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DECARBONIZATION OF THE US ENERGY SECTOR: WHERE WE ARE NOW AND WHERE DO WE NEED TO BE?

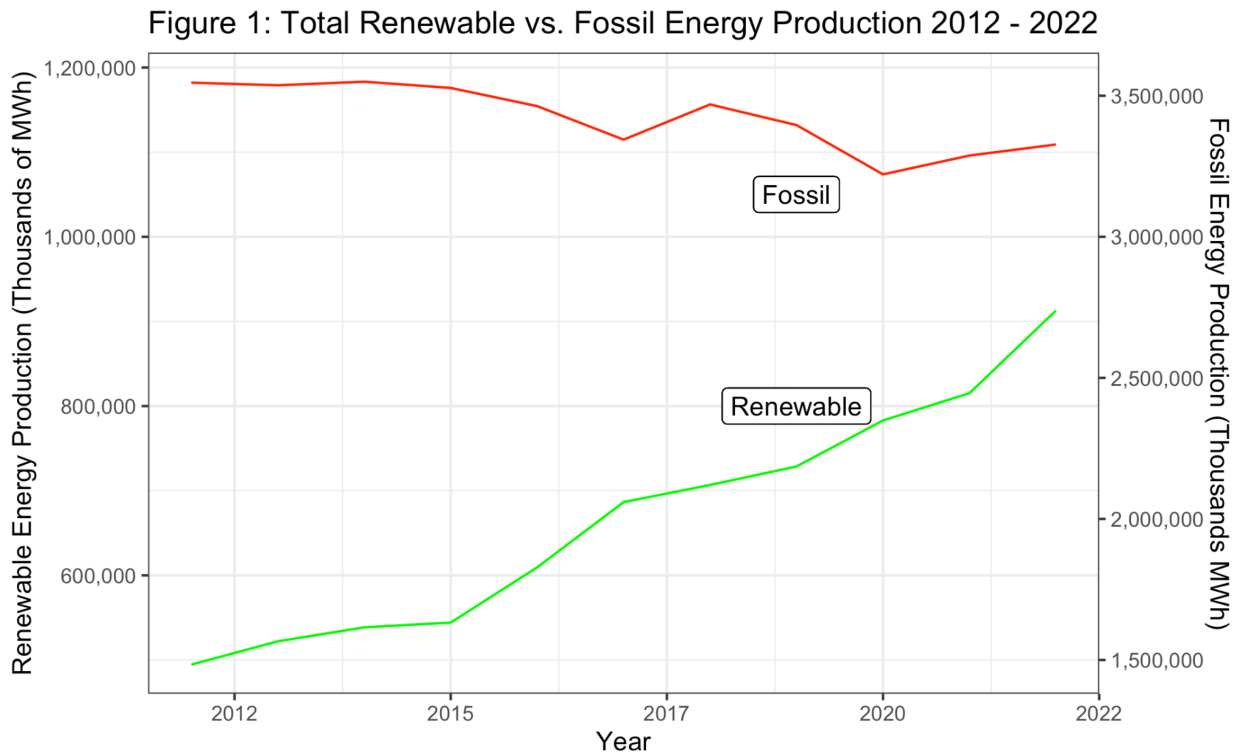
INTRODUCTION/BACKGROUND:

The United States and the International Panel on Climate Change(IPCC) have both set a goal of reaching Net-Zero emissions in the energy sector by 2050. This does not entail that all energy produced in the US will have to come from renewable resources, but rather that there must be a joining of renewable technologies and offsetting strategies to counter what emissions may still come from fossil fuels or other sources. Such offsetting strategies could include improved efficiency of sectors as well as carbon removal methods like DCR or forestation.

