Comparing Current Country-Specific Energy Mix Trends with their Targets

By Raina Lakhamraju

1. Introduction

Fires rage in Southern Europe; smoke from Canadian wildfires smother New York City in a yellow haze; uncharacteristically heavy rain causes floods throughout South Asia. If countries are supposedly on track to meet their climate goals for 2030, why are climate related catastrophes becoming increasinglyfrequent? In 2015, global leaders came together to create an international treaty known as the Paris Agreement which signified the need for immediate climate action. Since then, countries have set individual goals including energy mix targets and pledges for carbon neutrality. Even though t has been eight years since the agreementthe progress of these countries on their sustainability journey remains unclear.
The goal of this paper is to evaluate whether countries are on track to meet their climate goals. Particularly, this paper focuses on energy mix targets and the transition to renewable energy sources. Then, we look at and predict countries' annual carbon emissions. Finally, we examine the sensitivity of a country's desired energy mix to various fuel sources.

This paper is divided into six sections. The first section titled 'Methodology' includes the sources used as well as various forms of analysis that were used on the data. The second section showcases the visualizations and observation of the results that came from the analysis. The third section titled 'Discussion' details the implications and of the data and how this answers the overall question of this paper. The 'Limitations' section addresses certain factors that may impact the accuracy of the conclusions that we have drawn. Next, the conclusion restates the main question as well as the answer that we have concluded. The final section acknowledges people who had a vital contribution to the creation of this paper.

2. Methodology

2.1 Data Source Description

We obtained the energy mix data from an online database called 'Our World in Data' which was created by researchers at Oxford Martin School. This online database contains data from topics ranging from global biodiversity to energy consumption. We used two types of data.

The first type of data was historical energy mix data ranging from 1965 to 2021.

Entity	Year	Geo Biomass	Biofuels	Solar Consumption	Wind Consumption	Hydro	Nuclear	Gas	Coal	Oil
United State	1990	57.459316	16.73274	1.0964366	8.329152	864.27155	1723.0038	5170.609	5337.9976	9306.913
United State	1991	60.55176	19.38873	1.4141886	8.814071	849.61993	1829.6448	5283.972	5287.614	9108.51
United State	1992	64.815414	22.04472	1.2089486	8.62462	743.463	1848.1968	5463.51	5324.031	9297.387
United State	1993	66.92472	25.75947	1.4050486	8.977978	825.74207	1822.853	5599.419	5522.4526	9376.045
United State	1994	66.35486	28.846283	1.4840325	10.296024	766.8695	1912.9027	5731.081	5543.143	9619.747
United State	1995	63.26508	30.942383	1.521287	9.451174	920.2736	2011.3564	5979.83	5593.0537	9597.527
United State	1996	64.82596	22.19422	1.6007403	9.659704	1027.7001	2015.3182	6088.898	5847.301	9947.14
United State	1997	65.82008	28.103718	1.5751755	9.820893	1052.6086	1877.6708	6125.315	5970.778	10079.769
United State	1998	65.61713	31.054237	1.551412	9.037324	952.4145	2012.2524	6021.791	6029.3384	10251.112
United State	1999	66.47772	32.287457	1.5327319	13.405012	936.1981	2175.1917	6042.628	6020.095	10537.093
United State	2000	66.582825	37.003212	1.5332364	16.706276	806.55237	2251.771	6283.907	6286.536	10654.134

As shown in the sample above, the data shows multiple primary energy sources (Geo Biomass, Biofuels, Solar, Wind, Hydro, Nuclear, Gas, Goal, and Oil) as well as the amount of energy consumed from each source (in the form of TWh) during each year.

The second type of data that was used was historical carbon emissions.

Entity	Code	Year	GDP, PPP (constant 2017 international $	Annual CO_2 emissions
Canada	CAN	1996		507,510,750
Canada	CAN	1997	1,017,832,700,000	521,839,970
Canada	CAN	1998	1,046,296,800,000	529,649,540
Canada	CAN	1999	1,087,839,800,000	544,063,800
Canada	CAN	2000	1,141,337,200,000	566,690,400
Canada	CAN	2001	1,157,379,000,000	558,777,540
Canada	CAN	2002	1,196,986,200,000	564,050,900
Canada	CAN	2003	1,242,604,400,000	581,305,300
Canada	CAN	2004	1,291,240,300,000	579,592,060
Canada	CAN	2005	1,355,748,900,000	574,653,630
Canada	CAN	2006	1,412,226,900,000	568,450,940

The table contains information regarding the GDP and PPP of certain countries. However, the only information that we used was the column titled ‘Annual CO2 emissions.

2.2 Energy Mix Prediction vs Target

A country’s energy mix is the breakup of its energy consumption from different primary energy sources (coal, gas, oil, hydro, solar, etc.). Currently, many countries have set goals using their energy mix as a metric. The time frame to achieve these goals typically between 2030 and 2050. To evaluate whether countries are on track to meet their climate goals, we first predicted

the future energy mix of the 40 countries with the highest GDP and then compared these predictions with their target.

