THE IMPACT OF RENEWABLES IN ERCOT DURING THE SUMMER OF 2023

JOSHUA D. RHODES, PHD,
IDEASMITHS LLC

GridLAB

IdeaSmiths LLC

TABLE OF CONTENTS

INTRODUCTION

The deployment of renewable energy in Texas, particularly wind and solar, has grown significantly over the past decade. Texas has almost as much wind capacity as the next four states combined[1] and ERCOT recently surpassed CAISO to take the top spot for utility-scale solar.[2, 3] While the deployment of energy storage is currently small relative to other technologies, the capacity of these projects in the ERCOT interconnection queue exceeds ERCOT's 2023 peak demand by over 25 GW.[4] Previous analyses have shown that renewables have saved tens of billions of dollars in wholesale electricity costs over the past decade, potentially over $100B when water savings and emissions reductions are considered.[5] Further work has also shown that renewables, over their lifetimes, will pay tens of billions of dollars in local taxes and landowner payments through their lease terms, with the majority of those payments going to rural parts of the state that don't see much other economic development.[6] In general, the deployment of renewables has provided many positive benefits to Texans.

At a high level, this analysis compared how the ERCOT grid operated during the summer of 2023 with the current level of renewables against how we estimate that it would have operated if no renewables had ever been deployed on the system. The model formulation, as well as our assumptions of how the ERCOT grid would have evolved differently without renewables are further defined in the appendix at the end of this report.

Over the summer of 2023, wind and solar generated between 10.5 and 12.9 TWh each month, for a total of about 47 TWh of energy, or about 25% of all the electricity consumed in ERCOT over the same period of time. Figure 1 shows this breakdown of energy use and generation for each month of the summer.

1 https://windexchange.energy.gov/maps-data/321
2 http://www.caiso.com/informed/Pages/CleanGrid/default.aspx
3 https://www.ercot.com/mp/data-products/data-product-details?id=NP4-760-ER
4 About 114 GW of energy storage projects in the ERCOT interconnection queue vs. about 86 GW for ERCOT's all time high peak demand.
5 https://www.ideasmiths.net/wp-content/uploads/2023/05/Impact-of-Renewables-in-ERCOT_FINAL.pdf
6 https://www.ideasmiths.net/wp-content/uploads/2023/01/Economic-Impact-of-Renewable-Energy_JAN2023.pdf

ENERGY GENERATED BY RENEWABLES AND OTHER SOURCES IN ERCOT DURING THE SUMMER OF 2023

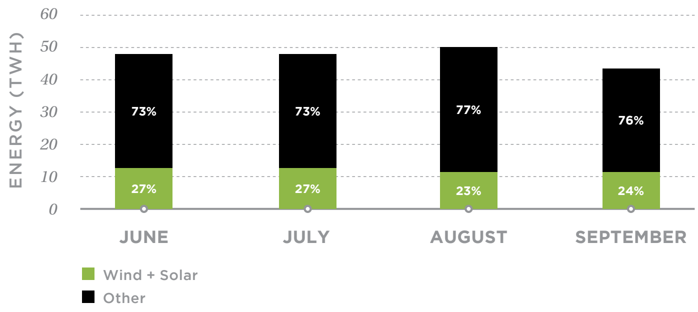

FIGURE 1.

Figure showing the amount and percentage of electricity generated by wind and solar during the summer of 2023, by month in ERCOT.

While Figure 1 shows that the month of August had the lowest percentage of electricity generated by wind and solar, it saw the second highest total energy generation (11.8 TWh), second only to July (12.9 TWh). However, even though the percentage of energy generation from wind and solar was lower during the month of August, we found that its value was significant. Further, we also found that renewables provide more benefits than just electricity cost savings alone.

The purpose of this analysis is to estimate the continued impacts of wind and solar generation on wholesale electricity market costs, water use, and emissions in ERCOT during the summer of 2023.[7] Because wind and solar power plants require no fuel and have low marginal costs, they reduce wholesale clearing prices in ERCOT, which can be economically beneficial for consumers. For the summer of 2023 (June through September), we estimate that renewables reduced wholesale energy expenditures by about $900 million, saving consumers significantly from what they might otherwise have had to pay. Figure 2 details the estimated monthly wholesale market savings from this analysis.