The IEA and Whitehouse have a loose outline of how this goal of decarbonization will be met. The "Long-Term Strategy of the United States" sets net-zero emissions as the main goal by 2050 along with interim targets by 2030 of reducing emissions by roughly 50%[1]. This report outlines five key approaches to reaching their goal, along with an overall emphasis of investment for supporting new technologies and solutions . The first and possibly most important aspect is their goal of achieving 100% clean energy in the electricity sector by 2035[1]. The US plan to achieve this will be through more deployment of energy sources based on wind, solar, nuclear, and hydroelectric power[1]. Despite the push to use only renewables within the electricity sector by 2035, the Whitehouse report does recognize that some fossil fuel power plants may need to continue running in the short term while transitioning. Decarbonizing the electricity sector will require improved technologies such as that of energy storage systems, along with policies/incentives for renewable energy growth while phasing out fossil fuel(FF) subsidies. The Long-Term plan also addresses the importance of decarbonizing the transportation sector through the deployment of electric vehicles and promoting public transit. Along with the transportation sector there must also be reductions of emissions in the industry and building sector, both of which can be improved through retrofitting and improving efficiency. Specifically in industry there can be emissions reduced through carbon capture storage(CCS) and circular economics that promotes recycling/reuse[1]. Reducing emissions through improved efficiency of buildings and industry will also help the electricity sector demand less energy, thereby making it easier to decarbonize.

Expanding the use and implementation of renewable energies will require widening deployment of energy storage technologies such as batteries and hydroelectric storage[2]. Expanding transmission infrastructure will also be vital, as most of the time renewable farms are located in areas with low energy demand, and there is a large need for this energy in farther away areas[2]. As there will be an increasing amount of land needed for implementing the renewable energy needed to reach net zero emissions, there will be directly correlated needs for expanded transmissions. This will reduce curtailment, creating more energy than can be used/stored, and also improve grid reliability.

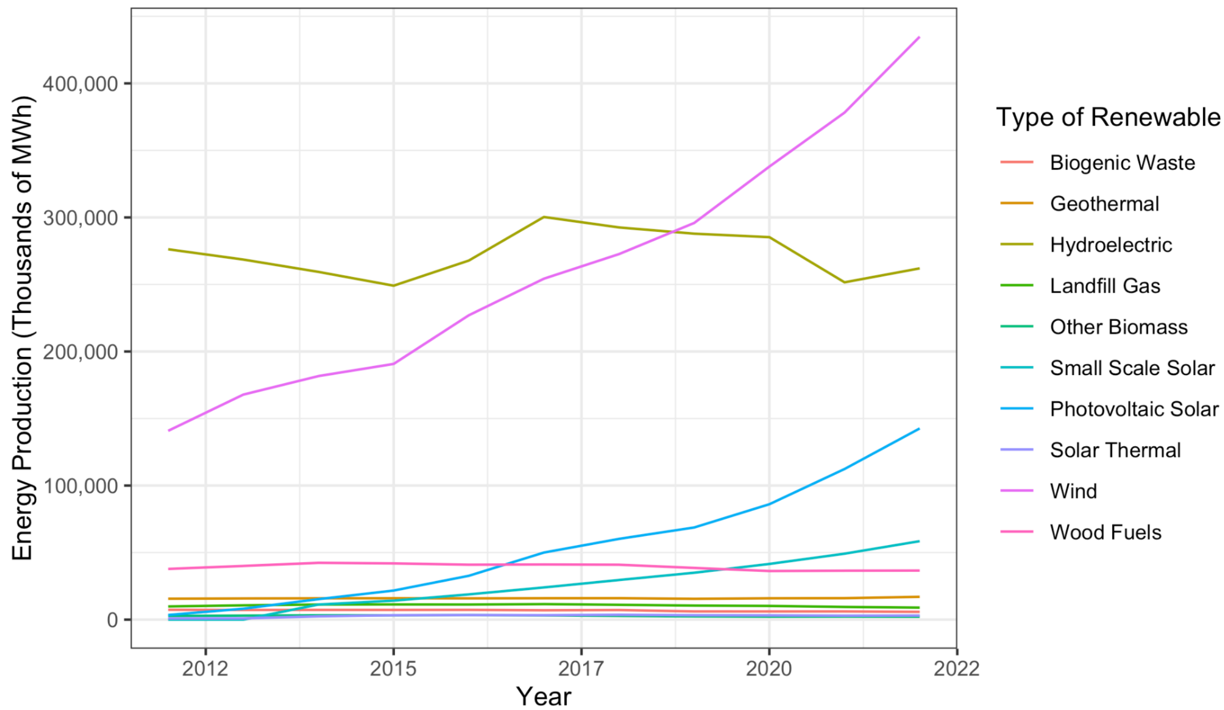
The United States has made large efforts already to reach net-zero emissions. In 2000 renewable energy accounted for 9.3% of total electricity generated in the US and in 2020 this number rose to 21%[2]. In tandem with increasing renewable energy reliance, there have also been vast improvements in energy efficiency, a key example being the Energy Star program. The energy star program has helped to reduce emissions by 2.7 billion metric tons since it was enacted in 1992[3]. There have been large steps taken in the transportation sector with Electric Vehicles; there were over 1.7 million electric vehicles in operation in 2021[4]. All of this along with increasing carbon capture/storage and emerging policies such as the Clean Air Act, Clean Power Plan, and the Paris Agreement have demonstrated that the United States is most certainly headed towards a less carbon intensive future. Despite all of the efforts and improvements that have been made in decarbonization, there is still the possibility that the US is not on track to meet the historic goals and benchmarks set by the Biden administration.



