Exploring the State of World Energy Economics

Project 2 Final Report
DATASCI 200
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Link to GitHub Repository:
https://github.com/UC-Berkeley-I-School/Project2_Brown_Koon_Williams

Introduction

Since the industrial revolution in the early 1800's, humanity's immense technological and societal prosperity has largely been characterized by an ever-increasing reliance on energy. For most of history this energy has been produced through environmentally harmful processes which continue to significantly change our planet's climate—changes that we now understand to be detrimental to global habitability. In the face of this impending climate problem, we believe that a comprehensive understanding on the current state of global energy production and consumption behavior will be paramount to developing effective solutions. Our project seeks to contribute towards this understanding by exploring relationships between the economic strength of individual countries, their reliance on fossil fuel based energy, and their adoption of renewable-based energy infrastructure. To facilitate this exploration, we have developed six guiding questions:

1. How does a country's GDP correlate with their total electricity demand?
2. How does energy efficiency change with respect to a country's GDP?
3. What is the relationship between a country's economic growth and their adoption of renewable energy infrastructure?
4. How does a country's GDP correlate with carbon intensity and renewable energy growth?
5. What trends can be observed in the shift from fossil fuel-based energy to renewable-based energy?
6. At what GDP level do countries begin to transition from fossil fuel-based energy to renewable-based energy?

Dataset

To support these analyses, we have selected the World Energy Consumption dataset authored by Hannah Ritchie, Pablo Rosado, Edouard Mathiew, and Max Roser. Originally published in 2020 by the *Our World in Data* team, this dataset is an aggregation of international energy statistics and socioeconomic indicators collected between the year 1900 and the present. The original dataset records 129 unique features for 2,785,110 samples. Each sample records data for a single country during a particular year. We chose this dataset because of its feature diversity and extensive coverage of energy consumption and production data across the world.

Data Cleaning

In its original state, the World Energy Consumption contained extraneous information beyond the scope of our research questions, and was characterized by sparsely populated samples. Before conducting our analyses, these issues needed to be addressed. To reduce the complexity of these data, we identified a small subset of features which we believed to be most applicable to our underlying research questions. This subset of features and their respective descriptions are presented below in Table 1. By default, these columns were properly formatted, and did not require any substantial processing.

Feature	Units	Description
country	N/A	Geographic region
iso_code	N/A	ISO country indicator
year	Year	Year of observation
population	Number of Citizens	Population of country
gdp	International Dollars	Gross Domestic Product
carbon_intensity_elec	grams of CO_2/KWh	Environmental impact of a country's electricity generation
electricity_demand	TWh	How much electricity is used by country
electricity_generation	TWh	How much electricity is generated by country
fossil_electricity	TWh	How much electricity is generated by fossil fuels
renewables_electricity	TWh	How much electricity is generated by renewables
fossil_energy_per_capita	TWh	Fossil fuel-based energy consumed per person
renewables_energy_per_capita	KWh/person	Renewable-based energy consumed per person
renewables_share_elec	% of Total Electricity	Share of total electricity generated by renewables

Table 1: Subset of features to be used in our analyses

With our features of interest selected, we then moved on to cleaning the underlying samples. To ensure consistent results in our analyses, we decided to drop samples containing any missing or invalid values for our selected feature set. Additionally, we decided to drop samples related to "aggregate indicators"—samples that the original dataset used to represent collections of countries and entire geographic regions.

Without knowing the process by which these aggregate samples were created, we felt it would be more appropriate to construct our own aggregations. Finally, we decided to narrow the scope of our analyses by only considering data collected between the years 2000 and 2018. In addition to supporting our explicit interest in the current state of global energy production and consumption, all samples within this range of dates contained valid data. By the end of this data cleaning process, our dataset contained 23,826 samples representing 13 unique data points for 66 countries.

Analyses

Exploring The Relationship Between GDP and Electricity Demand

The GDP vs. Electricity Demand graph clearly indicates a positive correlation between a country's economic output, as measured by GDP, and its electricity demand. This relationship underscores a fundamental aspect of modern economies: economic activities, especially industrialization, are energy-intensive. As nations develop and their economies grow, their energy needs, particularly for electricity, tend to increase. This trend is noticeable across countries of both large and small economic statuses.

The logarithmic scale used on both axes suggests that the relationship is linear: a percentage increase in GDP tends to be associated with a similar percentage increase in electricity demand.

