CRITICAL ANALYSIS OF RENEWABLE ENERGY RESOURCES

Aditya Raj
Delhi Technological University, Delhi
aditya.x21@hotmail.com

ABSTRACT

The objective of this assignment is to study the renewable energy and CO2 emission patterns of the country of significance. The country of significance is chosen as France. The assignment aims to find out about the trends of renewable energy performance of France by examining the data of consumption through the years and to also forecast the future trends in the different energy consumption.

This shall be achieved by examining the historical data and applying a simple linear regression model to infer different information about it and understand the dynamics of the country in terms of its energy production and consumption.

The statistical inference has been performed by the use of Google sheets along with some operations performed on MS Excel

1. France - Country of significance

The country of significance for this assignment has been chosen to be France. France is a country that is located in Western Europe and it holds great historical and cultural significance, being one of the oldest countries in the world. It happens to be one of the largest agricultural producers in Europe and is also one of the leading countries with industrial power in the world.

2. Energy in France

France has always been very reliable on nuclear energy and therefore its carbon dioxide emissions have been very less when compared to other G7 economies. The major sources of energy in France are : coal, natural gas, liquid fuels, renewable energy and nuclear power. As of 2020, the electricity produced from nuclear resources outnumbered all other sources as it formed 78% of the total electricity produced. The energy produced through renewable sources of energy stood at 19.1%. The rise of renewable energy in France has been significantly improving and is further expected to improve as the investments in renewable energy have been massively increased with the target to obtain 32% of total energy from renewable resources by the end of 2030.

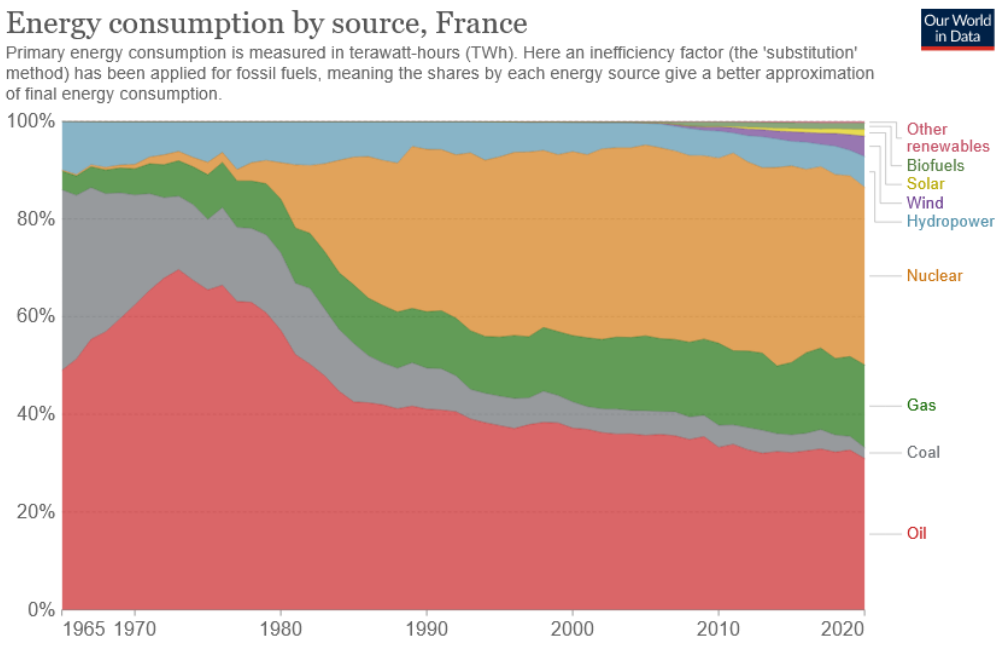


Fig 1 : Energy consumption by source

However, in the year 2021, in the report published by the International Energy Agency, it was highlighted that France was experiencing delays when it came to meeting the energy demands and climate goals. It was also highlighted that carbon emissions were increasing due to use of fossil fuels, especially in the transport sector.

The table given below shows an overview of the energy consumption in France :-

Year	Population (mn)	Prim. energy (TWh)	Production (TWh)	Import	Electricity (TWh)	CO_2 emission Mt
2004	62.2	3200	1575	1633	478	387
2007	63.6	3067	1589	1580	481	369
2008	64.1	3099	1506	1621	494	368
2009	64.5	2980	1582	1563	483	354
2012	65.4	2935	1564	1444	482	334
2013	65.9	2946	1585	1442	486	316

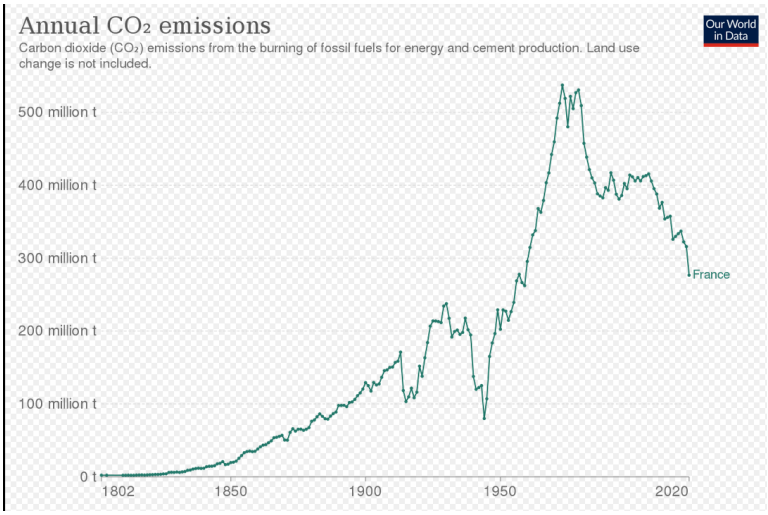


Fig : Annual CO_2 emissions

Electricity

The main contributor to production of electricity in France is nuclear power that accounts for about 72% of the total production of electricity, as of 2016. The percentage for the contribution of renewable energy sources and fossil fuels stood at 17% and 9% respectively. When it comes to the share of nuclear energy in production of electricity, France has the highest share of nuclear power, due to which it makes the country also one of the largest exporters of electricity in the world.

