Climate Change Solutions - Final Presentation

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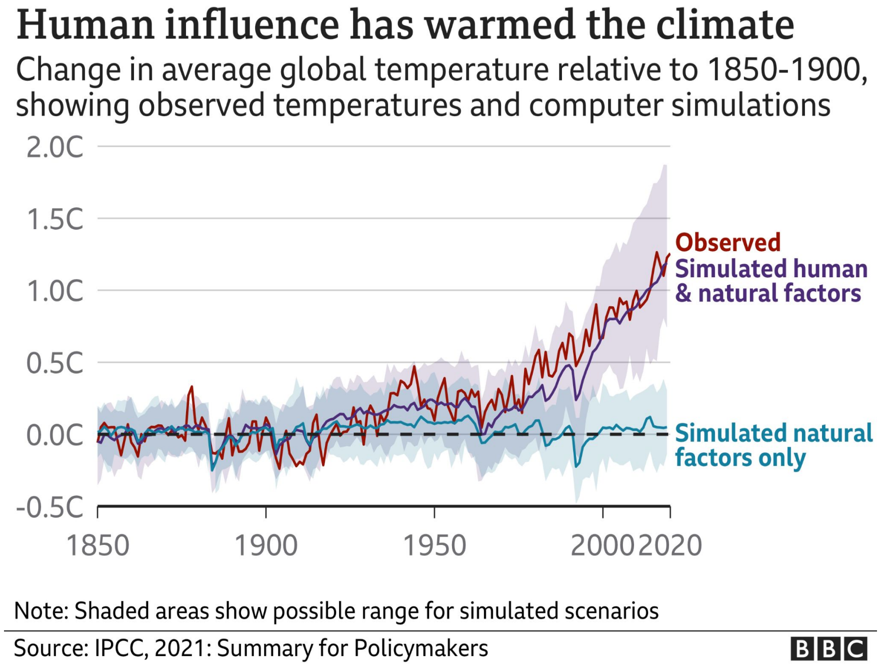
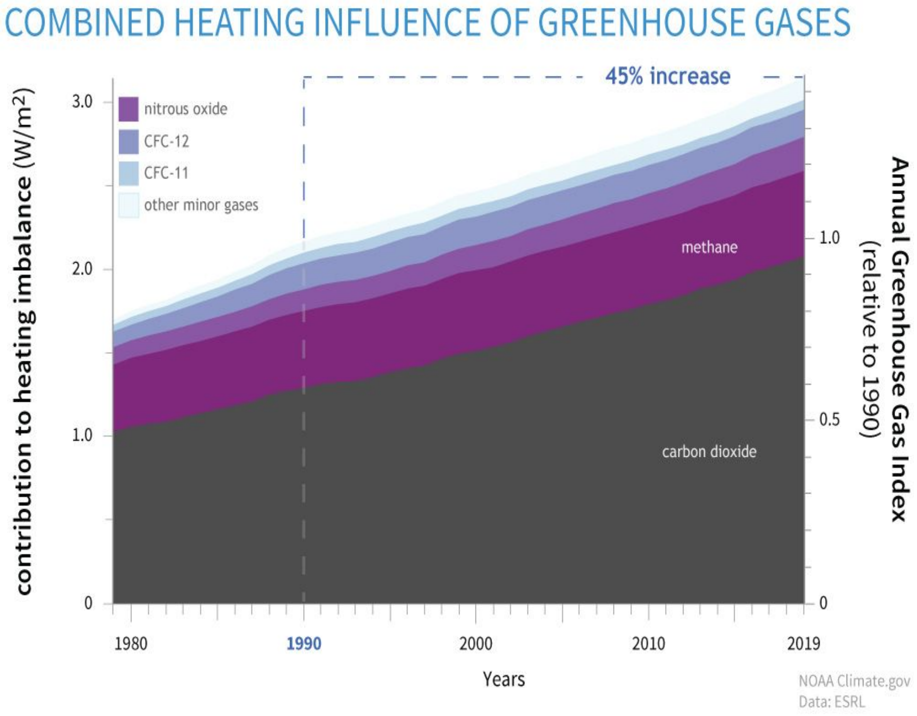
Climate Change Overview

- Global warming due to human-induced emissions of greenhouse gases
- Large scale shifts in weather patterns
- Increased wildfires, droughts, sea-level rise, reduced agricultural yields, etc.
- Intergovernmental Panel on Climate Change (IPCC) forecasts a temperature increase of 2.5-10 °F over next century
- Important that we understand how it impacts human health and how to prepare for it
- Project Goal: Showcase how our climate is affected with and without the implementation of several climate change solutions



CO2 Emissions

- The “Greenhouse Effect”
- Carbon dioxide, methane, nitrous oxide, etc.
- Ability to trap and radiate heat.
- Carbon dioxide is the most important of these gases
- More abundant, stays in the atmosphere longer and absorbs less heat per molecule.
- Responsible for two-thirds of the total energy imbalance that’s causing Earth’s temperature to rise.



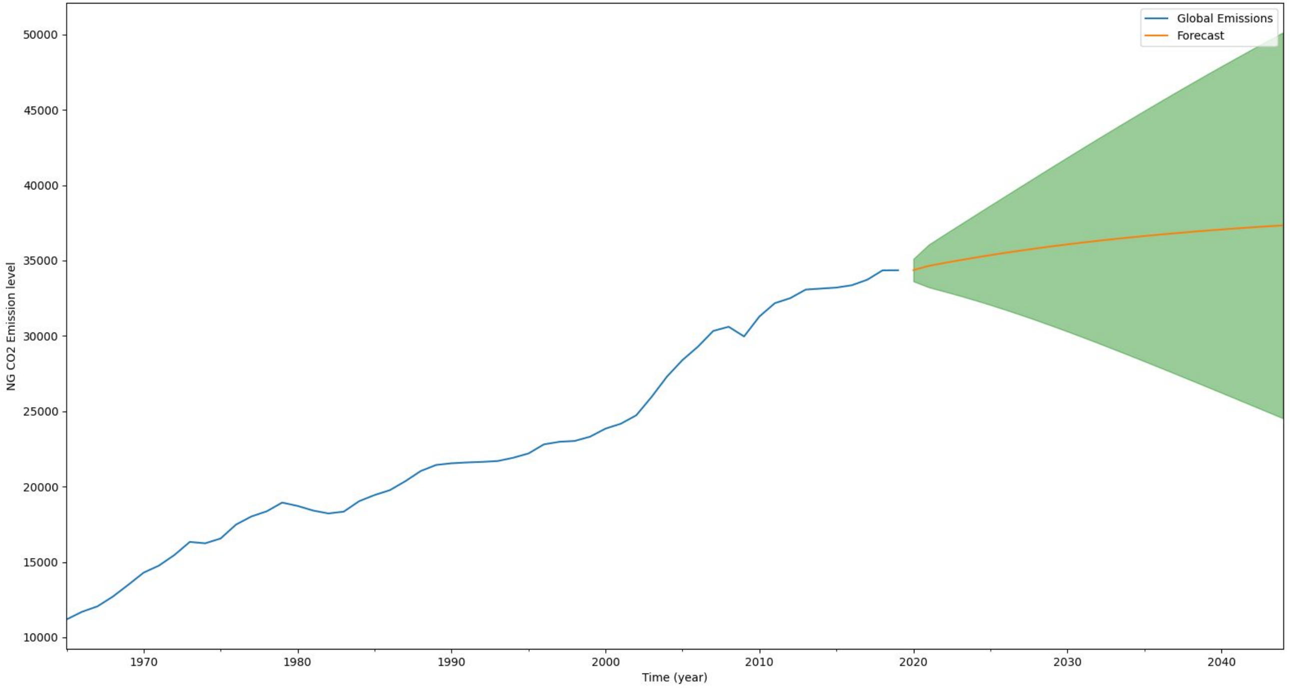
Base ARIMA Model

- ARIMA - Auto Regressive Integrated Moving Average
- Univariate Time Series Forecasting
- Characterized by 3 terms
  - P - the order of the AR term
  - Q - the order of the MA term
  - D - the number of differencing needed to make data stationary
- Objective is to identify these values

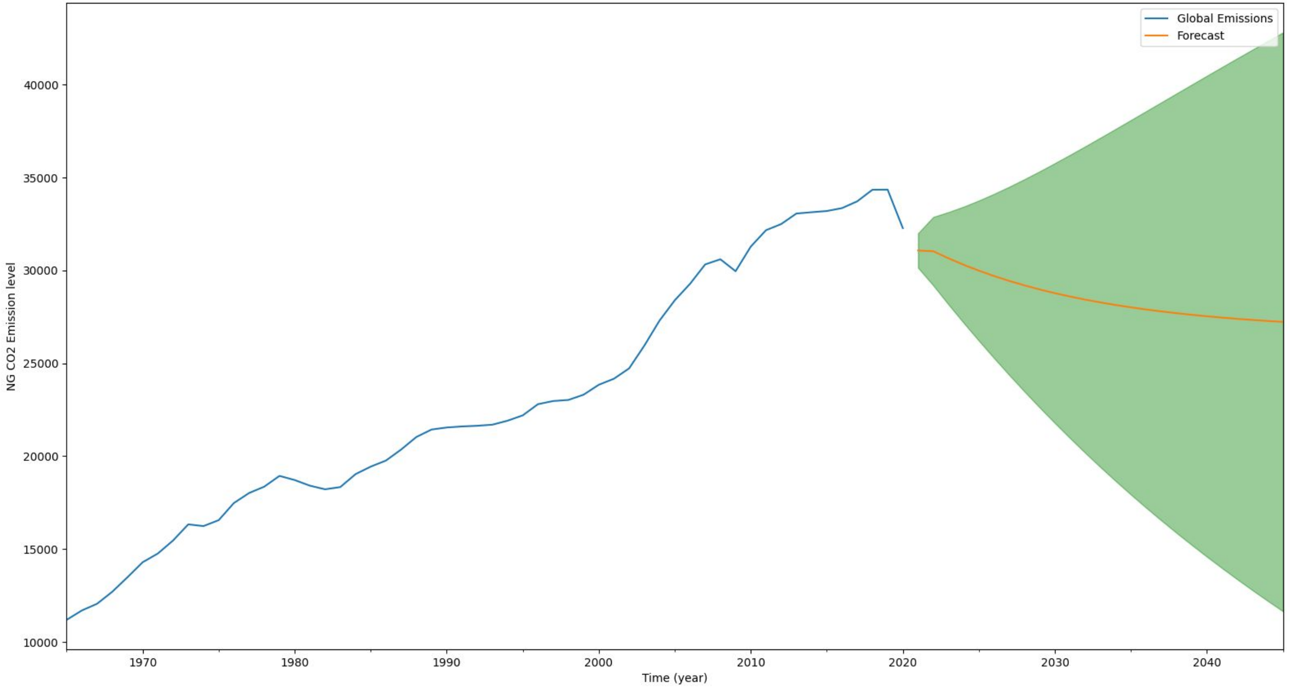
$$Y_t = \alpha + \beta_1 Y_{t-1} + \beta_2 Y_{t-2} + .. + \beta_p Y_{t-p} + \epsilon_1 \qquad Y_t = \alpha + \epsilon_t + \phi_1 \epsilon_{t-1} + \phi_2 \epsilon_{t-2} + .. + \phi_q \epsilon_{t-q}$$

$$Y_t = \alpha + \beta_1 Y_{t-1} + \beta_2 Y_{t-2} + .. + \beta_p Y_{t-p} \epsilon_t + \phi_1 \epsilon_{t-1} + \phi_2 \epsilon_{t-2} + .. + \phi_q \epsilon_{t-q}$$