MONTHLY SUMMER 2023 WHOLESALE MARKET SAVINGS FROM RENEWABLES IN ERCOT ($M)

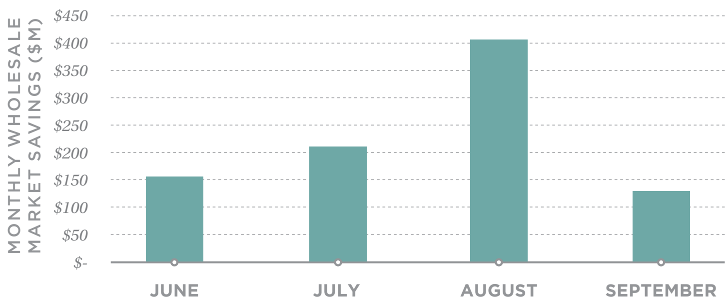

FIGURE 2.

Chart of monthly wholesale market savings due to renewables in ERCOT during the summer months of 2023.

7 For this analysis we define summer to be June 2023 through September 2023.

About 45% of the wholesale electricity cost savings came from the month of August, which is not surprising given the level of high prices experienced during that month.

While the impacts to wholesale electricity costs in ERCOT are significant, we also assess the impact of renewables on water use and emissions. Because renewable generation does not consume cooling water or produce emissions at the point of generation, offsets of other types of generation will generally serve to reduce the water and emissions intensity of the grid, providing additional economic, environmental, and public health benefits.

Texas power plants use trillions of gallons of water per year.[8] These withdrawals can increase water stress since a significant portion of Texas is often in some stage of drought[9] and many sources of water are fully allocated. Thermal power plants often share watersheds with growing population centers, so increasing the use of power plants that don't require water, such as wind and solar, can reduce water competition and system strain.

Reducing air pollution also yields significant health benefits for Texans. In some densely populated counties where pollution is very damaging to human health and productivity, avoided nitrogen oxides (NO_x) emissions are worth $12,000 per ton and avoided sulfur oxide (SO_x) emissions are worth up to $107,000 per ton due to fewer Texans having to seek medical attention for environmentally related respiratory problems.[10] In this analysis, we also considered the social cost of carbon dioxide (CO_2) emissions at $20/ton, to represent negative impacts of climate change, including more intense storms that can damage infrastructure and decrease economic productivity.

8 https://labs.waterdata.usgs.gov/visualizations/water-use-15/index.html#view=USA&category=thermoelectric

9 https://droughtmonitor.unl.edu/CurrentMap/StateDroughtMonitor.aspx?TX

10 Muller, Nicholas Z. Mendelsohn, Robert Nordhaus, William, "Environmental Accounting for Pollution in the United States Economy," American Economic Review 101 5 1649-75 2011 10.1257/aer.101.5.1649

RESULTS AND DISCUSSION

In this analysis, we estimate that the total amount of benefits from the presence of renewables on the ERCOT grid during the summer of 2023 to be about $1.9 billion dollars. This sum total of benefits includes wholesale electricity price reductions, reduced water use, and reduced emissions of thermal power plants. Figure 3 shows these benefits, by month, including our assumed monetary values for each portion beyond electricity costs.

TOTAL SUMMER 2023 BENEFITS FROM RENEWABLES IN ERCOT

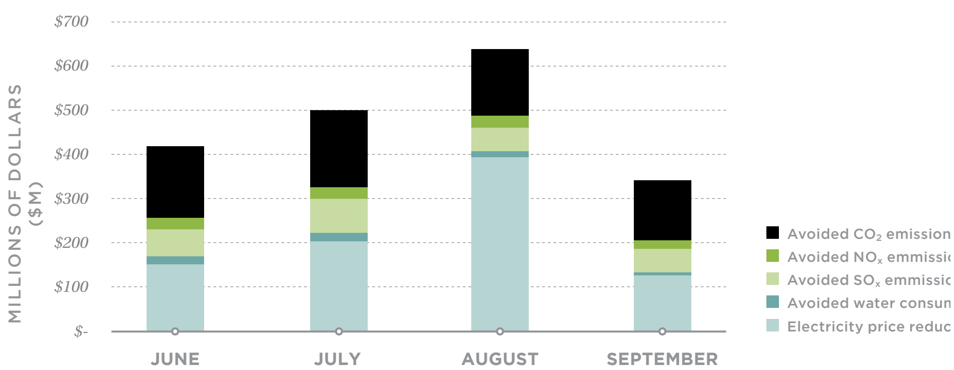

FIGURE 3.

Monthly benefits from renewables in ERCOT for the summer of 2023 vary from ~$340 million to ~$640 million and cumulatively sum to about $1.9 billion. Median levels of damages/values (across all Texas counties) were used to monetize the emissions and water use reductions (SO_x: $16,600/ton, NO_x: $4,750/ton, CO_2: $20/ton, water: $3/thousand gallons).

