The Effects Of Economical Factors On Climate Change

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***Abstract*— The purpose of this paper is to study how the climate has been affected in the last 30 years in Romania and other countries, while taking into account the economic background of each country. Understanding the complex relationship between economic activities and environmental degradation can lead to finding new strategies towards a sustainable future.**

I. Introduction

Over the past few decades, the climate has been experiencing significant changes due to human activities, primarily the emission of gases such as carbon dioxide (CO_2) into the atmosphere [1]. These changes have led to various environmental repercussions, including rising temperatures, altered precipitation patterns and changes in ecosystems. [1]

In this paper, we try to determine if and how different economic factors influence climate indicators, by observing 12 arbitrarily chosen countries: Australia, Brazil, Botswana, China, Democratic Republic of the Congo, Germany, United Kingdom, India, Norway, Niger, Romania and the United States, during the last 30 years, namely 1990 - 2020.

One of the hypothesises at the core of this paper is that small countries and countries that are still under development are not as pollutant as larger countries or already developed countries. However, although not as pollutant as the other ones, each country would suffer from climate changes, in one or multiple ways, during the established interval of 30 years.

To understand the effects of climate change on the mentioned countries, the following climate indicators have been analyzed: average yearly temperature per country, average yearly precipitation per country, carbon dioxide (CO_2) emissions per country, burned area from forest fires, human deforestation and reforestation. The economical indicators studied were population per country, types and prevalence of industries per country, GDP and GDP growth, energy use, fossil fuel use and air transport.

II. Data

A. Data Acquisition and Meaning

All the data used throughout the elaboration of the paper is public and free of charge.

1. Temperature and precipitation
Temperature and precipitation for each of the studied countries came from the Climate Change Knowledge Portal [2], which provides the users with extensive time series type datasets. The dataset used throughout this research is produced by the Climatic Research Unit (CRU) of the University of East Anglia (UEA). It is derived by the interpolation of monthly climate anomalies from extensive networks of weather station observations. 24 datasets have been accessed through WorldBank, 12 datasets with average yearly temperatures for each country studied and 12 datasets with average yearly precipitations for each country studied. The temperature is measured in degrees Celsius (C) and the precipitations are measured in millimeters of depth of water (mm).

2. Carbon Dioxide (CO_2) emissions
A large dataset of (CO_2) emissions can be found on the Global Carbon Atlas [3]. The platform, made possible by [4], [5], [6], provides the yearly carbon print for almost all countries in the world. The data is measured in Metric Tonnes of CO_2. The original dataset is made up of four main datasets from historical emissions (1750–2019): global and national emission estimates for coal, oil, natural gas, and peat fuel extraction from the Carbon Dioxide Information Analysis Center (CDIAC) for the time period 1750–2017. The data is periodically reviewed by experts in the field. The emissions dataset takes into account energy and cement production segments, as these segments also produce a large amount of emissions themselves.

3. Burned area
With temperatures on the rise, it's theorized that forest fires would happen more often now compared to 30 years ago. In order to study this theory, a dataset of global monthly burned area [7] is used. The dataset covers burned area for the studied countries during 2002-2019. The area of each country is split in cropland, forest, grass and shrubland, wetlands and other burned areas, observed each month since 2002 up to 2019. To make use of this data, the four enumerated categories have been summed in a "total burned area" by country. The data itself was gathered by the means of MODIS sensors [8] that observe the Earth's surface every 1 - 2 days.

4. Forest changes - deforestation and reforestation

One of the potential reasons for high temperatures in the studied countries is losing more forest area than gaining, year after year. To study this, we make use of the deforestation dataset from WorldBank [9], that contains data for 1990 - 2020 time interval, obtained from the Global Forest Resources Assessments.

The Global Forest Resources Assessments (FRA) are now produced every five years, based on two primary sources of data: Country Reports prepared by National Correspondents and remote sensing that is conducted by FAO together with national focal points and regional partners. The dataset itself contains a catalog of countries and forest area changes (negative or positive numbers) by year.