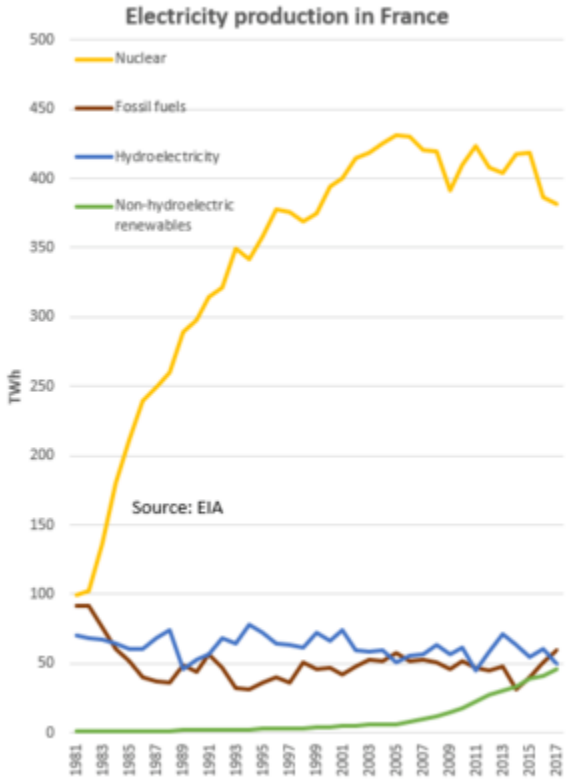


Fig 3 : Electricity production in France

Renewable energy

France had committed to a target of producing about 25% of its total energy from renewable energy resources by 2020 under the EU renewable energy directive of 2009. In October 2016, the “Programmation pluriannuelle de l'énergie” showed a commitment in order to rebalance the production of electricity from renewable sources of energy. According to the above publication, it is expected that the renewable energy capacity will

increase from 41GW in 2014 to about 78GW by the year 2023. One of the major targets of France's renewable energy production is to enhance energy efficiency by a great margin and to reduce heat wastage especially in particular for buildings and thermal insulation. France has a great potential in order to use renewable energy resources in the transport sector.

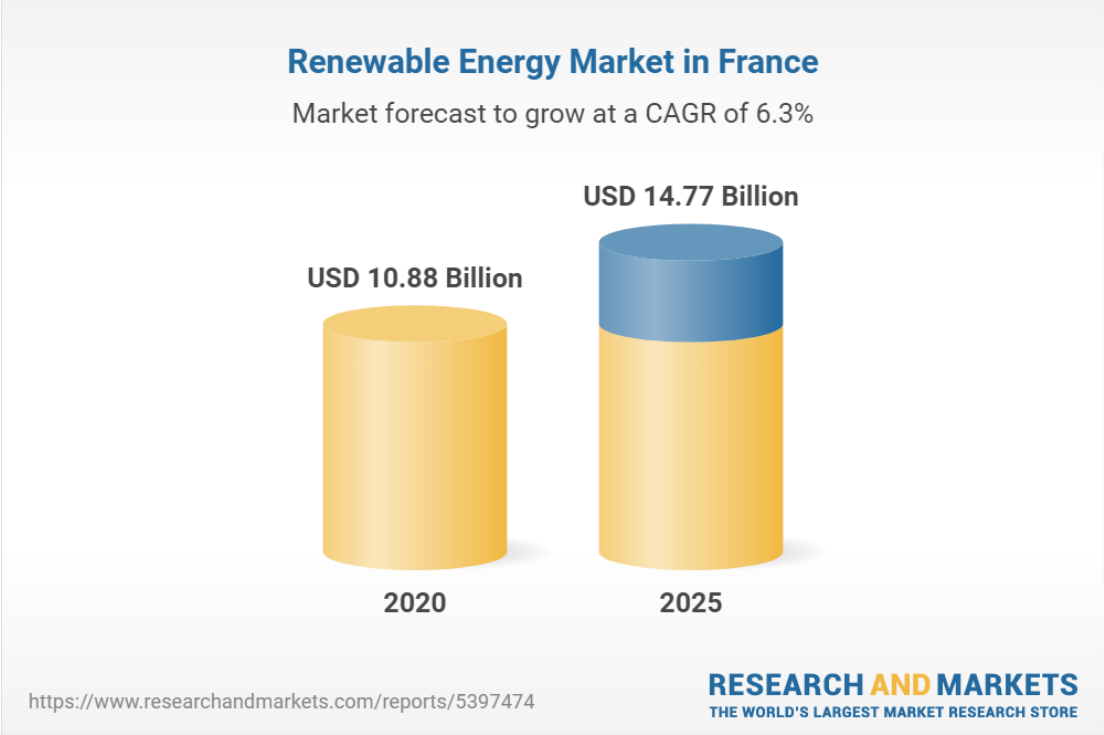


Fig : Renewable energy market in France

Renewable energy - overview and targets

	2014	2018	2023
Onshore wind	9300	15000	21800
Offshore wind		500	3000
Marine energy			100

Solar PV	5300	10200	18200
Hydroelectricity	25300	25300	25800
Bio-energy	357	540	790
Methanisation	85	137	237
Geothermal Power		8	53

