Transmission Constraints on Renewable Energy in Texas

Quantifying the Economic and Environmental Cost of Curtailed Renewable Energy

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2023-12-10

1 Abstract

The upward trajectory of clean energy deployment has been a prominent trend in recent years. With technological advancements and policy incentives, analyses have pointed to large expected increases in wind and solar generation capacities. This paper quantifies the economic and environmental impact of substituting lost wind and solar energy with fossil fuel alternatives, estimating the cost of operating fossil fuels and calculating the associated carbon emissions. Based on the results of the study, solar and wind curtailment in 2022 resulted in $13.7 million spent in operating fossil fuels to substitute lost renewable energy and is associated with 221,288 metric tons of carbon emissions. More robust study is needed to account for the intricacies of the existing transmission infrastructure in ERCOT and evaluate long-term economic implications. This paper serves as a foundational step in recognizing the implications of curtailment.

2 Introduction

With the accelerated deployment of clean energy in recent years, increased wind and solar generation capacity has caused strain on the grid. Although renewable energy operates at very low marginal costs and greatly reduces carbon emissions on the environment, energy produced by wind and solar is unable to make it to market if there is not enough transmission available. In 2022, the U.S. government passed the Inflation Reduction Act (IRA), a notable piece of legislation designed to address climate concerns. With tax credits, grants, loans, domestic manufacturing incentives, and Infrastructure Bill incentives, the IRA promotes the expansion of renewable energy and carbon management in the country, and models have consistently shown that IRA leads to large increases in wind and solar deployment (Bistline, et al. 2023).

However, continued expansion of generation capacity for renewables would be a challenge given present transmission issues, which is often reported by the popular press (Shenk, 2023). Transmission investments in the past have helped increased wind penetration. In Texas, high wind penetration numbers benefit from Competitive Renewable Energy Zone (CREZ) initiative that brought in $6.8 billion in investments in nearly 3,600-miles of new transmission lines with approximately 18,000 MW of capacity to accomodate wind resources in West Texas. Although wind generation makes up the majority of renewable energy generation in Texas, ERCOT forecasted that a range of 14.5 GW to 28.1 GW of solar generation capacity is to be added by 2031 (Tsai & Gulen, 2017). The completion of the CREZ lines not only increased the number of wind penetration hours but also helped mitigate negative pricing and helped nodal price convergence (Tsai & Gulen, 2017). In general, transmission investments has promoted wind and solar generation capacity expansion.

Given the current circumstances within ERCOT, transmission constraints continues to be a problem in regards to wind and solar curtailment. The purpose of this paper is to quantify the economic and environmental impact of substituting lost wind and solar energy with fossil fuel alternatives, estimating the cost of operating fossil fuels and calculating the associated carbon emissions. Although the findings of this paper represents only a fraction of the broader landscape, the insights gleaned from this analysis can offer valuable initial perspectives.

3 Literature Review

The current literature provides different approaches in understanding the relationship between transmission and renewable energy. Within this expansive realm of research, various perspectives and methodologies converge to shed light on the multifaceted dynamics at play. Collectively, the diverse array of research available not only underscores the complexity of the relationship between transmission infrastructure and renewable energy but also highlights the interdisciplinary nature at play.

In a 2022 study by Jacob LaRiviere and Xueying Lyu, the authors used the roll-out of a large transmission expansion in ERCOT to measure the market impacts of the transmission expansion on benefits of increased renewable capacity. They looked at the value of transmission expansion and estimated that the annual benefits of CREZ conditional on installed wind capacity was at a lower bound of roughly $370 million per year to $645 million per year (LaRiviere & Lyu, 2022). They also performed a back of the envelope calculation examining the benefits of mitigated fossil fuel generation from increased trade of wind energy. If 10% of wind generation was curtailed in their sample period, the non-market impacts of CO2 using a price per ton estimate are roughly $115 million per year (2022).