Using the historical energy mix table as time series data and the AAA version of the Exponential Smoothing (ETS) algorithm, we were able to create accurate predictions of the future energy mix of individual countries.

The energy mix targets of various countries are available on the International Energy Agency online database. For each goal, we identified the time frame, parameter, and target. As shown in the table below, China has a goal to reach 25% non-fossil fuels the energy mix by 2035. Their target year is 2035, the target parameter is non-fossil fuels, and the target is 25%.

Target Year	Target	Target Parameter	Total Energy Consumption	Renewable Energy	% Renewable	Non Fossil Energy	% Non Fossil
2035	25%	non fossil fuels	53906.99	6257.23	11.61%	7382.60	13.70%

In the target year of 2035, we calculated that 11.61% of China's energy mix consists of renewable energy. We are then able to directly compare this to China's goal which was to achieve 25% renewable energy in the energy mix.

We quantified this comparison by calculating the percent that countries were falling short of their targets by.

2.3 Carbon Emissions Prediction

Carbon Dioxide accounts for 76% of global greenhouse gasses which is why it is a crucial metric when evaluating the sustainability of a country. It is estimated that over two-thirds of CO2 emissions come from energy production. Moreover, there is a strong correlation between a country's energy mix and its CO2 production. In order to better understand the current path that countries are on in terms of sustainability, we used regression to predict annual carbon emissions using energy mix data. The data used for regression came from the two tables mentioned above - the historical energy mix table and the historical carbon emissions. The energy mix table documents energy consumption from individual energy sources. Before analyzing the data, we had to calculate the total annual energy consumption by finding the sum of the consumption from each energy source. Afterwards, we sorted and merged the two tables to create a table containing annual energy consumption and annual carbon emissions. For example, data from Argentina looks as shown below.

Entity	Year	Total Energy Consumption	Carbon Emissions
Argentina	1965	328.5188851	81991043
Argentina	1966	339.1649355	84648063
Argentina	1967	349.0211064	87107947
Argentina	1968	360.8298392	90055147
Argentina	1969	372.89756	93066984
Argentina	1970	353.3496886	88188266
Argentina	1971	374.5989805	93491621
Argentina	1972	379.2679014	94656881
Argentina	1973	396.3664293	98924298
Argentina	1974	412.1173858	102855390
Argentina	1975	402.8722893	100548017
Argentina	1976	422.5401791	105456690
Argentina	1977	441.2913071	110136559
Argentina	1978	441.9466588	110300120
Argentina	1979	474.4878871	118421695
Argentina	1980	471.7620346	117741382
Argentina	1981	457.812877	114259979
Argentina	1982	466.2607284	116368377
Argentina	1983	485.8652166	121261226
Argentina	1984	487.2390961	121604116
Argentina	1985	481.3692704	120139137
Argentina	1986	508.5860572	126931848

Then, in order to confirm a correlation between the two factors, we used the correlation coefficient to determine the relationship between the factors of historical energy mix and historical carbon emissions. Next, we created a function that takes energy consumption as an input and outputs carbon emissions. Using this function, we predicted the carbon emissions of 40 countries between the years of 2022 and 2030.

2.4 Energy Mix Sensitivity

Determining the status of countries in terms of their energy mix goal is only one part of the puzzle. Countries are not yet on track to reach their targets. But how do countries determine what to focus their time and money on in order to increase their chance of reaching their goals? This paper proposes a method that uses a country's energy mix data to identify the country's energy mix sensitivity. We used the United States as a case study. Our forecast function takes historical data as an input and outputs a prediction for future data. To determine energy mix sensitivity, we need to alter the input data. However, we cannot change energy consumption in the past. What we can do is alter the energy consumption predictions for the next three years (2023, 2024, and 2025) and include this in the input data. Using this method, we can alter the input data to a certain degree and evaluate its effect on the output. We previously forecasted the individual energy consumption for each energy source. Moreover, we altered each energy source individually and noted the result. Our alteration depended on the goal of the country. Since the United States aims to increase the share of renewable energy in the energy mix, we decreased consumption from non-renewable sources and increased consumption from renewable sources. The alterations were 5%, 10%, 15%, 20%, 25%, and 30%. For example, if we increase solar energy consumption by 5% for the years 2023, 2024, and 2025, how does this affect the predicted share of renewables in 2030? What is the net increase in the share of