Forecasted Global CO2 Emissions from data until 2019



Forecasted Global CO2 Emissions from data until 2020

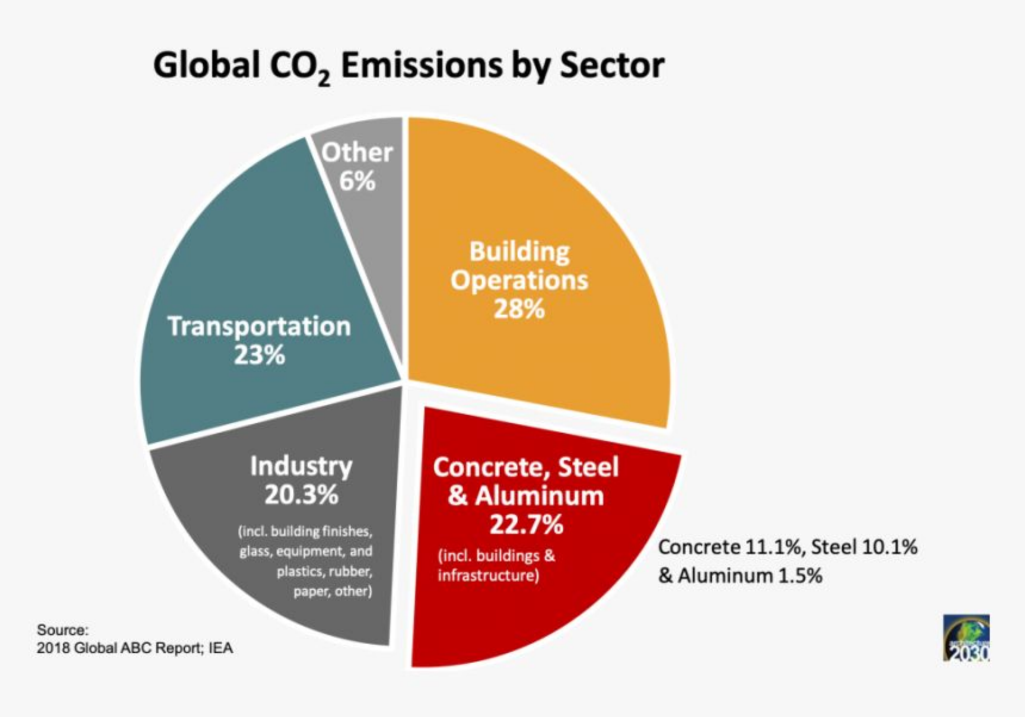


The Solutions

- Responding to climate change involves two possible approaches: reducing and stabilizing the levels of heat-trapping greenhouse gases in the atmosphere (mitigation) and/or adapting to the climate change already in the pipeline (adaptation). Below are the solutions we've decided to explore:
  - Renewable resources
  - Carbon Capture and Sequestration
  - Electric Vehicles
  - GSAS Standard Buildings

Renewable Resources

- Changing our main energy sources to clean and renewable energy is the best way to stop using fossil fuels
- Wind, solar, geothermal, and hydro
- Transportation Sector: 23%
- Building Operations Sector: 28%
- Utilization of fossil fuels for heat, power, or chemical processes



The Data

- Bp's Statistical Review of World Energy
- 1965 - 2020
- CO_2 - million tonnes
- Nuclear generation
- Hydroelectric generation
- Geothermal generation
- Unit - Terawatt-hours

year	co2	nuclear_generation	hydroelectricity_generation
1965	11189.7	25.5	923.2
1966	11694.9	34.4	983.8
1967	12055.5	41	1005.7
1968	12701.5	52.1	1059.3
1969	13483.7	61.8	1121.7
1970	14291.7	78.9	1174.6
1971	14762.4	109.7	1227.1
1972	15463.1	152.2	1284.6
1973	16332.1	203.9	1303
1974	16239.6	266.6	1431.3
1975	16557.2	369.8	1448.9
1976	17479.5	432.7	1443.1

VARS Model

- VARS - Vector Auto Regression
- Multivariate Time Series Forecasting
- Modeled as a system of equations with one equation per variable (time series)
- 2 time series -> system of 2 equations

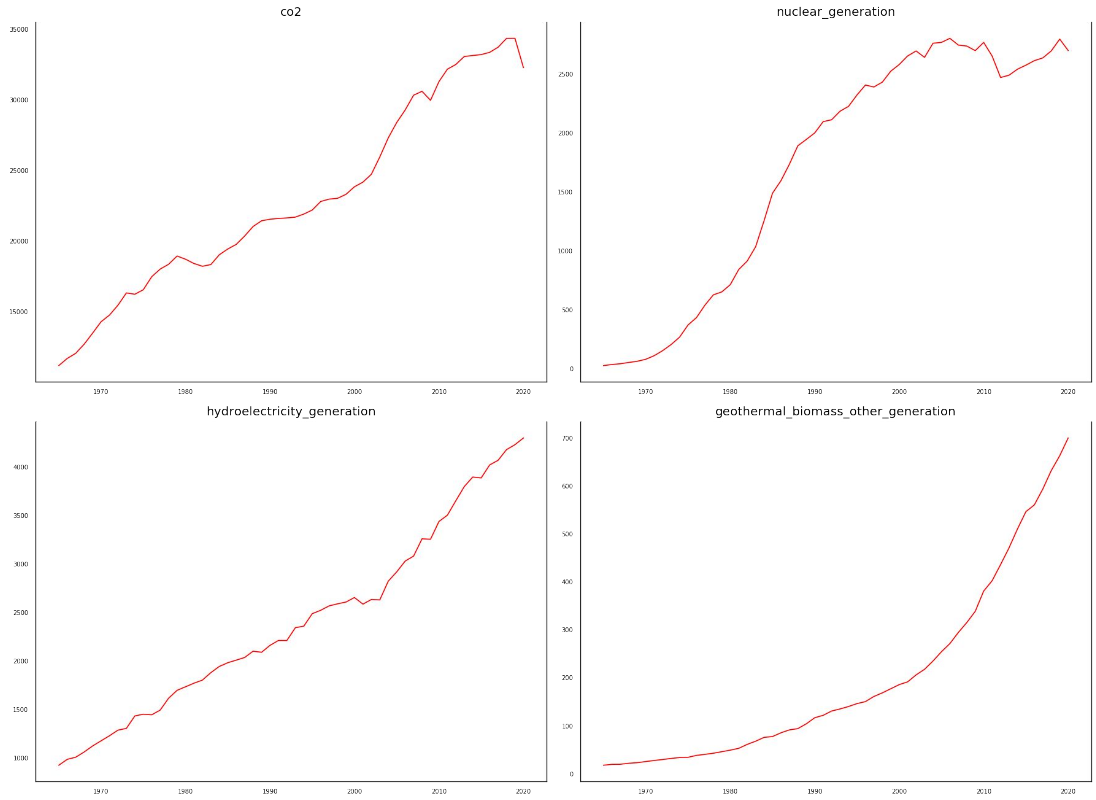
$$Y_{1,t} = \alpha_1 + \beta_{11,1} Y_{1,t-1} + \beta_{12,1} Y_{2,t-1} + \epsilon_{1,t}$$
$$Y_{2,t} = \alpha_2 + \beta_{21,1} Y_{1,t-1} + \beta_{22,1} Y_{2,t-1} + \epsilon_{2,t}$$

$$Y_{1,t} = \alpha_1 + \beta_{11,1} Y_{1,t-1} + \beta_{12,1} Y_{2,t-1} + \beta_{11,2} Y_{1,t-2} + \beta_{12,2} Y_{2,t-2} + \epsilon_{1,t}$$
$$Y_{2,t} = \alpha_2 + \beta_{21,1} Y_{1,t-1} + \beta_{22,1} Y_{2,t-1} + \beta_{21,2} Y_{1,t-2} + \beta_{22,2} Y_{2,t-2} + \epsilon_{2,t}$$

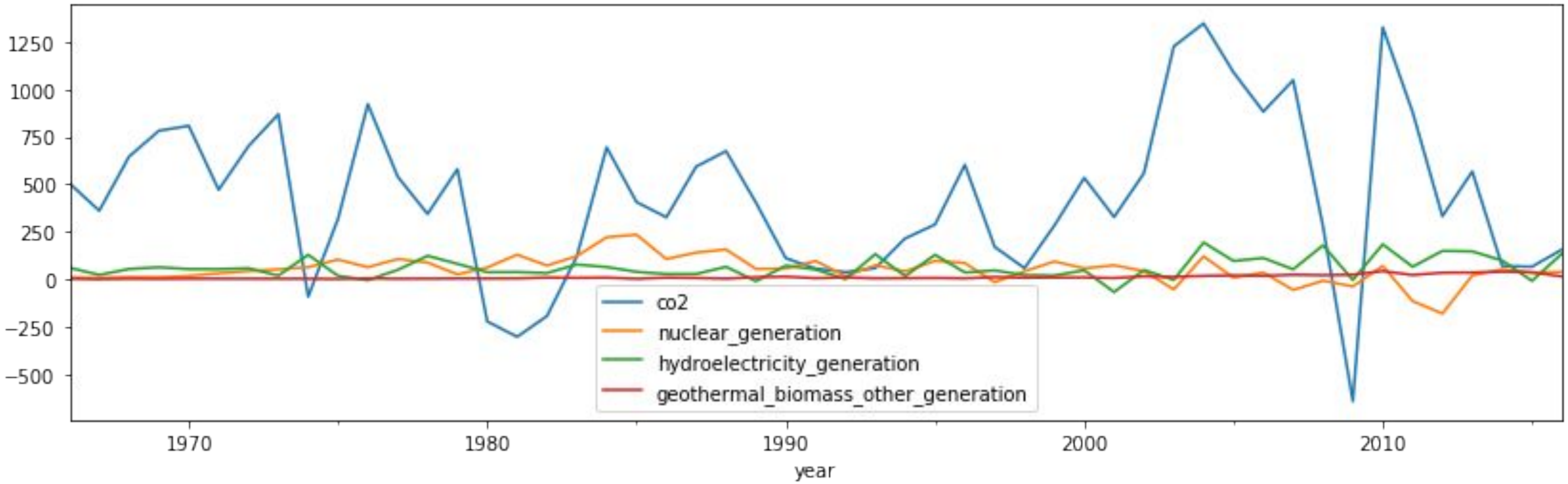
Initial Problems

- Testing for stationarity and Data Cleaning
    - Augmented Dickey-Fuller Test
    - Solar and wind generation causing problems
    - Taking log
- Selecting Order P
    - Usual practice is to look at the AIC
- Inverting the transformation
    - Convert forecasts back to original scale
    - Three differences
    - Take most recent values of the original series’ training data and adding it to a cumulative sum of forecasted values.