With this information it is important to visualize and understand the trends of the energy sector, along with where the US currently stands in relation to the aforementioned goals. Figure 1 shows the energy production, in thousands of megawatt hours, of renewables and fossil fuel sources from 2012 to 2022. The electricity generation from renewables has increased 45.8%, while fossil fuel energy production has only fallen 6.2% within the 10 year span. Fossil fuels still dominate the energy sector, with an energy generation of 3,327,284 thousand MWh produced. While renewable sources were only responsible for 912,870 thousand MWh that same year. This is roughly 21.5% of the total utility level energy production. This means that the remaining fossil generated energy needs to be replaced with zero emissions sources by 2050.

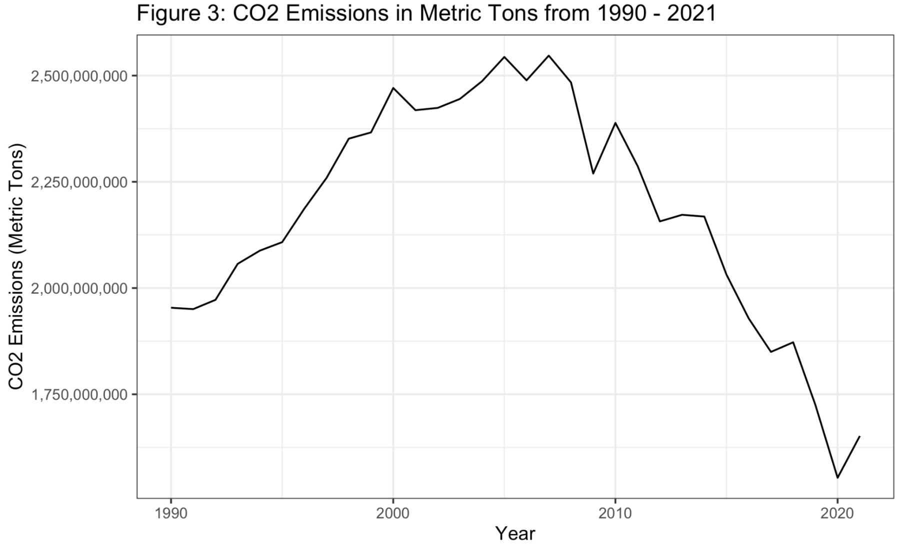
Figure 2 looks at the sectors identified by the EIA that are classified as renewable, and their respective energy generations in thousands of megawatt hours over the same period of time. There are three clear renewables that make up the largest share of energy production: hydroelectric, wind, and photovoltaic solar. Combined they account for 92% of 2022's renewable energy generation. One point of concern is hydroelectric being one of these larger sources, because there have been pushes against further expansion due to the environmental consequences. As for other sources, biomass has a visible climb and has numerous applications beyond energy production. Including BECCS, which will play an integral role in reaching the 2050 goals considering CDR will be needed to achieve net zero carbon emissions. These are the renewables that will likely bear the most responsibility in increasing energy production from the renewable sector.

Figure 2: Renewable Energy Production by Sector 2012 - 2022



Looking beyond generation, a big point of the 2050 goals is “net-zero emissions”, meaning that while having renewables produce a significant amount of the energy we consume will inevitably lead to this goal, we also need to be watching the CO2 emissions from the energy sector. This is because the U.S’s goal can be achieved by, and realistically cannot be achieved without, also offsetting emissions of the energy sector. This may be possible through various CDR technologies and in some cases, as mentioned above, can be both energy generating and capturing through something like BECCS or other CCS that utilizes both a renewable energy and capture technology. With all this in mind, we sought to conservatively analyze and visualize our current trajectory as a country.