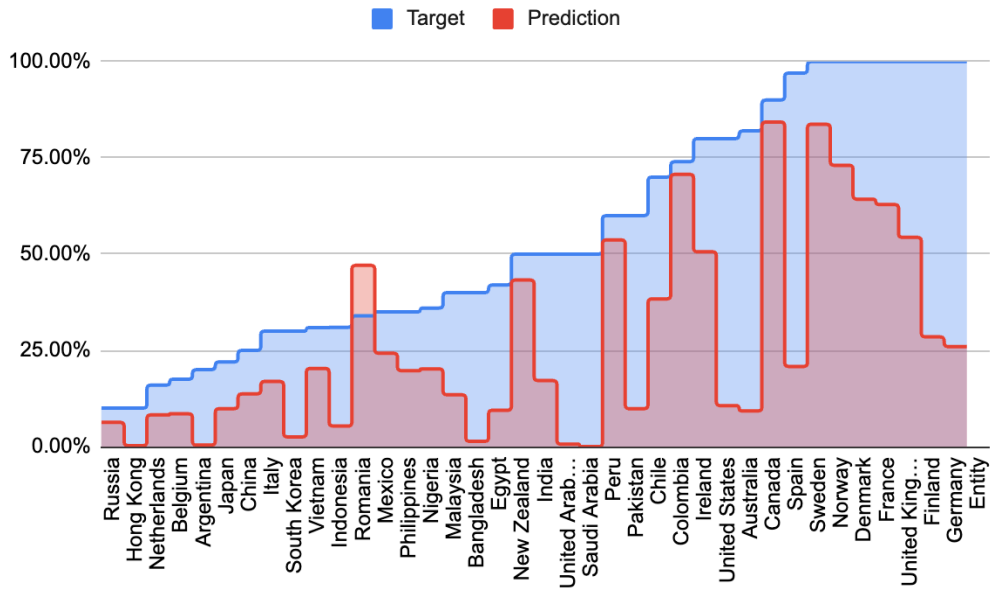
renewables? Or, if we decrease energy consumption from oil by 10% for the years 2023, 2024, and 2025, how does this affect the precited energy mix in 2030? How much closer did we get to the goal? By comparing how the prediction defers depending on the change made, we can see what energy sources make the most impact. Therefore, countries can identify what exactly they need to focus their time and money on to achieve optimal results. We carried out this methodology for each energy source and created a table documenting the change vs. the net increase in the predicted share of renewables in 2030.

	Geo Biomass	Biofuels	Solar)	Wind	Hydro	Nuclear	Gas	Coal	Oil
5%	0.04%	0.23%	0.11%	1.52%	0.27%	0.10%	0.63%	0.18%	0.57%
10%	0.09%	0.59%	0.24%	1.82%	0.57%	0.22%	1.20%	0.34%	1.19%
15%	0.13%	0.84%	0.37%	2.33%	0.72%	0.32%	1.55%	0.50%	1.84%
20%	0.19%	1.42%	0.51%	2.70%	1.99%	0.42%	2.05%	0.66%	2.47%
25%	0.23%	1.67%	0.67%	2.84%	2.84%	0.51%	2.51%	0.82%	3.11%
30%	0.29%	2.51%	0.84%	3.22%	3.22%	0.58%	2.97%	0.98%	3.74%

3. Results

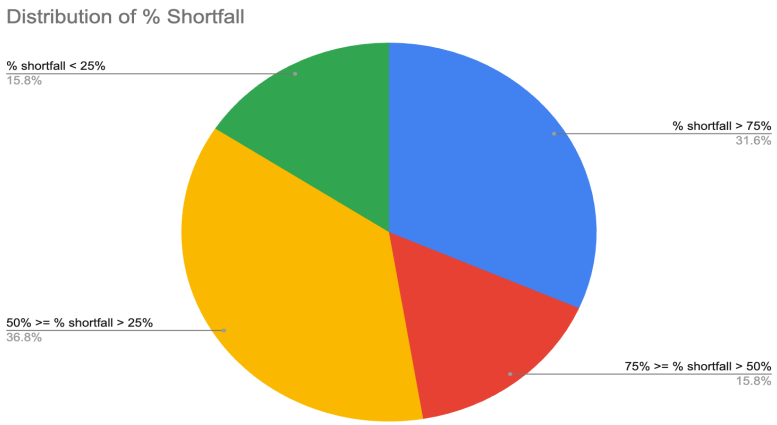
3.1 Energy Mix Observations

Observation 1: Target vs. Prediction



Majority of countries base their energy mix goal on what share of their energy consumption comes from renewable energy sources. In the graph above, the blue represents the percent of the energy mix which was targeted to be renewable. The red is what percent of the energy mix is renewable according to the predictions. This graph shows a visual depiction of how far off each country is from its goal. The countries on the left are the ones closest to reaching their goals while the ones on the right are the farthest. We can clearly see that most countries have not reached their energy mix targets.