5. Population per country

In order to put into perspective how each inhabitant of the studied countries contribute to the emissions produced by the country, we make use of population numbers for 1990 - 2022, taken from another population dataset from WorldBank [10]. The dataset covers 237 countries since 1950 up until 2022 and the data is gathered by the Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat.

6. Economic data

For examining key economic factors and understanding global and regional trends, we have used the information received from WorldBank [10] for 1990-2020. The main indicators used are:

- GDP growth (annual %): Measures the annual growth rate of a country's GDP (Gross Domestic Product) over a specific year.
- GDP per capita growth (annual %): Represents the GDP divided by the total population of a country.
- Forest area (sq. km): Indicates the total area of a country covered by forests in square kilometers.
- Rural population (% of total population): Indicates the percentage of a country's population residing in rural areas.
- Urban population (% of total population): Indicates the percentage of a country's population residing in urban areas.
- Energy use (kg of oil equivalent per capita): Represents the amount of energy consumed per capita in kilograms of oil equivalent.
- Electric power consumption (kWh per capita): Measures the electricity consumption per capita in kilowatt-hours.
- Population in urban agglomerations of more than 1 million (% of total population): Indicates the percentage of a country's population living in urban agglomerations (cities) with a population of more than 1 million.
- Industry (% of GDP): Represents the contribution of the industry sector, including manufacturing and construction, to a country's GDP as a percentage.
- Inflation (annual %): Measures the annual inflation rate based on changes in consumer prices.
- Imports (% of GDP): Indicates the percentage of imports of goods and services in relation to a country's GDP.
- Agriculture, forestry, and fishing (% of GDP): Represents the contribution of the agriculture, forestry, and fishing to a country's GDP as a percentage.
- Fossil fuel energy consumption (% of total): Indicates the percentage of fossil fuel energy consumed in a country's total energy consumption.

B. Data Processing and Initial Visualizations

All datasets used throughout this research came in tabular form. To analyze the data, we chose to use Python, and, more specifically, using dataframes that can contain the data and make it easily accessible at all times. Therefore, each dataset downloaded had to be transformed into a dataframe, as part of preprocessing the data. This eased telling how the data looked like at a first glance.

For example, the average yearly temperatures, measured in degrees Celsius, for all countries studied can be explored using the dataframe in figure 1. Similarly, the other dataframes contain data regarding precipitations, measured in millimetres of depth of water per year, burned area per year, measured in hectares, forest change per year, measured in hectares and population number per year.

Year	AUS	BRA	BWA	CHN	COD	DEU	GBR	IND	NER	NOR	ROU	USA
1990	22.04	25.12	21.80	7.48	24.34	9.81	9.54	24.38	27.95	2.86	10.05	9.36
1991	22.20	25.05	21.58	7.07	24.13	8.73	8.70	24.47	27.76	2.00	8.95	9.34
1992	21.68	24.91	22.43	6.81	24.07	9.64	8.86	24.35	27.06	2.32	9.49	8.89
1993	21.91	25.02	21.97	6.87	24.03	8.76	8.48	24.59	27.67	1.34	8.97	8.71
1994	21.84	25.14	21.46	7.47	24.06	9.94	9.05	24.46	27.37	1.42	10.61	9.23

Fig. 1: Example of temperature data inside a Pandas's dataframe: columns are the year of when the measurement is done and the country codes corresponding to studied countries.

For the economical data we had missing values of some columns like Electric Power Consumption, Urban Agglomeration or Fuel Exports, for specific countries and years. To address these missing values, we have replaced them using the mean value of each indicator for the corresponding country during the period from 1990 to 2020, in order to maintain consistency and preserve the overall trend of the indicator for the given country. We have also created a Waffle Chart (Fig. 2) in order to see how each country contributes to the whole.

