The Impact of Renewables in ERCOT

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Executive Summary

This report quantifies the impacts of renewables in ERCOT on wholesale clearing prices and avoided fuel costs, water use, and emissions by comparing how the market would have performed with and without wind and solar from 2010 to August 2022. This analysis found that the build out of renewables from 2010 and beyond has yielded significant benefits and savings to Texans in the ERCOT service area, cumulatively worth as much as $106 billion.

- The widespread adoption of renewables reduced wholesale electricity costs by about $27.8 billion between 2010 and August 2022, saving consumers significantly from what they might otherwise have had to pay.

- In the first eight months of 2022, renewables reduced ERCOT wholesale electricity market costs by about $7.4B (~$925M per month) and are on-track to exceed $11B in cost savings by the end of the year.

- Renewables have reduced wholesale electricity market prices on average between $1.17/MWh (in 2012) and $20.60/MWh (in 2022) by offsetting more expensive power plants.

- This analysis also indicates that renewables can provide a price hedge against the volatility of natural gas and coal prices in ERCOT, both of which were significantly more expensive in 2022 than the preceding years.

- Without renewables, power plants would have consumed an additional 244 billion gallons of water from 2010 to August 2022, adding water stress to regions that are often in drought. At typical wholesale water rates of $3 to $7 per thousand gallons, 244 billion gallons of water is worth between $0.7B and $1.7B.

- Emissions reductions have saved Texans between $10.2B and $76.4B in total in lower healthcare and other environmentally related costs.

- Summing up all benefit streams, we estimate that, between 2010 and August 2022, renewables provided between $38.7B and $106B (about $48.2B using median values for water and emissions) in total benefits to Texas residents in the ERCOT service territory.

Introduction

The purpose of this analysis is to estimate the impacts of wind and solar generation on wholesale electricity market costs, water use, and emissions in ERCOT. Because wind and solar power plants require no fuel and therefore have low marginal costs, they reduce wholesale clearing prices in ERCOT, which can be economically beneficial for consumers. **The widespread adoption of renewables reduced wholesale energy expenditures by about $7.4B in the first 8 months of 2022 and $27.8B cumulatively from 2010 to August 2022, saving consumers significantly from what they might otherwise have had to pay (see Figure 1).**