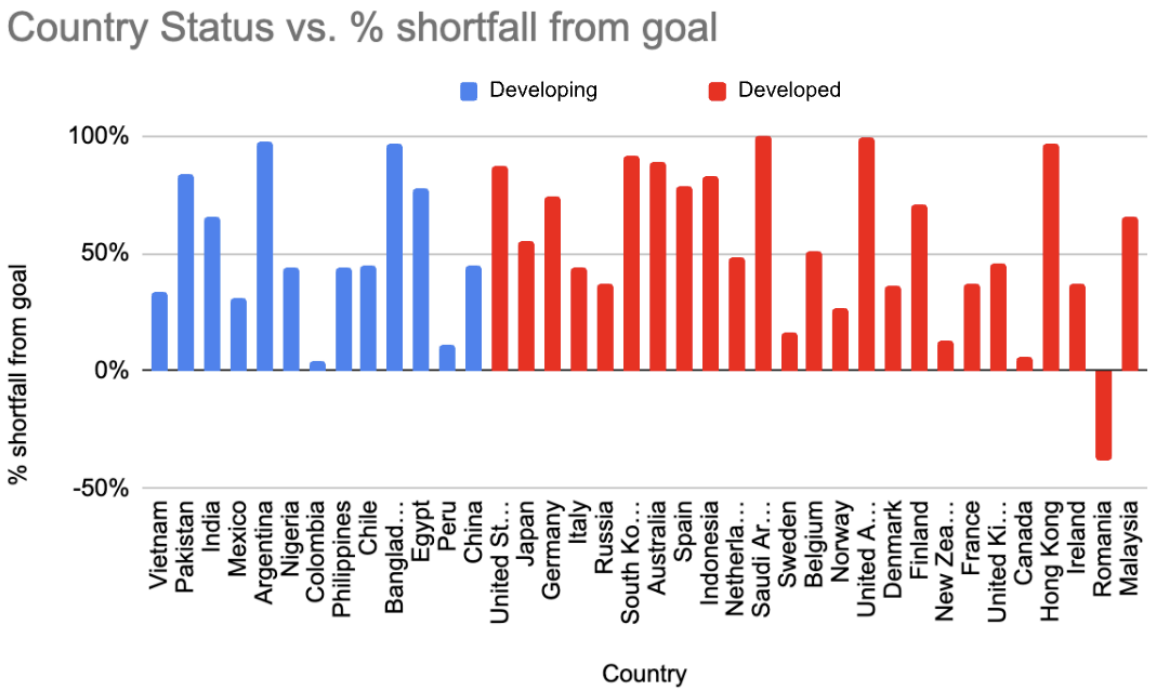
Observation 2: % shortfall Distribution



This visualization uses the % shortfall value which is the normalized gap between the prediction and target for each of the countries. Each country was sorted into 4 buckets.
a) Where the % shortfall is less than 75%
b) Where the % shortfall falls between 50% and 75%
c) Where the % shortfall falls between 25% and 50%
d) Where the % shortfall is less than 25%

The pie chart above depicts what share of countries fall into each bucket. From this chart we can conclude that most countries have a % shortfall that is between 25% and 50%.