The line of best fit, shown in red, underscores this correlation and shows the average trajectory of the relationship. However, the dispersion of data points around the line indicates variability in how different countries convert economic output into electricity demand. This variability could be influenced by numerous factors such as the energy efficiency of different economies, the types of energy they use, or the proportion of the economy dedicated to energy-intensive industries.It is important to note that there are countries that lie both above and below the line of best fit, meaning that some counties have higher electricity demand with relation to GDP and some have less, but on average electricity demand rises linearly with rises in GDP.

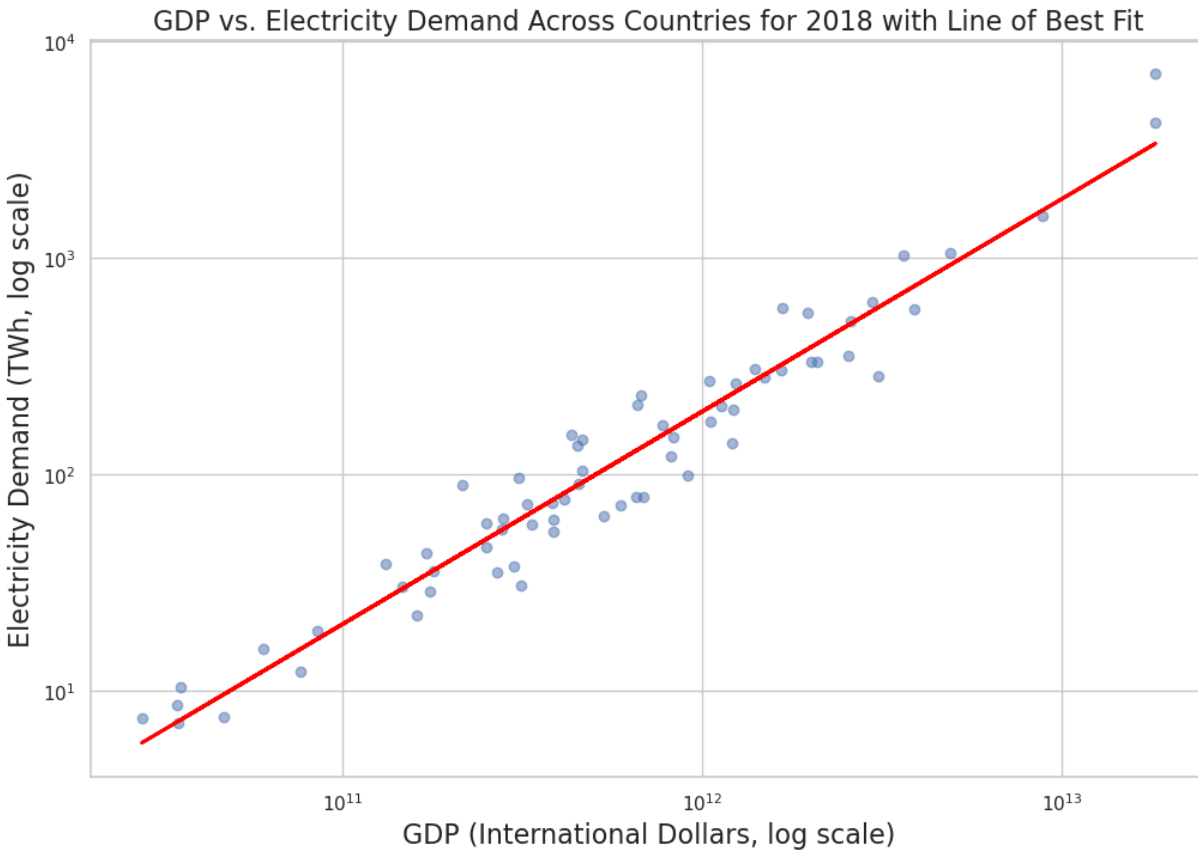

Figure 1.1: Scatter plot of electricity demand (logarithmically scaled) and GDP (logarithmically scaled) for countries in 2018 (line of best fit shown in red)

Exploring Energy Efficiency with Relation to GDP through Energy Use per Capita

Energy efficiency refers to using less energy to perform the same task or produce the same outcome. While a country may become more energy-efficient, this does not necessarily mean that its total energy consumption per capita will decrease. In fact, the increased wealth often leads to a lifestyle that has higher energy demands, which can offset the gains made from energy efficiency.