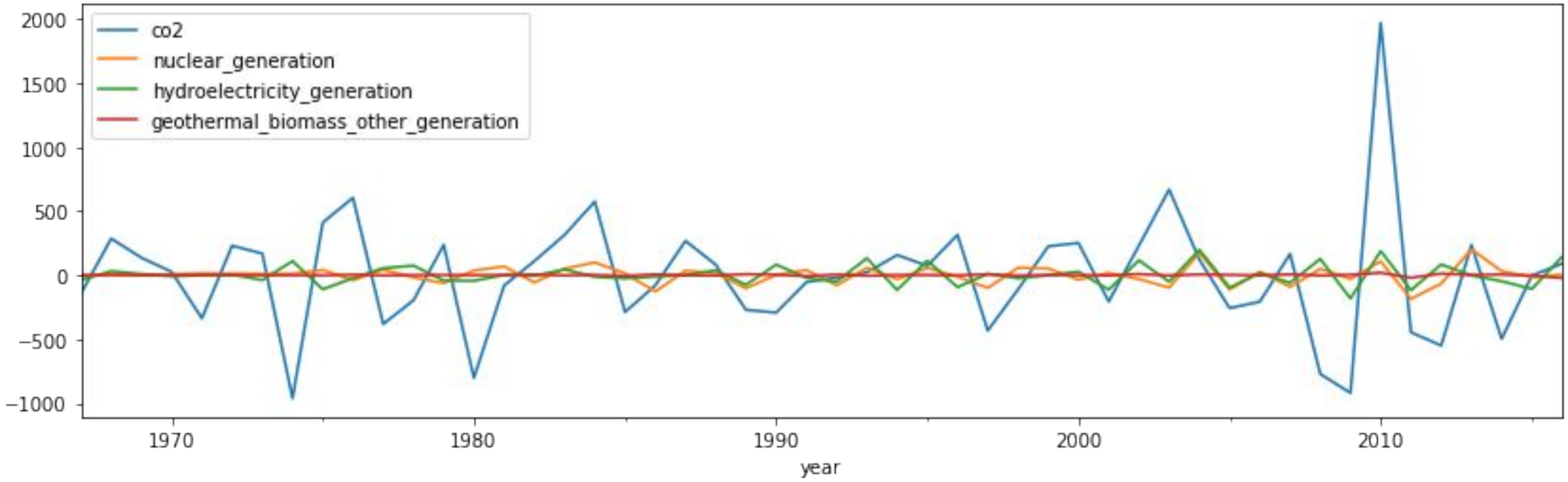
Time Series Visualization



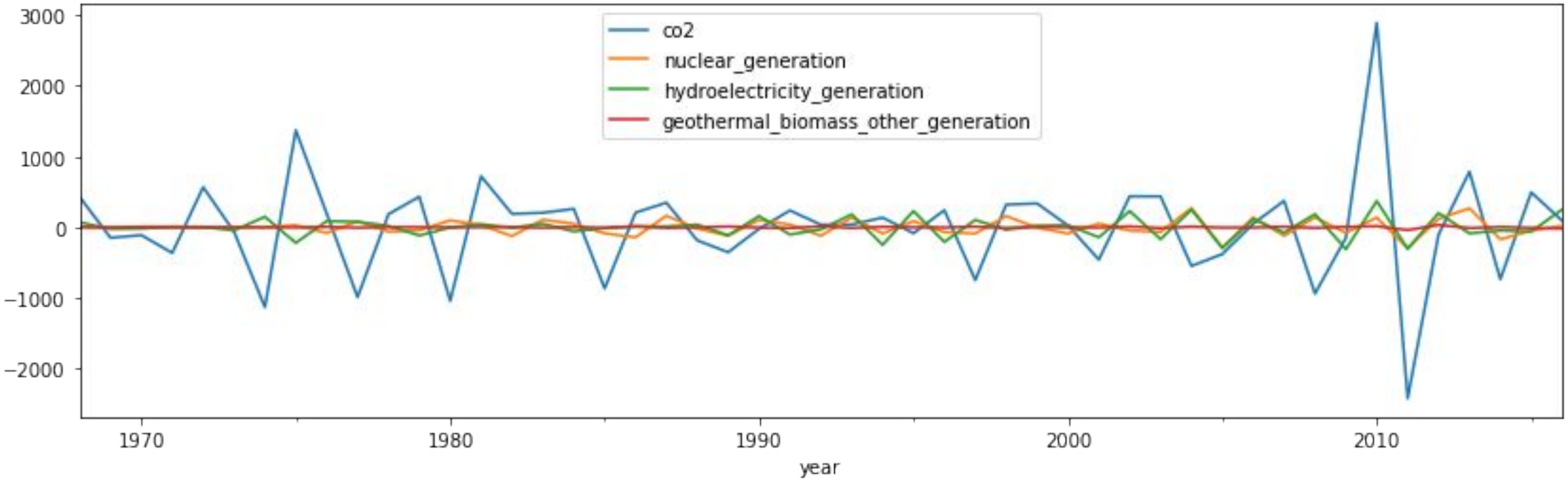
Stationary Tests



First Difference

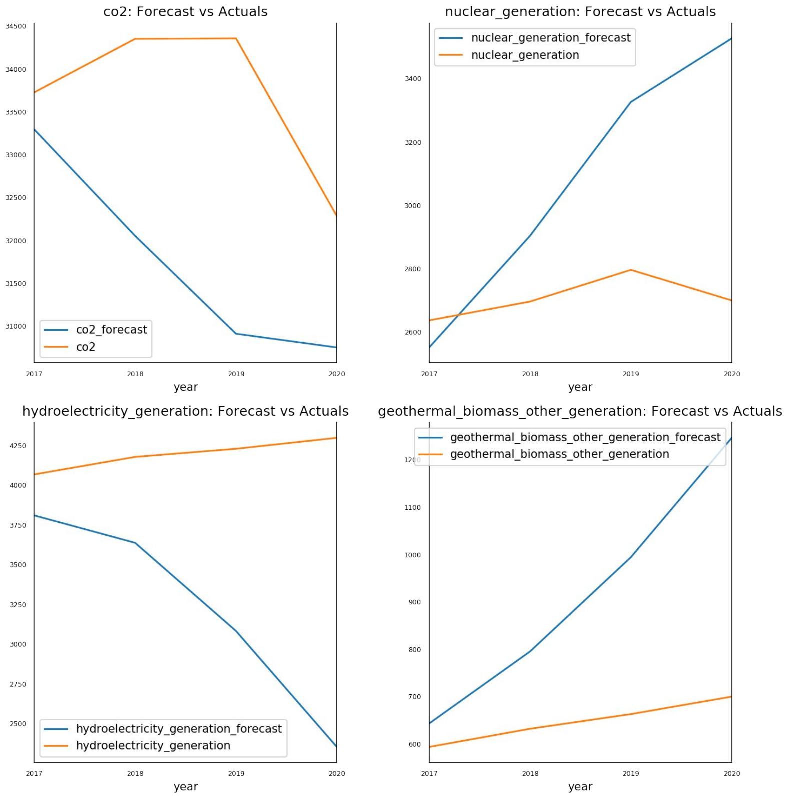


Second Difference



Third Difference

Forecast Vs Actuals

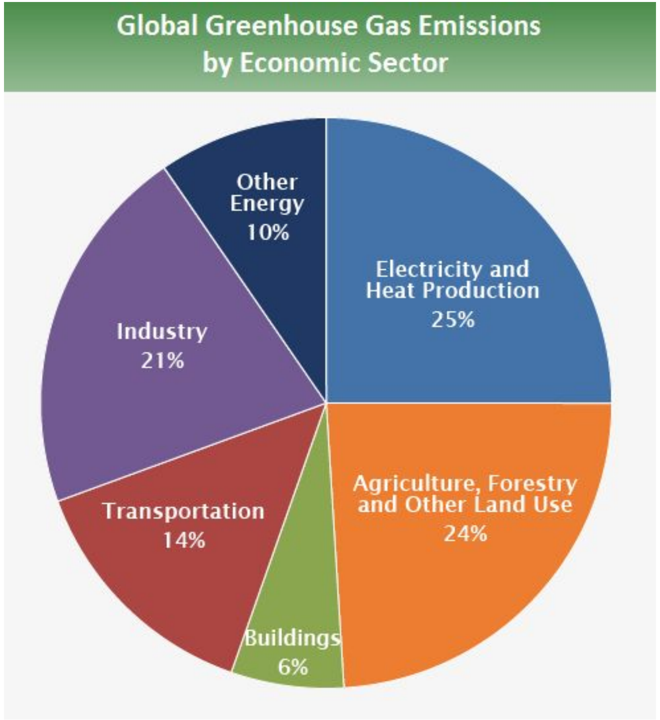


Carbon Capture and Sequestration (CCS)

- About 13.8 Gt of CO2 is produced annually by stationary sources worldwide.
- Carbon capturing can serve as a way to reduce the amount of carbon dioxide released into the atmosphere by these stationary sources.
- The goal of CCS technology is to achieve net zero emissions from related sectors by 2050
- We can use past and present data of CCS facilities to model and predict future global CO2 storage capacities

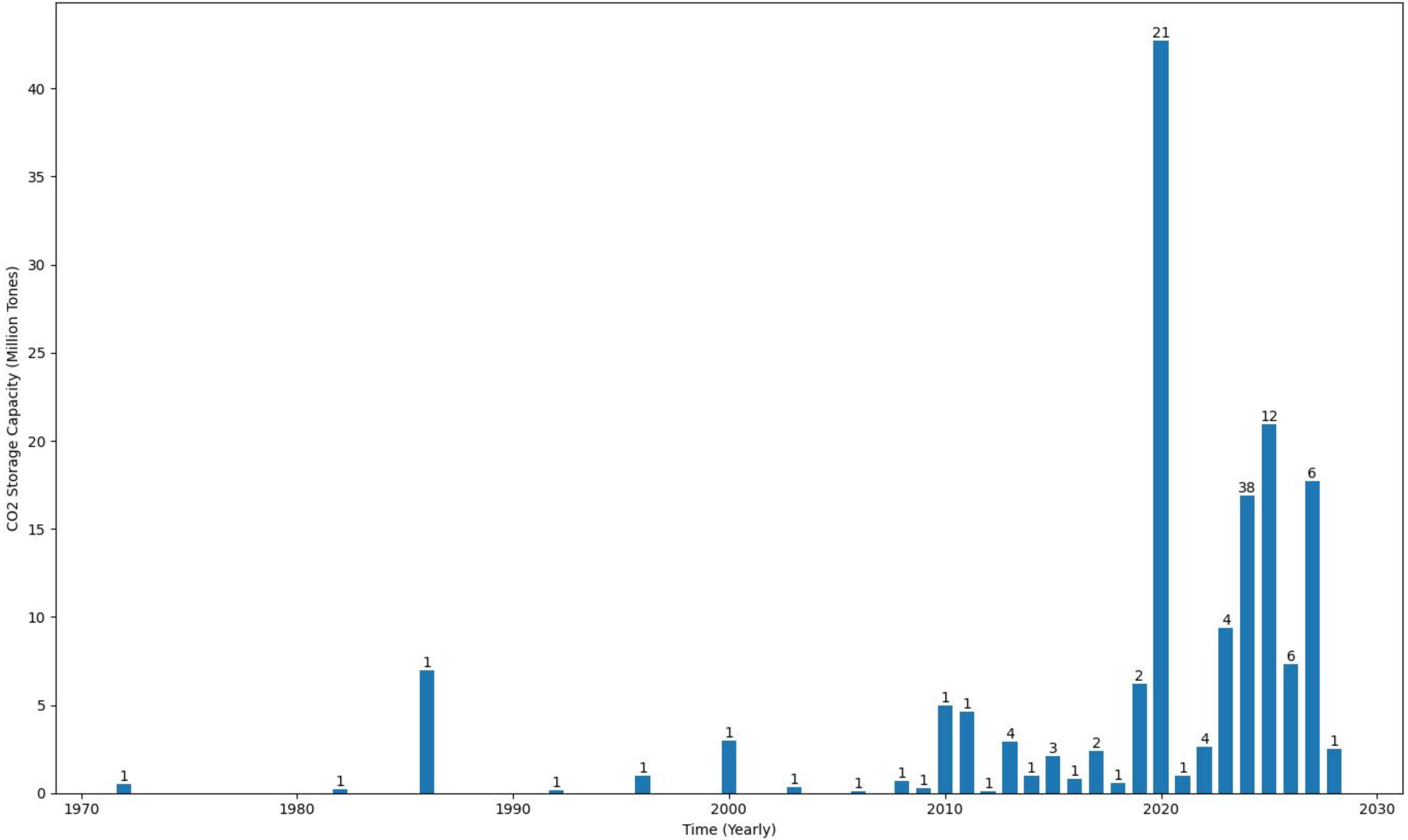
Significance of Carbon Capture and Sequestration

- Energy producing sectors account for approximately 35% of global annual greenhouse gas emissions.
- Industry related sectors account for approximately 21% of global annual greenhouse gas emissions.