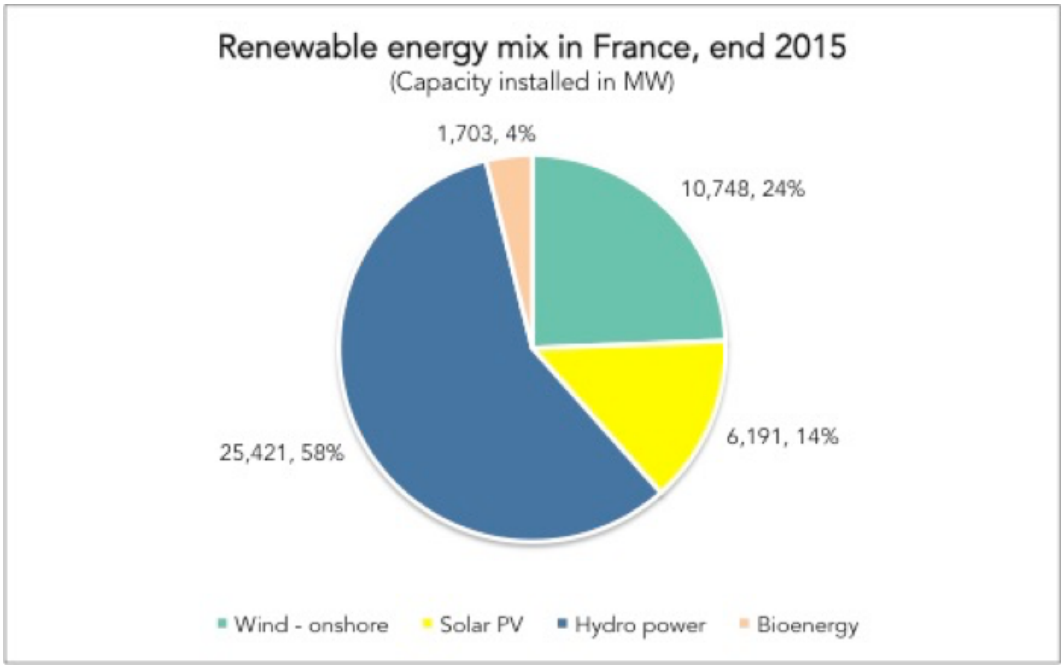


Fig : Renewable energy distribution in France

Hydroelectric Power

In France, hydroelectric power accounts as the largest single source of renewable energy as it accounts for about 12% of the total power consumption domestically as of 2016. As of 2014, there was 25,400 MW of installed power capacity in France arising from 2,600 hydroelectric power plants of different sizes and capacities. As of 2014, France was at the no.10 in terms of the largest producers of hydroelectric power and was the second largest in Europe in the same.

Wind Power

Among the European countries, France has the second largest potential power generation through Wind. France's wind capacity in 2008 was 3,577 MW and has risen to 10,358 MW in 2015 which is a considerable increase as the country progresses to realize its potential. It has been planned to almost double the capacity from onshore wind power by the year 2023. It has been expected that France will have about 11GW of offshore wind and marine energy by the end of the year 2023.

Solar Power

In 2008. France's Solar PV power was about 104 MW. It grew to 6549 MW in 2015 and France went on to become the 7th largest solar PV installed capacity in the world. The President of France, Mr. Francois Hollande and the Prime Minister of India, Mr. Narendra Modi laid the foundation stone for the International Solar Alliance in January 2016. The aim of the ISA was said to focus development of solar energy and solar products from countries that lie between the two tropics.

Tidal Power

The world's first tidal power station was opened in France in 1966 and it was also the largest tidal power station until a few years ago. It has a peak output of about 240 MW that accounts for an annual output of 500GWh.

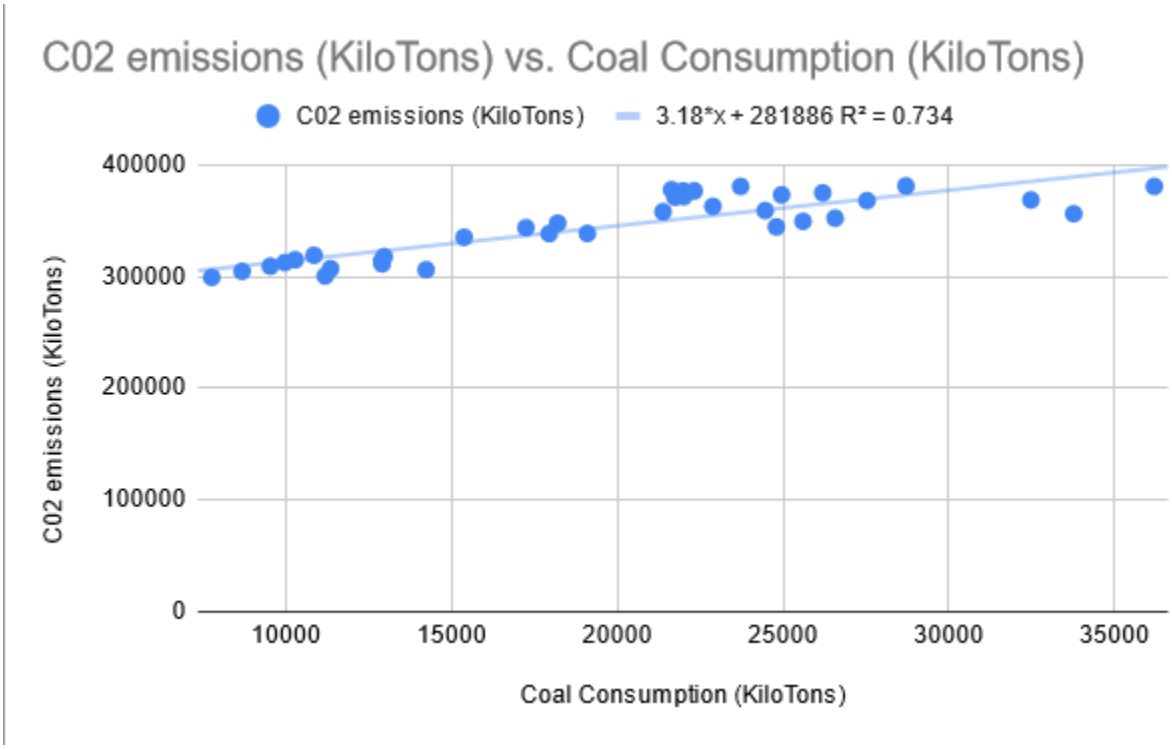
3. CO_2 emission vs Coal Consumption

The data of coal consumption and CO_2 emission was collected for the years 1990-2019. Firstly, the data was plotted on a scatter plot on Google sheets.

By the use of the scatter plot, the equation of the regression line was obtained as :-

$$y = 3.18x + 281886$$

and the value of the coefficient of determination was found to be $R^2 = 0.734$



The value of R^2 suggests that the two entities are not perfectly correlated however they are upto an extent. The prediction results yielded shall be correct up to an extent.

From the graph it can be seen that as the coal consumption increases the CO_2 emissions have significantly gone up and they are bound to increase even further if the coal consumption is not reduced. This calls for the need to switch to greener and better fuels.