The bar chart challenges the assumption that increased wealth will naturally lead to energy efficiency sufficient to offset the rise in energy consumption. If countries continue to consume more energy per capita as they grow wealthier, this poses a significant challenge in addressing global warming. It suggests that without a deliberate shift to low-carbon energy sources and sustainable consumption patterns, economic growth may lead to increased greenhouse gas emissions.

The relationship shown in the bar chart underscores the importance of sustainable development. As countries aim to grow their economies, it becomes crucial to invest in renewable energy and energy-saving technologies. This could ensure that the increased wealth does not correspond to a proportionate increase in carbon emissions. The chart could be used to argue for stronger policies that promote sustainable energy alongside economic development.

The data visualized in the bar chart indicates that a one-size-fits-all approach to energy policy may not be effective. Policymakers need to take into account the specific stage of economic development and the corresponding energy consumption patterns to design targeted interventions that encourage energy efficiency and the transition to renewable energy sources.

The increase in energy usage per capita with rising GDP per capita may reflect changes in consumer behavior. In wealthier societies, there is often a higher demand for consumer goods, more extensive infrastructure, and a higher prevalence of energy-intensive lifestyles. This highlights the need for public awareness and incentives for energy conservation.

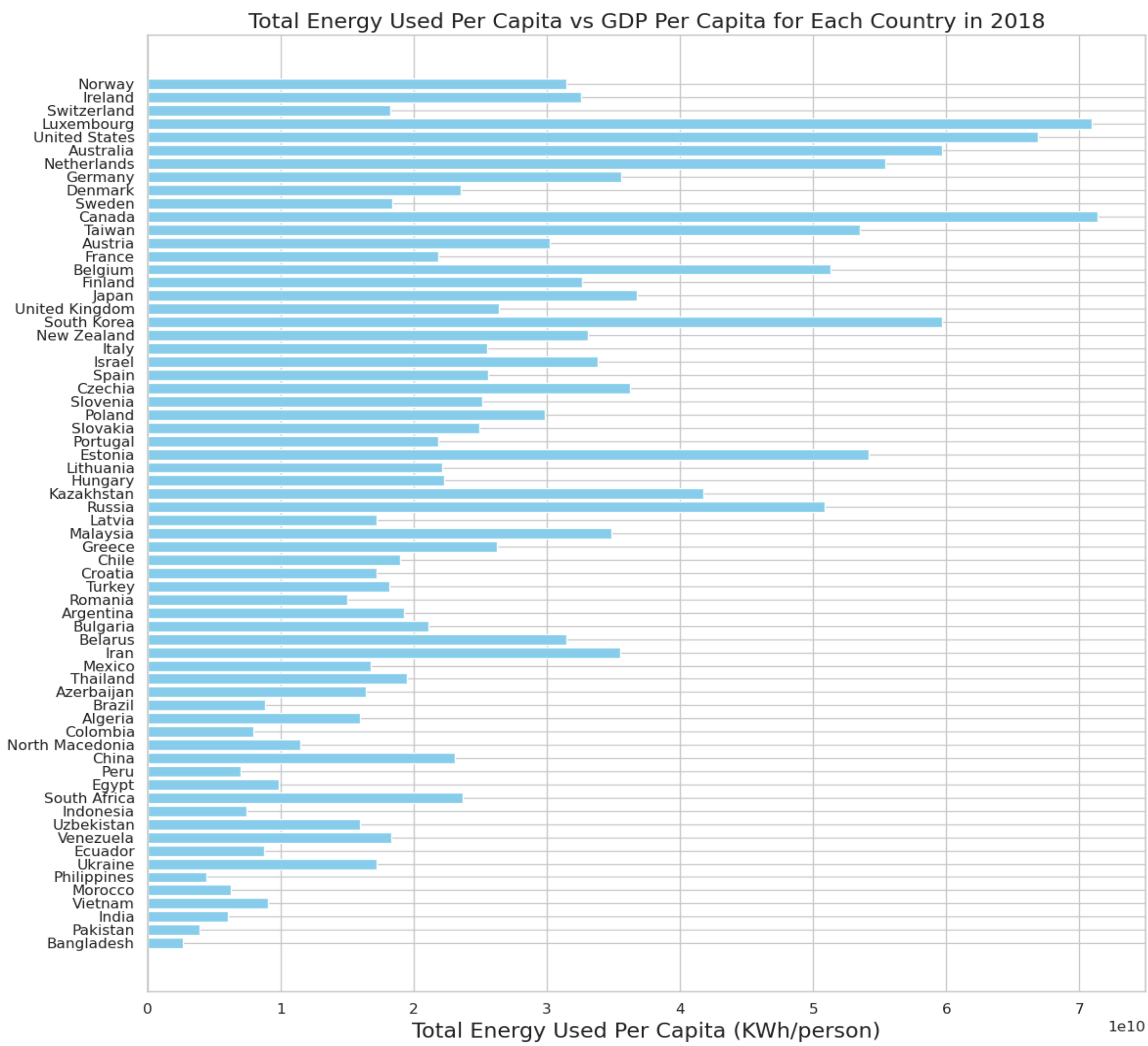

Figure 2.1: Bar chart of total energy consumed per capita for countries in 2018

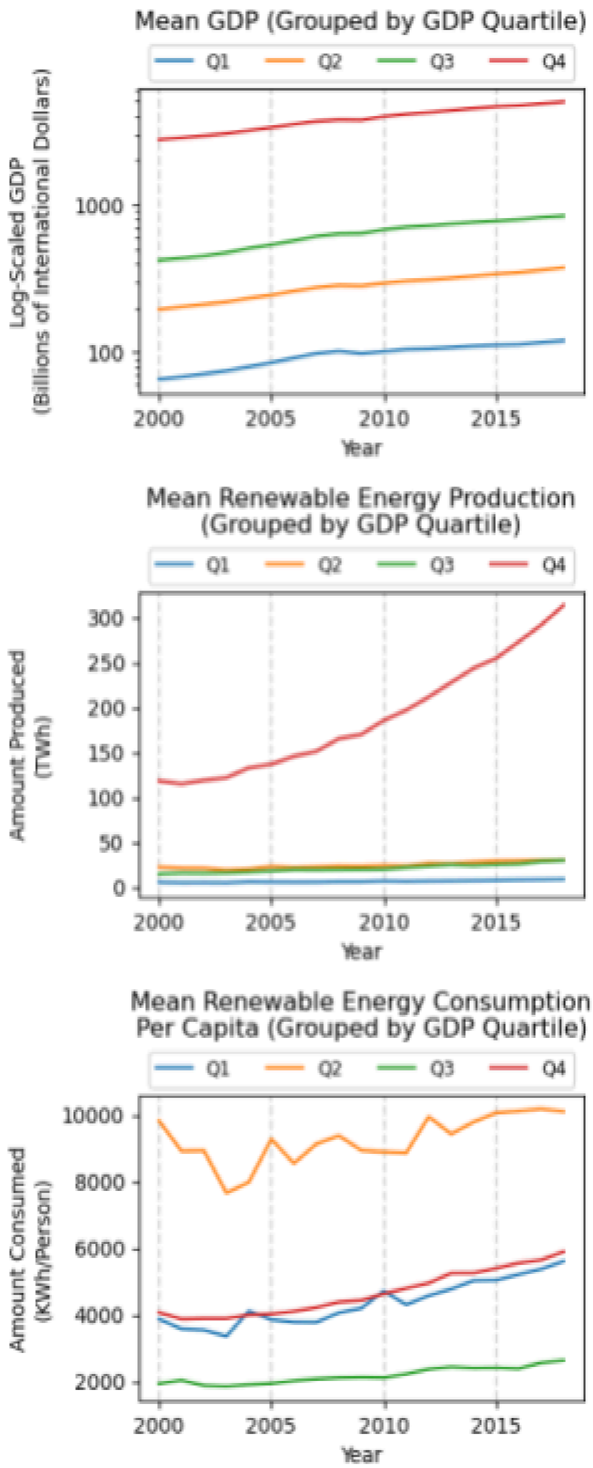

Figure 3.1: Stacked line plot exploring the relationship between GDP and Renewable Energy Consumption/Production (countries grouped by GDP quantile) between 2000 and 2018

Exploring the Economic Impact of Adopting Renewable Energy Infrastructure

As public interest groups and international authorities urge governments to adopt sustainable energy infrastructure, many policy makers are interested to know how investments in renewable energy relate to economic performance. To investigate these concerns, we explored how GDP changes with respect to renewable energy production and consumption. To reduce complexity while maintaining the nuances of varying economic statuses, we grouped countries into quantiles based on their mean GDP (Q1, Q2, Q3, and Q4). Additionally, we log-transformed the mean GDP to better depict fluctuations for countries in the lower quartiles.