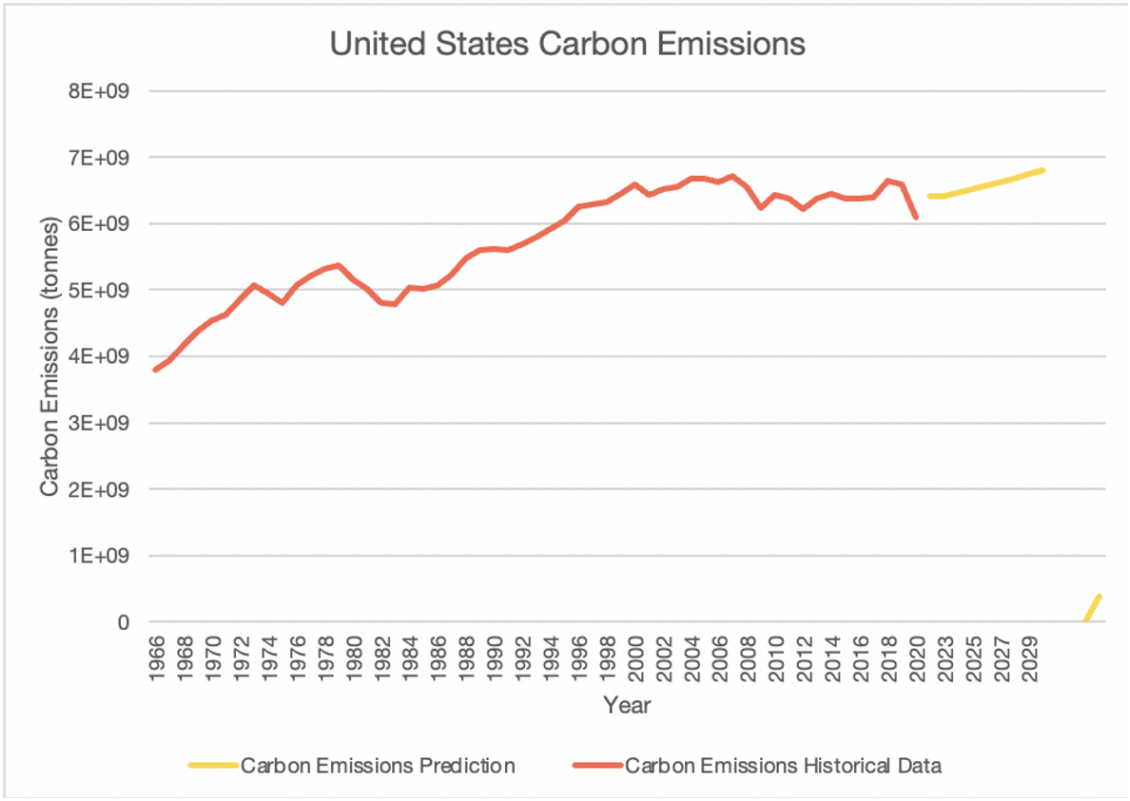
Observation 3: Developing Countries

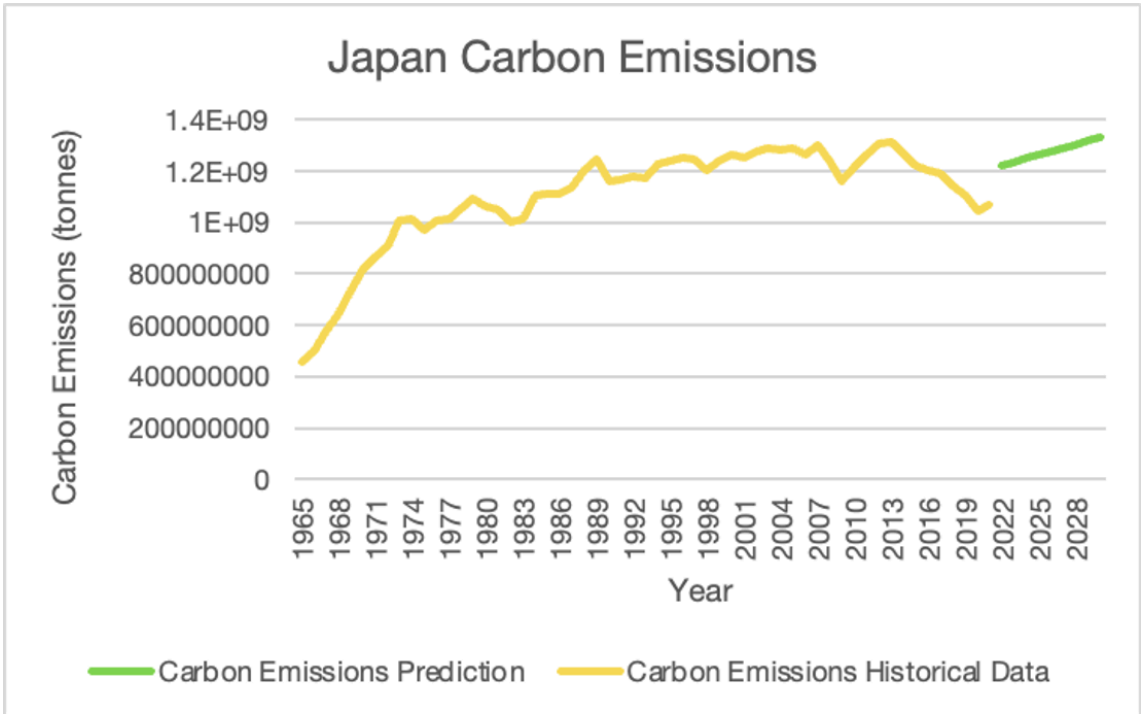


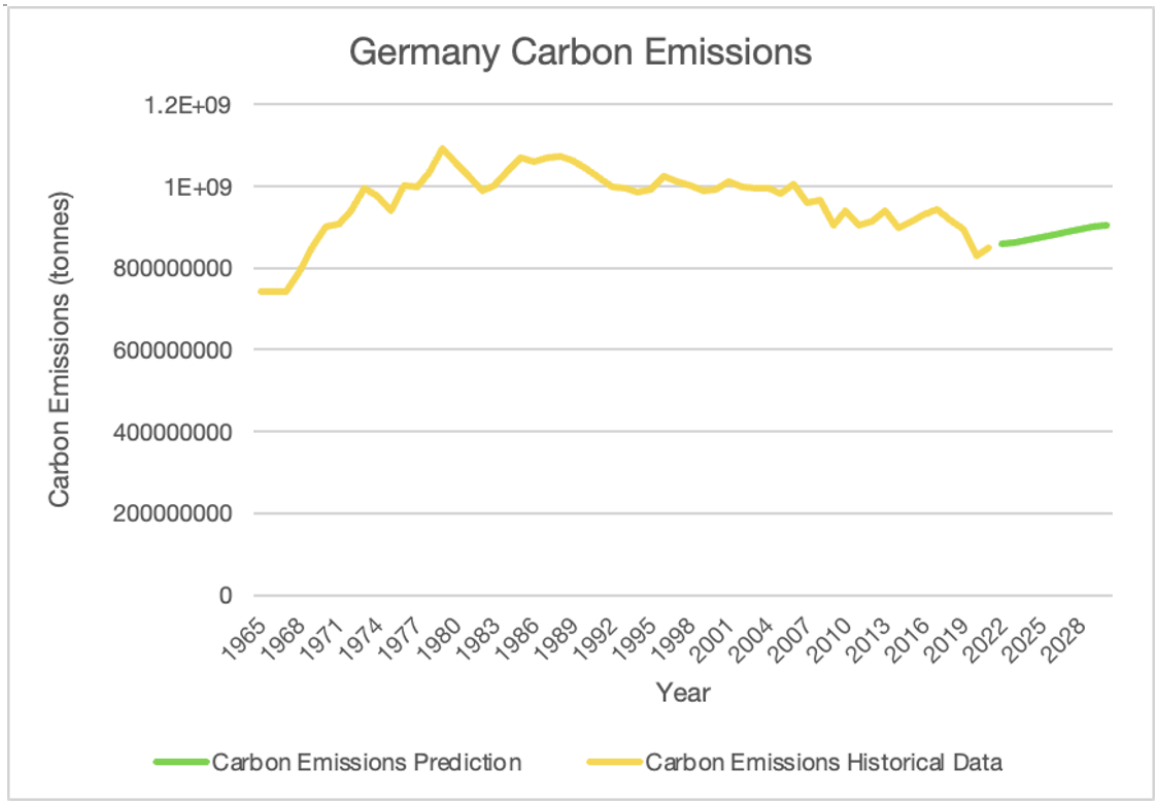
This visualization was used to identify a potential correlation between the economic status of the country (developing vs. developed) and their % shortfall from the goal. In the graph above, the bars in blue are developing countries and the bars in red are developed countries. Based on this chart, there is no apparent correlation between economic status and % shortfall.