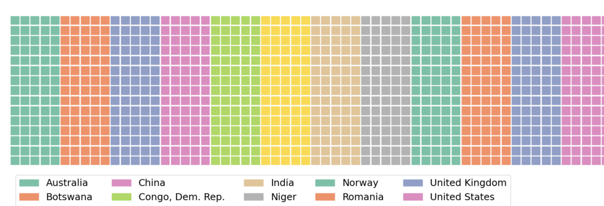

Fig. 2: Waffle Chart which indicates how each country contributes to the whole

III. Results

The results obtained during the research are under the form of graphs, charts, overlayed geographical maps and other visualizations. All the results can help describe a clearer picture of the effects of climate change on the studied countries and the relationship between economical factors and climate change indicators.

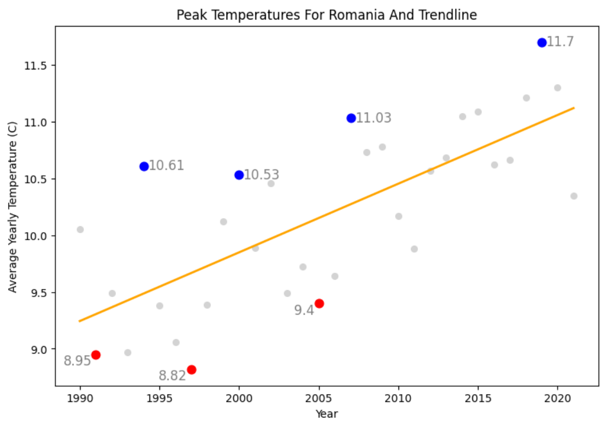

Fig. 3: Peak Temperatures For Romania And Trendline - Romania has an average temperature of 9 degrees Celsius at the start of 1990, which is a low peak. During the 30 year time span, high temperature peaks occur at almost every 5 years and last high temperature peak observed is 11.7 degrees.

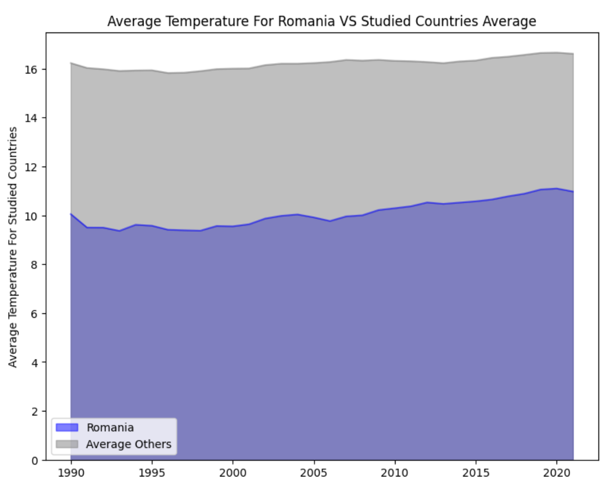

Fig. 4: Average Temperature For Romania VS Studied Countries Average - Romania's temperature on average represented as an area compared to the other countries average temperature. The observable difference between Romania and the other countries is an approximate 5 degrees Celsius.

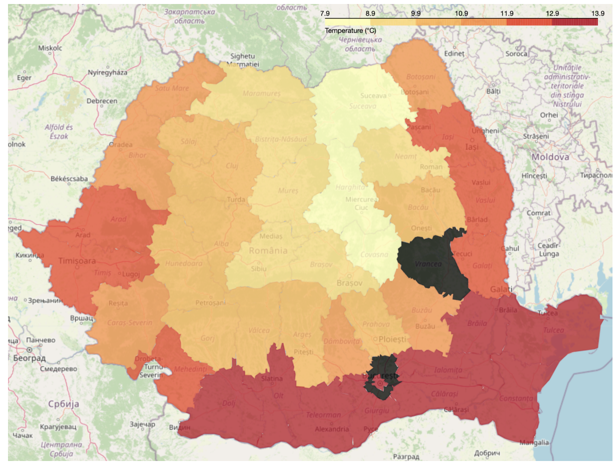

Fig. 5: Romania Heatmap 2020 By County - Visual representation of temperatures and counties of Romania mapped over Romania's administrative map. The counties are color coded to match the temperatures measured: the lighter the color, the cooler the county and the more intense the color, the warmer the county.

