**Data Visualization Topics**

CST2106

**Final Project Report**

**Global Energy Consumption - Navigating the Path to Sustainability**

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**Table of Contents**

1. Executive Summary
2. Background
3. Analysis
   1. Total Energy Consumption
   2. Energy Consumption by Source type
   3. Per capita Energy Consumption
   4. Annual Changes in Total Energy Consumption
   5. Fossil Fuel Consumption
      1. Fossil Fuel Consumption in USA
      2. Fossil Fuel Consumption in China
      3. Fossil Fuel Consumption in Russia
      4. Fossil Fuel Consumption in Germany
   6. Renewable Energy Consumption
      1. Renewable Energy Consumption in Canada
      2. Renewable Energy Consumption in Japan
      3. Comparing USA and Germany
      4. Will countries make to their targets
   7. Prediction Modelling
4. Conclusion & Recommendations
5. References

**Abbreviations**

Energy Metrics:

KWh – kilowatt-hours

TWh – terawatt hours

**Tools**

Data Cleaning:

Power BI and MS Excel

Visualizations:

Power BI

Prediction Modeling:

Jupyter Notebook

**Executive Summary**

The world is undergoing a transformative shift in its energy landscape as it grapples with the challenges of the finite nature of traditional fossil fuels. Global energy consumption has risen steadily, driven by population growth, industrialization, and technological advancements. In response to environmental concerns, countries worldwide are increasingly turning towards renewable energy sources to meet their growing energy demands. This shift is characterized by a significant increase in the adoption of solar, wind, hydropower, and other sustainable alternatives. Governments, businesses, and individuals are investing in cleaner technologies, policy frameworks, and infrastructure to accelerate the transition to a more sustainable and low-carbon energy future.

We have chosen this topic to analyze energy consumption around the world from 1980-2022. We have analyzed the total consumption, consumption based on GDP and per capita. The dataset[1][2] we are working with is from 1900 – 2022 and has a lot of inconsistencies since historical data for all countries is not readily available or not publicly available and some of the countries were not formed. For the total consumption we have focused on the world but for a deeper analysis in fossil fuels and renewable energy we have focused on a set number of countries. The dataset mainly focuses on energy consumption based on different types of sources like fossil fuels, renewables, nuclear, etc. by country.

For a deep analysis, we have compared the total consumption of energy between companies with factors like population and GDP. We have compared their fossil fuel consumption and what are their trends over the years and later we have moved to renewable sources and how some countries have taken to reduce the fossil fuel dependency and move towards a sustainable and clean energy. To conclude, we tried to predict some of the features of consumption and how countries are doing to hit their clean energy targets.

**Background**

The landscape of global energy consumption has undergone profound transformations over the decades. From the late 20th century to the present day, an unprecedented surge in population growth, urbanization, and industrialization has driven an insatiable demand for energy resources. Fossil fuels, primarily coal, oil, and natural gas, have historically fueled this burgeoning appetite for power, propelling economies and societies forward. However, this unchecked reliance on finite and environmentally taxing resources has triggered a confluence of challenges. Recognizing the urgent need for a sustainable energy paradigm, the 21st century has witnessed a paradigm shift in global energy conversations. This backdrop sets the stage for our analysis of "Global Energy Consumption - Navigating the Path to Sustainability," a critical exploration that seeks to illuminate the trajectory of global energy consumption and the emergent path towards a more sustainable, resilient, and environmentally conscious energy future.

**Analysis**

For the analysis of energy consumption, we have filtered the dataset[1][2] from the years 1980-2022 in which for the total consumption we tried to showcase all the countries but for a deeper analysis forward we have kept to certain set of countries. We have also made changes to the original dataset to remove data from the year 1900-1959 since there were a lot of missing data of countries who hasn’t published numbers or in some instances countries like Pakistan or Bangladesh who were not formed prior to 1947. Then we additionally filtered data from 1980-2022 to have more consistent data values available. There is still a lot of missing data and we decided to replace those values with ‘0’ since using mean or average numbers were skewing some of the other analysis that we had to do so we chose this approach.