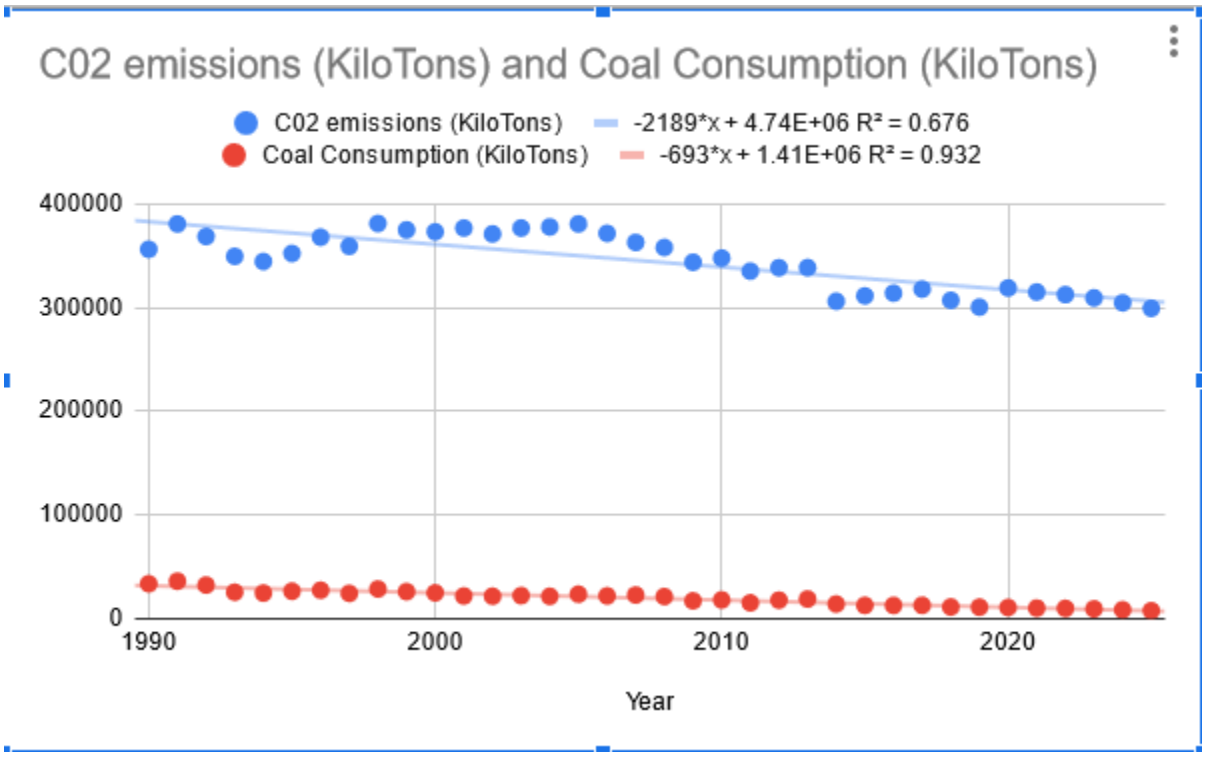
<u>C02 emission and Coal consumption vs Time with prediction</u>

Analyzing coal consumption over time, we obtain the regression line equation as :-

$$y = -693x + 1.41e+06$$

Since the line has a negative slope, it means that the coal consumption has decreased over time which is a good sign and shows a shift towards renewable energy sources for energy production.

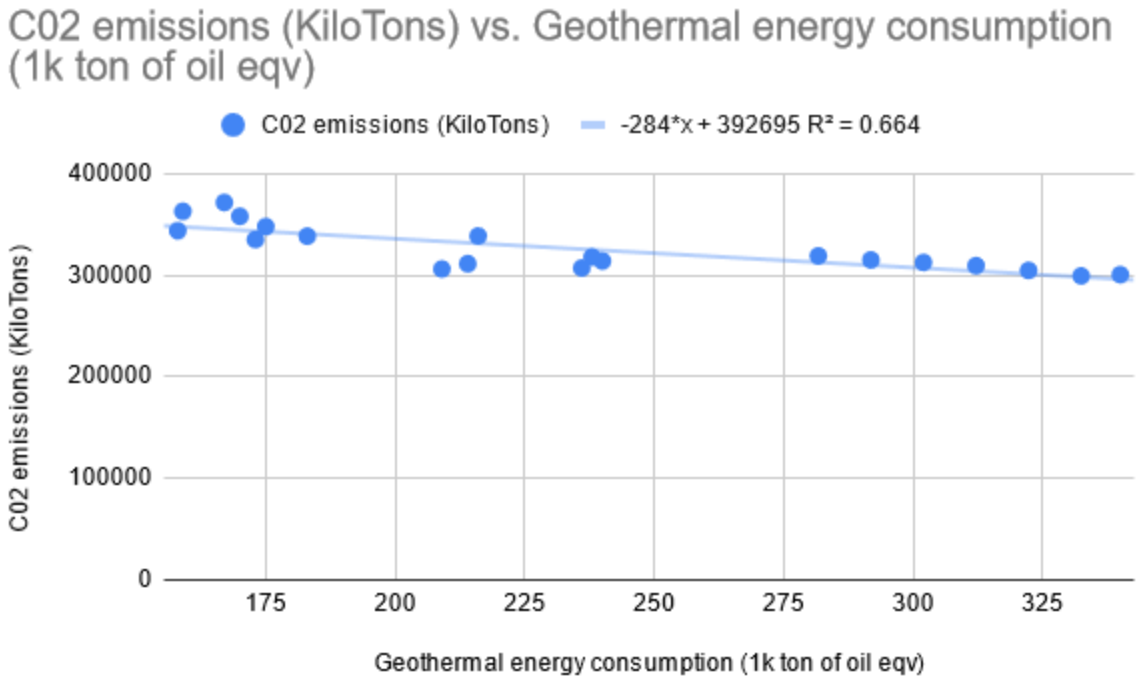
The R^2 value for coal is obtained as 0.932, thereby the prediction for years to come until 2025 is almost accurate and the inference obtained is that the coal consumption shall keep reducing over time.