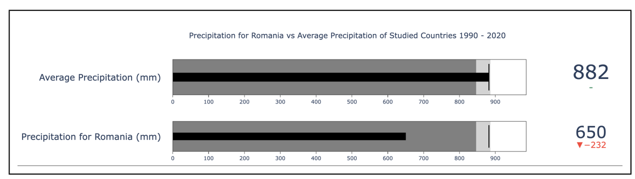

Fig. 6: Precipitation for Romania vs Average Precipitation of Studied Countries 1990 - 2020 - Romania has an average of 650 millimeters depth of water per year, while the other countries average 880 mm per year.

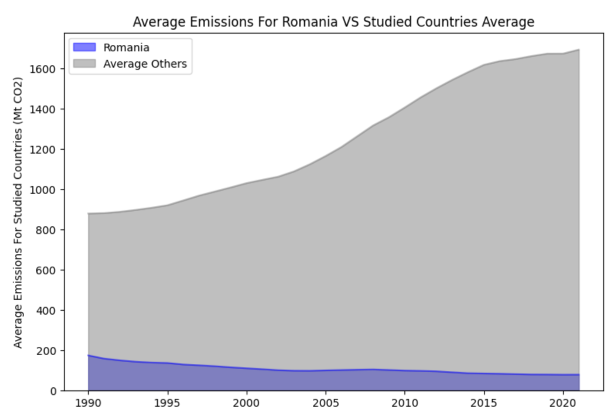

Fig. 7: Average Emissions For Romania VS Studied Countries Average. Romania, blue, starts with 200 Mt CO_2 emissions in 1990 and slowly decreases to 120 Mt CO_2 in 2020. The average emissions for other countries start from 900 Mt CO_2 in 1990 and increase to above 1600 Mt CO_2 by 2020.

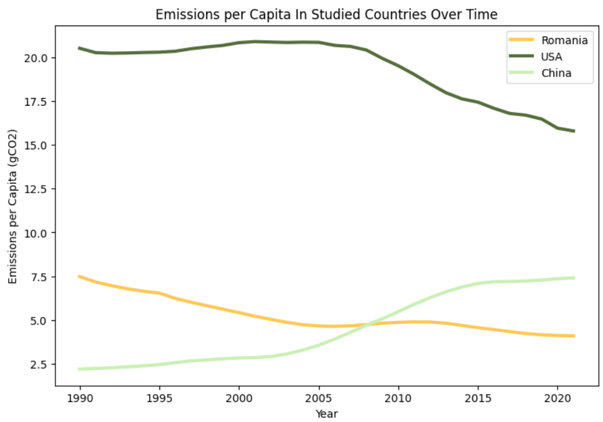

Fig. 8: Emissions per Capita In Studied Countries Over Time - Graph comparing Romania, USA and China by taking into account the amount of emissions, measured in grams of CO_2 per year compared to population number in the countries.

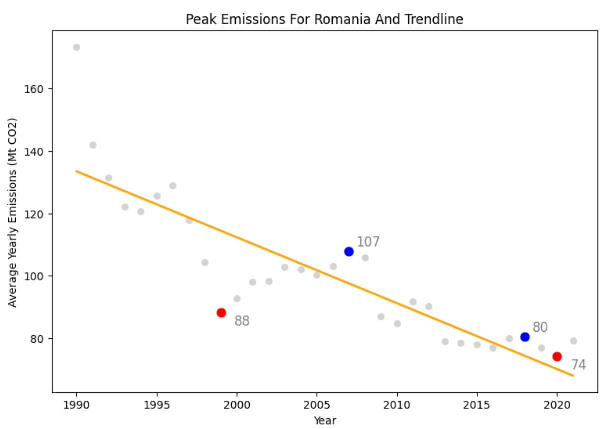

Fig. 9: Peak Emissions For Romania And Trend line - Evolution of emissions, measured in metric tonnes of CO_2, for Romania, by observing average yearly emissions.