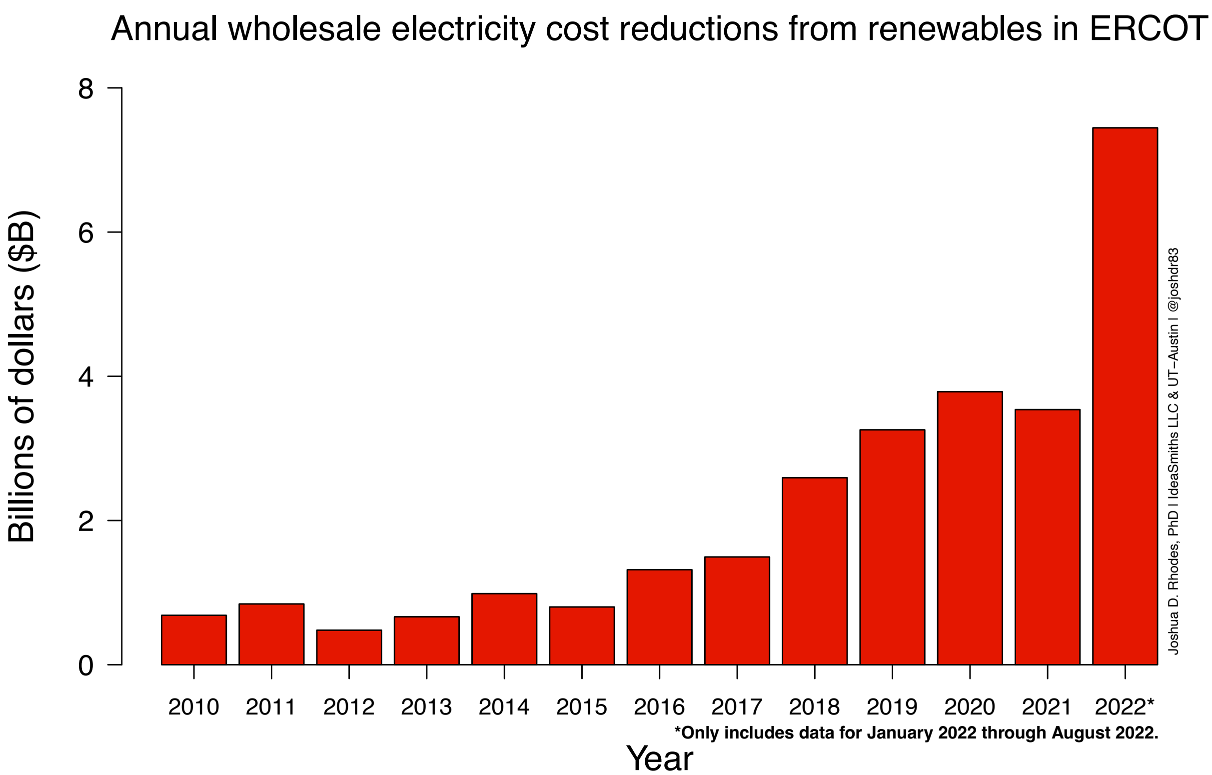

Figure 1: The estimated total annual reduction in ERCOT wholesale market costs due to wind and solar was approximately 1 to 8 billion dollars.

The effect has been larger in 2022 because 1) there was more wind and solar generation and 2) gas and coal prices were much higher than in preceding years. If current market conditions persist, it is likely that wholesale electricity market cost savings will exceed $11B for 2022.

In this analysis, we also assess the impact of renewables on water use and emissions of the ERCOT grid. 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.

In 2015, Texas power plants withdrew almost four trillion gallons of water for power plant cooling[1]. At the same time, a significant portion of Texas is often in some stage of drought[2] and many sources of water are fully allocated. New water rights can be difficult to obtain, and water-thirsty municipalities or economic sectors, such as agriculture and oil and gas extraction, could benefit from increased water availability[3] enabled because of avoided water use in the thermoelectric power sector. Many thermal power plants share the same watersheds as growing cities that are eager to expand water resources, so increasing the use of power plants that don't require water, such as renewables, can reduce water competition and system strain.

Reducing air pollution yields significant health benefits for Texans as well. In some densely populated counties where pollution is very damaging to human health, avoided nitrogen oxides (NO_x) emissions are worth $12,000 per ton and avoided sulfur oxide (SO_x) emissions[4] are worth up to $107,000 per ton due to fewer Texans having to seek medical attention for environmentally related respiratory problems. In this analysis, we also considered the social cost of carbon dioxide (CO_2) emissions at $10-$50/ton, to represent negative impacts of climate change, including more intense storms that can damage infrastructure and decrease economic productivity.

Data

Electricity model data

The model used historical system load data[5] as well as same-year wind and solar generation data for computation. For years when actual wind and solar generation data were not available[6], typical ERCOT wind and solar profiles were normalized by installed capacities[7] to estimate their effect on the marginal bid stack. Power plant specific data were taken from previous grid studies[8,9], ERCOT SARA reports[10], and EIA 860[11] datasets. Each set of annual data were matched with their yearly average natural gas and coal prices[12,13]. Due to a lack of

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[1] https://owi.usgs.gov/vizlab/water-use-15/#view=TX&category=thermoelectric

[2] https://droughtmonitor.unl.edu/CurrentMap/StateDroughtMonitor.aspx?TX

[3] Cook, Margaret A., Ashlynn S. Stillwell, Carey W. King, Michael E. Webber, "Alternative Water Sources for Hydraulic Fracturing in Texas," *World Environmental and Water Resources Congress 2013,* https://ascelibrary.org/doi/abs/10.1061/9780784412947.279

[4] 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 http://www.aeaweb.org/articles?id=10.1257/aer.101.5.1649

[5] https://www.ercot.com/gridinfo/load/load_hist

[6] 2010-2014 for wind and 2010-2017 for solar

[7] http://www.ercot.com/gridinfo/resource

[8] 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.