Figure 3.1, shows a positive relationship between economic growth and renewable energy production/consumption for all quartiles (the wealthiest countries showing the most rapid increase in renewable energy production). Interestingly, countries with GDPs in the second quartile had the highest relative renewable energy consumption. We suspect this might be due to rapid population growth which warrants higher energy consumption overall. The similarities between renewable energy consumption per capita for countries in the first/fourth quartiles is also interesting. One possible explanation for this behavior is the inclusion of small, wealthy, and energy conscious countries in the first quartile (New Zealand and Finland) which notably raise the overall mean renewable energy consumption per capita.

Exploring the Relationship between GDP, Carbon Intensity, and Renewable Energy Growth

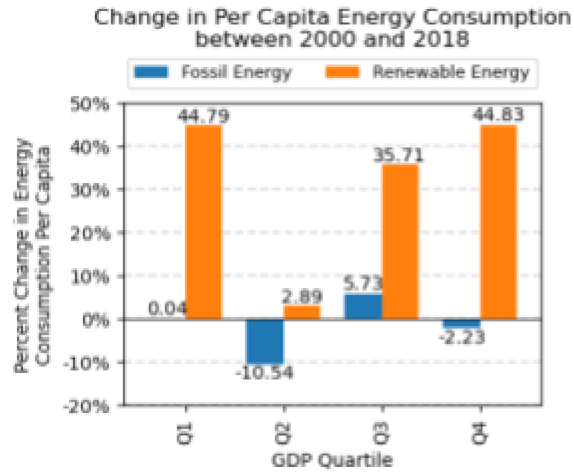

Figure 4.1: Bar plot of change in energy consumption per capita by GDP quartile (broken down by energy type)

We looked at the per capita change in energy consumption for each GDP quartile to better understand how GDP relates to renewable energy growth (Figure 4.1). At first glance, this figure supports expectations: wealthier countries (upper 50% of GDP) saw larger increases in the consumption of renewable energy (likely due to having more economic resources to invest in renewable energy infrastructure). Interestingly, this large change in energy consumption is also observed by countries in the first GDP quartile. Once again, we attribute this to the inclusion of small, energy conscious countries in the first quartile. Another interesting feature is the decrease in fossil energy consumption for countries in the second and fourth quartiles. We attribute this to be the results of wide-spread adoption of renewable energy infrastructure. For the second quartile however, we also suspect a handful of outlying energy-conscious countries (Norway) inflated these values.

To better understand the relationship between a country's GDP and their carbon footprint, we created a choropleth map (Figure 4.2). Although this map is incomplete (countries with missing/inconsistent data have been excluded), it depicts a positive relationship between GDP and the amount of CO2 emitted by a country's energy production. This generally aligns with expectations—countries with higher GDP tend to have larger populations, and therefore generate more energy and pollution. However, there are notable exceptions to this rule, such as certain countries in central and western Europe. We attribute these exceptions to countries with higher GDP per capita but relatively low population size, and stricter carbon emission policies.