1. **Total Energy Consumption:**

A screenshot of a graph

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Figure a.1

How much energy does the world consume?

The interactive dashboard[3] shown in Figure a.1 displays the total primary energy consumption of the selected country in a specific year selected with some numbers of energy by population or GDP with a breakdown by source. Looking at the world cumulative numbers, taking the year 2022 as a baseline, the total primary energy consumption around the world was 167,787.67 TWh. Looking at the population (based on this dataset) is 7.98 billion and that dictates that each person used 21,000 KWh energy. And we have increased around 1840 TWh consumption compared to previous year.

A graph with a line going up

Description automatically generated

Figure a.2

This visualization clearly shows the increasing rate of energy consumption around the world as a cumulative value.

1. **Energy consumption by source type:**

We have looked at the total energy consumption but where does that energy come from. Lets look at the different type of energy sources. The type of energy sources covered in this data set are fossil fuels (coal,oil,gas), renewables(solar,wind,hydro,biofuel), nuclear, low carbon and other renewable types.

A graph of a graph

Description automatically generated with medium confidence

Figure b.1

To visualize this problem, we have used stacked line char to show different proportions of source types over time in a global scenario. This vividly shows that coal,oil and gas are the top contributors as sources for energy production and consumption. However, it can be seen that from the year 2005 and onwards the slight uptick in renewables has been growing. There are certain points in time where it can be seen that the overall consumption has dropped, out of those notables years, 2020 covid pandamic is one of them. To put it into numbers, the over all coal usage is 26.7%, oil is31.57% and gas is 23.49%. That makes fossil fuels as major contributos at 81% of the consumption source.

1. **Energy consumption per capita:**

When assessing total energy consumption, variations among countries frequently stem from differences in population size; larger countries naturally exhibit higher energy consumption due to their larger populations. How do countries stack up when we examine energy consumption on a per capita basis?

A screenshot of a graph

Description automatically generated

Figure c.1

The figure above shows overall per capita consumption over the time period of 1980-2022. The left side of the dashboard dictates per capita consumption in select countries like US, Russia, Japan, China and India. Where we can see that US and Russia has the highest per capita consumption among those set of countries. But if you talk about worldwide the the right side of the dashboard shows that Qatar and UAE tops those charts in per capita consumption. Qatar tops at whooping 194,221 KWh per person followed by UAE. Even though China and India has overall higher consumption but due to higher population demographic, their per capita consumption is lower.It has been observed that this value keeps growing over the past decade and possibly in the future as well.

1. **Annual changes in Energy consumption YoY:**

It has been observed that the total energy consumption has been growing every year with exceptions of certail world level events.We have analysed how much it differs from the previous year to find some insights.

A screenshot of a graph

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Figure d.1

The visualization above represents the change in energy consumption % over the previous year. Comparing US, China and India overall, we can see that the there were ups and downs in consumption over the last decade. The only notable event that can be seen is the covid-19 pandemic in 2020 where the consumption dropped all over the world then it increased in 2021 and then it was reduced a bit the following year. The chart on the right shows the countries who had the highest change over the previous years.

1. **Fossil fuel consumption**

Over the years, coal, oil and gas are the three major energy sources dominating the global context of fossil fuel consumption. Fossil energy has played a crucial role in technological advancements, encouraging social, economic, and developmental progress over time. In this section, we will analyze and find insights on the historical fossil fuel consumption and how the dependency is decreasing across the world, and some select countries.