We estimate that renewables provided between $344 and $643 million dollars worth of benefits per month for a combined total of $1.9 billion dollars during the summer of 2023. The largest benefit category was wholesale electricity price reductions, followed by CO_2 emissions reductions, avoided SO_2, avoided NO_x, and avoided water consumption. Benefits generally increased each month through August as the summer got hotter, but then began to fall as temperatures declined and less energy was consumed across the system.

Figure 4 through Figure 8 show our modeled reduction in water withdrawals and water consumption, as well as reductions in CO_2, NO_x, and SO_2 due to renewables over the summer of 2023.

Thermal power plants' water usage is measured in two ways: withdrawal and consumption. Water withdrawals refer to the amount of water that power plants intake for all uses. Most of the water that power plants withdraw is used for cooling and is then returned to its source, such as a river or reservoir, albeit at a higher temperature. Returning water at higher temperatures can be problematic during heatwaves and drought, as some power plants have been forced to derate their output to not endanger aquatic ecosystems. Figure 4 shows our estimate of the amount of water that was not withdrawn during the summer of 2023 in ERCOT due to the presence of renewables.

MONTHLY SUMMER 2023 WATER WITHDRAWL SAVINGS FROM RENEWABLES IN ERCOT (BILLION GALLONS)

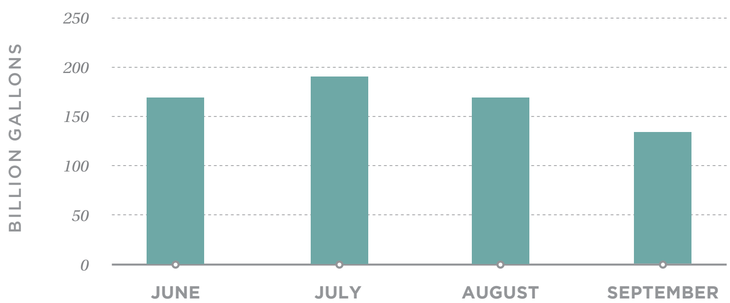

FIGURE 4.

Chart of monthly water withdrawal savings due to renewables in ERCOT during the summer months of 2023.

In this analysis, we estimate that renewables reduced water withdrawals between 138 and 191 billion gallons per month, for a total summer 2023 savings of about 665 billion gallons — about the annual water use of about 7.3 million Texans. Some portion of the water that is withdrawn by power plants is consumed, mostly through evaporation in cooling towers, and not returned to the local water system. Figure 5 shows our estimated level of water consumption savings from renewables in ERCOT in the summer of 2023.

MONTHLY SUMMER 2023 WATER CONSUMPTION SAVINGS FROM RENEWABLES IN ERCOT (BILLION GALLONS)

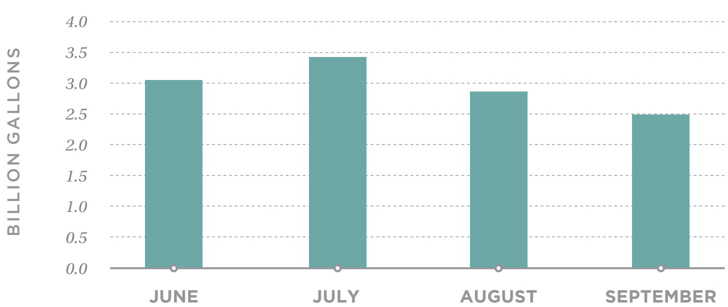

FIGURE 5.

Chart of monthly water consumption savings due to renewables in ERCOT during the summer months of 2023.

Consumed water is water that is lost to the local system and is not available for other uses "downstream". We estimate that renewables saved between 2.5 to 3.4 billion gallons of water consumption per month, for a total of 11.9 billion gallons over the summer of 2023. Assuming a value of $3/thousand gallons, 11.9 billion gallons of extra water is worth about $37.5 million dollars.

This analysis also considered the emissions reduction impacts of renewables on the ERCOT system. Figure 6 shows our estimated monthly CO_2 savings over the summer of 2023 in ERCOT.

MONTHLY SUMMER 2023 CO_2 SAVINGS FROM RENEWABLES IN ERCOT (MILLION TONS)

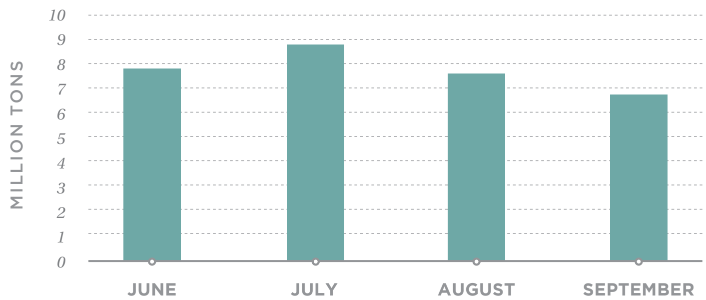

FIGURE 6.