Figure 3: CO2 Emissions in Metric Tons from 1990 - 2021



<u>RESULTS:</u>

Beginning the analysis required the consolidation and cleaning of data from the EIA. Below shows code performed by us utilizing the programming language

R. Cleaning the data was an integral part of ensuring that the model and figures created would be accurate and run correctly.

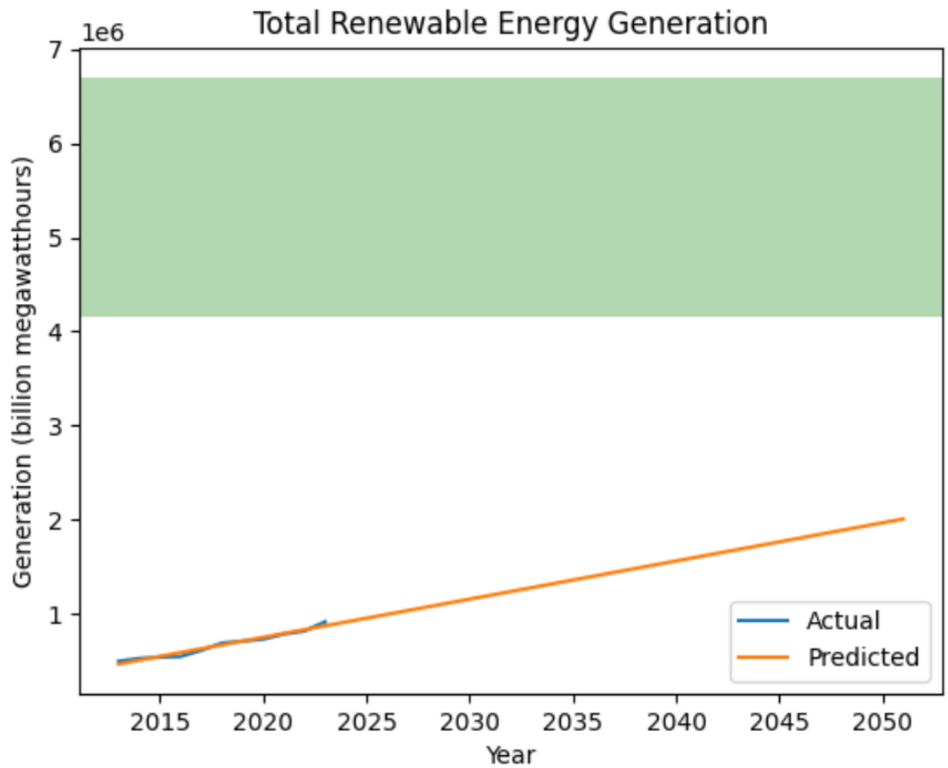
```r
#import/clean datasets

#emissions data
CO2_state <- read_excel(here("data/emission_annual.xlsx")) |>
             clean_names() |>
             filter(producer_type == "Total Electric Power Industry",
                    energy_source == "All Sources", state != "US-TOTAL") |>
             select(year, state, producer_type, energy_source, co2_metric_tons)

CO2_total <- read_excel(here("data/emission_annual.xlsx")) |>
             clean_names() |>
             filter(producer_type == "Total Electric Power Industry",
                    energy_source == "All Sources", state == "US-TOTAL") |>
             select(year, state, producer_type, energy_source, co2_metric_tons)

#fossil fuel data
fossil_energy <- read_excel(here("data/fossil_energy.xlsx"),
                            range = "A6:G16", col_names = F) |>
                 rename(year = 1, coal = 2, petroleum_liquids = 3,
                        petroleum_coke = 4, natural_gas = 5, other_gas = 6,
                        nuclear = 7) |>
                 mutate(year = as.integer(year),
                        total = rowSums(across(where(is.numeric))))

#energy totals by year
energy_year <- read_excel(here("data/renewable_energy.xlsx"),
                          range = cell_rows(6:16), col_names = F) |>
               rename(year = 1, wind = 2, solar_photovoltaic = 3,
                      solar_thermal = 4, wood_fuels = 5, landfill_gas = 6,
                      biogenic_waste = 7, other_biomass = 8, geothermal = 9,
                      hydroelectric = 10, total_utility_level = 11,
                      small_photo_solar = 12, total_photo_solar = 13,
                      total_solar = 14) |>
               mutate(small_photo_solar = as.numeric(small_photo_solar),
                      total_photo_solar = as.numeric(total_photo_solar),
                      total_solar = as.numeric(total_solar))

#replace n/a in energy totals
energy_year[is.na(energy_year)] <- 0

#energy by month for 2020
energy_2020 <- read_excel(here("data/renewable_energy.xlsx"),
                          range = cell_rows(17:29)) |>
               rename(month = 1, wind = 2, solar_photovoltaic = 3,
                      solar_thermal = 4, wood_fuels = 5, landfill_gas = 6,
                      biogenic_waste = 7, other_biomass = 8, geothermal = 9,
                      hydroelectric = 10, total_utility_level = 11,
                      small_photo_solar = 12, total_photo_solar = 13,
                      total_solar = 14)

#energy by month for 2021
energy_2021 <- read_excel(here("data/renewable_energy.xlsx"),
                          range = cell_rows(30:42)) |>
               rename(month = 1, wind = 2, solar_photovoltaic = 3,
                      solar_thermal = 4, wood_fuels = 5, landfill_gas = 6,
                      biogenic_waste = 7, other_biomass = 8, geothermal = 9,
                      hydroelectric = 10, total_utility_level = 11,
                      small_photo_solar = 12, total_photo_solar = 13,
                      total_solar = 14)

#energy by month for 2022
energy_2022 <- read_excel(here("data/renewable_energy.xlsx"),
                          range = cell_rows(43:55)) |>
               rename(month = 1, wind = 2, solar_photovoltaic = 3,
                      solar_thermal = 4, wood_fuels = 5, landfill_gas = 6,
                      biogenic_waste = 7, other_biomass = 8, geothermal = 9,
                      hydroelectric = 10, total_utility_level = 11,
                      small_photo_solar = 12, total_photo_solar = 13,
                      total_solar = 14)
```