A screenshot of a graph

Description automatically generated

Figure e.1

* Analysis of the data reveals increasing consumption of this fossil fuel since 1980. Initial coal consumption is 20,857 thousand terawatt-hours (TWh), oil consumption is 35,525 TWh and gas consumption is 14,236 TWh.
* Fast forward to the final year in our data set, 2022, the data shows further increases in the consumption of these fossil fuels: coal, oil and gas became 44854 TWh, 52969.59 TWh, and 39413.04 TWh.
* To achieve maximum sustainable Energy Usage, we must push for reductions in non-sustainable sources such as coal and oil, noting that natural gas is relatively sustainable.
* Many countries have also begun to limit the use of renewable energy, indicating a collective commitment to limiting environmental impact.
* The project we are proposing is a world in which natural gas replaces oil and coal as the primary source of energy worldwide. This supports the global trend towards the use of environmentally friendly energy that will lead to a more sustainable environment in the future

**e.i) Fossil fuel consumption in USA**

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Description automatically generated

Figure e.i.1

* The figure below shows fossil fuel consumption in the U.S, which represents most of it being oil. This shows the importance of oil as a primary source of energy widely used by organizations and industries.
* The year 2007 marks an important turning point in the line graph, with a significant fall in coal and a small drop in oil. Looking into the figures, in 2007, the quantity of coal was 6,333 TWh while that of the oil was 11,001 TWh. Fast-forwarding to 2022, the figures show that during this time, oil saw a decrease down to 10,041 TWh, while coal experienced an impressive reduction of 2,741 TWh.
* At the same time, an apparent rise in natural gas use is evident in this case. Use of natural gas increased from 6,241 TWh in 2007 to 8,812 TWh in 2022. This movement in consumption trends shows that steps were taken to shift towards green energy options.
* This indicates that the U.S. government embarked on strategic moves in 2007 whereby consumption of coal was greatly reduced, and oil use reduced moderately. This is during a growth in consumption of natural gas, and hence showing that it was not random but a concerted effort to use the more sustainable sources of energy.
* This is a shift in line with global trend to move away from unsustainable energy sources and toward green energies.

**e.ii) Fossil fuel consumption in China**

A screenshot of a graph

Description automatically generated

Figure e.ii.1

* The Rise in usage of China’s fossil fuel consumption is remarkable which may be due to industrialization, population expansions and technological advancement.
* Coal becomes the leading fuel accounting for more than two-thirds (74%) of the total share. An important observation is the jump in coal consumption between 2000 and 2014 which rose from 9,467 TWh to 24,599 TWh.
* This information indicates that although China grew tremendously, it did not make major steps to switch to renewables.
* The fact that they have stuck with coal as the main energy source shows that they are still committed to the age-old but unsustainable ways of doing things.

**e.iii) Fossil fuel consumption in Russia**

A screenshot of a graph

Description automatically generated

Fig e.iii

* This trend of fossil fuel consumption in Russia different from the trend of countries already analyzed. Russia can be singled out as a major consumer of natural gas with the percentage, being 54% of their energy.
* There is achange in the data, especially in 1992, when there was a decrease in the consumption of both coal and oil in Russia. Coal consumption reduced from about 1,825 TWh in 1990 to 1,362 TWh by 1996. In the same manner, oil demand dropped from 3 984 TWh to 1 539 TWh during this time.
* These observations indicate a move by the Russian government to reduce dependence on oil and coal. The visible cuts in coal and oil supplies are consistent with possible policy options for a greener energy
* The domination of Russia in natural gas usage from start suggests strategic emphasis on a cleaner and greener energy alternative.

**e.iv) Fossil fuel consumption in Germany**

A screenshot of a graph

Description automatically generated

Figure e.iv.1

* The energy consumption patterns of the USA, China, Russia and Germany shows very different ways of using fossil fuels and converting into clean energy.
* As regards the US, there seems to be a aim at putting a stop to non-sustainable forms of energy. There is decline in coal and oil consumption with increase in natural gas usage, points to an effort to convert into sustainable options.
* On the other hand, China still tends to keep coal as their main energy type showing not enough efforts for green options. Rapid industrialization and population growth have contributed to a considerable increase in total fossil fuel consumption which brings it to be the difficulties encountered in controlling energy needs when developing countries undergo rapid industrialization and population growth like China.
* In this case, Russia differs because it has focused on natural gas as the primary source of energy. The reduction in coal and oil consumption in 1992 is noticeable, thus concludes that the country may have been taking measures to decrease coal and oil usage.
* However, analyzing Germany we see a complete shift from fossil fuel to renewable energy resources. A successful move to sustainable and environment-friendly energy practices is implemented by the consistent reduction in coal and oil usage and a corresponding dramatic increase in renewable energy adoption.
* Thus, each of the countries have their own path in terms of the energy consumption development strategy. The United States and Germany make efforts to shift away from non-sustainable sources while China struggles to balance out its energy demands, and Russia traditionally prefers natural gas as a source of energy. These are the global views on how energy policies can interact industrial development as well as environmental sustainability.

