Investigating the Environmental Kuznets Curve: A Cross-Country Analysis of Developed and Developing Countries

EECS 6414 Data Analytics and Visualization Project Report

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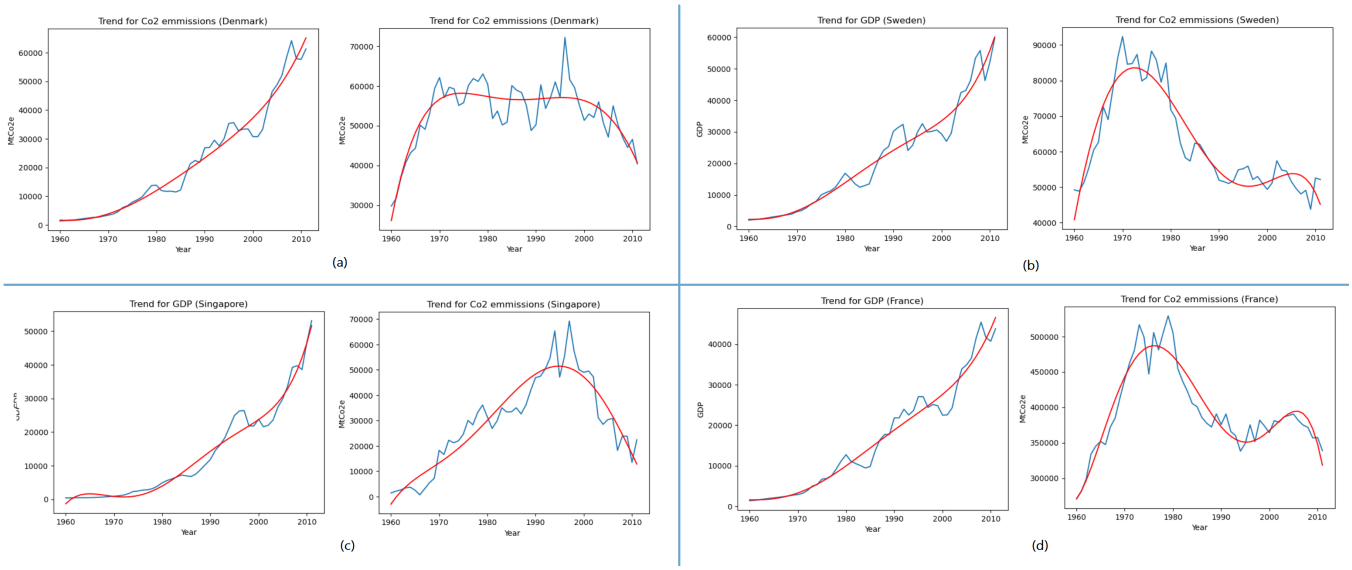

Figure 1: Countries conforming to EKC regarding GDP - CO2 emissions before the year 2000.

ABSTRACT

This paper examines the relationship between environmental degradation and the economic growth of various counties. It evaluates the validity of the Environmental Kuznets curve (EKC) theory between the countries' GDP and their CO2 emissions and forest area. We grouped the countries with similar environmental impacts by studying the correlation coefficient and the significance of GDP on CO2 and forest area change. Countries conforming to EKC with either CO2 or forest areas were also identified. Finally, an interactive dashboard was developed and introduced to better visualize the relationship between GDP and CO2, and forest area.

KEYWORDS

EKC, environmental degradation, GDP, data analysis

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1 INTRODUCTION

Sustainability has been a critical topic of research and discussion in conglomerates, large enterprises and governments. Several countries have initiated publishing annual sustainability reports to highlight key sustainability initiatives. The Paris Agreement warns that even a minimal increase in temperature (as little as 1.5°C above pre-industrial levels) can result in significant impacts, including rising sea levels and more frequent extreme weather events. Reducing emissions and transitioning to a low-carbon economy is more necessary than ever since the world is close to the tipping point.

The Environmental Kuznets Curve (EKC) is a theoretical framework that attempts to explain the relationship between economic development and environmental degradation [6]. The EKC, often portrayed as an inverted U-shape on a graph, suggests that as an economy develops and moves from an agricultural to an industrial stage, environmental degradation initially increases but decreases as the economy becomes more affluent. This theory assumes that as countries become wealthier, they can invest more in environmental

protection and clean technologies. At the same time, people experience a shift in values and priorities, including a growing concern for environmental protection.