A 2020 study by Liuzixuan Lin and Andrew A. Chien showed that stranded power in ERCOT is a persistent issue. They found that as the grid evolves, it has returned to a point where 15% of wind power is curtailed or cleared at negative prices. The results of their study show that stranded power is increasing alongside the growth of wind generation and is related to factors such as transmission constraints, grid load, and wind generation (Lin & Chien, 2020).

In contrast to the comprehensive and intricate views presented in existing literature, this paper adopts a more streamlined approach. It endeavors to distill the complexity surrounding curtailed renewable energy into a more accessible framework, aiming to quantify the economic and environmental costs incurred when fossil fuels are employed as substitutes for lost wind and solar energy.

4 Data

In this paper, the data for ERCOT system-wide wind and solar output is extracted from Arcus Power's NRGStream, which is a service that amalgamates data from sources such as ERCOT. In order to calculate curtailed energy, I use ERCOT wind and solar generation curtailment percentages reported by the Energy Information Administration (EIA). In 2022, ERCOT curtailed 5% of total wind generation and 9% of total solar generation. By 2035, the EIA projects that ERCOT will curtail 13% of wind generation and 19% of solar generation (U.S. EIA, 2023). The 2022 curtailment percentages represent the lower-bound estimates in calculations, while the 2035 projections represent the upper-bound estimates in calculations.

To calculate the cost of operating fossil fuels, I use the Average Power Plant Operating Expense values that were provided by EIA. The values accounted for expenses for major U.S. Investor-Owned Electric utilities from 2012 to 2022. In this paper, we use the total cost of operating, maintaining, and fueling fossil steam. To calculate the carbon emissions associated with operating fossil fuels, I use to the national marginal emission factor that is provided by the United States Environmental Protection Agency (U.S. EPA). The emission factor is based on the 2019 U.S. national weighted average CO2 marginal emission rate.

Table 1: Solar and Wind Production (MW)

year	wind_total	solar_total	combined_total
2017	2,594,728	87,961.96	2,682,690
2018	2,910,708	124,661.09	3,035,369
2019	3,197,172	166,990.75	3,364,162
2020	3,629,837	345,723.30	3,975,560
2021	3,977,897	635,095.84	4,612,993
2022	4,474,928	983,321.48	5,458,250
2023	4,075,484	1,224,860.46	5,300,344

From Table 1, we see that there is a steady increase in combined solar and wind production from 2017 to 2022. It is important to note that 2023 values in the table only include production values until November 26, 2023. Because the year is not yet over, the combined wind and solar production value for 2023 is lower in comparison to 2022.

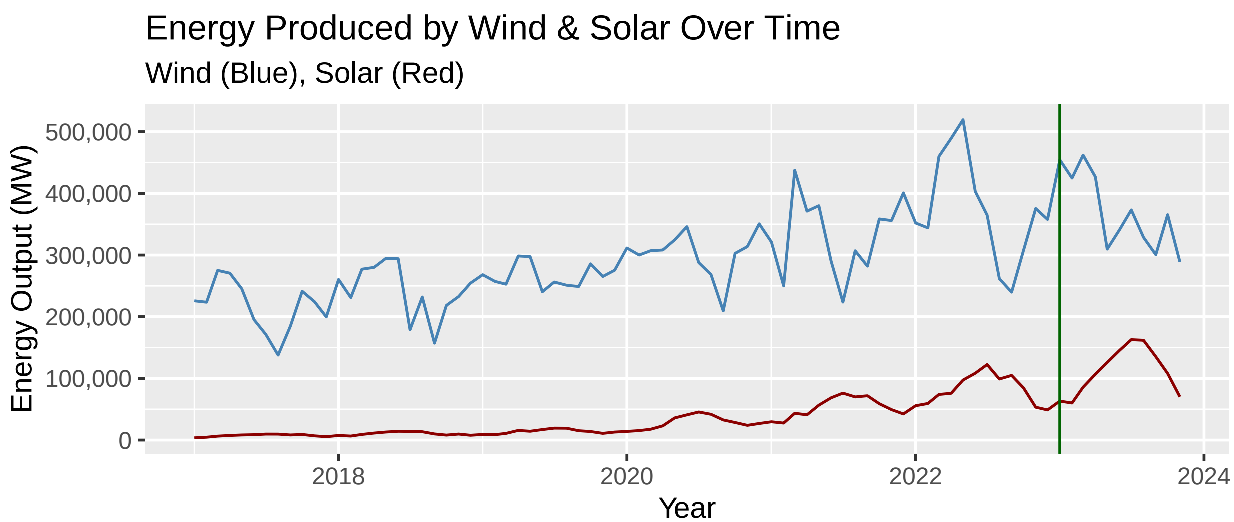

Figure 1.