Below is a python snippet of the script that creates our linear regression model, excluding any lines that are used for organizing and cleaning the data, as well as plotting it. In this code I extract the years from the index to use as X and the output values as y. I then fit the Linear Regression by initializing an empty list for storing modified values, and looping through each energy source to append new fitted models to the list. The prediction begins by defining the start

```python
X = df_yearly.index.astype(np.int64).values.reshape(-1, 1) / 10**9
y = df_yearly.drop(columns=['Total Renewable Generation at Utility Scale Facilities']).values
models = []
for i in range(y.shape[1]):
    model = LinearRegression()
    model.fit(X, y[:, i])
    models.append(model)


start_date = df_yearly.index[0]
end_date = datetime.datetime(2050, 12, 31)
date_range = pd.date_range(start_date, end_date, freq='Y')
X_future = date_range.astype(np.int64).values.reshape(-1, 1) / 10**9
y_future = []

for i, model in enumerate(models):
    y_future.append(model.predict(X_future).reshape(-1, 1))
y_future = np.hstack(y_future)


fig, axes = plt.subplots(nrows=3, ncols=3, figsize=(20, 10))
for i, ax in enumerate(axes.flat):
    col = df_yearly.columns[i]
    ax.plot(df_yearly.index, df_yearly[col], label='Actual')
    ax.plot(date_range, y_future[:, i], label='Predicted')
    ax.set_xlabel('Year')
    ax.set_ylabel('Generation (thousand megawatthours)')
    ax.set_title(col)
    ax.legend()
plt.tight_layout()
plt.show()
y1=4.16e6
y2=6.7e6
```

and end date, which is then used for predicting the energy generation of each renewable and storing the results. All of the dataset for this is from an EIA dataset that we first had to clean and process before using for our model[7].