This project examines the gross domestic product (GDP) relationship with CO2 emissions and forest area in multiple countries and evaluates whether EKC holds for them. Two categories of countries, developed and developing, have been examined. Furthermore, this project introduces a dashboard that visualizes this relationship. The World Bank's Indicators dataset [1] has been used from 1960 to 2014. We looked at 24 countries, all among the top 30 GDP countries. The countries were divided into two categories of *developed* or *developing* based on their level of economic development. The studied countries are as follows:

- Developing countries: China, United Arab Emirates, Kuwait, France, Brunei Darussalam, and Israel
- Developed countries: Luxembourg, Norway, Qatar, Switzerland, Australia, Denmark, Sweden, Singapore, United States, Ireland, Netherlands, Iceland, Austria, Canada, Finland, Germany, Belgium, and the United Kingdom

This project aimed to answer a few questions, such as whether different countries follow the same economic development and environmental degradation pattern, how GDP, CO2 emissions, and forest area are connected, and whether there are differences between developed and developing countries. Rigorous data analysis was done to understand how economic development affects the environment and find ways to lessen the negative impact of economic growth. This analysis contributes to understanding how economic growth affects the environment and what countries have found ways to reduce environmental degradation while increasing their GDP. Some potential applications of this project are the government's economic planning, carbon capture and control programs, net-zero emission initiatives, and identification of green-washing exercises and malpractices.

2 RELATED WORK

Studies have used different measures of environmental degradation when studying the Environmental Kuznets Curve (EKC) hypothesis. Grossman and Krueger [2] used air pollution as a measure of environmental degradation. They studied sulfur dioxide (SO2) emissions in their work on the EKC hypothesis. They found evidence that the relationship between income and SO2 emissions followed the pattern predicted by the EKC hypothesis, with increasing levels of SO2 emissions at low-income levels and declining levels of SO2 emissions at high-income levels.

CO2 emissions have been a popular measure of environmental degradation. Köksal et al. [5] studied CO2 emissions as the environmental degradation measure in the OECD countries. They found evidence of an inverted U-shaped relationship between income and CO2 emissions per capita in some countries and a positive relationship between income and CO2 emissions per capita in others. In another study with CO2 emission as the environmental degradation measure, Zhang et al. [8] found evidence of an inverted U-shaped relationship between income and CO2 emissions per capita in the BRICS countries. Wang et al. [7] used chemical oxygen demand (COD) as a measure of water pollution, i.e., environmental degradation, in their study. They found evidence of an inverted U-shaped relationship between income and COD in some cities in China, which is consistent with EKC. However, in other cities in China, they found evidence of a positive relationship between income and COD, meaning that as income increased, COD also increased. Other environmental degradation measures, such as deforestation [1], biodiversity loss [3], natural resource depletion [4], etc., have been explored in the context of EKC.

This project does not focus on a single measure of environmental degradation but rather considers multiple measures to examine the broader relationship between economic development and environmental degradation. It examines a wide range of countries divided into developed and developing countries. Additionally, we introduce a dashboard that visualizes this relationship for multiple countries.

3 METHODOLOGY

Our study examines the relationship between economic growth and two environmental variables: CO2 emissions and forest area. The independent variable in our study is GDP, and the dependent variables are CO2 emissions and forest area. As a part of our study, we were interested in studying the relationship between GDP and two environmental variables, CO2 emissions and forest area. By calculating the correlation coefficient between these variables, we can quantify the strength and direction of their relationship.

A positive correlation would mean that as GDP increases, so does the variable being studied (CO2 emissions or forest area), while a negative correlation would mean the opposite. The Pearson correlation coefficient measures the strength and direction of the linear relationship between two continuous variables. It ranges from -1 to +1, with -1 indicating a perfect negative linear relationship, +1 indicating a perfect positive linear relationship, and 0 indicating no linear relationship. It is calculated by dividing the covariance of the two variables by the product of their standard deviations.