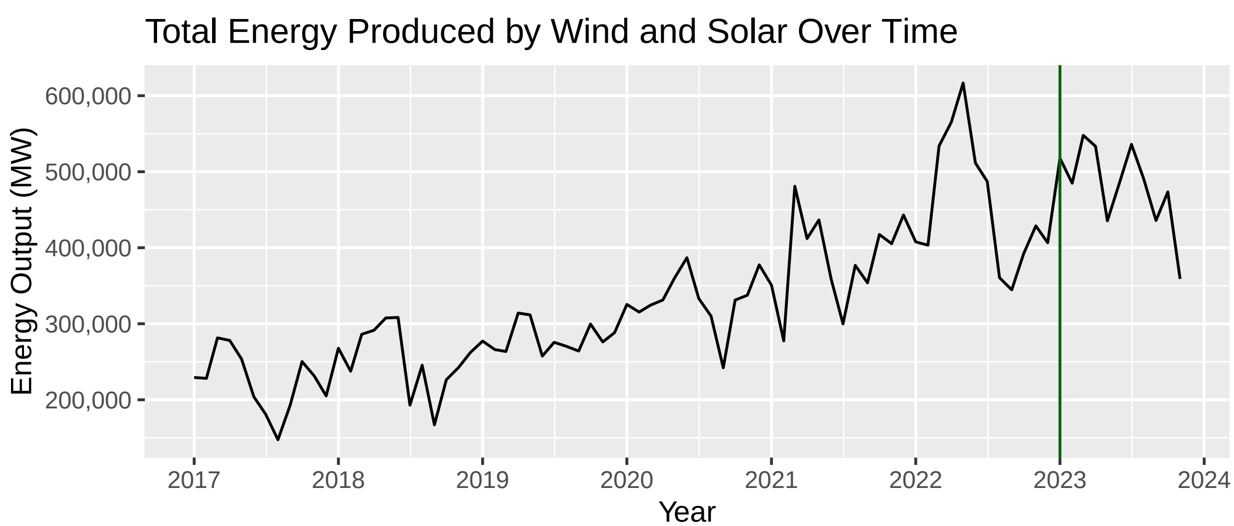

Figure 2.

Figure 1 plots energy production for wind and solar. From this figure, we see that wind produces significantly more energy than solar, although we see a higher spike in solar energy production in 2023. However, wind production appears to be facing a decrease in production in the recent months in 2023. This drop in wind energy production can be attributed to the effect of El Niño, which is known to significantly decrease wind speed and power generation (Watts et al., 2017). Figure 2 represents the combined total energy production by wind and solar, which shows a general upwards trend.

5 Methods

In this paper, I attempt to estimate the cost implicated with substituting wasted renewable energy for traditional fossil fuels. To calculate curtailed energy, multiply the production output of wind and solar with their respective curtailment percentages. 2022 curtailment percentages represents the lower bound in this paper's calculations, while 2035 percentages represent the upper bound calculations. In order to find the cost of operating fossil fuels in lieu of wind or solar, we would multiply total energy curtailed by the average cost to operate fossil fuel power plants.

$$lower_{bound} = output_{wind} * 0.05 + output_{solar} * 0.13$$

$$upper_{bound} = output_{wind} * 0.09 + output_{solar} * 0.19$$

To calculate the carbon emissions associated with operating fossil fuels, I use to the national marginal emission factor that is provided by the U.S. EPA. The emission factor is represented by the following. Carbon emission is found by multiplying total curtailed energy with the emissions factor.

$$emissionfactor = \frac{1562lbsCO_2}{MWh} * \frac{1ton}{2204.6lbs} = 0.7087$$

6 Results

Calculating the lower and upper bounds for curtailed energy, we get an estimation of curtailed wind and solar energy using the EIA's 2022 curtailment estimation for the lower bound and the EIA's projected 2035 curtailment for the upper bound. It is important to note that the most accurate values from these estimations are 2022 lower bound estimations. This is because we have the most accurate curtailment percentages for this particular year.