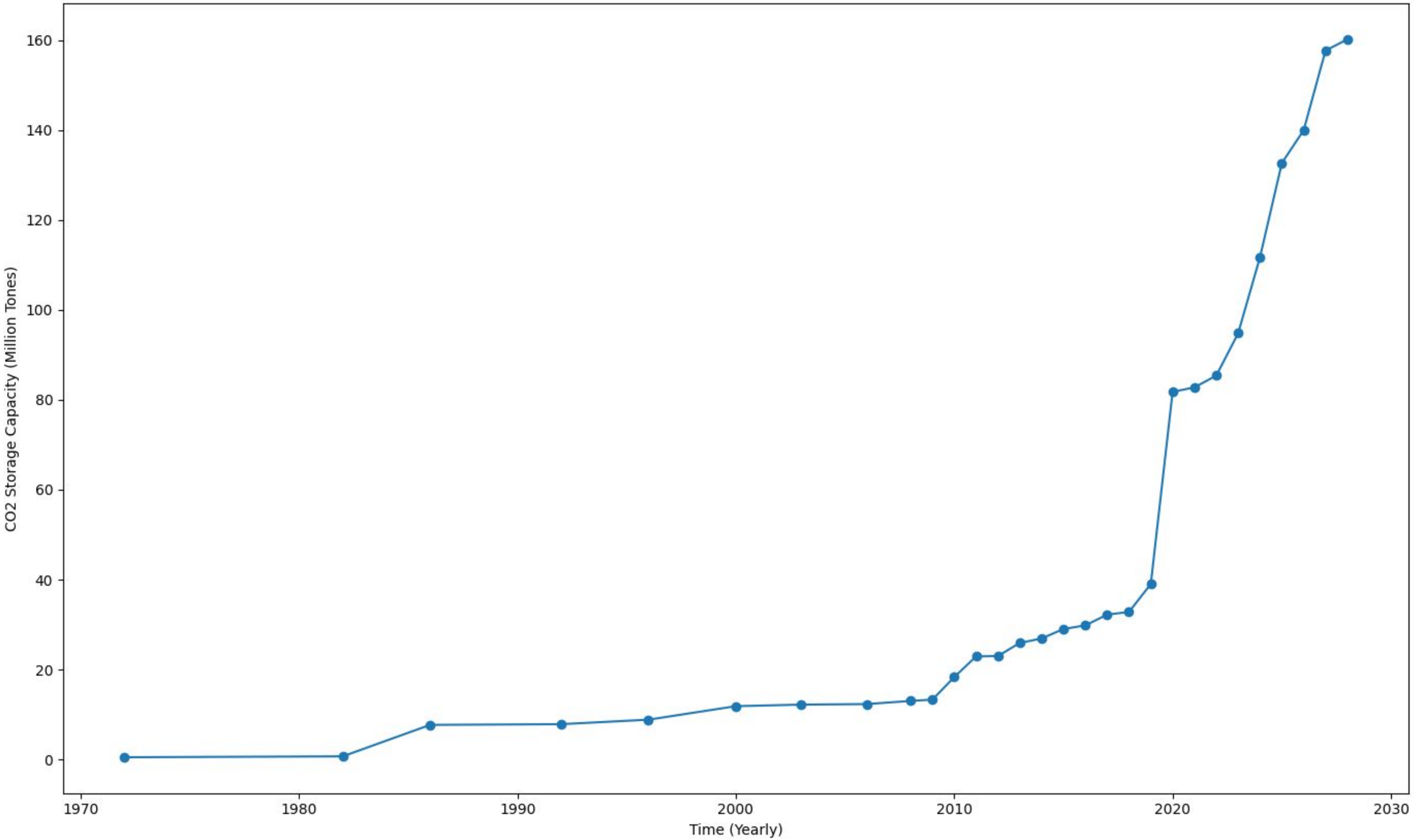


Source: “Global Greenhouse Gas Emissions Data - EPA”

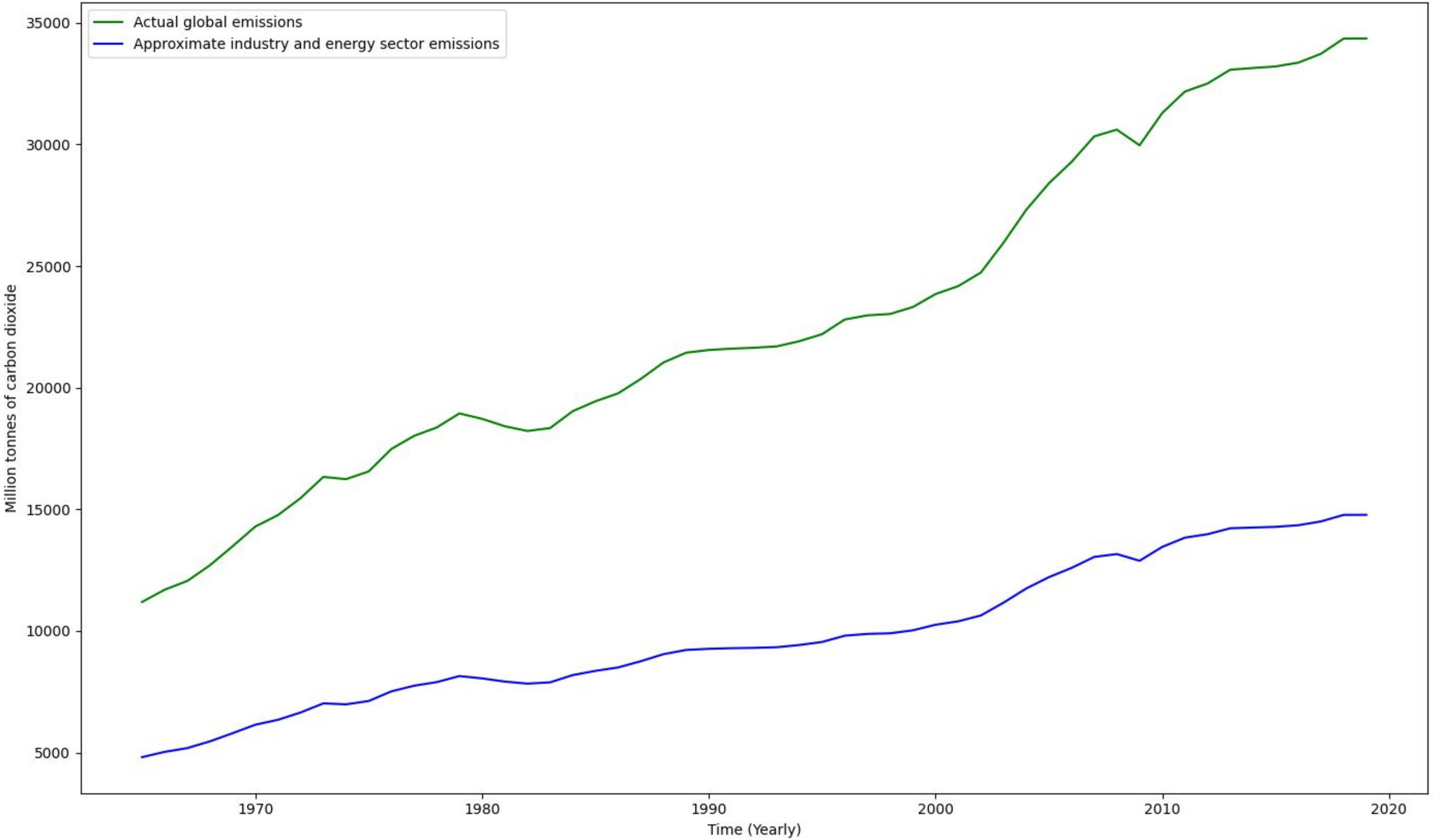
Operational CCS Facilities and CO2 Storage Capacity From 1972 to 2028



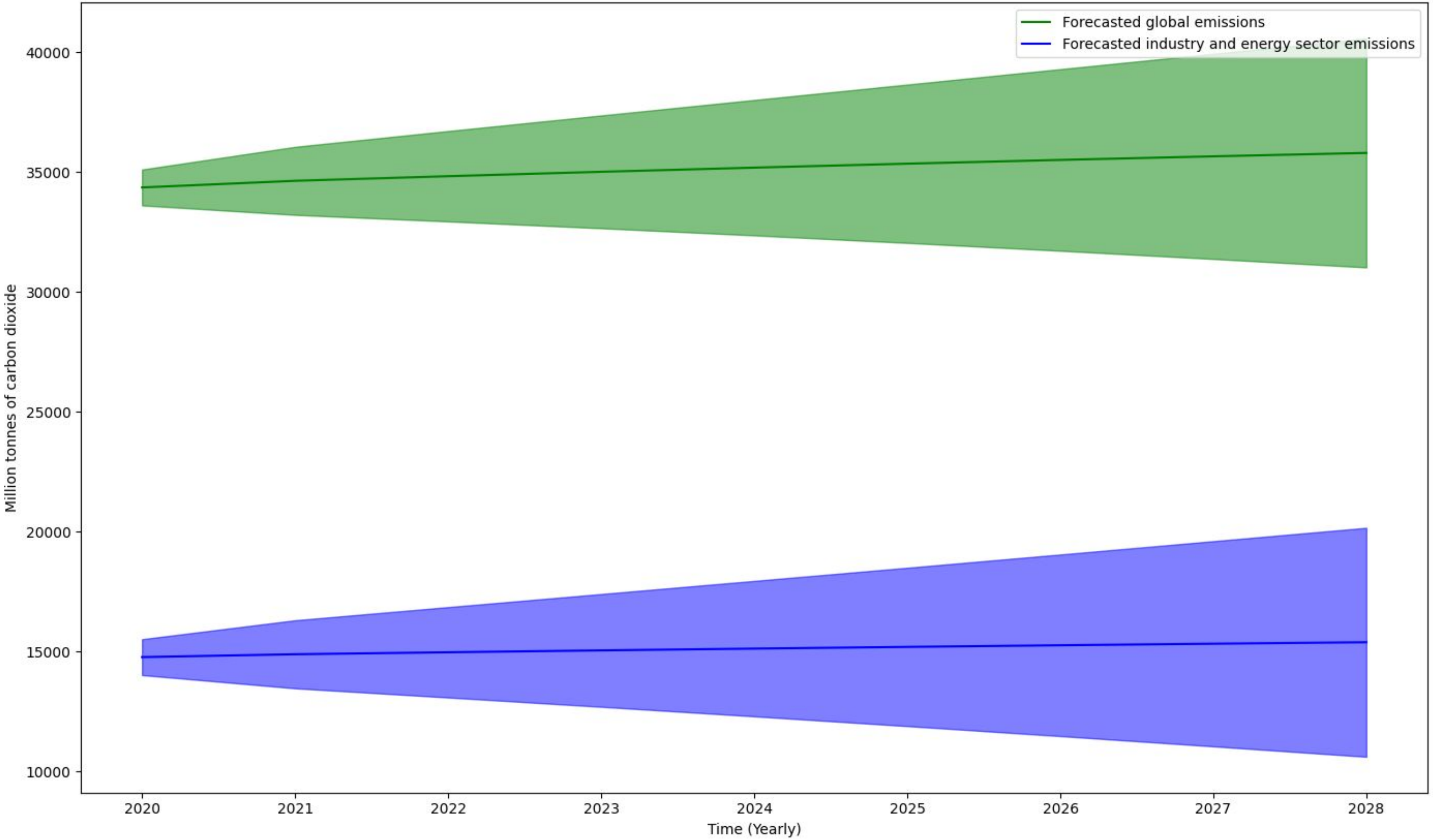
Cumulative Global CO2 Storage Capacity Using CCS