For CO_2 emissions, the regression line has a negative slope indicating that the CO_2 emissions are decreasing over time. The prediction of CO_2 emissions in future might not be as accurate as for coal consumption as the R^2 value obtained is 0.676 which is not very significant. However, it is a good sign as both CO_2 emissions and coal consumption have decreased over time and are predicted to decline further.

4. CO_2 emission vs Geothermal Energy consumption

The use of Geothermal energy for electricity and energy production has been on the rise in France. The data for geothermal energy production and consumption was collected for the years 2006-2019.



Analyzing the scatter plot in the above line, we observe that the regression line obtained has a negative slope and the equation of the line is given as :-

$$y = -284x + 392695$$

The negative slope indicates that as the Geothermal energy consumption has increased over the years, the CO_2 emission has been impacted in a negative manner as it has decreased by a significant amount. The R^2 value of 0.664 is obtained that does not show very significant correlation, but to some extent. This is a positive sign as other renewable sources of energy are being used for production of energy, the CO_2 emissions are decreasing.

<u>Geothermal energy consumption and C02 emission vs Time with prediction</u>

The equation of the regression line for the CO_2 emissions when plotted against time is obtained as :-

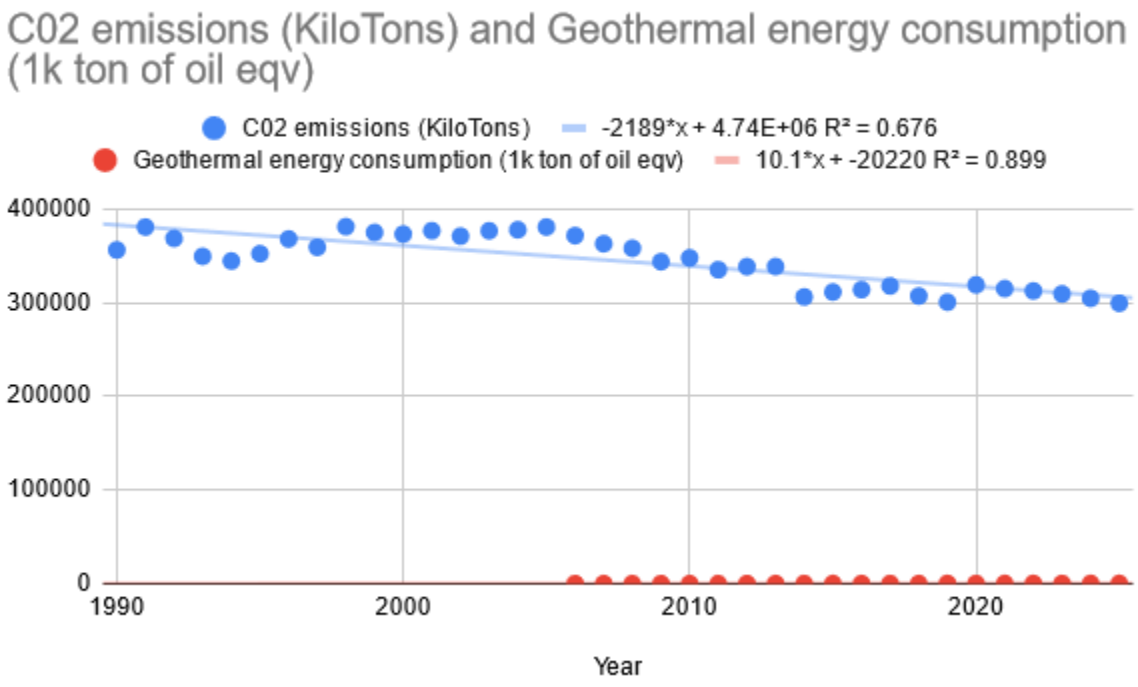
$$y = -2189x + 4.74e + 0.06$$

The negative slope indicates that CO_2 emissions have decreased over time and shall decrease further.

The equation of the regression line for the Geothermal energy consumption is given as :-

$$y = 10.1x - 2\text{-}20220$$

The positive slope indicates that the usage of geothermal energy for energy production has increased significantly and shall increase over the next 6 years. The value of R^2 obtained 0.899 which means that predicted values for geothermal energy consumption are almost accurate.



5. <u>CO_2 emission vs Solar Energy Consumption</u>

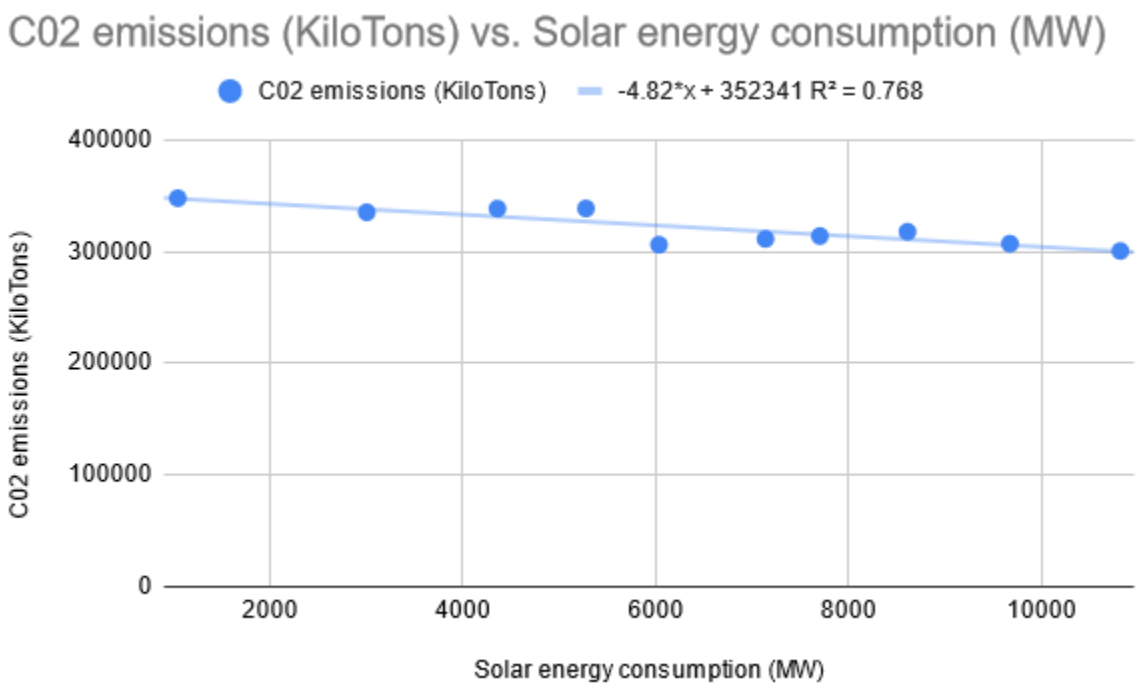
The data for solar energy consumption for France for the years 2010-2019 was collected and was plotted against the Carbon dioxide emissions of the country and the following plot was obtained.