To explore the relationship between GDP, CO2 emissions, and forest area across countries over the years, we calculated Pearson's correlation coefficient between GDP and CO2 emissions and similarly between GDP and forest area for all countries over the years. It is calculated by dividing the difference between the sample means of two groups by their standard error, representing the sample means' variability. Similarly, to determine the statistical significance of the relationship between the two variables, we calculated the t-value between GDP and CO2 emissions and between GDP and forest area for all countries over the years. T-value is calculated by dividing the difference between the sample means of two groups by their standard error, representing the sample means' variability. In the context of this project, we use the t-value to determine if the relationship between GDP and CO2 emissions or forest area is statistically significant. A significant t-value indicates that the difference between the means is not likely due to chance and suggests a real relationship between the two variables. The regression lines for all the countries were plotted to determine their GDP and environmental degradation trends.

Visualizing the relationship between countries' GDP and environmental degradation in one graph was tricky. Fig. 2 shows one

[1] https://data.worldbank.org/indicator

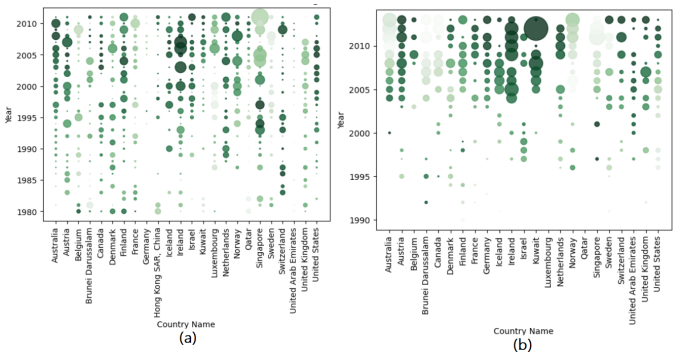

Figure 2: The relationship between GDP and environmental degradation using circle dimension and size: a) GDP vs. CO2 emissions. b) GDP vs. Forest area.

of our attempts to represent this relationship in one plot. The dimension of the circles represents the country's GDP. In Fig. 2a, the darker circles show a higher CO2 emission while the lighter circles show lower amounts. Similarly, in Fig. 2b, the darker circles show a higher forest area percentage while the lighter circles show lower amounts. We developed an interactive dashboard using Python and the Panel [2] to improve the visualisation. The dashboard allows the user to explore the effects of GDP on CO2 emissions and forest area by choosing different year values and countries. The dashboard consists of two separate tabs for the GDP vs. CO2 emissions and GDP vs. forest area; see Fig. 3. Upon selecting a year from the year slider, the dashboard presents a table with countries' GDP value, GDP change from the previous year, CO2 or forest area value depending on the selected tab, and finally, CO2 or forest area change of the prior year. A dot plot is also updated based on the selected year, with the y-axis representing the country's GDP and the x-axis either CO2 or forest area. This plot allows the user to see where each country is located compared to the other countries. The country name, GDP, and CO2 or forest area value are shown upon hovering over each dot. The dashboard also represents an interactive bar chart and a box plot for developed and developing countries. The bar chart and the box plot are updated based on the selected year. Finally, the dashboard allows the user to compare the countries' GDP with CO2 or forest area by plotting their line charts side by side for the selected country.

The dot plot and interactive bar chart allow for a quick overview of each country's position and performance, while the line chart enables a more in-depth analysis of the trends over time. This dashboard can be a useful tool for policymakers, researchers, and environmental activists who seek to understand the relationship between economic development and environmental sustainability. It also enables users to identify countries that are performing well and to analyze their policies, potentially providing insights that could be used to create effective environmental policies.