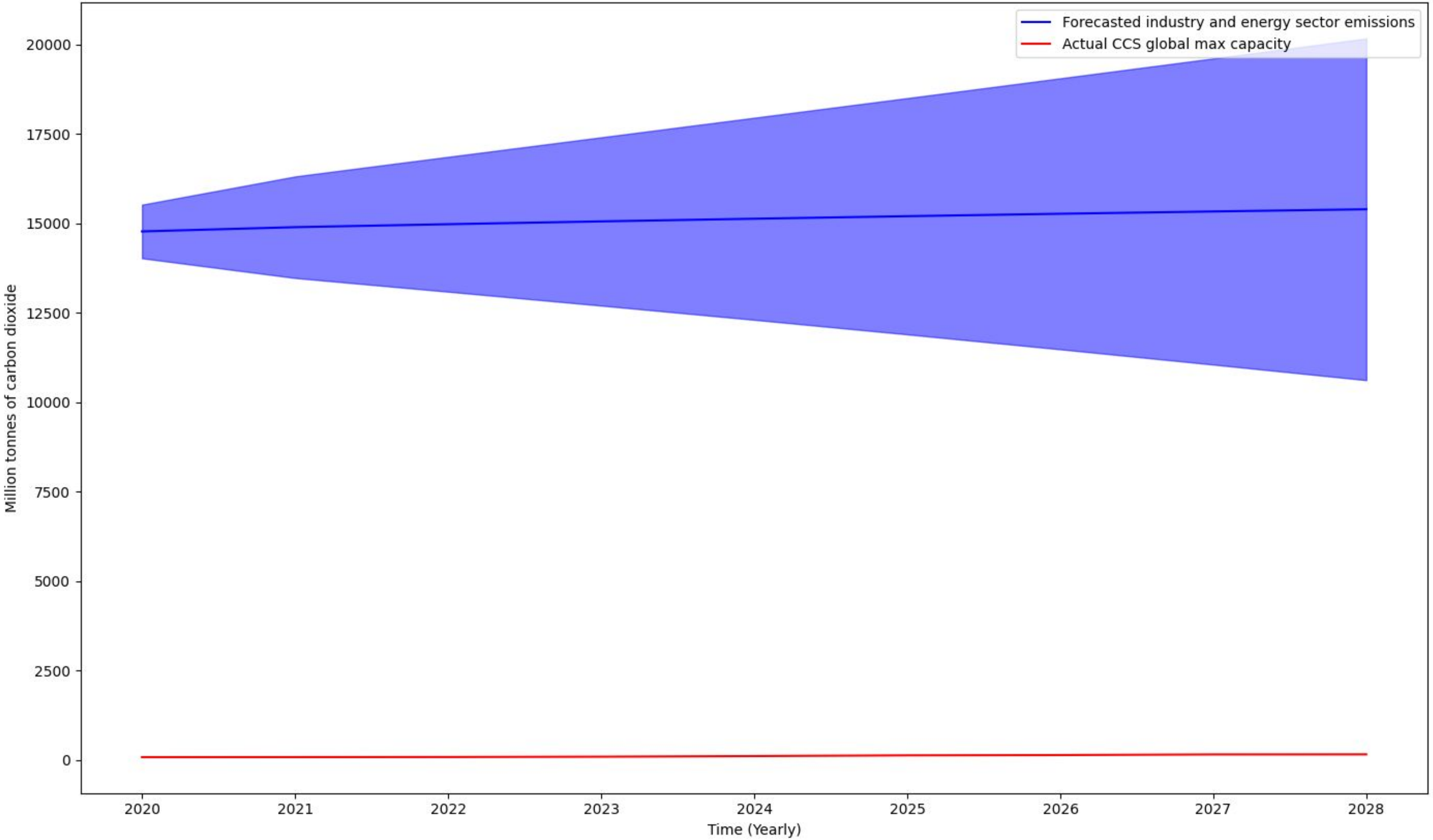
Global Carbon Emissions vs Emissions From Industry and Energy Sectors



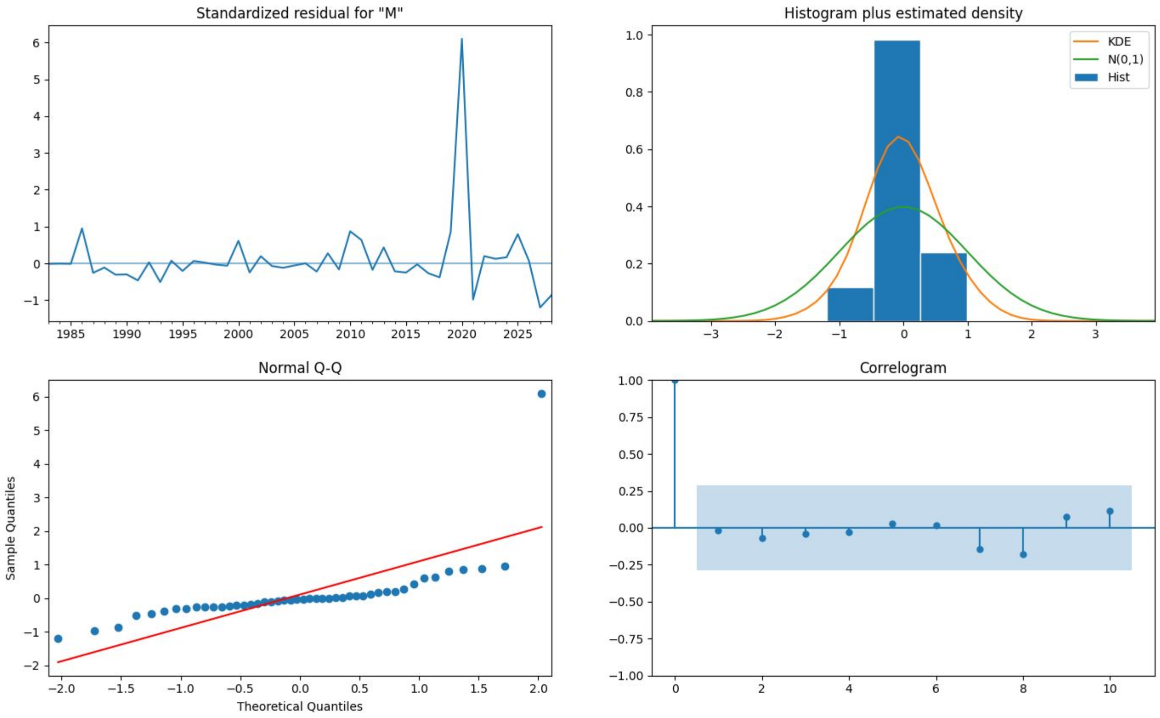
Emissions Forecast for Global vs Industry and Energy Sectors Using ARIMA Model



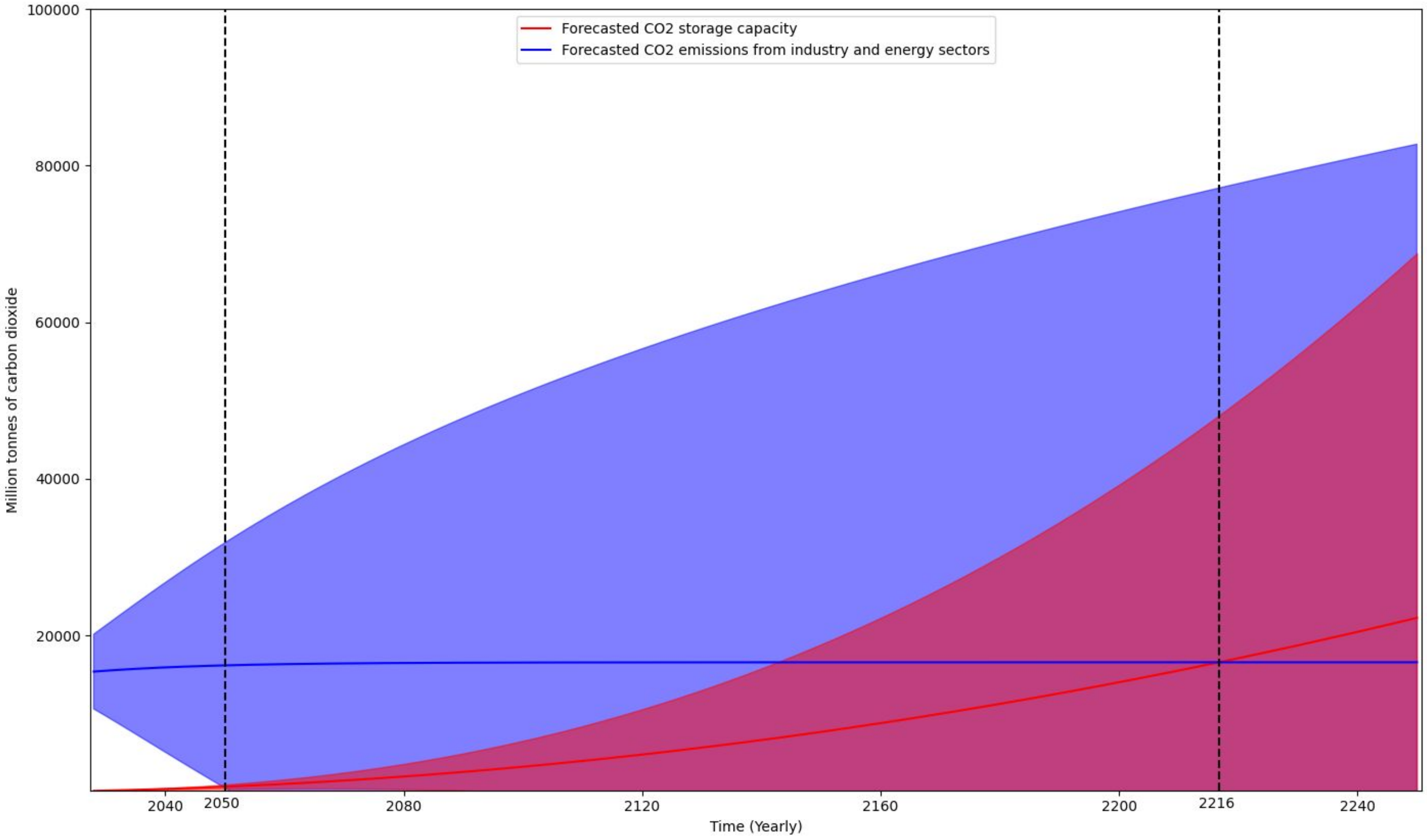
Actual CO2 Storage Capacity vs Forecasted Emissions From Related Sectors



Optimal Parameter Selection: p = 2, d = 3, q = 7



Forecasted CO2 Storage Capacity Growth and Net Zero



Solution 3 - Adoption of Electric Vehicles (EV)

- In the US, transportation accounts for roughly 25-30% of emissions.
- Half of that amount is from passenger vehicles.
- An average passenger vehicle emits 4.6 metric tons of CO_2 every year.
- As a result, the US has set a target for 50% of car sales be EVs by 2030.
- This model aims to forecast if the US is on track to meet this goal and illustrate the effectiveness of the solution.

Modeling Process

- Forecast US emissions, US car sales, US EV registrations and US EV sales.
- Determine the relationship between EV sales and EV registrations.
- Compare car sales and EV sales to see if the goal will be met. If not, plot hypothetical scenarios where the goal is met.
- Calculate the effect on emissions based on the results above.
- Verify if the results are reasonable.