Chart of monthly CO_2 savings due to renewables in ERCOT during the summer months of 2023.

We estimate that renewables saved between 6.9 and 8.8 million tons of CO_2 emissions per month, for a total savings of about 31.3 million tons for the summer of 2023 — about 5% of the total annual CO_2 emissions of the entire state of Texas.[11] Assuming a value of $20/ton, 31.3 million tons of avoided CO_2 emissions is worth about $626 million dollars.

While the impacts of CO_2 emissions are felt globally, other types of emissions have more local impacts. Pollutants such as sulfur dioxides (SO_2) and nitrous oxides (NO_x) degrade air quality and contribute to increased levels of mortality and morbidity. These pollutants can also exacerbate conditions such as asthma and reduce the economic productivity and longevity of the workforce.[12] Figure 7 shows our estimated reductions in SO_2 emissions due to renewables in ERCOT over the summer of 2023.

MONTHLY SUMMER 2023 SO_2 SAVINGS FROM RENEWABLES IN ERCOT (THOUSAND TONS)

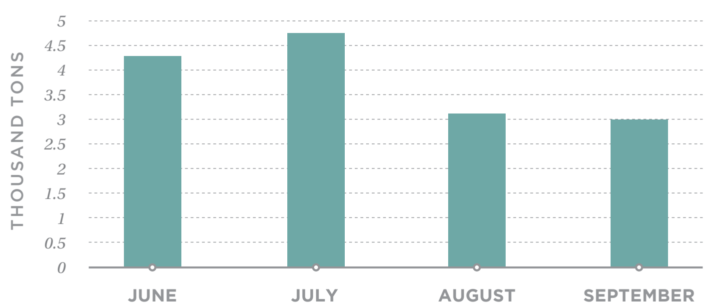

FIGURE 7.

Chart of monthly SO_2 savings due to renewables in ERCOT during the summer months of 2023.

11 https://www.eia.gov/environment/emissions/state/
12 https://www.jstor.org/stable/23045618

We estimate that renewables reduced SO_2 emissions by between 3 and 4.8 thousand tons per month, for a total reduction of about 15.1 thousand tons over the summer of 2023. Figure 8 shows our estimated reductions in NO_x emissions due to renewables in ERCOT over the same time period. Assuming damages of about $16,000/ton, 15.1 thousand tons of avoided SO_2 emissions is worth about $251 million dollars.

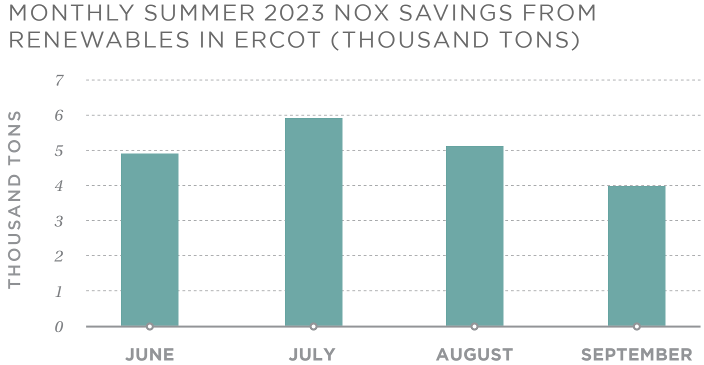

FIGURE 8.

Chart of monthly NO_x savings due to renewables in ERCOT during the summer months of 2023.

We estimate that renewables reduced NO_x emissions by between 4 and 5.9 thousand tons per month, for a total reduction of about 19.8 thousand tons over the summer of 2023. Assuming damages of $4,750/ton, 19.8 thousand tons of avoided NO_x emissions is worth about $94.3 million dollars.

ACKNOWLEDGEMENTS

This work was funded by GridLab.[13]

ABOUT US

IdeaSmiths LLC[14] was founded in 2013 to provide clients with access to professional analysis and development of energy systems and technologies. Our team focuses on energy system modeling and assessment of emerging innovations, and has provided support to investors, legal firms, and Fortune 500 companies trying to better understand opportunities in the energy marketplace.

13 https://gridlab.org/
14 https://www.ideasmiths.net/

APPENDIX

METHODOLOGY AND DATA

THE MODEL

This analysis utilized a marginal cost bid stack-based model of ERCOT to estimate which power plants would meet demand in every hour during the summer of 2023. Figure 8 though Figure 11 show model results for multiple scenarios of load, natural gas price, and installed capacity of renewables. In each case, the vertical black line indicates the demand and the power plants to the left of that line are dispatched to meet that demand while the power plants to the right are not dispatched. Which power plants are dispatched to meet demand determines how much water is consumed and how much pollution is emitted. The market clearing price is determined by the intersection of demand with the bid stack.