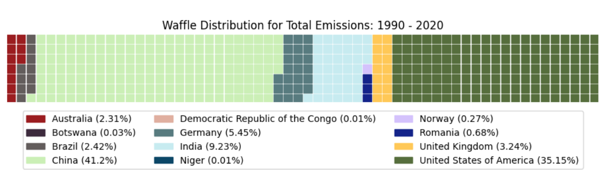

Fig. 10: Waffle Distribution for Total Emissions - 1990 - 2020 - All countries studied occupy one or more than one square, depending on how much quantity of Mt CO_2 the country generated in total over the 30 years time span. Some countries are not shown in the graph because these countries do not produce enough CO_2.

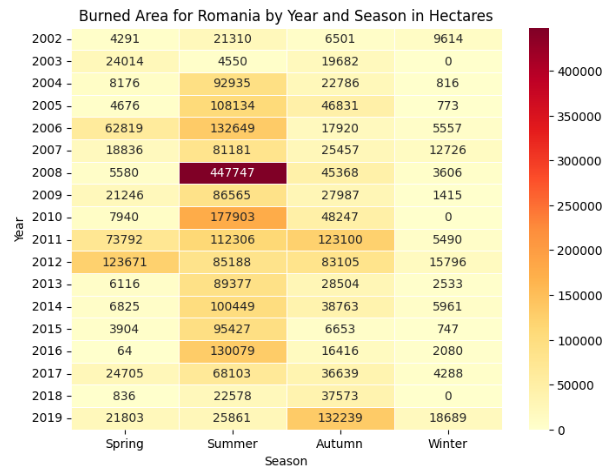

Fig. 11: Burned Area by Year and Season in Hectares - Visualization of area burned each year in Romania, with values ranging from no burnt areas (white) to heavily burned areas (red).

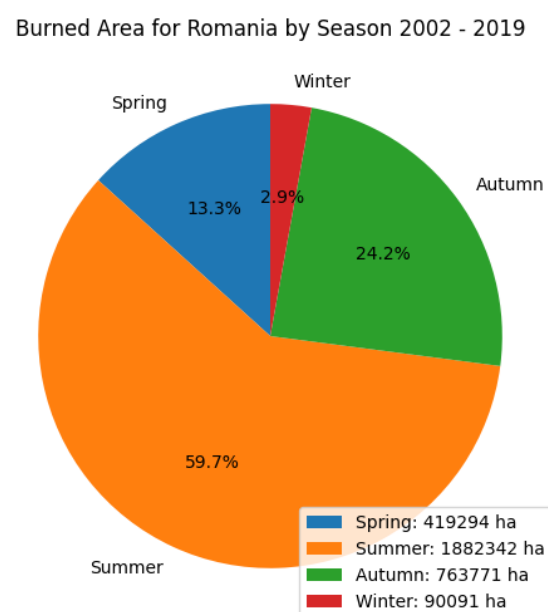

Fig. 12: Burned Area for Romania by Season 2002 - 2019 - Pie chart showing burnt area by season, using percentages, taking into account all burnt area over the 30 years time interval, for Romania.

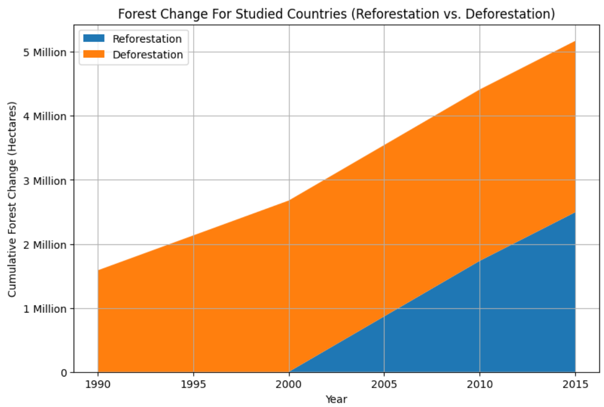

Fig. 13: Forest Change For Studied Countries (Reforestation vs. Deforestation) - Area graph showing amount of forest suffering from deforestation (orange) and reforestation (blue). The area for the graph is measured in millions of hectares.