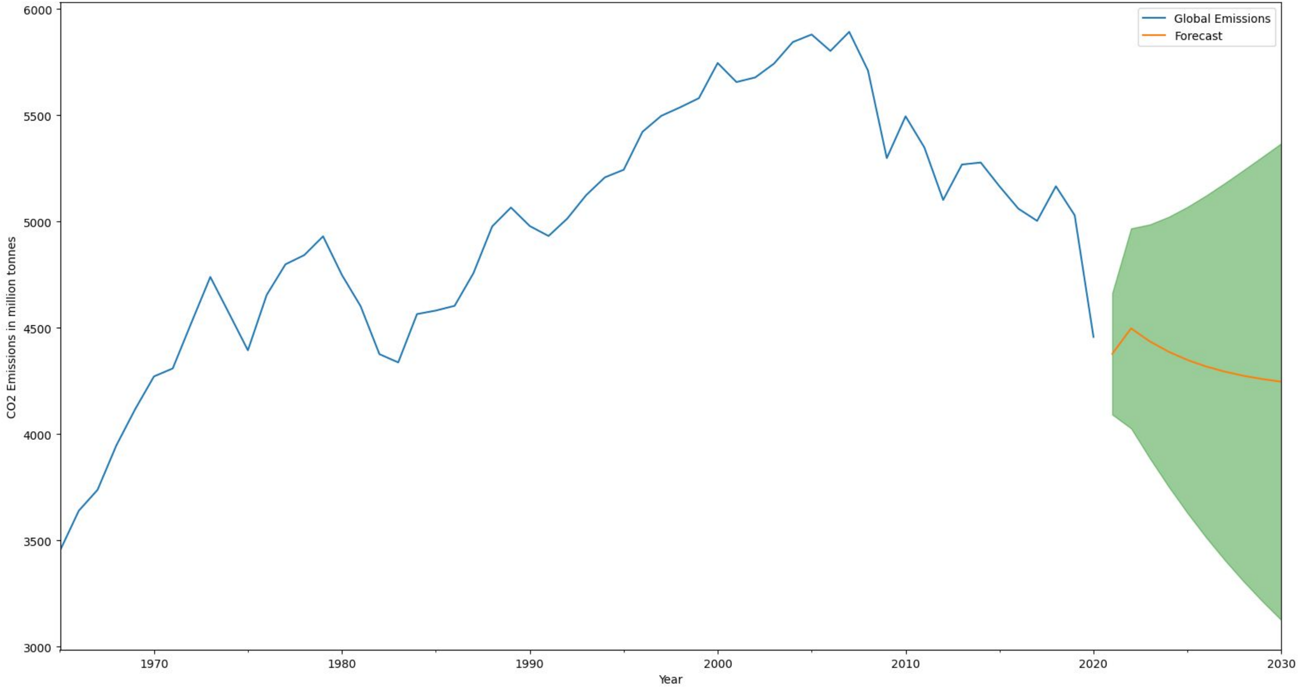
Assumptions for the entire forecasting period

- The average CO_2 emitted by traditional vehicles is constant.
- No major trends, legislation, or events will disrupt the market one way or another.
- All EV sales are for personal use, none get replaced prematurely due to reasons like accidents, and all EVs last 10 years.
- Plug-in hybrid owners do not use the battery at all.
- No other climate change solutions are in place.

Modeling Limitations

- EVs are not old enough to produce datasets that show stable diagnostics results.
- Furthermore, this means the possible number of lags and the values for p, d, and q are limited.
- Relevant datasets are taken from various different sources and most are by year so seasonal ARIMA cannot be used.

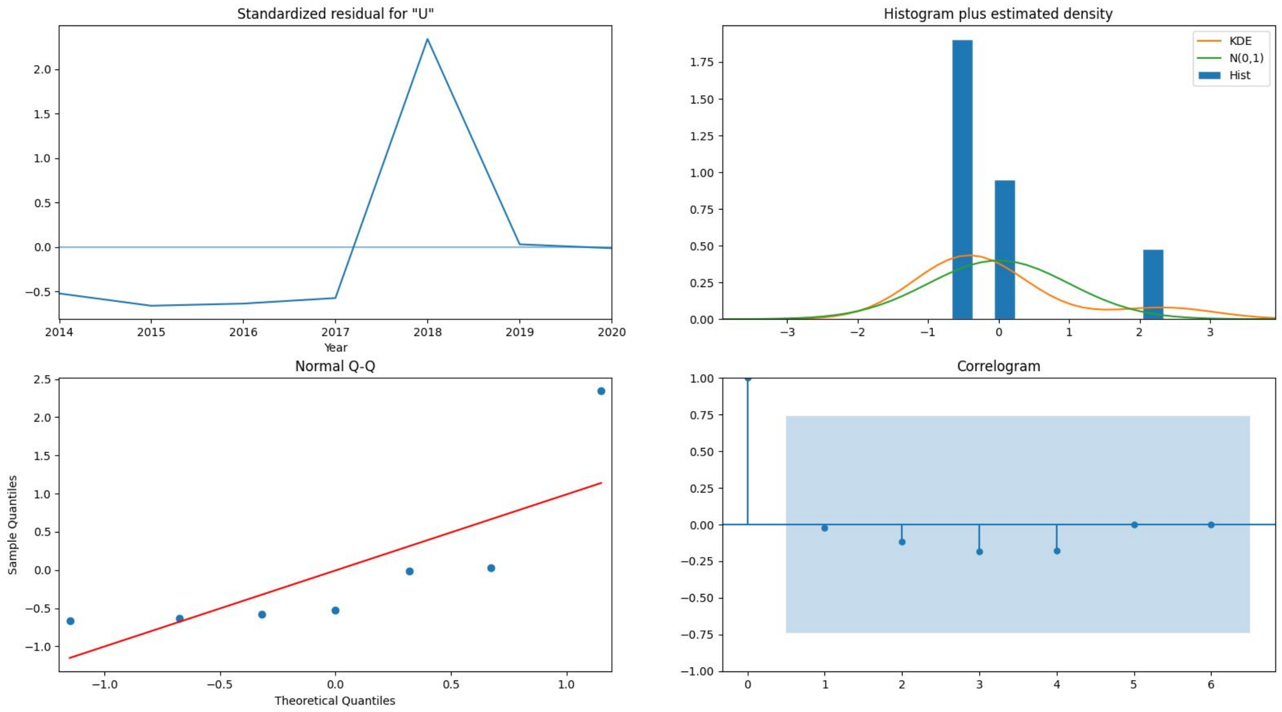
Forecasted US Emissions until 2030 in million tonnes



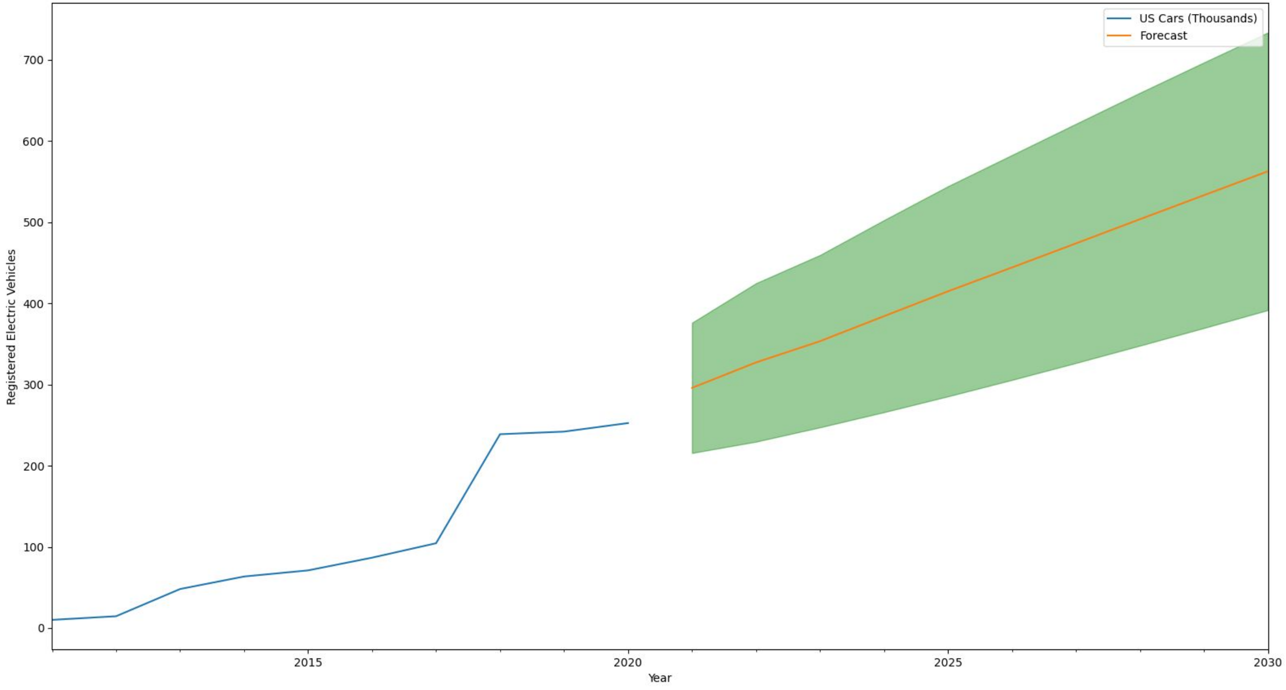
Positive correlation between sales and registrations

```
λ solution_draft.py
EV Sales in thousands[ 10.111  14.585  48.094  63.525  71.064  86.731 104.492 238.823 242.03
 252.548]
EV Registrations in thousands[  9.75   14.65   47.69   63.42   71.05   86.73 104.49 238.82 241.91 256.37]
[[1.        0.9999396]
 [0.9999396 1.       ]]
```

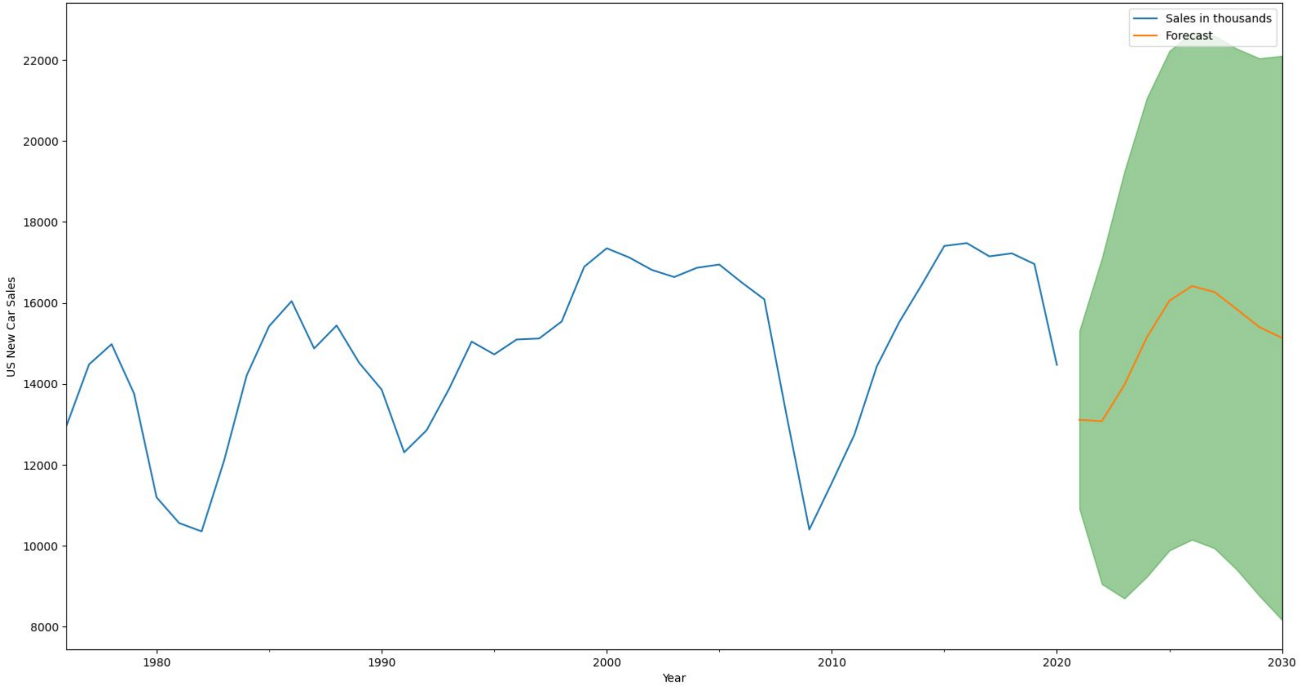
Diagnostics using ARIMA(3, 0, 0) and Lags = 6