The equation of the regression line obtained from the plot is :-

$$y = -4.82x + 352341$$

The negative slope indicates that the carbon dioxide emissions have decreased as the solar energy consumption has increased. This is a positive sign that indicates a shift from fossil fuels to produce energy to greener methods such as solar energy PV methods. The

solar energy potential of France is huge and it is the right time for the country to analyze it's potential and to invest more into the solar energy production sector.



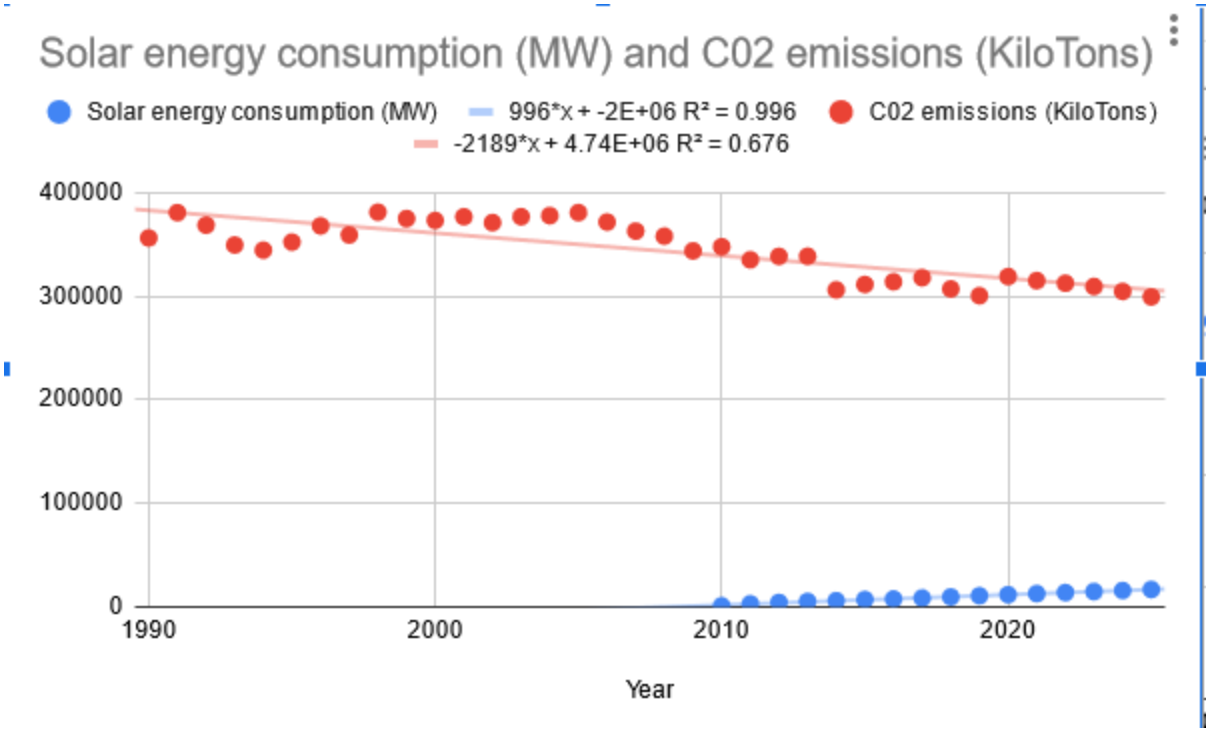
The R^2 value obtained is 0.768 which shows significant correlation between the two variables showing that CO_2 emissions are impacted by the solar energy consumption in the country.

Solar energy consumption and C02 emission vs Time with prediction

The solar energy consumption over time was plotted along with CO_2 emissions over time for France. The equation of the linear regression line was obtained as :-

$$y = 996x + 2e+06$$

The line has a positive slope indicating that solar energy consumption has increased over time along with CO_2 emissions going down indicating that solar energy consumption positively impacts the environment. The R^2 value for solar energy consumption is obtained as 0.996, indicating that the predicted values for future rise in solar energy consumption are accurate.



6. <u>CO_2 emission vs Wind Energy consumption</u>

The wind energy production potential of France is one of the greatest in Europe. The data for wind energy production and consumption for France was collected for the years 1997-2019. The data was plotted on a scatter plot.

The linear regression line for the CO2 emission vs Wind energy production has the equation :-

$$y = -4.92x + 374010$$

The negative slope of the line indicates that CO2 emissions have decreased as the wind energy consumption has increased significantly. This is a good shift towards moving from fossil fuels for energy production to using renewable energy sources such as wind. The offshore and onshore wind generation capacity is set to increase as well.