Model Structure

The model was executed via the following steps:

- For each hour of the summer (2,928 hours total), ERCOT demand[15] as well as hourly-matching wind and solar output were used to create two scenarios: 1) total demand and 2) net demand (net demand level = demand less wind and solar output).
- Thermal generator fuel prices and variable operations and maintenance costs were used to calculate the marginal cost of all thermal and hydroelectric power plants available to meet demand in each hour.
- All thermal and hydroelectric generators were ordered from lowest cost to highest cost and their available capacities were summed up starting with the lowest cost generator until enough capacity was added to meet each scenario – these power plants were dispatched during that hour.
- For each hour (for both scenarios), the emissions and water consumption of the dispatched power plants were summed, and then all hours of each month were summed up for the summer.
- The difference in the emissions and water consumption totals between the two scenarios was output as the value of having renewables in the system.

15 Total amount of electricity being consumed by all customers in ERCOT for that hour.

Model execution

For every hour during the summer of 2023, the model used demand, wind and solar generation, and fuel prices to 1) calculate the marginal cost of each power plant, 2) sort the power plants from lowest cost to highest cost, and 3) dispatch the lowest cost plants to meet the demand.[16]

There are three major drivers that affect how prices are formed and which power plants are dispatched: 1) demand, 2) natural gas and coal fuel prices, and 3) output from renewables.

Effect of changing demand on bid stack and market price

ERCOT demand changes throughout the day and different power plants are used to meet that demand; Figure 9 and Figure 10 show this difference. In Figure 9, early morning ERCOT demand is 40 GW and the resulting electricity price is about $31/MWh. In Figure 10, afternoon demand has increased to 63 GW and more power plants have been dispatched to meet that demand. Because these extra power plants have higher marginal costs, the wholesale market cost has increased to the marginal generator, almost $50/MWh.

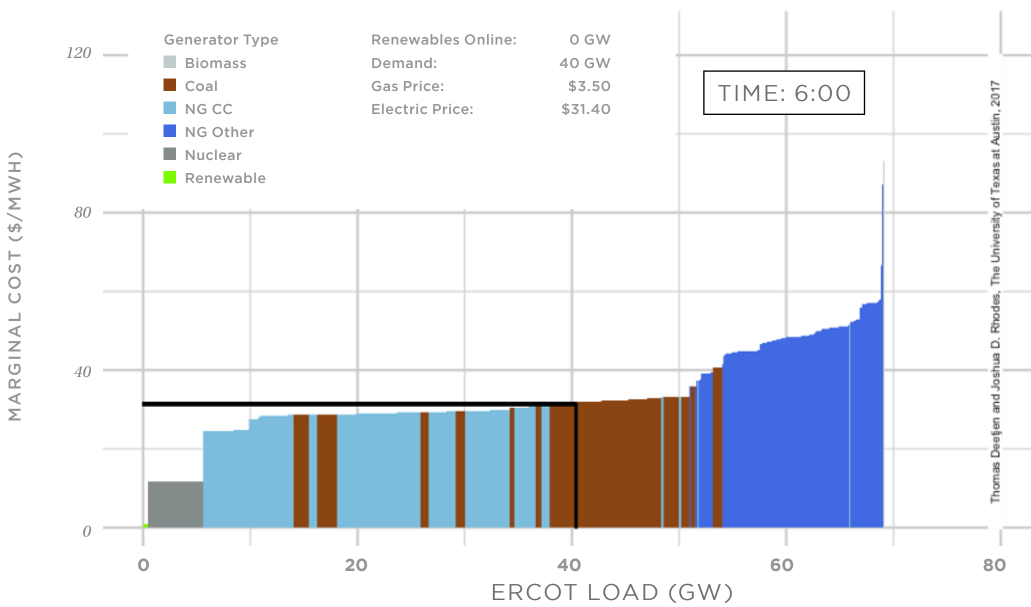

FIGURE 9.

ERCOT bid stack and clearing price of $31.40/MWh at a load of 40 GW and natural gas price of $3.50/MMBTU.

