and Information can identify the most polluted Wilayat and ascertain the number of people suffering, Municipalities can take corrective measures in Polluted area by undertaking green initiatives and Ministry of Oil and Gas can use this application to track the emission from their processing plants

5. Conclusion

Following conclusions can be drawn from this study:

- This study gives an easy presentation of CO_2 emissions on a web map on year-to-year basis.
- As compared to other countries in GCC, Oman is contributing less CO_2 to the environment considering geographic area and population.

Recently Oman launched a National Air Quality Index (NAQI) portal and installed several air quality index monitoring Stations across the country. The data from this portal can be used to create a heatmap for each of the 63 wilayat in Oman. This will help the local administrators to plan the development in each wilayat and control the emission in accordingly. The other scope for future work is to enhance the program and show the data on map with a click on heatmap or a mouse pointer movement over the heatmap and develop a mobile application which can easily reach many people. This would create awareness among the citizens and help in achieving the national sustainable development goal in Oman. Although the CO_2 emissions are not reduced in Oman, but this application will give a starting point to the administrators in Oman for identifying and visualizing the locations which need urgent attention.

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