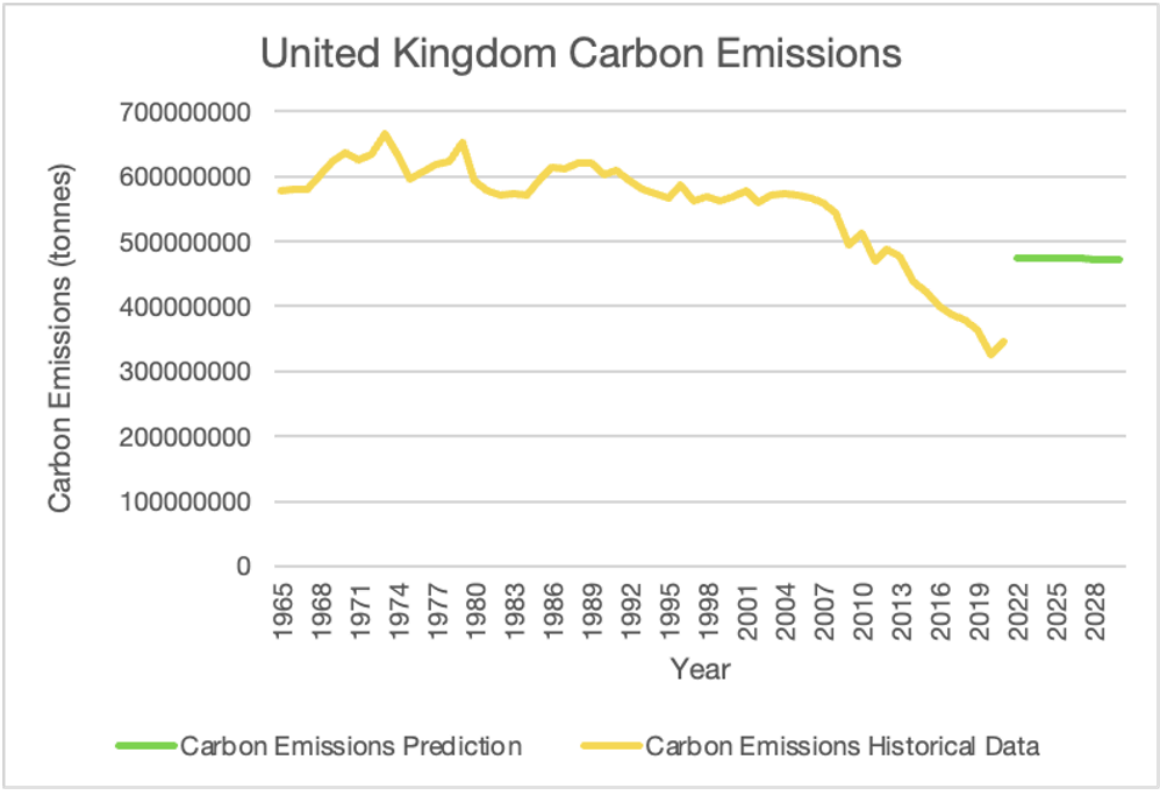
3.2 Carbon Emissions Observations

From our Carbon Emissions predictions, we graphed the emissions of the 5 countries with the Highest GDP (United States, China, Japan, Germany, India, and United Kingdom). In order to differentiate the historical emissions data and the predictions, they are graphed in different colors and marked with a key.