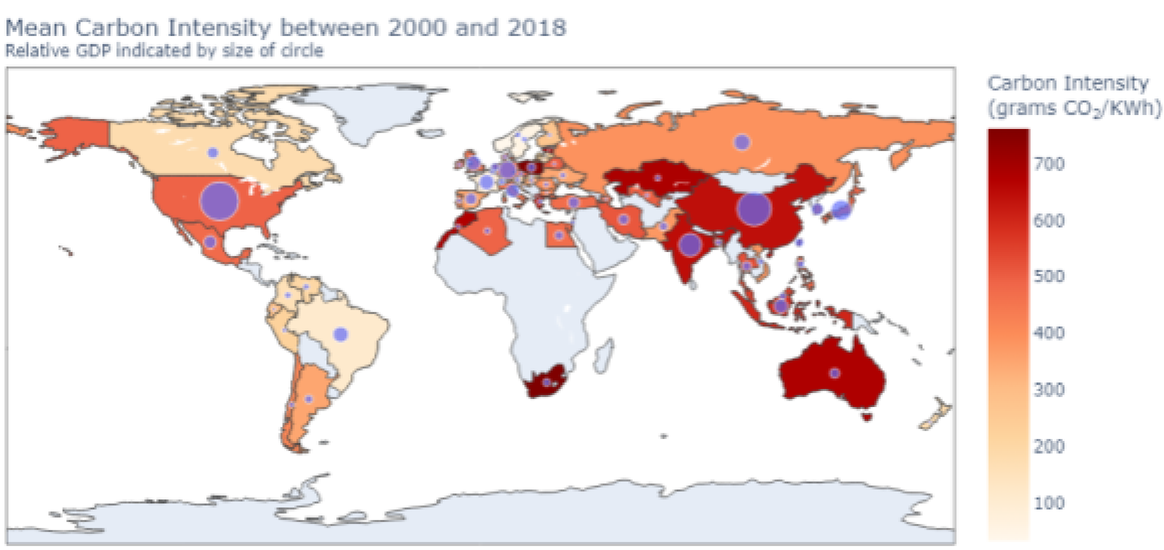

Figure 4.2: Map of carbon intensity (indicated by color) and GDP (indicated by circle size) by Country

Exploring Trends in the Shift from Fossil Fuel Usage to Renewable Energy Across Regions

Next we wanted to explore any trends in different regions in the past two decades with regards to a shift from fossil fuels to renewable energy. To better define this shift, we looked at the variable 'renewables_share_elec,' which captures the percentage of total electricity generation that is driven by renewable energy.

The figure below shows that countries in South America have always had the highest percentage of renewable energy output, with Oceania (here only containing Australia and New Zealand) coming in second and bridging the gap in recent years. It was interesting to note that Europe, North America and Asia were around the middle of the pack, and even though these regions contain countries with high GDPs, they're being beat out by South America. One possible explanation for this could be that although bigger countries might have higher levels of renewable energy output, they're still heavily reliant on fossil fuels to meet the energy needs of their population. It's important to note, however, that we again suspect a few energy-conscious countries - in this case countries such as Brazil, Colombia and Venezuela that have respective mean renewable energy shares of ~84%, ~77% and 69% - to be inflating these categories.

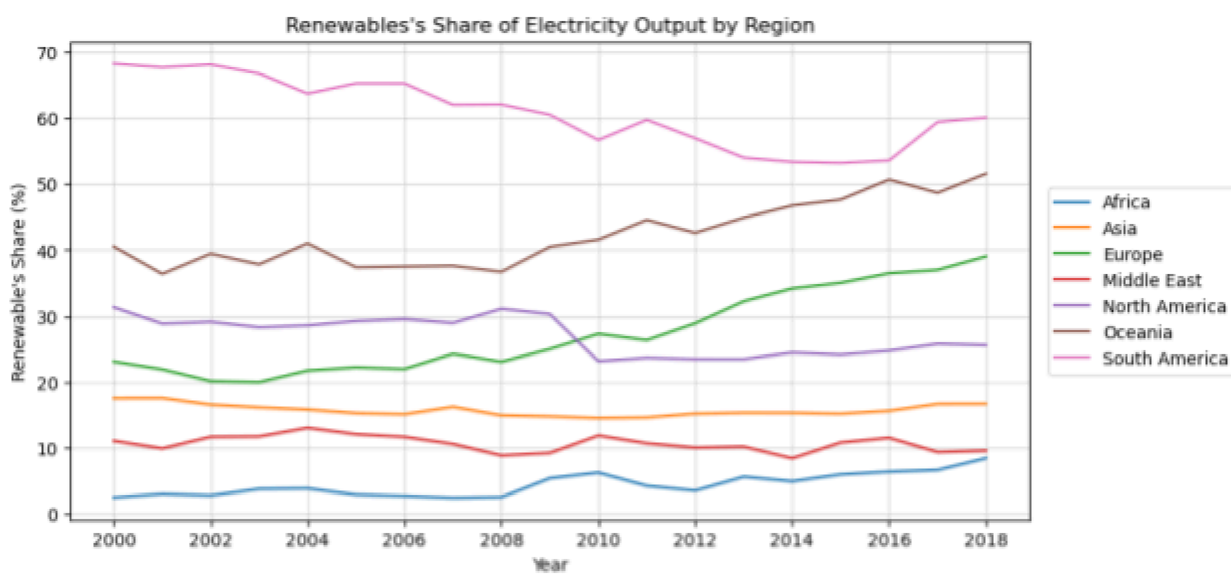

Figure 5.1 shows a time series of each region's mean percentage of renewable energy to total energy outputted for the past two decades