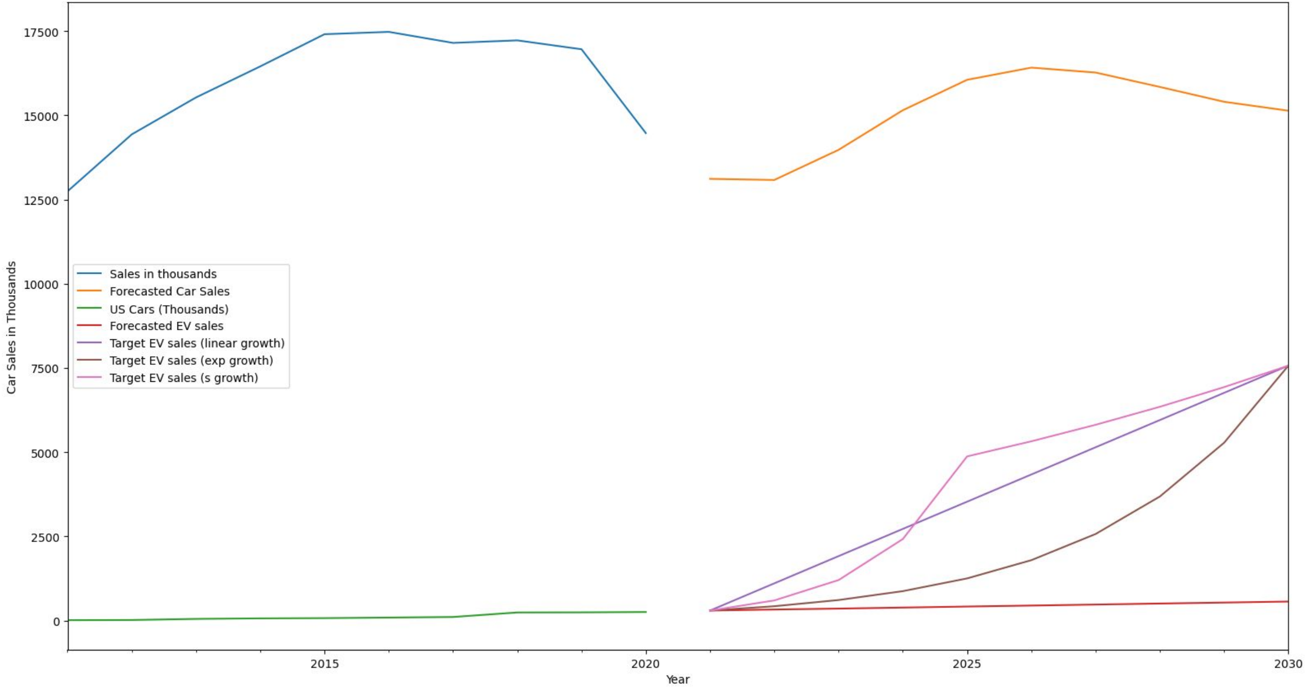
Forecasted EV sales/registrations until 2030 in thousands



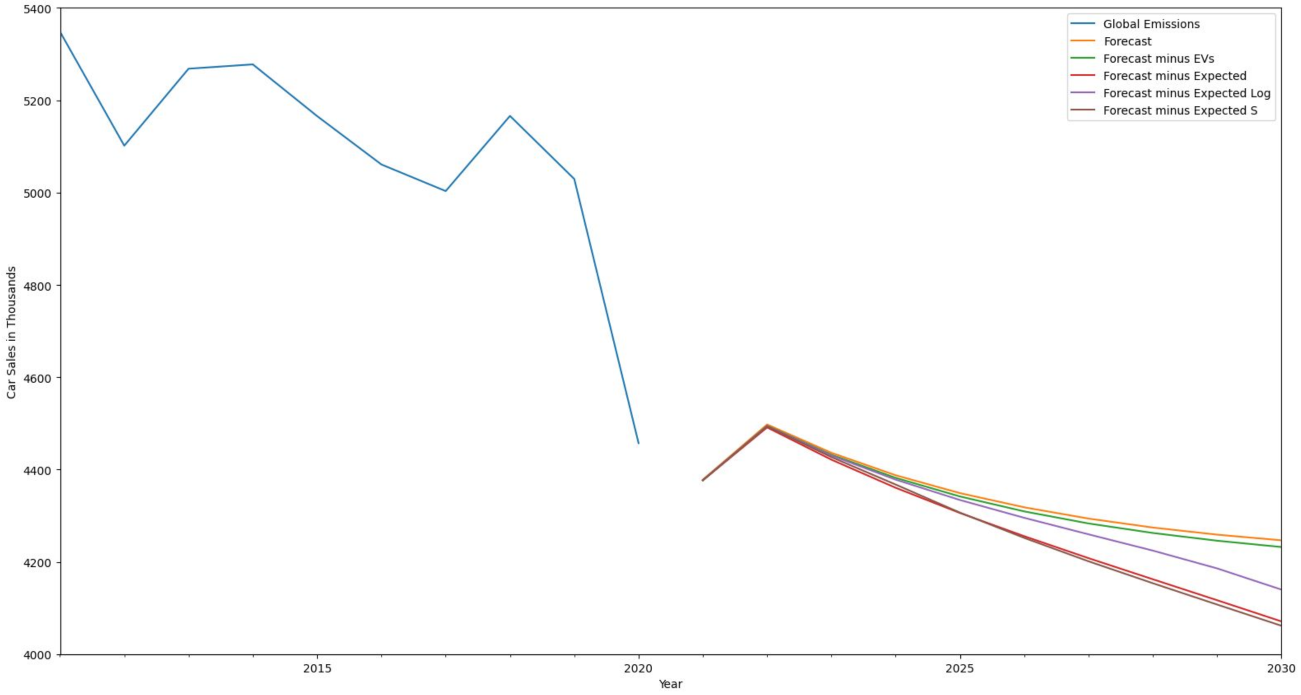
Forecasted vehicle sales until 2030 in thousands



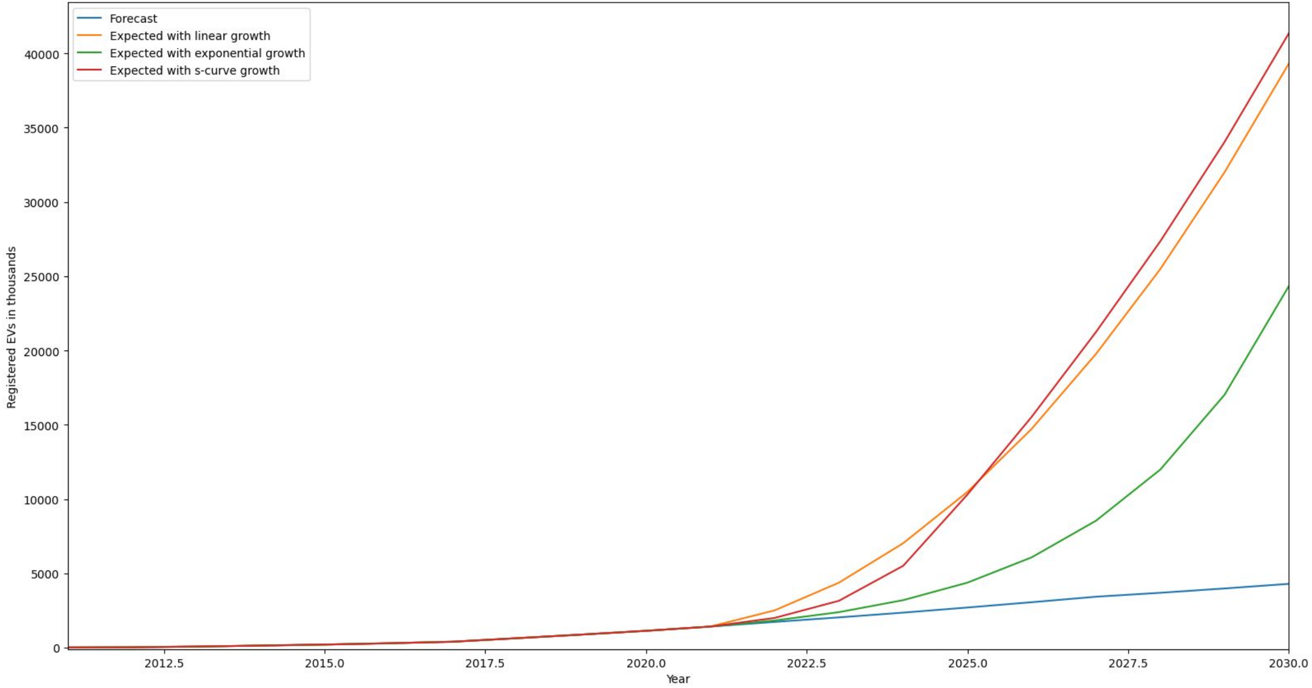
Sales comparison



Effect of EV sales on emissions



Cumulative registered EVs over time in thousands



Verification

- Estimated number of registered vehicles by 2030: 309,309,894
- Percentage of light passenger vehicles: 35%
- Number of light passenger vehicles: 108,258,463

- Estimated US emissions by 2030: 4246.67 million tonnes
- Percentage contributed by light passenger vehicles: 15%
- Emissions caused by light passenger vehicles: 637 million tonnes

- Market Share = Registered EVs / Registered Light Vehicles
- Theoretical Decrease = Market Share * 637 million tonnes
- Actual Decrease = Emissions w/o solution - Emissions w/ solution

Results

	% of EVs on the road	Emissions by 2030	Decrease from forecast	Theoretical decrease
Predicted	3.97%	4232.13	14.54	25.26
50% Linear Growth	36.32%	4071.00	175.67	231.37
50% Exp. Growth	22.48%	4139.91	106.76	143.22
50% S Growth	38.21%	4061.62	185.05	243.37

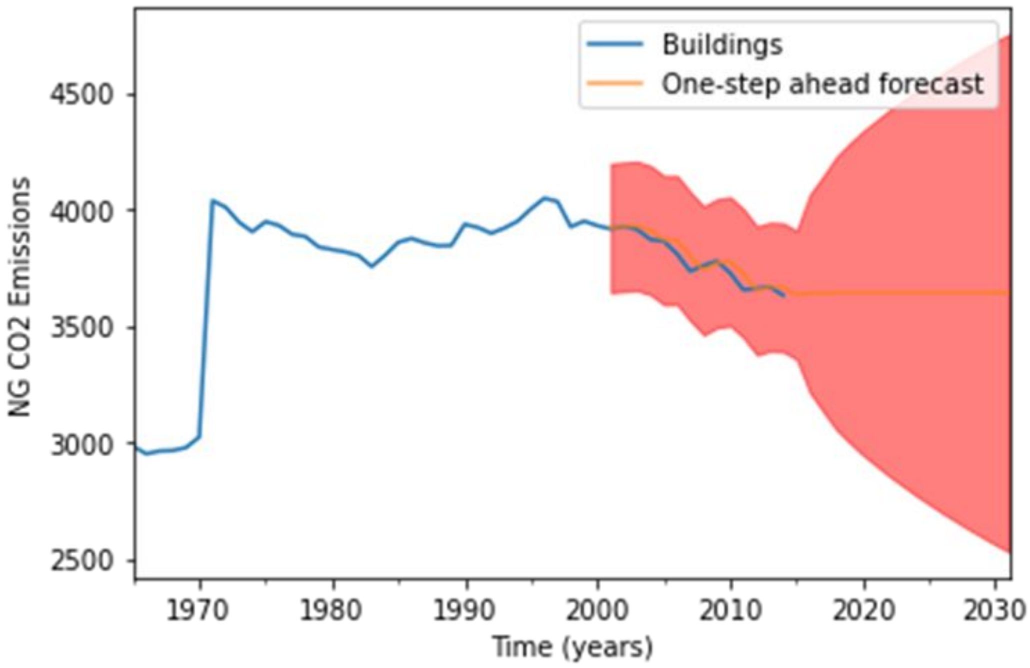
Analysis

- Forecasted decrease in emissions in all cases is lower than the theoretical decrease.
- The theoretical decrease is calculated naively, there are multiple factors that would imply it is lower than the value given some examples are as follows.
- The average American household owns approximately 1.85 cars meaning not all vehicles travel the same amount of miles.
- While the range of EVs have been improving, most cars used for long distance driving are internal combustion engines.
- Given these factors, the assumptions mentioned previously, and the limitations of the model and the datasets, the results are reasonable enough.