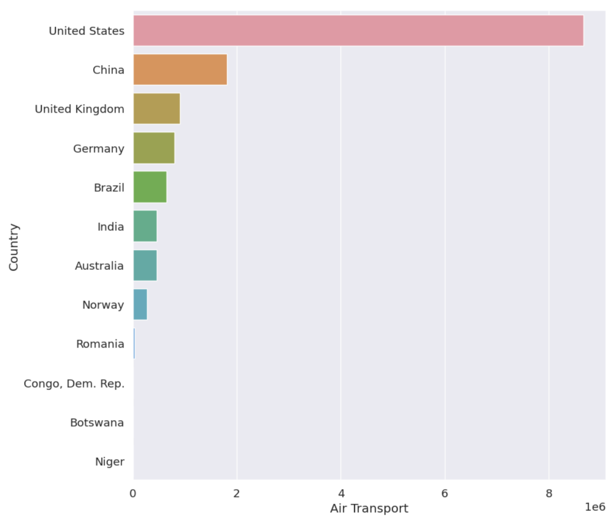

Fig. 14: Air Transport Usage By Country - Horizontal bar chart that shows the amount of air transport for each country

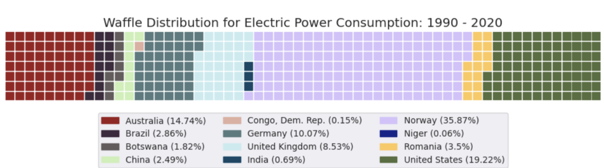

Fig. 15: Waffle Distribution for Electric Power Consumption 1990-2020 - indicates the total electrical power consumption by country for the 30 years studied.

IV. Discussion and Conclusions

A. Discussing the results obtained

Starting the discussion with analysing the temperature changes, Fig. 3 and Fig. 4, it can be observed that the temperatures, on average, both in Romania and in other countries, have increased significantly. If the average temperature in 1990 was approximately 9.5 and 16 degrees Celsius for Romania and the average of the other studied countries respectively, by 2020 the new temperatures have increased with 1.5 degrees Celsius for Romania and 0.6 degrees Celsius for the other countries on average.

Observing the peak highs and peak lows for the average temperatures recorded in Romania over the last 30 years, Fig. 3, we can tell that after 2010 there are no low peaks in temperature to be found. This phenomenon, together with the steady increase in temperatures, could potentially continue past 2020.

Romania's Heatmap in Fig. 5 paints a clear picture of which are the most affected counties by the increase in temperature. The South and the South East of Romania have an yearly average of 12 - 13 degrees Celsius, in 2020, while the Center of the country, surrounded by mountains, has, in certain parts, almost half that (8 degrees).

Precipitations, on average, have lower values for Romania than when compared to the rest of the countries studied, Fig. 6, by at least 230 mm per year. Although not included, the precipitations increased over the years in Romania. The difference between 1990 and 2020 is not as significant as the temperature difference, but there exists a 50 mm difference in measured precipitations.

By observing the emissions produced by Romania and the other studied countries, it can be assessed that past 1990, emissions started a slow decrease for Romania, but did the opposite for the other countries. Fig. 7 shows Romania going from 200 $MtCO_2$ in 1990 to close to 100 $MtCO_2$ in 2020. On the other hand, the other countries average emissions increased from 900 $MtCO_2$ to over 1600 $MtCO_2$. Based on this, we can approximate that Romania, when compared to the other studied countries, emits 16 times less CO_2. This decrease inCO_2 emissions can be clearly observed in Fig. 9, with the latest high peak in producing CO_2 happening towards 2018 and the peak being 80 Mt CO_2.