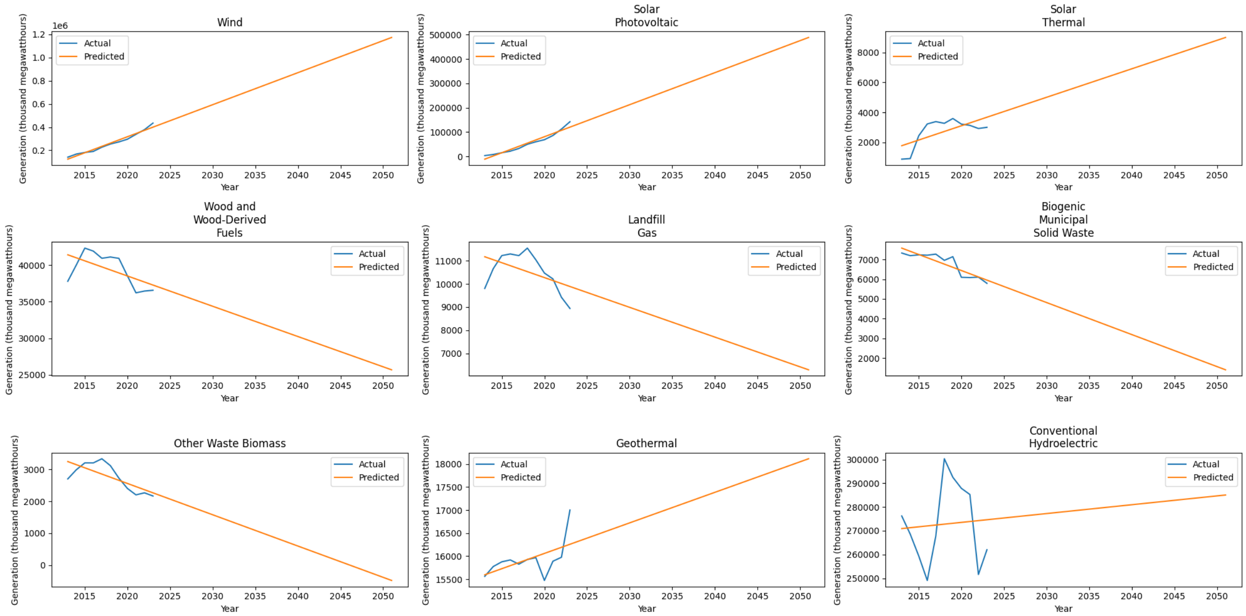
Figure 4: Linear regression of total renewable energy generation(electricity sector)



Predicting the energy output of the renewable energy sector is a very difficult task that would require numerous factors to be taken into account, such as confidence levels in current/upcoming policy, estimations of upcoming renewable implementation, forecasted economic growth, and many more. For this analysis, we did not have the time nor the skill to make such an all encompassing model. With this in mind, we built a conservative estimation model using a linear regression. It takes into account the cumulative energy outputs of each renewable energy from 2012-2022 and creates a regression that predicts the output for future years based on linear slope. The dataset comes from "U.S. Electric Power Industry Estimated Emissions by State (EIA-767, EIA-906, EIA-920, and EIA-923)," which holds a spreadsheet of different renewable energy sources from 2012-2022 and their energy production output in thousand MWH[7]. On the graph above there is the blue shaded region, which spans from 4.1e6 to 6.7e6 thousand megawatt-hours. This is the estimation of energy production needed in 2050 to support the United States in reaching net-zero emissions[1, fig.5].

From 2012 to 2022, it seems that renewable energy implementation has been relatively linear, as the regression did seem to fit it quite well. It is however important to note that this model is conservative, and the last few years of our dataset tended to increase at a higher rate than the previous years. Despite this, our model would demonstrate that in regards to renewable energy production within the electricity sector, the United States is not at all on track to reach the needs of 4.1 to 6.7 trillion kilowatt hours. There will need to be adjustments made to the United State's Long-Term plan in order to achieve decarbonization.

Figure 5: subplots of linear regression for each form of renewable energy



Here is the linear regression for each energy source, While the linear regression for total renewable production may be a relatively good fit to the data, there can be seen in these graphs very poor correlations with some of the energy sources.

<u>DISCUSSION:</u>

If the United States is not on track to reach their goals of renewable energy production by 2050, what steps could be taken to ensure adequate renewable energy production? One key step that the government could make is the increasing of government funding for research and development. Increasing economic incentive would entice private research/industry to focus their efforts on improving renewable energy, as it would allow it to be more cost effective and accessible[5]. Similarly, there can be policies put in place to support investments in renewable energy. Such policies could be tax incentives, subsidies, or grants for private research. All of this could make clean energy more enticing to consumers, in turn increasing the deployment of new projects[6]. There could also be policy enacted that would entail setting more aggressive decarbonization targets, or perhaps even enforcing decarbonization steps to be taken by private corporations. This would create more urgency and only serve to accelerate progress towards reaching the Long-Term energy goal.