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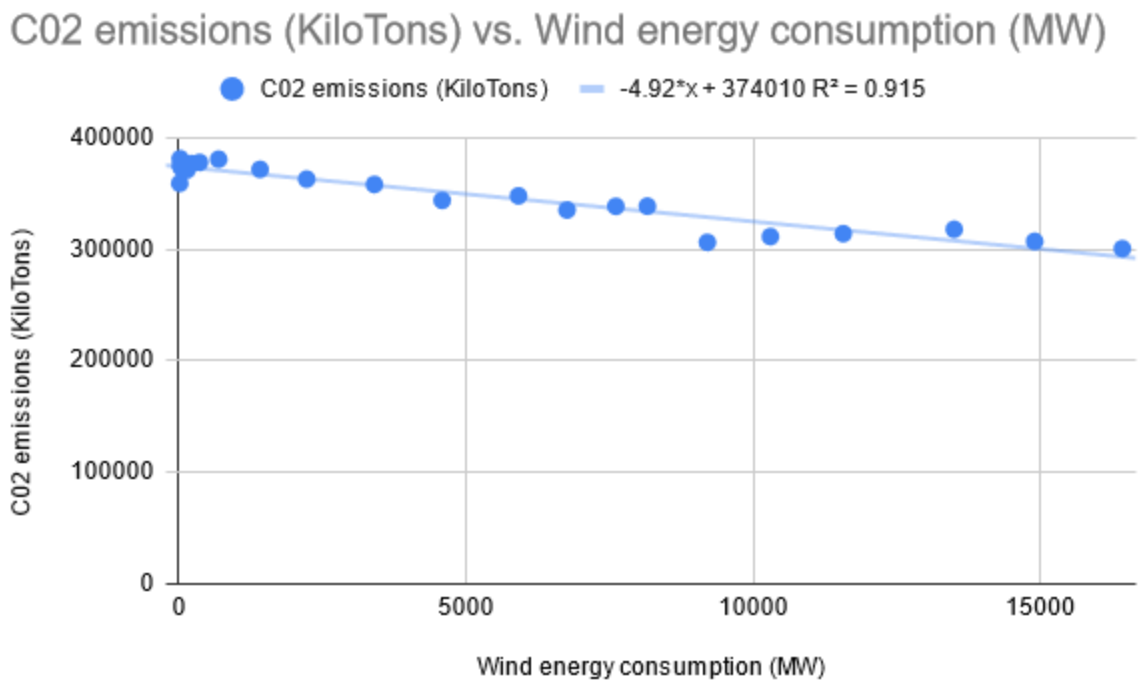


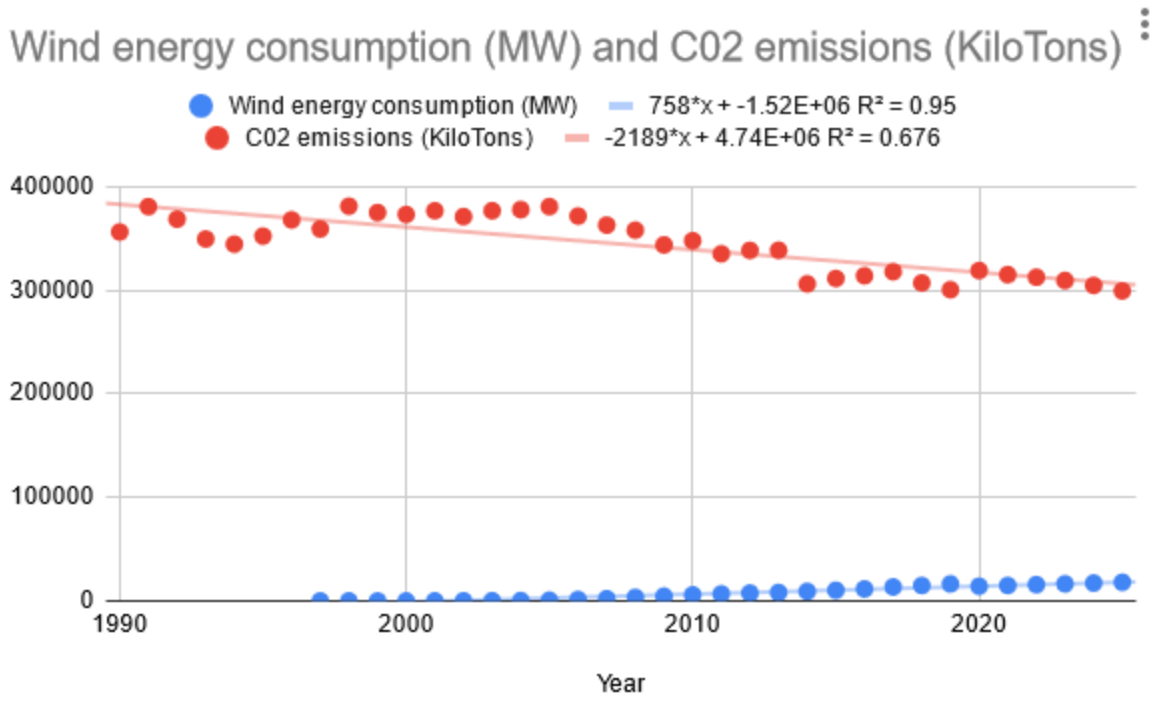
Solar energy consumption and C02 emission vs Time with prediction

The regression line equation for wind energy consumption over the years was obtained as:-

$$y = 758x + 1.52e + 06$$

The equation has a positive slope indicating that the wind energy consumption has increased over the years therefore indicating that the shift in energy production through renewable sources has been significant.

The R^2 value obtained is 0.95 which denotes significant correlation and thus the prediction for the years leading upto the year 2025 are accurate and the wind energy production is bound to increase in the coming years. As the wind energy consumption shall increase, the CO_2 emissions are set to decrease in the coming years as the shift towards renewable energy has been quick and significant in order to reduce carbon footprint and to complete targets. The emphasis on renewable energy sources has been huge and it is only expected to rise and rise further.



7. <u>CO_2 emissions vs Population</u>

Population has started to become a headache for most leading countries in the world as the demand for energy has been on the rise due to ever increasing population. Population growth poses several other challenges to economies and calls for better policy making.