Table 2: Curtailment for Solar and Wind (MW)

Year	Solar Curtailment (Lower Bound)	Solar Curtailment (Upper Bound)	Wind Curtailment (Lower Bound)	Wind Curtailment (Upper Bound)	Combined Curtailment (Lower Bound)	Combined Curtailment (Upper Bound)
2017	7,916.576	16,712.77	129,736.4	337,314.6	137,653.0	354,027.4
2018	11,219.498	23,685.61	145,535.4	378,392.0	156,754.9	402,077.6
2019	15,029.167	31,728.24	159,858.6	415,632.3	174,887.8	447,360.6
2020	31,115.097	65,687.43	181,491.8	471,878.8	212,606.9	537,566.2
2021	57,158.626	120,668.21	198,894.9	517,126.6	256,053.5	637,794.8
2022	88,498.933	186,831.08	223,746.4	581,740.7	312,245.3	768,571.8
2023	110,237.441	232,723.49	203,774.2	529,812.9	314,011.6	762,536.4

Table 3: Cost of Operating Fossil Fuels (USD)

Year	Curtailed Solar Cost (Lower Bound)	Curtailed Solar Cost (Upper Bound)	Curtailed Wind Cost (Lower Bound)	Curtailed Wind Cost (Upper Bound)	Combined Cost (Lower Bound)	Combined Cost (Upper Bound
2017	$280,326	$591,799	$4,593,966	$11,944,311	$4,874,292	$12,536,110
2018	$402,331	$849,366	$5,218,899	$13,569,137	$5,621,230	$14,418,503
2019	$550,969	$1,163,157	$5,860,416	$15,237,081	$6,411,385	$16,400,238
2020	$1,084,672	$2,289,864	$6,326,805	$16,449,694	$7,411,478	$18,739,557
2021	$2,038,277	$4,303,028	$7,092,590	$18,440,735	$9,130,867	$22,743,763
2022	$3,883,333	$8,198,148	$9,817,993	$25,526,781	$13,701,326	$33,724,929
2023	$4,837,219	$10,211,907	$8,941,611	$23,248,188	$13,778,830	$33,460,095

Calculating the cost of operating fossil fuels due to renewable energy curtailment is about $13.7 million in 2022 for combined wind and solar curtailment. For solar curtailment alone, $3.9 million would go to operating fossil fuels and $8.9 million would be spent because of wind curtailment. If curtailment percentages remains the same from 2022 to 2023, solar curtailment has already resulted in an accumulated $4.8 million cost, which is higher than costs in 2022 even though the year has not yet concluded. The spike in the cost for solar curtailment results in a higher combined solar and wind cost for 2023 compared to cost in 2022. Because the year has not concluded, we can assume that combined cost for the full year would exceed the current cost estimation.

Table 4: CO_2 Emissions from Operating Fossil Fuels (metric ton)

Year	Emissions from Solar (Lower Bound)	Emissions from Solar (Upper Bound)	Emissions from Wind (Lower Bound)	Emissions from Wind (Upper Bound)	Emissions from Solar and Wind (Lower Bound)	Emissions from Solar and Wind (Upper Bound)
2017	5,610	11,844	91,944	239,055	97,555	250,899
2018	7,951	16,786	103,141	268,166	111,092	284,952
2019	10,651	22,486	113,292	294,559	123,943	317,044
2020	22,051	46,553	128,623	334,420	150,675	380,973
2021	40,508	85,518	140,957	366,488	181,465	452,005
2022	62,719	132,407	158,569	412,280	221,288	544,687
2023	78,125	164,931	144,415	375,478	222,540	540,410