After analyzing the emissions produced while taking into account the population number of some select countries, namely Romania, USA and China, it can be observed that Romanians emit the least CO_2 per capita, while Americans emit at least 3 times as much, but their emissions are on a descending trendline for the past 15 years. China, however, can be seen doing the exact opposite, starting their increase in emissions around the same time Americans started their decrease, Fig. 8. By computing the total CO_2 emissions of the studied countries, Fig. 10, it can be observed that USA and China combined make up at least 75% of the emissions produced during 1990 - 2020.

The burned area dataset could give some insight into how the rise in temperatures during the years affects spontaneous

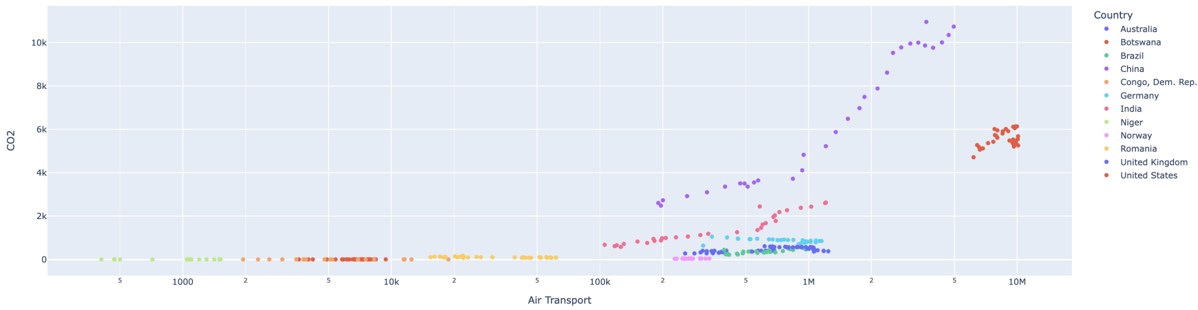

Fig. 16: Dependency between the Air Transport and CO_2 emissions for each country in the 1990-2020

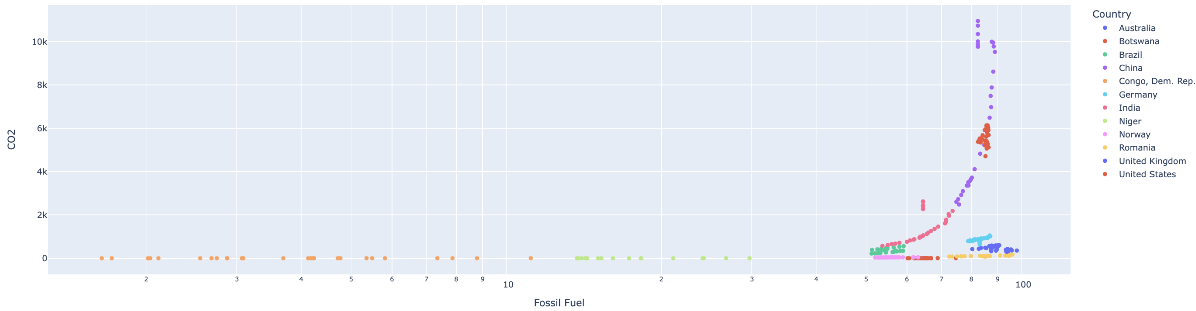

Fig. 17: Dependency between the Fossil Fuel Energy Consumed and CO_2 emissions for each country in the 1990-2020

fires, which could lead to large portions of burnt area. However, the data visualizations do not support this claim, Fig. 11, with burned area reaching a maximum, for Romania, in 2007 - 2008, with a summer that burned almost 450000 hectares. After 2008, the burned area decreases year after year.

Although a correlation between higher temperatures and larger burned area cannot be established, it is certain that the summers are the highest contributors to burned area. Almost 60% of total burnt area, summed over a time span of 17 years observed in Romania, has happened during summer, Fig. 12.