.A graph of energy consumption

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Figure e.4.2

This figure shows the renewable energy usage in Germany, and we see a gradual increase in usage on the amount of renewable energy usage this conclude that some countries like Germany shifted their focus from fossil fuels to renewable energy source of energy for good environment and clean energy.

1. **Renewable Energy Consumption**

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Figure f.1

The above dashboard shows the area graph of Total Renewable Energy consumption for all the from the year 1980 to 2022 as well as a pie chart that shows breakdown of renewable energy consumption into 5 components i.e. Solar Energy, hydro Energy, Biofuel Energy, Wind Energy and a category of other renewable energy sources which is a combination of geothermal, biomass etc. This category was available in the dataset possibly due to low contribution of induvial sources that cannot provide meaningful insights.

The donut chart on the bottom right provides breakdown on amount (percentage) of electricity generated from each type of energy source. From the area we observe that over the years, hydro power has been a major contributor of energy source from renewable energy sector. It becomes more evident from the energy breakdown donut chart that almost 3/4th of the renewable energy consumption is through hydro energy. Moreover, hydro energy is responsible for 3/4th electricity generated from renewable energy sector.

Another insight is that the consumption of solar and wind energy accelerated rapidly after 2005.

A graph showing the growth of the company's stock market

Description automatically generatedFigure f.2

This is a line graph of Fossil Fuel consumption ratio and Renewable energy consumption ratio from the year 1960 to 2022. Fossil Fuel consumption ratio is the ratio of fossil fuel consumption and total energy consumption for a particular year. Similarly, renewable energy consumption ratio is the ratio of net renewable energy consumption value and the total energy consumption value for a particular year.

From the graph we observe that during 1960’s, the fossil fuel ratio was quite high at around 88% and the renewable energy ratio was around 6%.

From the graph we observe that during 1960’s, the fossil fuel ratio was quite high at around 88% and the renewable energy ratio was around 6%. The graph shows gradual decrease in dependency on fossil fuel to around 81% in 2022. In contrast, the contribution of renewable energy has increased more than double to 14% in 2022. Thus, the popularity of renewable energy is increasing tremendously.

**f.i) Renewable Energy Consumption in Canada**

A screenshot of a graph

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Figure f.i.1

**Deep Analysis:**

* The solar, wind, and hydro reveal a year-on-year growth, mirroring the growing interest in these renewables.
* The late 1990s through present suggest higher utilization of biofuel demonstrating a growing trend.
* Hydroelectric power is the most dominant renewable resource in Canada, taking up 95 percent of all consumption.
* This is because Canada has a lot of water resources, making hydroelectricity the most reliable and widely use renewable energy source in the country.
* The ever-present importance of hydroelectricity illustrates how it defines Canada’s renewable energy.

**f.ii) Renewable energy consumption in Japan**

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Figure f.ii.1

**Deep Analysis:**

* Solar and wind energy that have seen considerable growth over the years
* Hydroelectric power fluctuates slightly only in some years
* Likewise, biofuel and other renewables also display different trends that may arise from technological advancements and/or policy changes.
* Solar energy has become a tremendous rising source and is currently a major contributor in the renewable energy sector.
* Investment increases in wind power infrastructure have led to a steady and substantial growth of wind energy.
* Hydroelectric power has retained its stability as the main one of the constant sources over the years.
* The data concludes a diverfication in usage of each Renewable energy resources.
* Japan is most reliant on hydro as the primary source of energy because of the geographical reason making water most accessible to them just like Canada.
* It supports what Japan strives for diversifying its energy supplies and promoting green strategies.