United States Carbon Emissions
Carbon Emissions (tonnes)
8E+09
7E+09
6E+09
5E+09
4E+09
3E+09
2E+09
1E+09
0
1966 1968 1970 1972 1974 1976 1978 1980 1982 1984 1986 1988 1990 1992 1994 1996 1998 2000 2002 2004 2006 2008 2010 2012 2014 2016 2018 2020 2023 2025 2027 2029
Year
Carbon Emissions Prediction
Carbon Emissions Historical Data


Japan Carbon Emissions
Carbon Emissions (tonnes)
1.4E+09
1.2E+09
1E+09
800000000
600000000
400000000
200000000
0
1965 1968 1971 1974 1977 1980 1983 1986 1989 1992 1995 1998 2001 2004 2007 2010 2013 2016 2019 2022 2025 2028
Year
Carbon Emissions Prediction
Carbon Emissions Historical Data


Germany Carbon Emissions
Carbon Emissions (tonnes)
1.2E+09
1E+09
800000000
600000000
400000000
200000000
0
1965
1968
1971
1974
1977
1980
1983
1986
1989
1992
1995
1998
2001
2004
2007
2010
2013
2016
2019
2022
2025
2028
Year
Carbon Emissions Prediction
Carbon Emissions Historical Data


United Kingdom Carbon Emissions
Carbon Emissions (tonnes)
700000000
600000000
500000000
400000000
300000000
200000000
100000000
0
1965
1968
1971
1974
1977
1980
1983
1986
1989
1992
1995
1998
2001
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2007
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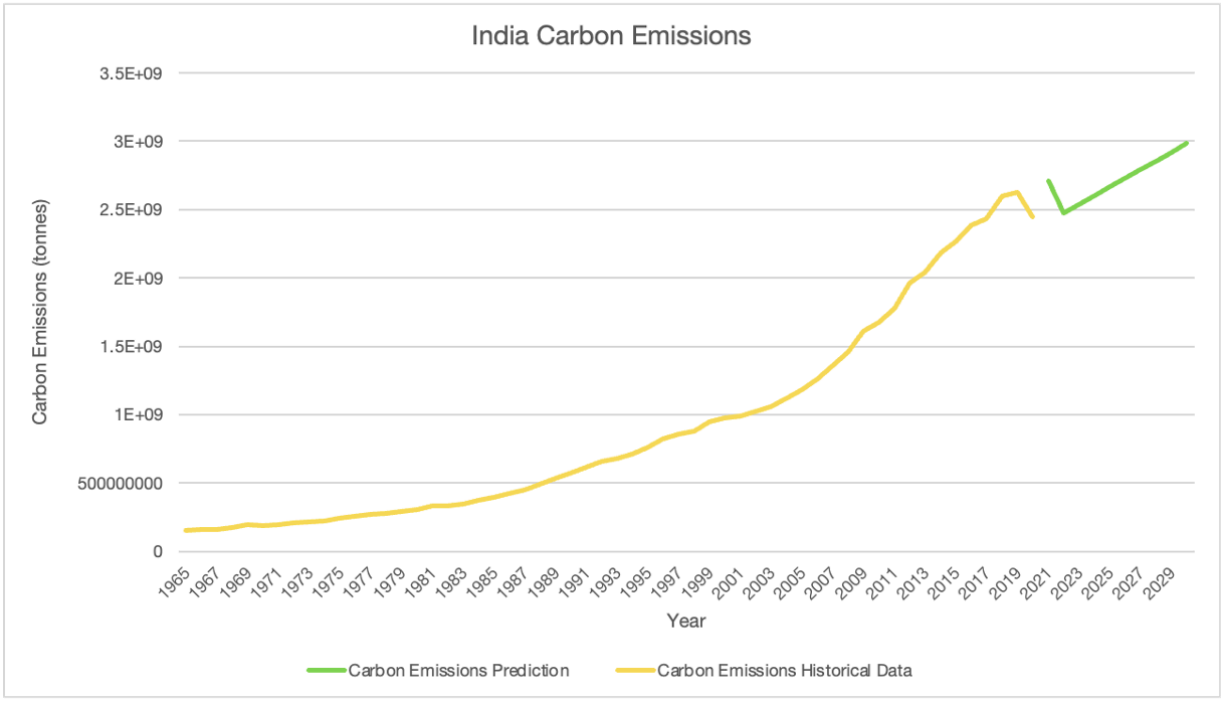
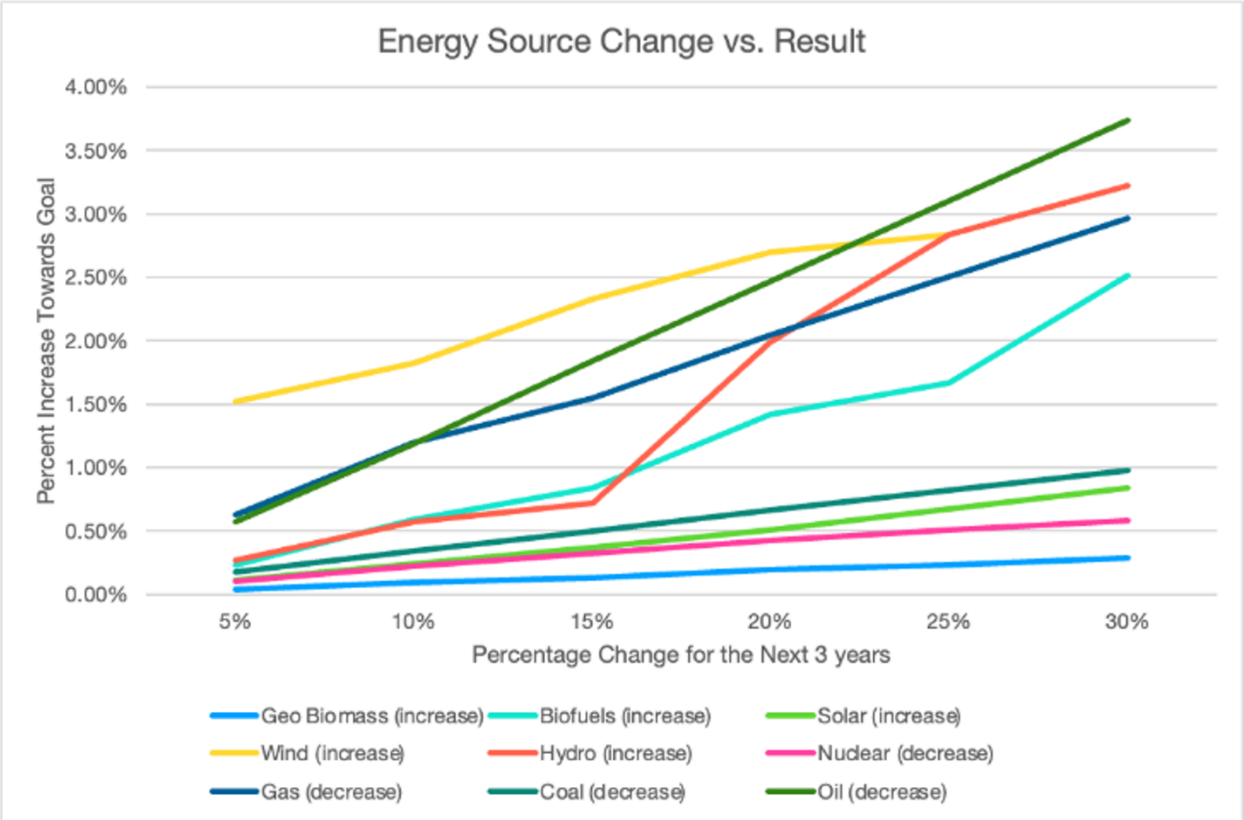
2022
2025
2028
Year
Carbon Emissions Prediction
Carbon Emissions Historical Data