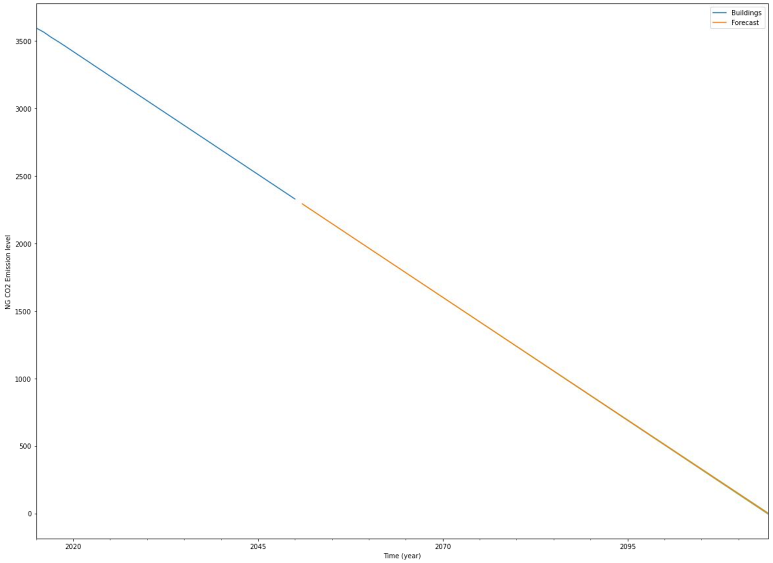
Solution 4 - Implementation of Energy Efficient Buildings

- Building Generate nearly 35% of Annual Global CO2 emissions
- Building operations are responsible for 22% and 12% rely on the operation
- If we can reduce the CO2 emission caused by buildings, there may be significant changes in the emission rates

Predicted CO2 emission till 2030 based on current data



On an ideal environment with current infrastructures and innovations, the reduction of carbon emission can be decreased by 40% by year 2050. With the given rate however, there can be a zero emission by year 2114



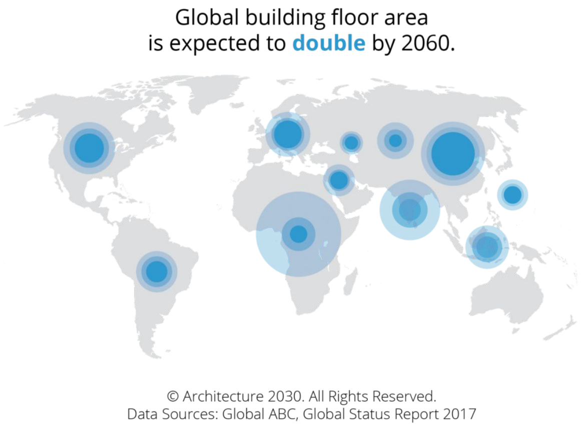
2110	146.150668
2111	109.759051
2112	73.367710
2113	36.976646
2114	0.585859

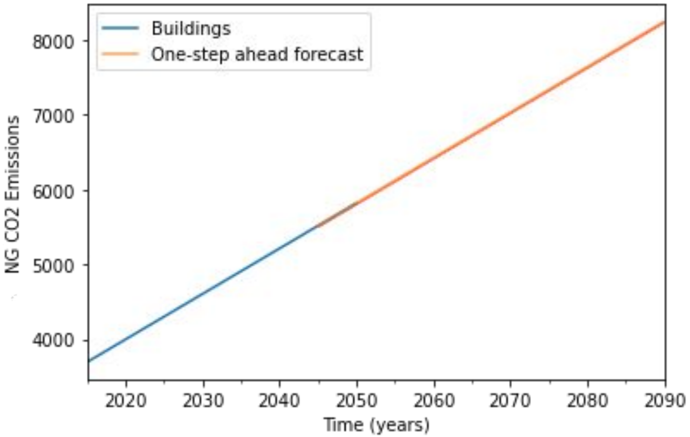
2051	2293.744822
2052	2257.338340
2053	2220.929484
2054	2184.523050
2055	2148.115186

Modes of improvement on carbon reduction includes

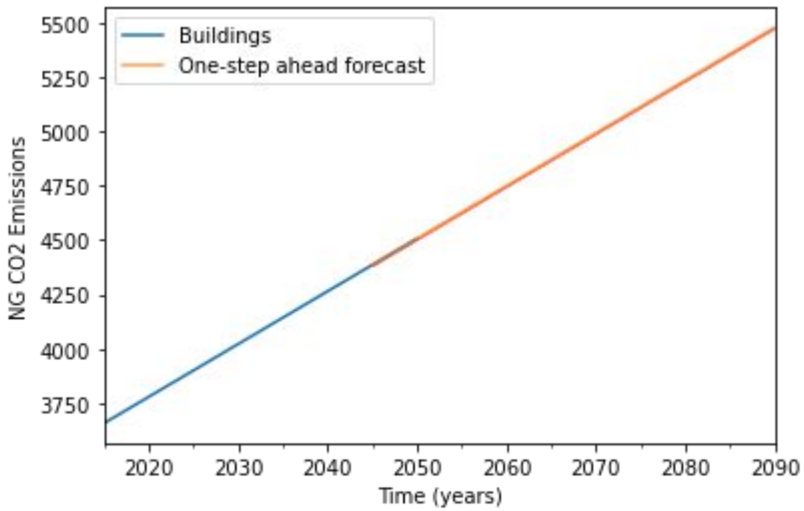
- Reuse – reuse of existing materials and designing for deconstructions
- Reduce – Include material optimization and the specification of low to zero carbon materials
- Sequester – including the design of carbon sequester sites ad the use of carbon sequestering materials

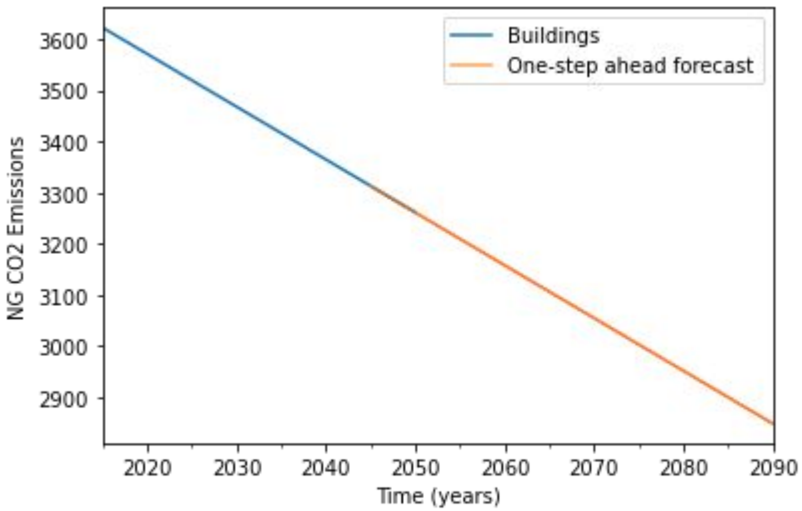
However, the growth rate of the buildings are very high and keeping that in consideration, without implementing any forms of solutions, the CO2 emission rate will be highly increase resulting in almost double emission rate by the year 2060





Applying current solution approaches that includes renewable resources such as relying on solar power and energy efficient materials and another approach is while including the renewable resources, also including reconstruction of old building to more efficient ones



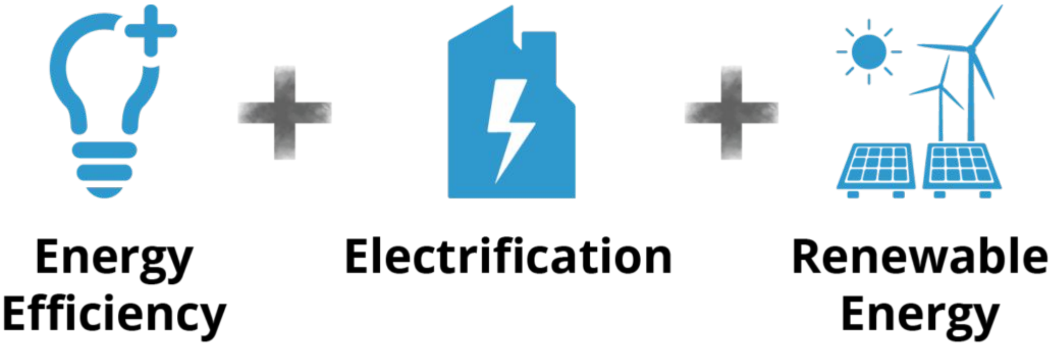


But these are based on Ideal situations,one of the reason why the graphs are linear. But in realistic point of view. There are always uncertainties and the situations are non ideal. We have to consider the following variables and solution approaches

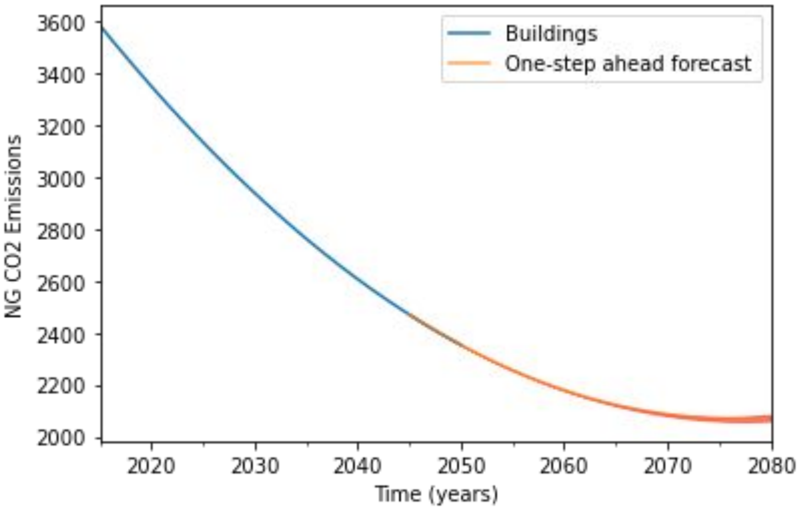
- By the year 2060, building numbers is likely to be doubled that means CO2 emission sources are doubled as well

  Steps to reduce those emissions

- Existing building will need to undergo energy upgrades involving a combination of improvements in EEB, shift to electric or district heating system powered by carbon-free resources compared to the gas powered. And more reliant on Renewable sources of energy, and electrification of buildings while source being Renewable energy
- New buildings will require to implement all those resources, in addition to that, reuse of materials is a must because production of construction materials are responsible for a lot CO2 emission as well



Prediction of CO2 emission, with cumulation of addressed variables



Analysis and Limitation

- The buildings will always keep on increasing
- The only option we have is reduction of CO_2
- Even applying all these solution, it is likely that with current resources, at one point the CO_2 emission will rise again
- Given the current resources, zero carbon emission from Building is not possible, but can only be improved

Conclusion

- Renewable Resources -The original and predicted values of a majority of our time series don’t show a similar pattern. Mean absolute percentage error was only 6% for CO2 emissions, indicating how much closer the forecast is than it actually looks.
- Carbon Capturing and Sequestration - With the current rate of growth in CCS facilities, net zero carbon dioxide emissions will be achievable by the year 2216 based on the forecast obtained with our ARIMA model. In order to achieve the Paris Agreement’s goal of net zero by 2050 dramatic increase is necessary to the number of facilities produced in the next few years.
- Electric Vehicles - The results are consistent with what is expected. Less cars that emit CO_2 mean less emissions. However, the model does not measure emissions caused by producing EVs nor whether the power grid can handle it.
- EEB - Use of EEB can significantly reduce the CO2 emission from building sectors if planned and implemented efficiently and have the potential to even have lesser CO2 emission than today while doubling the number of buildings.

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