16 https://theconversation.com/are-solar-and-wind-really-killing-coal-nuclear-and-grid-reliability-76741

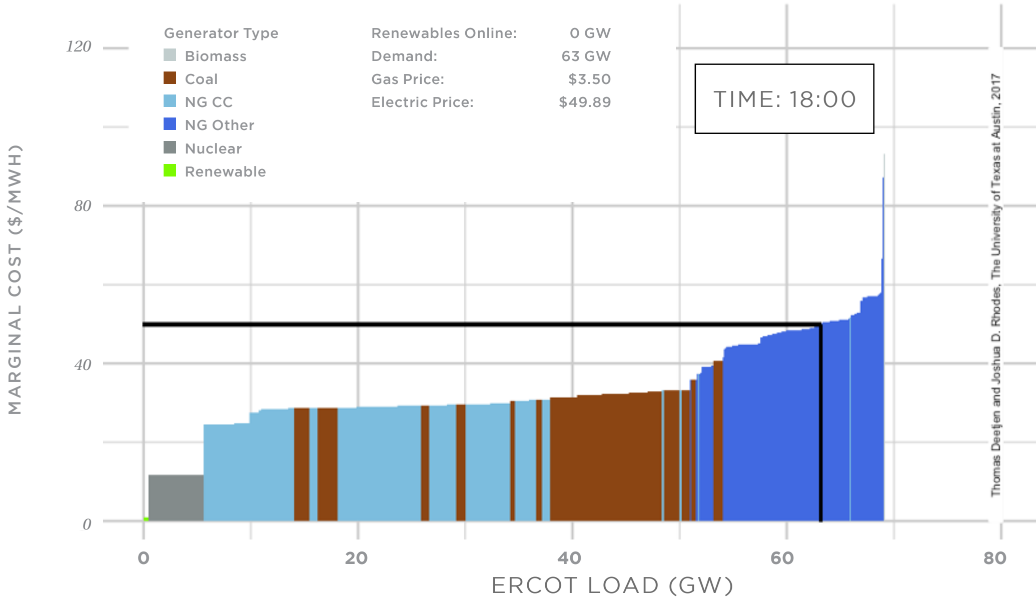

FIGURE 10.

ERCOT bid stack and clearing price of $49.89/MWh at a load of 63 GW and natural gas price of $3.50/MMBTU.

Effect of more renewables on bid stack and market price

When renewables are available to produce electricity, they typically bid at very low cost and consequently are routinely dispatched before other generation sources. Thus, renewables shift the bid stack of thermal generators to the right (whereas fuel prices change their magnitude). Since a majority of the natural gas combined cycle plants (NG CC - light blue in bid stack figures) have a similar dispatch cost to each other, the stack slope is very low. Therefore, high levels of renewables only impact the price to the extent of the differences in dispatch cost between thermal generators in that part of the curve, which is minimal. For renewables to have a major impact on price (at low NG prices), they would need to push essentially all natural gas generation out of the dispatch zone. Negative prices do occur in ERCOT, but these prices are typically located at nodes in the western part of the state and are the result of transmission constraints.

Figure 11 shows that with 2 GW of renewables online, the wholesale electricity price is about $31.24 and Figure 12 shows that, with 10 GW of renewables online, the wholesale electricity price is $29.61 (holding constant demand and natural gas prices).

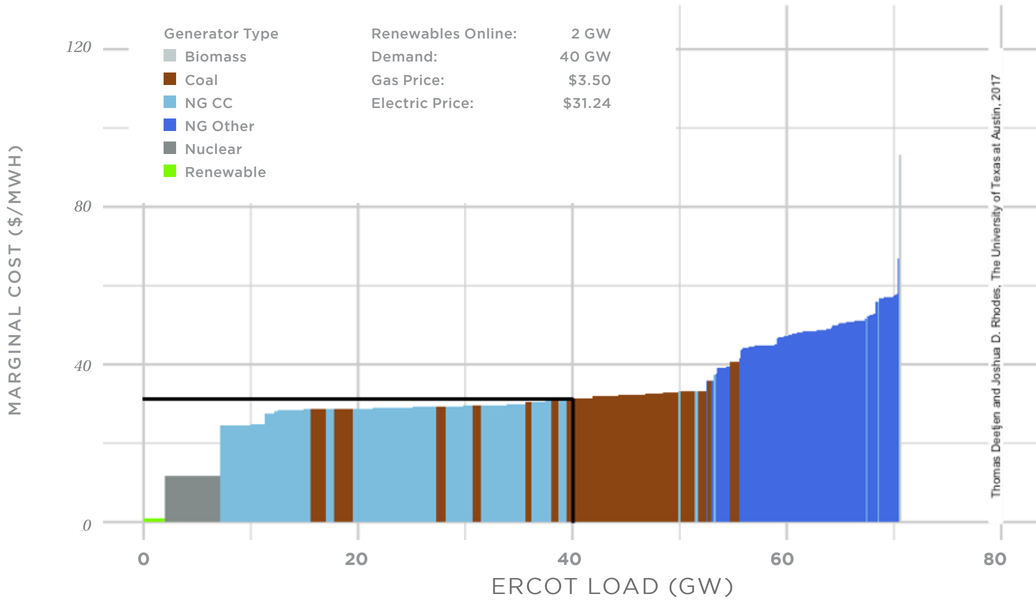

FIGURE 11.