3.3 Energy Mix Sensitivity Observations

The graph below depicts the relationship between the alteration made (in the years 2023, 2034, and 2025) and the net percent increase in the share of renewables in the energy mix. This relationship is shown for each individual energy source. For example, looking at the graph, we can conclude that if energy consumed from Hydropower is increased by 30% for the next three years, the share of renewables in 2030 will be increased by approximately 3.25%. We can see that increasing Hydro and Wind Energy Consumption as well as decreasing Energy Consumption from oil cause the greatest increase in the share of renewables.



4. Discussion

Joe Biden, the President of The United States declared climate change as “the number one issue facing humanity.” He publicly pledged to slash greenhouse gas emissions in half by 2030 and reach net zero by 2050. However, both the forecasted energy mix and carbon emissions of The United States indicate that this goal is not attainable.

Looking at the Energy Mix Analysis as well as the Carbon Emissions Analysis, two things are made clear.

1. Most countries are missing their renewable energy targets with 84.2% of countries having a % shortfall of over 25%. This indicates that while several global leaders have implied that they are on track to reaching their energy targets, most countries are heading in the opposite direction. We can further conclude that there is no correlation between a country’s economic status and the shortfall from its target. Therefore, this shortfall is not related to the money or resources that the country possesses. There are developing countries (such as Colombia and Peru) who relatively on track to meet their goals, developing countries who are falling short by a large amount (such as Saudi Arabia and United Arab Emirates), and vise versa.

2. 140 countries have set or are considering net zero targets. However, based on predictions using both historical data and energy mix data, the carbon emissions of many countries are predicted to experience an upward trend. Take China for example. China has set a net zero target for 2060. However, their carbon emissions have been increasing for the past 50 years and show no sign of decreasing. Many major countries such as The United States, Japan, and India are in a similar situation. What does this mean? If we continue the same path that we are on now, it is inevitable that we will experience a global temperature increase greater than 1.5 degrees Celsius.

5. Limitations

They are two main factors that limit the accuracy of the conclusions that we have drawn based on our analysis.

The first factor is the data source. Both the energy mix data and the carbon emissions data were found on the 'Our World in Energy' website. Since we these data sets were used as time series data, our conclusions are directly influenced by its accuracy.

The second factor is the sensitivity of the algorithms we used to forecast energy mix and carbon emissions data. The algorithms may not be capturing very recent trends in the data and be more influenced by earlier historic data.

6. Conclusion

Based on the data above, not only are countries failing to reach their sustainability targets, but additionally, we risk missing the global goal created during the Paris Agreement as well. Country's need to improve transparency regarding their country's sustainability journey and current position. Only with a realistic view of their country's status can their leaders set achievable energy goals. Further, countries need to be more strategic when taking action to reach their goals. For instance, investing in renewable energy may have the best potential to be scalable given their geographic location, available resources, etc. Finally, more time and money need to be invested in pushing forward the environmental agenda as our current pace is simply insufficient.

7. Acknowledgements

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