**f.iii) Comparing US and Germany**

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Figure f.3.1

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Figure f.iii.2

**Deep Analysis: US vs. Germany - Renewable Energy Generation**

The primary renewable energy sources include Solar, Wind, Hydro, Biofuel, and Other renewables.

US

* Solar and Wind Growth: A significant growth in solar and wind energy is observed indicating a shift towards these technologies.
* Biofuel Contribution: Biofuel seems to play an important role in the US renewable energy consumption, showing consistent growth.
* Hydro Stability: Hydroelectric power was dominant before 2000, however, the contribution of other renewable energy sources has rapidly increased.

Germany

* Wind Dominance: Germany exhibits a strong reliance on wind energy, which has consistently increased over the years similar to US.
* Solar Growth: Solar energy has shown significant growth, contributing substantially to the renewable energy sector.
* Biofuel and Hydro Stability: Biofuel and hydro sources contribute consistently without major fluctuations.
* Overall Growth: Germany's renewable energy generation has seen a steady increase, aligning with its commitment to sustainable practices.

**Comparative Analysis:**

Dominant Sources:

* Currently, US and Germany both have a large part of renewable energy consumption through wind energy

Technology Adoption:

* US: It shows a diversified approach with substantial growth in almost all renewable sources consumption and electricity production
* Germany: A focus on wind and solar, aligning with Germany's commitment to phasing out nuclear power.
* Significant growth in solar highlights a commitment to decentralized energy production.

**f.iv) Will countries make to their targets**

**A screenshot of a computer

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Figure f.iv.1

The progress report on Canada's 2030 Emissions Reduction Plan indicates that the country is expected to surpass its interim target, reducing greenhouse gas emissions by 20% compared to 2005 levels by 2030 (8). Canada's ambitious plan aims to achieve a 40% reduction in emissions below 2005 levels by 2030, with a long-term goal of achieving net-zero emissions by 2050. This comprehensive approach involves measures such as clean fuels, green taxes, and green products, supported by a budget of 9.1 billion dollars, covering various sectors like industries, agriculture, transport, and buildings (8).

In the United States, the Biden-led government has set renewable energy targets requiring 80% of all power to be derived from renewable sources by 2030 and a complete transition to carbon-free electrical power by 2035 (8). The shift from fossil fuels is emphasized in the context of the Inflammation Reduction Act, which allocates close to 370 billion dollars to support investments in greener technologies (8).

Similarly, Japan aims to double the share of renewable energy in its electricity mix by 2030, with targets to reduce greenhouse gas emissions by 46% relative to 2013 levels and achieve carbon neutrality by 2050 (8). Germany, part of the G7 group committed to a carbon-free energy sector by 2035, has set individual targets for renewable energy generation and greenhouse gas reduction (8).

These countries collectively recognize the urgency of addressing climate change and have set renewable energy goals as part of their strategies to transition to green and clean energy sources

1. **Prediction Modelling**

For prediction modelling, our aim is to predict the Total energy consumption. For this we chose features such as ‘year’, ‘population’, ‘country’ and ‘gdp’. Thus, our label is ‘primary\_energy\_consumption’ column and the rest mentioned are input features. We have implemented the model in python programming language using scikit learn library.

Before we start to build the model, it is important to prepare the data. We have taken two steps to prepare the data. First, we have considered countries where the primary and renewable energy consumption was relatively very high. These countries include Brazil, Canada, China, France, Germany, India, Italy, Japan, Norway, Russia, Spain, Sweden and United States. Therefore, we separate the data for these countries and have created a new dataset.