ERCOT bid stack with 2 GW of renewables online, a clearing price of $31.24/MWh at a load of 40 GW, and natural gas price of $3.50/MMBTU.

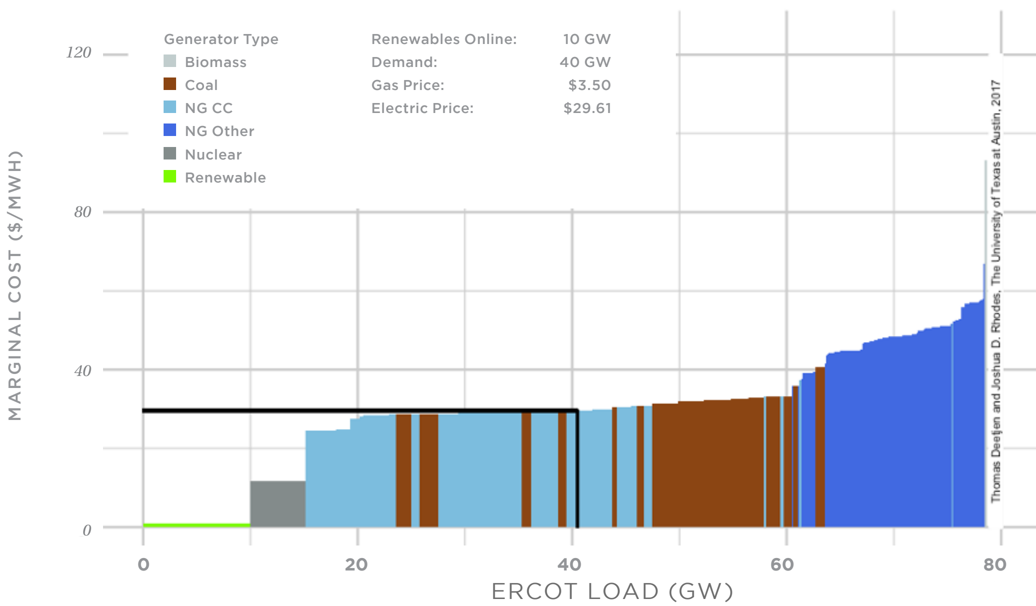

FIGURE 12.

ERCOT bid stack with 10 GW of renewables online, a clearing price of $29.61/MWh at a load of 40 GW, and natural gas price of $3.50/MMBTU.

Previous analyses that utilized a similar model structure also considered the interannual variations in fuel prices for both coal and power plants. Because this analysis was completed over a shorter period of time, the fuel price impact to the bid stack was not considered in this work.

Datasets used in the model

As indicated in the model description, the model required multiple datasets, including ERCOT system load, ERCOT wind and solar production profiles, and thermal power plant fleet information. ERCOT actual system load, wind production, and solar production profiles for summer 2023 were obtained using the GridStatus.io Python API.[17] Current power plant fleet specific data were taken from previous grid studies[18,19] ERCOT SARA reports[20], and EIA 860[21] datasets.

Emissions and water reduction benefit range values

While this analysis directly models the reduction in electricity costs due to renewables, we consider the value of reduced water consumption and power plant emissions. Table 1 shows a breakdown of the water and emissions ranges used.

TABLE 1.

Estimated value of reduced power plant water consumption and emissions. The SO_2 and NO_x damages are median county-level average damage values.[22] The CO_2 damages and water costs are from the lower end of wholesale water rates and climate damages.

EXTERNALITY	COSTS/DAMAGES
SO_2	*$16,600/ton*
NO_x	*$4,750/ton*
CO_2	*$20/ton*
Water	*$3/thousand gallons*

17 https://www.gridstatus.io/

18 Thomas A. Deetjen, Jared B. Garrison, Joshua D. Rhodes, Michael E. Webber, "Solar PV integration cost variation due to array orientation and geographic location in the Electric Reliability Council of Texas," Applied Energy, Volume 180, 2016, Pages 607-616, ISSN 0306-2619, https://doi.org/10.1016/j.apenergy.2016.08.012.

19 Cohen SM, Rochelle GT, Webber ME., "Turning CO2 Capture On and Off in Response to Electric Grid Demand: A Baseline Analysis of Emissions and Economics." ASME. Energy Sustainability, ASME 2008 2nd International Conference on Energy Sustainability, Volume 1 ():127-136. doi:10.1115/ES2008-54296.