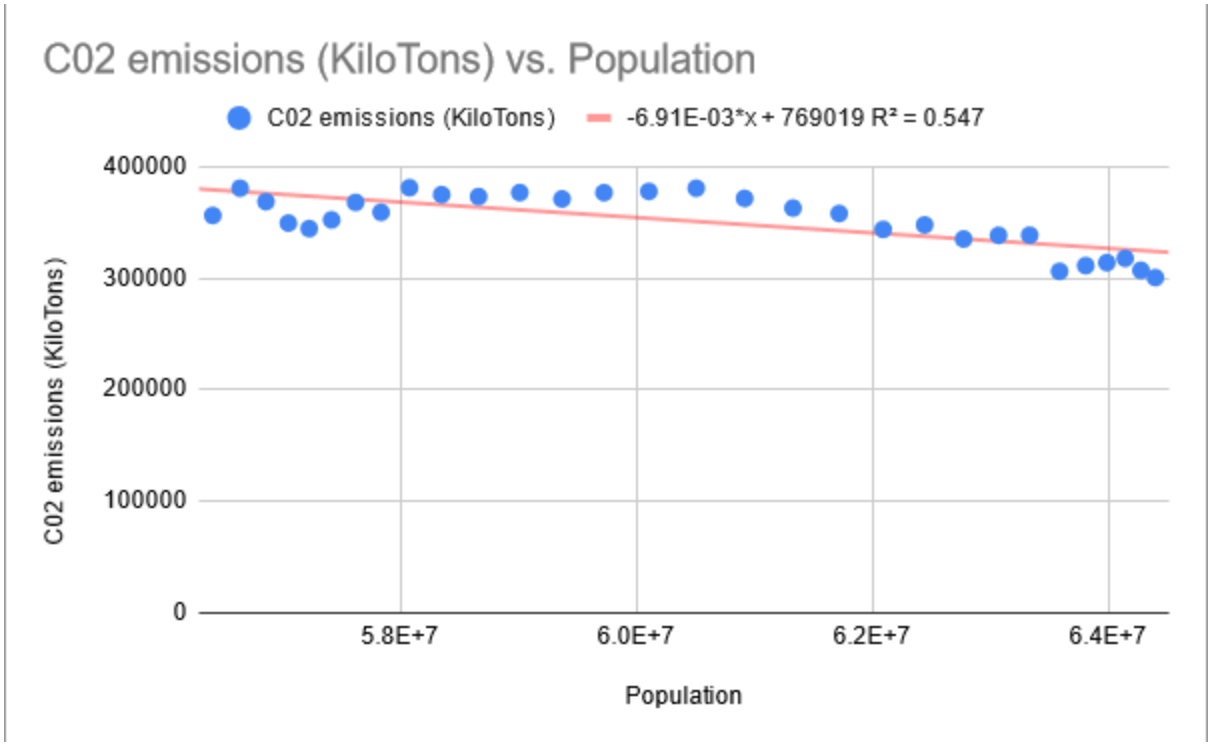
The population data for France was collected for the years 1990-2019.

The scatter plot below shows that CO_2 emissions fluctuated with increase in population, however now the CO_2 emissions are reducing even with a rise in population. This is supported by the regression line equation :-

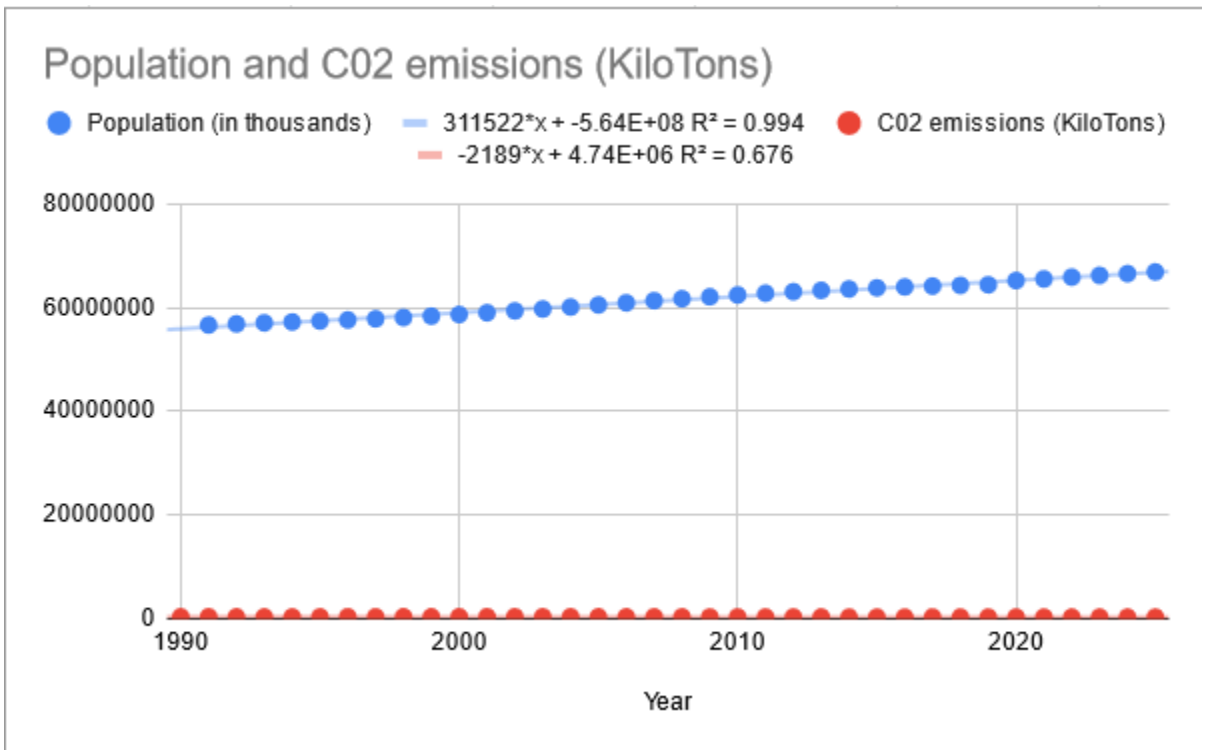
$$y = -6.91e\text{-}03x + 769019$$

As the line has a negative slope, the CO_2 emissions have reduced with the growing population. This is in contrast with many other countries, however this is a massive achievement highlighting the importance of renewable energy resources.

The R^2 value obtained is 0.547 that does not show very significant correlation between the two entities.



Population and C02 emission vs Time with prediction



The regression line equation for population has a positive slope showing population has increased over time. The R^2 value for population is obtained as 0.994 showing significant correlation and thus making future predictions for population growth almost accurate.

CONCLUSION

Econometric tools serve as great analytical tools in order to understand performance of firms and economies, for example in this case, of France. Through this analysis, major policy decisions shall be taken which shall improve the economy's performance.

As for renewable energy resources, it is the need of the hour to shift from fossil fuels as sources of energy to renewable sources of energy in order to reduce carbon emissions and to develop sustainably and without polluting the environment. The aim of this assignment was to analyze the trends in performance of France in renewable energy resource usage along with its carbon emissions over the years which was performed successfully.

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