Secondly, for the model, ‘country’ is categorical field and does not much provide value alone. Therefore, we have applied one hot encoding on the country feature which provides much more value. Lastly, the features ‘population’ and ‘gdp’ have numeric values and the energy consumption values are relatively low. Hence, we have decided to apply scaling to our data and used standard scaler to our data.

Next, since the data falls within the category of time series, we have chosen to implement two models namely Linear Regression and Random Forest. First we split the data, into train and test sets. We have chosen 15% of the data as test data, selected randomly. Moreover, for Random Forest Model, we have chosen RandomForestRegressor we have chosen hyperparameters n\_estimators as 270 and max\_depth as 3.

**Results**:

The following results were obtained from the two models.

|  |  |  |
| --- | --- | --- |
|  | RSME | R2 score |
| Linear Regression | 1757.47 | 0.9174 |
| Random Forest | 1594.13 | 0.9321 |

To measure the performance of the models we have chosen root mean squared error. From the two models, it is evident that Random Forest model is comparatively better suited to predict the primary energy consumption values as it has a lower value of root mean squared error. However, the values of error being high for both the models suggest that model was not able to converge accurately or the model needs more data points to lower the error value and be of use.

**Conclusions & Recommendations**

* As per the trend observed in the total primary energy consumption around the world, it has been increasing over the years steadily which co-relates to increase in population around the world and increase in overall GDP per country. The change can be skewed by some world events but it has been observed that it will jump back to its normal track the following year. Currently China is leading the highest energy consumption at 44,275 TWh and Qatar is leading the per capita consumption at 194,221 KWh.
* Among Fossil Fuel, the coal consumption trend in US seems to be declining, however the same for China is increasing.
* Russia has shifted its focus on Natural Gas among the fossil fuel and is highly dependent of hydropower in the renewable energy sector.
* Germany has been highly successful in reducing the dependency on fossil fuel with steady decline year-on-year from 1980 to 2022.
* In the Renewable energy, Canada has been highly reliant on Hydropower and still continues to do so with gradual growth in the wind and solar energy.
* US and Germany currently have shifted focus towards wind energy. While on the other hand Japan has been striving and leading in solar energy sector.
* Overall, the Fossil Fuel component in the Renewable Energy is decreasing stedily while the component of renewable energy is rising rapidly.
* Many countries have set some very ambitious targets for the renewable energy adoption for 2030. However, most of them are still very far from achieving those targets and will have to make very significant investments to achieve those targets.
* To improve the performance of the model, it should be trained with more data values which can include adding additional years data or additional countries data.
* The model used input features such as population and gdp. To improve the performance of the model, more features that are highly correlated should be included as input.

**References**

[1] Hannah Ritchie, Max Roser and Pablo Rosado (2023) - “Energy” Published online at OurWorldInData.org. Retrieved from: 'https://ourworldindata.org/energy' [Online Resource]

[2] Our World in Data, "Energy Data," GitHub. [Online]. Available: <https://github.com/owid/energy-data>. [Accessed: November 21, 2023].

[3] TopoJSON, "world-atlas," GitHub. [Online]. Available: <https://github.com/topojson/world-atlas>. [Accessed: November 27, 2023].

[4] U.S. Energy Information Administration (EIA), "U.S. Energy Information Administration," [Online]. Available: <https://www.eia.gov/>.

[5] German Federal Ministry for Economic Affairs and Energy (Bundesministerium für Wirtschaft und Energie), "German Federal Ministry for Economic Affairs and Energy," [Online]. Available: <https://www.bmwi.de/Navigation/EN/Home/home.html>.

[6] Natural Resources Canada, "Natural Resources Canada," [Online]. Available: <https://natural-resources.canada.ca/home>.

[7] Ministry of Economy, Trade and Industry (METI), Japan, "Ministry of Economy, Trade and Industry (METI)," [Online]. Available: <https://www.meti.go.jp/english/>.

[8]Oğuz, S. (2023, November 8). Progress on 2030 Renewable Energy Targets by Country. Visual Capitalist. https://www.visualcapitalist.com/progress-on-2030-renewable-energy-targets-by-country/.