As mentioned in the introduction, there will most likely also be a need for improved transmissions infrastructure to allow for increasing renewable production[2.] Improving transmission would allow for solar or wind farms to be located in cheaper to build areas while still providing energy to other areas[2]. Placing these farms on land with high renewable potential and exporting the energy to high energy demand areas would improve feasibility and cost efficiency. This will be an essential step to expanding renewable energy production, as the amount of land that is available will act as a limiting factor, and better transmission infrastructure will make this far less of a concern.

Another factor that will help us overcome the gap between our model and where we need to be is storage of energy to distribute it during periods of low renewable production. This will help replace the role of fossil fuels because that is a primary reason that fossil fuels are still needed. In the world of renewables it is a common saying that the sun doesn't always shine and the wind doesn't always blow. During different times of day or year there are significant changes in energy production. Batteries would aid in mitigating the lack of output during these different times. Also since it would replace fossil fuels role with renewables down the line, it would help reduce CO2 emissions and increase renewable energy availability. There are new policies, such as some proposed in early 2022 that were a part of the infrastructure investment and jobs act, offering billions of dollars in battery storage related funding that will dramatically increase progress toward net zero [8].

Another important policy that was introduced in 2022 was the inflation reduction act which through the next ten years will significantly expand support for renewable energy via tax credits and other measures [9]. There is also the rural clean energy initiative which is going to allocate $300 million to rural areas for aiding in transition to renewable energy. On top of this there is also an additional $6.5 billion for financing of rural renewable energy/storage projects [10]. Both of these new policies will aid with helping renewables reach rural areas and as we mentioned before help with creating large amounts of renewable energy in rural areas that can also be made available to denser populated regions. Ideally these will also lead to an increase in small solar, as it has grown 81% since 2014, and is starting to make up a larger share of the solar sector. It will also help ease concerns over land use with all the various sectors competing in the coming years.

CONCLUSION:

Based on our modeling, the United States is not on track to reach its decarbonization goals by 2050. It is important however to keep in mind that our model is conservative, and can be used to understand where we will end up with the bare minimum being done. The policy and steps discussed above are just a few examples of ways that the US is and should be making meaningful steps towards improving our trajectory toward our 2050 net zero energy sector. With how low our predictions came in relation to where we need to be with energy production, it should create a sense of urgency with the policy that needs to be created and how fast we should be moving to raise the slope of the baseline.

Works Cited

1. *The White House*. https://www.whitehouse.gov/wp-content/uploads/2021/10/US-Long-Term-Strategy.pdf.
2. “U.S. Energy Information Administration - EIA - Independent Statistics and Analysis.” *EIA*, https://www.eia.gov/energyexplained/renewables/.
3. Energy Star. “Environmental Impacts.”Energy Star, US Environmental Protection Agency, n.d.,www.energystar.gox/about/images. Accessed 16 Mar. 2023.
4. International Energy Agency. “Homepage.” International Energy Agency, n.d., www.iea.org/. Accessed 16 Mar. 2023.
5. US Department of Energy. “Homepage.” Us Department of Energy n.d., www.energy.gov/. Accessed 16 Mar. 2023.
6. National Renewable Energy Laboratory. “Homepage.” National Renewable Energy Laboratory, n.d., www.nrel.gov/. Accessed 16 Mar. 2023.
7. US Energy Information Administration. “State Electricity Profiles: Data for 2019.” US Energy information Administration,2021,www.eia.gov/electricity/data/state/emission_annual.xlsx.
8. “Resource Infrastructure Investment and Jobs Act: Implementation and Key Resources.” *National Conference of State Legislatures*, https://www.ncsl.org/state-federal/infrastructure-investment-and-jobs-act-implementation-and-key-resources.
9. Iea. “Solar PV – Analysis.” *IEA*, Sept. 2022, https://www.iea.org/reports/solar-pv.
10. Iea. “Rural Clean Energy Initiative & Support to Rural Energy Transition – Policies.” *IEA*, 30 Nov. 2022, https://www.iea.org/policies/16609-rural-clean-energy-initiative-support-to-rural-energy-transition.