Exploring the Relationship Between GDP and Shifts from Fossil Fuel Usage to Renewable Energy

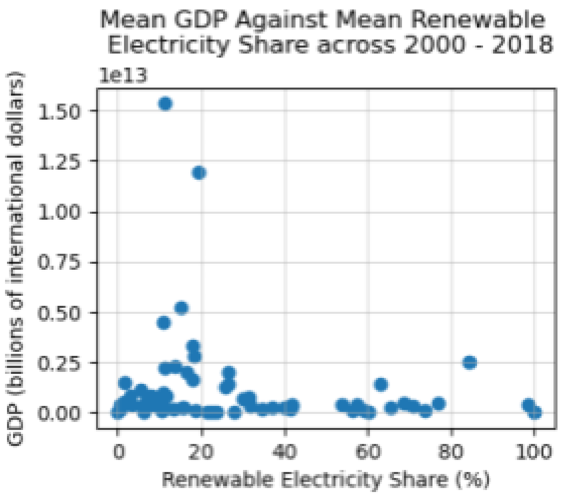

Figure 6.1

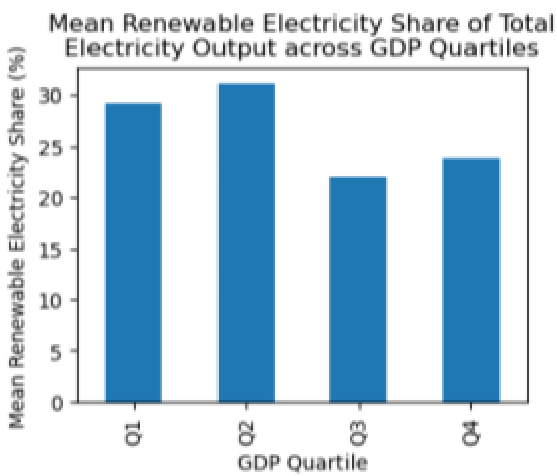

Figure 6.2

Figure 6.1 shows a scatterplot of the relationship between GDP (in billions of international dollars) and Renewable Electricity Share (%) for each country. Figure 6.2 shows a bar graph of the mean Renewable Electricity Share (%) for countries in each GDP Quartile.

Lastly, we looked at the relationship between GDP and renewable energy's share of total electricity output. First we graphed a scatter plot of the countries' mean GDP and mean renewable energy share across the years (Figure 6.1). The relationship wasn't entirely clear, with some major outliers with high GDPs, so we again grouped countries into quartiles of their respective GDP size and plotted a bar chart showing each quartile's mean renewable energy share (Figure 6.2).

This chart shows that on average, lower GDP countries actually have a higher ratio of renewable energy to fossil fuel output. Again, this could be inflated by lower GDP countries that are especially environmentally conscious like certain Nordic and South American countries, but it's important to note that this trend holds up when you consider the fact that countries with the highest GDPs like the United States, China and Germany all have relatively low mean renewable energy shares (11.29%, 19.26% and 18.11% respectively).

Navigating the Future: Balancing Economic Growth with Sustainable Energy Transition

The findings from our project underscore the complex interplay between economic growth, energy consumption, and the transition to renewable energy sources. Our analyses reveal a positive correlation between GDP and electricity demand across countries, highlighting the energy-intensive nature of economic development. Additionally, our data challenge the assumption that increased wealth automatically leads to greater energy efficiency and reduced carbon footprints. Instead, it suggests that without strategic interventions, economic growth could exacerbate environmental challenges.

The insights gained from examining the shifts from fossil fuels to renewable energy emphasize the importance of tailored energy policies that consider each country's unique economic and social context. Despite the higher renewable energy shares observed in lower GDP countries, the global trend indicates a gradual shift towards renewable energy across all economic spectra, driven by both necessity and increasing environmental awareness.

As nations continue to develop, integrating sustainable practices and infrastructure becomes paramount to ensure that economic advancements do not come at an environmental cost. This project not only contributes to our understanding of the current landscape of global energy production and consumption but also highlights the critical need for policies that promote sustainable energy alongside economic development. The pursuit of renewable energy is not just an environmental imperative but a socio-economic opportunity that can lead to more resilient and sustainable growth models.

This study acts as a call to action for policymakers, industry leaders, and the global community to forge a path towards a sustainable future, leveraging the insights provided to make informed decisions that balance economic growth with environmental stewardship.