[2]https://panel.holoviz.org/index.html

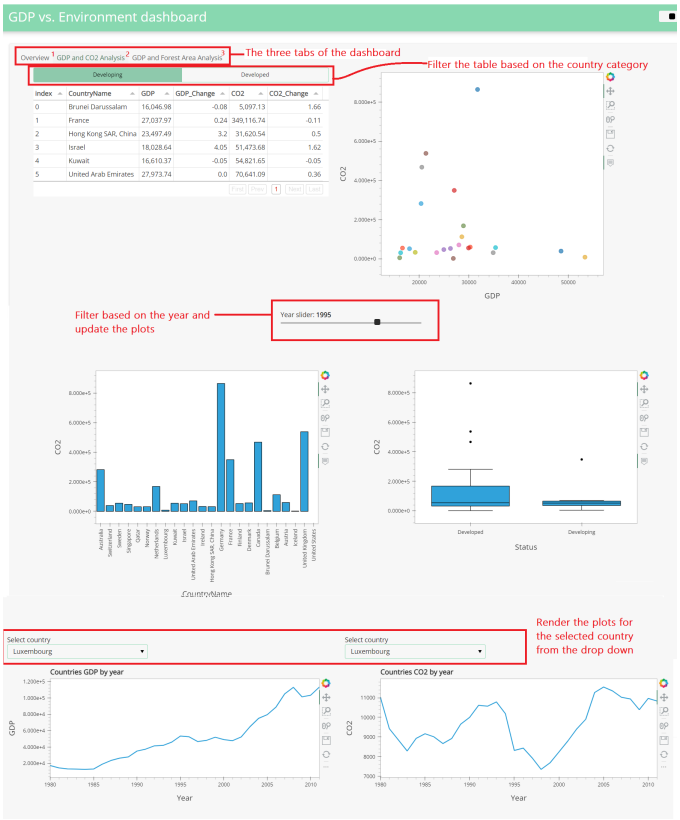

Figure 3: The GDP vs. Environmental degradation dashboard.

4 EVALUATION AND RESULTS

We performed multiple analyses of the data to get a more accurate result. Below we discuss the performed analysis.

4.1 Correlation Analysis

We calculated the Pearson's correlation coefficient between GDP and CO2 and similarly between GDP and forest area for all countries over the years. Below, we discuss our findings.

4.1.1 GDP and CO2. Australia, Iceland, Ireland, Kuwait, Norway, Qatar and the USA have a positive correlation coefficient above 0.8, indicating a strong positive relationship between their GDP and CO2 emissions. This suggests that these countries economic growth is highly dependent on carbon emissions, and efforts to reduce carbon emissions may pose a significant challenge to their economic development. Belgium, France, Luxembourg, Sweden, and the UK have a negative correlation coefficient of below -0.25, suggesting that their economic growth is not strongly related to CO2 emissions. This could mean that these countries have been successful in decoupling their economic growth from carbon emissions. Austria, Canada, Finland, Israel, and Switzerland, have a positive correlation coefficient between 0.5 and 0.8, indicating a moderate positive relationship between their GDP and CO2 emissions.

Hong Kong has the highest positive correlation coefficient of 0.93, suggesting it is highly dependent on CO2 emissions for economic growth. Developed vs. Developing countries There is a clear difference between the correlation coefficient values of developed and developing countries. Developed countries generally have a stronger positive correlation between their GDP and CO2 emissions, indicating a greater dependence on carbon-intensive industries for economic growth. Developing countries have a wider range of correlation coefficient values, with some countries highly dependent on carbon emissions for economic growth and others showing potential for decoupling economic growth from carbon emissions.

4.1.2 GDP and Forest area. Firstly, it is essential to understand that a negative correlation coefficient suggests an inverse relationship, meaning that as GDP increases, the forest area decreases, and vice versa. Australia, Canada, Norway, and Singapore have a negative correlation coefficient, implying that their GDP growth is associated with a decrease in the forest area. This could indicate that these countries may be more industrialized and have a higher demand for resources, leading to deforestation.

On the other hand, Belgium, France, Ireland, Israel, Kuwait, the Netherlands, Switzerland, the UAE, the UK, and the USA have a positive correlation coefficient, suggesting that their GDP growth is associated with an increase in the forest area. This could indicate that these countries are adopting more sustainable practices and policies, such as reforestation initiatives, leading to an increase in the forest area.

4.2 Grouping the Countries

We calculated the t-value between GDP and CO2 and similarly between GDP and forest area for all countries over the years. Based on a p-value < 0.05, we determined whether GDP had a significant effect on CO2 emissions or forest area. Finally, we grouped the countries based on their t-values and significance into three groups. Below, we discuss the groups and our findings.

4.2.1 GDP and CO2.

(1) Positive GDP-CO2 Relationship: The countries with significant positive t-values indicate a strong positive relationship between GDP and CO2 emissions. These countries tend to have high levels of industrialization and economic growth, which contributes to higher levels of carbon emissions. This group contains Australia, Austria, Brunei, Darussalam, Canada, Finland, Hong Kong, Iceland, Ireland, Kuwait, Netherlands, Norway, Qatar, Singapore, Switzerland, UAE, and the USA.
(2) Negative GDP-CO2 Relationship: The countries with significant negative t-values, such as Germany, Luxembourg, Sweden, and the UK, show a negative relationship between GDP and CO2 emissions. This may be due to their efforts to reduce carbon emissions through policies and regulations, as well as investments in renewable energy and other green initiatives.
(3) Weak or No GDP - CO2 Relationship: The countries with insignificant t-values, such as Belgium, France, and Denmark, suggest that there is no significant relationship between GDP and CO2 emissions in these countries. This may be due to their focus on sustainable development and green technologies, which allows them to achieve economic growth without increasing carbon emissions.