20 https://www.ercot.com/gridinfo/resource

21 https://www.eia.gov/electricity/data/eia860/

22 https://www.jstor.org/stable/23045618

Counterfactual thermal power plant fleet

To model the impacts of no renewables in the ERCOT system, it was necessary to estimate how the ERCOT thermal fleet would have evolved without these technologies. It is likely that some of the technology and price influences would have still been the same, such as the impact of the low cost natural gas prices resulting from hydraulic fracturing. On the other hand, it is possible that load in ERCOT wouldn't have grown as fast as it did in the past given the absence of low-cost renewables or the arrival of loads that came to Texas because of the ability to consume renewable energy. Absent renewables, it is assumed that the additional capacity needed would have been a mix of natural gas power plants that did not retire and new builds. This fleet would have significantly increased the volumes of natural gas consumed, which could have served to raise the fuel's cost, which would have then also impacted the power plant fleet. It is assumed that the same regulatory pressure that has resulted in the retirement of the coal fleet, including lower cost natural gas, would have continued.

Given these uncertainties, we estimated that the EROCT thermal power plant fleet would have essentially evolved to consist of more natural gas power plants and that the same number of coal power plants would have retired as has historically been observed. To that end, we estimate that, over the summer of 2023, ERCOT would have had an additional ~14,840 MW of natural gas power plants if it had never built any renewables. This level of capacity was arrived at by taking the actual 2023 thermal fleet and adding capacity until it exceeded the 2023 summer peak by a few thousand MWs to simulate the scarcity and the low levels of reserves seen this summer. We felt that this assumption was justified given the dynamics of an energy-only electricity market. This ~14,840 MW of additional natural gas capacity was then scaled by the fraction of each natural gas technology type that currently exists on the system. Table 2 shows our estimated counterfactual natural gas capacity that would have been on the ERCOT system, absent the development of any renewables.

TABLE 2.

Table of estimated additional counterfactual natural gas capacity, by type, in ERCOT, during the summer of 2023 absent any renewables.

NATURAL GAS TECHNOLOGY	COUNTERFACTUAL CAPACITY (MW)
Natural gas combined cycle	*8,740*
Natural gas boiler	*3,640*
Simple cycle natural gas turbine	*2,240*
Natural gas internal combustion engine	*220*

Note that this counterfactual capacity is assumed to consist of both new builds (combined cycle, simple cycle, and ICE units) as well as fewer historical retirements (natural gas boilers).[23]

23 About 6,500 MW of natural gas boilers have retired in Texas since 2010: https://www.eia.gov/electricity/data/eia860/

Limitations of the model

The model used in this analysis utilizes a simplified marginal dispatch and is not able to fully model real-world grid operation aspects such as nodal pricing, scarcity events, extreme weather events, transmission constraints, generator ramping, and minimum thermal generator load constraints. Not all generators bid their marginal cost for all hours. Under some circumstances, renewable generation is curtailed, but the number of hours when this happens tends to be low[24] Actual generation profiles of wind and solar were used, so any curtailment was considered. However, since the purpose of this analysis was to provide a yearly and total estimate of the effect of renewables in ERCOT, this top-level approach is reasonable.

Ramping and minimum thermal generator load constraints can erode some of the emissions benefits of renewable energy, but these benefit reductions have been found to be small.[25,26] Recent work indicates that high levels of solar in ERCOT would increase ancillary costs by the tens of millions but reduce dispatch costs by the hundreds of millions.[27]

24 https://www.energy.gov/eere/analysis/downloads/2016-renewable-energy-grid-integration-data-book

25 Meehan C, Webber M, Nagasawa K. The Net Impact of Wind Energy Generation on Emissions of Carbon Dioxide in Texas. ASME. Energy Sustainability, ASME 2012 6th International Conference on Energy Sustainability, Parts A and B ():651-659. doi:10.1115/ES2012-91217.

26 Meehan, Colin Markey. "Estimating Emissions Impacts to the Bulk Power System of Increased Electric Vehicle and Renewable Energy Usage." The University of Texas at Austin, 2013. https://repositories.lib.utexas.edu/bitstream/handle/2152/23624/MEEHAN-THESIS-2013.pdf?sequence=1

27 Thomas A. Deetjen, Jared B. Garrison, Joshua D. Rhodes, Michael E. Webber, "Solar PV integration cost variation due to array orientation and geographic location in the Electric Reliability Council of Texas," Applied Energy, Volume 180, 2016, Pages 607-616, https://doi.org/10.1016/j.apenergy.2016.08.012.