Table 4 illustrates the calculated estimations of carbon dioxide emissions stemming from the utilization of fossil fuels required to compensate for curtailed solar and wind energy. In 2022, the curtailed solar energy led to the release of 62,719 metric tons of CO_2 emissions from fossil fuels, while curtailed wind energy contributed to emissions amounting to 158,569 metric tons. As 2023 progresses, the estimation for emissions resulting from solar curtailment surpasses the previous year's estimations. Similar to the results for operating costs, emissions from solar curtailment in 2023 so far has already resulted in higher carbon emissions compared to the estimation in 2022. Although 2023 has not yet closed, solar curtailment emissions in addition to combined curtailment emissions are higher than the estimation in 2022. This escalation could signal a troubling trajectory, indicating potentially higher overall emissions compared to the preceding year.

7 Limitations

The process of this project is not without its limitations. The time horizon for this study was limited to due to the lack of data availability on NRGStream. It would be insightful to be able to map the changes in wind and solar energy production before, during, and after the CREZ project. Another issue of the study is that accurate curtailment percentages was not available for each year. Given more time and closer study of the methods available in the literature, I would be able to more accurately measure curtailed energy by year. However, given the time constraints, achieving this level of granularity was not realizable.

Future studies on wind and solar energy curtailment could also attempt to predict future curtailment. A more detailed project would examine wind and solar curtailment in the different regions of Texas where wind and solar farms are clustered and transmission is especially constrained. Examining data based on location would provide a more accurate representation of the cost of transmission constraints on wind and solar. These potential avenues for future studies would not only address the issues this project has encountered but also provide more comprehensive and insightful analyses in the realm of renewable energy curtailment.

8 Conclusion

The upward trajectory of clean energy deployment has been a prominent trend in recent years, signaling a significant shift towards sustainability in the energy sector. Wind and solar plants, in particular, have emerged as frontrunners in this movement due to their operational advantages. These renewable sources operate at remarkably low marginal costs, positioning them as economically favorable options for energy production. Their capacity to generate substantial power without incurring high ongoing expenses has contributed significantly to their growing prominence in the energy landscape, especially in Texas where solar and wind resources are particularly high.

The Inflation Reduction Act (IRA), a pivotal legislation enacted by the U.S. government in 2022, stands as a testament to the nation's commitment toward mitigating climate change. While the IRA lays down the groundwork for incentivizing and fostering the growth of renewable energy, the ambitious goal of scaling up renewable energy production is impeded by limitations in the existing transmission infrastructure, especially within ERCOT. This paper attempts to estimate the cost of substituting curtailed wind and solar energy given current constraints.

The analysis conducted in this paper reveals substantial economic and environmental impacts. Solar and wind curtailment in 2022 resulted in $13.7 million spent in operating fossil fuels to substitute lost renewable energy and is associated with 221,288 metric tons of carbon emissions. The EIA projected that ERCOT would curtail 13% of wind generation and 19% of solar generation by 2035. Imposing these curtailment percentages on 2022 wind and solar generation values, the cost of operating fossil fuels in lieu of lost renewable energy would be $33.7 million with an associated 544,687 metric tons of carbon emissions by 2035. If we assume that wind and solar generation capacity will increase steadily over time due to technological and governmental incentives, then these estimations are conservative estimates of the economic and environmental costs of curtailed renewable energy.

The limitations inherent in this study underscore the complexity of evaluating the viability and cost-effectiveness of transmission investments to facilitate the sustained growth of wind and solar generation capacity in Texas. While the insights gleaned from this analysis offer valuable initial perspectives, they represent a fraction of the broader landscape that demands more comprehensive scrutiny. More robust study is needed to account for the intricacies of the existing transmission infrastructure in ERCOT and evaluate long-term economic implications. Ultimately, while this study serves as a foundational step in recognizing the implications of curtailment, it highlights the necessity for a more expansive and detailed analysis that encompasses the diverse dimensions inherent in enhancing transmission infrastructure to facilitate the continued growth of wind and solar energy in Texas.

9 References

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