We identified Israel as an outlier. Israel has a highly significant positive t-value, indicating a strong relationship between GDP and CO2 emissions. This may be due to their high dependence on fossil fuels and lack of investment in green technologies.

4.2.2 GDP and forest area.

(1) Positive GDP-Forest Area Relationship: Austria, Belgium, Brunei, Darussalam, France, Germany, Iceland, Ireland, Israel, Kuwait, Netherlands, Switzerland, UAE, and USA. These countries have a significant positive correlation between GDP and forest area.
(2) Negative GDP-Forest Area Relationship: Australia, Canada, Norway, and Singapore. These countries have a significant negative correlation between GDP and forest area.
(3) Weak or No GDP-Forest Area Relationship: Denmark, Finland, Luxembourg, and Sweden. These countries have an insignificant correlation between GDP and forest area.

4.3 EKC Analysis

4.3.1 GDP and CO2. In this section, we studied the countries' GDP vs. CO2 growth to determine if the country is conforming to the EKC theory. We looked at countries that, while having a GDP growth, showed a reduction in CO2 emissions. This left us with the following countries: Singapore, Denmark, Sweden, France, the USA, Austria, and Canada. We divided the countries into two groups based on when they passed the EKC pivot point, which is the point where CO2 emissions start to decrease. The first group includes countries that passed the pivot point before 2000, which means they have been able to sustain their reduction in CO2 emissions for a more extended period. The second group includes countries that passed the pivot point after 2000, and their CO2 emissions reduction is more recent, which means it remains to be seen if they will continue to reduce emissions or experience an increase in the future. The countries that passed the EKC pivot point before 2000 are France, Singapore, Denmark, and Sweden. Fig. 1 shows the GDP vs CO2 trend for these countries. The countries that passed the pivot point after 2000 are the USA, Austria, and Canada; refer to Fig. 4. Note that all the EKC conforming countries in the second group (i.e., countries that passed the pivot point after 2000) are the countries that belonged to the *Positive GDP-CO2 Relationship* group. Denmark and France in the first group (i.e., countries that passed the pivot point before 2000) showed weak or no GDP - CO2 relationship, Sweden showed a negative relationship, and finally, although Singapore passed the pivot point before the year 2000, it belonged to the *Positive GDP-CO2 Relationship* group. Fig. 5a shows the GDP vs. CO2 for the countries in the first group, and Fig. 5b shows it for the second group. An inverted U shape, as suggested by EKC, is more apparent for the countries that passed the pivot point before the year 2000.

4.3.2 GDP and forest area. After analyzing the regression trends of countries that exhibited GDP growth, it was observed that none of them displayed an initial decline in forest area, followed by a subsequent increase as the GDP continued to rise. Consequently,