Deforestation is on the rise and this phenomenon can be observed in Fig. 13 as well. Even before 1990, the rates of deforestation, or the rate of forest area becoming smaller by the year, has been disproportionate to the frequency of reforestation. For Romania, the rate of deforestation is not larger than the reforestation, but when observing the overall situation for all countries in this study, it can be assessed that the reforestation area, measured in millions of hectares, is at least twice as small compared to deforestation, which trends to increase in the future.

In Fig 14. there can be observed the air transport for each country, which is very important because, as shown in the Fig. 16, there is a strong correlation between the usage of air transport and the level of CO_2 emissions. As it can be observed, from the horizontal bar chart, USA and China have the biggest impact on the airplane traffic. Although not shown in the paper, even if we consider the airplane transport per population, these two countries are on the top of this list. Moreover, there was a decline in the air transport for 2020, which might be due to it being the year when the COVID pandemic has started.

In Fig 15. we can see how much electric power each country consumes. Surprisingly, Norway and Australia are very high on this list having almost 50% on this distribution, despite not having a huge population.

Analysing the dependency between air transport and the consumption of fossil fuel energy, Fig. 15 and Fig. 16, it can clearly be observed that there is a strong connection between the amount of usage of airplanes over the years for all the countries and the CO_2 emissions. In the second plot, we can observe the obvious exponential dependency between the consumption of energy based on fossil fuel and the carbon dioxide emissions.

B. *Comparing with the state-of-the-art*

In one of the studies related to climate change research for Romania, done in 2019, Elena Mateescu identifies year 2018 as hottest year in the last 30 years and computes the temperature difference between 2018 and 1988 to be 1.58 degrees Celsius [11]. This is in accordance with the peaks and temperature differences found in our research as well, therefore giving the temperature dataset used throughout this research more integrity and further supporting the validity of the claims of this paper. The author warns that if the trend continues, we can expect to see a 5 to 6 degrees Celsius difference starting 2071 (referencing the 1971 baseline).

In another study from 2021, authors have similar results when comparing our researched CO_2 emissions with their researched CO_2 emissions. Besides the similarity in results, the authors make use of regression models to forecast how the emissions will evolve in the future. The current prediction is reaching 60 $MtCO_2$ by 2030 and net 0 emissions post 2050 [12].

C. Conclusions

Climate change has resulted in significant temperature increases globally, including Romania, with an average temperature rise of approximately 1.5 degrees Celsius over the past 30 years. This increasing trend is expected to continue beyond 2020.

The increase in temperatures has not been evenly distributed across Romania, with the southern regions experiencing higher average temperatures compared to the mountainous central regions. Precipitations have shown a slight increase over the years, although they remain lower than the average precipitation levels in the other studied countries.

Romania has achieved a notable reduction in CO_2 emissions over the past 30 years with emissions decreasing from 200 $MtCO_2$ in 1990 to around 100 $MtCO_2$ in 2020. This reduction is in contrast to the increasing emissions observed in the other studied countries.

While this research provides valuable insights into the relationship between economic factors and climate change, it is important to acknowledge several limitations. The data on which this study relied on may be subject to measurement errors or inconsistencies. Besides, the analysis focused on a small set of economic indicators and did not account for all possible variables that could influence climate change. Another limitation is establishing causality between economic factors and climate change, which is challenging.

Despite the mentioned limitations, this research yielded significant results, similar to results obtained by related work in the field of climate change for Romania. The findings of this study could be further used to promote significant policies for addressing the negative effects of economic factors on climate change. Policymakers should consider implementing policies to promote sustainable practices and using renewable energy sources. Going forward, towards the zero emissions target, incorporating this type of insights into policy development should become a priority not only for Romania, but for the whole world.

In conclusion, this research highlights the intricate relationship between economic factors and climate change. The findings underscore the need for proactive policy measures that promote sustainable economic practices and mitigate the negative impact of economic activities on the environment.

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