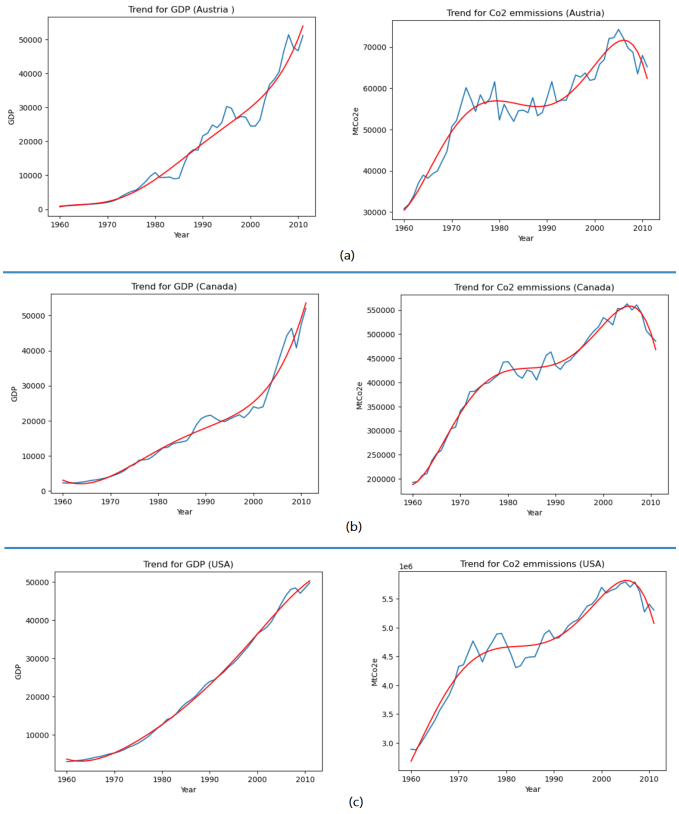

Figure 4: Countries conforming to EKC regarding GDP - CO2 emissions after the year 2000.

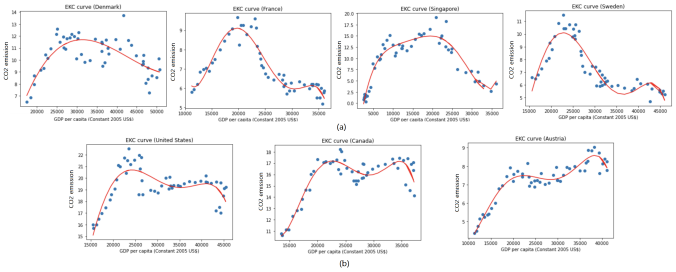

Figure 5: Countries GDP - CO2 trend line: a) countries that passed the pivot point before 2000. b) countries that passed the pivot point after the year 2000.

it can be concluded that none of the countries adhered to the EKC hypothesis concerning the relationship between GDP and forest area. Fig. 6 illustrates the trend line for some countries that showed a significantly positive relationship between GDP and forest area.

5 CONCLUSION

In conclusion, our study examined the relationship between economic growth and two environmental variables, CO2 emissions and forest area. We found a significant positive correlation between

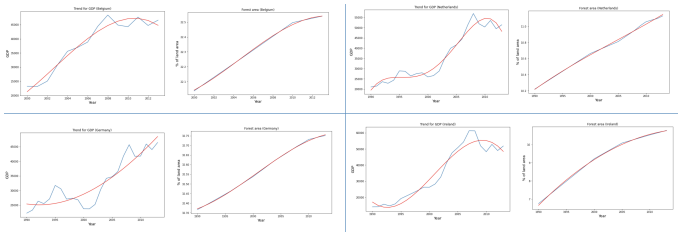

Figure 6: Countries GDP - forest area trend line.

GDP and CO2 emissions for several developed countries, suggesting that their economic growth is highly dependent on carbon emissions. In contrast, some developed countries showed a negative or no correlation between GDP and CO2 emissions, indicating that they have successfully decoupled economic growth from carbon emissions. Developing countries also exhibited a wide range of correlation coefficient values, suggesting potential for either dependence or decoupling. We identified Denmark, Sweden, Singapore, and France as countries conforming to EKC and having passed their pivot point before 2000. Note that only France is among developing countries. Furthermore, we identified Austria, Canada, and the USA, all developed countries potentially conforming to EKC. They have passed their pivot point after 2000 and, although suggesting a decrease in CO2 in recent years, have not yet shown a substantial trend.

Regarding forest area, our findings showed the majority of the studied countries have a significantly positive relationship between their GDP and forest area. However, none conformed to EKC.

We developed an interactive dashboard using Python and the Panel library to enable users to explore the effects of GDP on CO2 emissions and forest area by selecting different countries and year values. This dashboard can be useful for policymakers, researchers, and anyone interested in understanding the relationship between economic growth and the environment. Overall, our study contributes to the ongoing discussions about the sustainable development of countries worldwide

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One potential future work could involve analyzing more countries to see if there are patterns or trends in which countries can maintain a green rating over time. This could include studying those countries' environmental policies and regulations, as well as the behaviours and attitudes of their citizens towards sustainability and environmental protection. Another area of potential future work could be to examine in more detail the policies and initiatives contributing to a country's green rating. This could involve conducting case studies of individual countries to identify which policies are working well and why and identify areas where improvements could be made.

In addition, future research could explore the relationship between a country's green rating and economic performance. This could involve analyzing data on GDP growth, employment rates, and other economic indicators to determine whether there is a correlation between environmental sustainability and economic success.

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