[9] 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.

[10] https://www.ercot.com/gridinfo/resource

[11] https://www.eia.gov/electricity/data/eia860/

[12] https://www.eia.gov/dnav/ng/hist/n3045us3a.htm

[13] https://www.eia.gov/coal/production/quarterly/

available data, the delivered price of coal was estimated to be $2.50/MMBTU for years 2010-2016. Coal price data were available from 2017-2022 and those prices were used.

*Table 1: Model input values for each year. Values for 2022 (marked with a *) are from capacities marked as "Cumulative MW Installed" in ERCOT's Capacity Changes By Fuel Type Monthly for August 2022. Capacity values that include "Cumulative MW Synchronized" are 35,838 MW for wind and 12,791 MW for solar.*

Year	Wind capacity (MW)	Solar capacity (MW)	Natural gas price ($/MMBTU)	Coal price ($/MMBTU)
2010	9,458	15	$5.08	$2.50
2011	9,603	15	$4.72	$2.50
2012	10,698	72	$3.41	$2.50
2013	11,100	121	$4.33	$2.50
2014	12,729	169	$5.00	$2.50
2015	15,857	289	$3.26	$2.50
2016	17,662	566	$2.88	$2.50
2017	20,698	1,068	$3.39	$2.86
2018	21,777	1,857	$3.22	$3.19
2019	23,860	2,281	$2.47	$3.20
2020	25,121	3,974	$1.99	$3.20
2021	28,417	8,274	$3.64	$3.26
2022	30,408*	8,661*	$6.24	$3.72

Thermal power plant marginal costs vary depending on their specific characteristics. Thus, power plant-specific heat rates, water withdrawal rates, water consumption rates, and emissions rates were used to approximate the real-world behavior of power plants in ERCOT. Solar and wind were expected to bid into the market below the cost of any thermal generator and thus their power was assumed to be taken by the market.

Emissions and water reduction benefit range values

While this analysis directly models the reduction in electricity costs due to renewables, we present a range of values for reduced water consumption and emissions. The low range uses values of; SO_x: $10,068/ton, NO_x: $1,578/ton, CO_2: $10/ton, water: $3/thousand gallons. The high range uses values of; SO_x: $107,150/ton, NO_x: $11,956/ton, CO_2: $50/ton, water: $7/thousand gallons. Median emissions and water values are SOx: $16,600/ton, NOx: $4,750/ton, CO2: $20/ton, and water: $3/thousand gallons.

Results

The results of this analysis indicate that between 2010 and August 2022, if there had been no solar or wind generation in ERCOT, the power sector would have withdrawn 8 trillion more gallons of water[14], consumed 244 billion more gallons of water[15], emitted 416 thousand tons

[14] Water withdrawals refer to water that used by a power plant for cooling but returned to a watershed
[15] Water consumption refers to water that is consumed (evaporated) by a power plant's cooling system and is not available for other uses

more SO_2, emitted 318 thousand tons more NO_x, and emitted 558 million tons more CO_2. That magnitude of additional water consumption and emissions would have induced between $10.5B and $77.3B in environmental and public health costs[16] over this time period[17]. Also, if wind and solar had not existed during this time period, higher wholesale electricity market prices would have resulted in an additional $27.8B in costs.

Impact of renewables on wholesale electricity market prices

Renewables affect the average wholesale electricity market prices by providing energy at zero or near-zero prices. In electricity markets, this type of bidding behavior will lead to lower overall market prices. Figure 2 indicates that renewables have reduced wholesale electricity market prices on average between $1.17/MWh (in 2012) and $20.60/MWh in (January – August 2022) per year. The higher reductions in 2022 result from wind and solar offsetting historically high natural gas and coal prices.

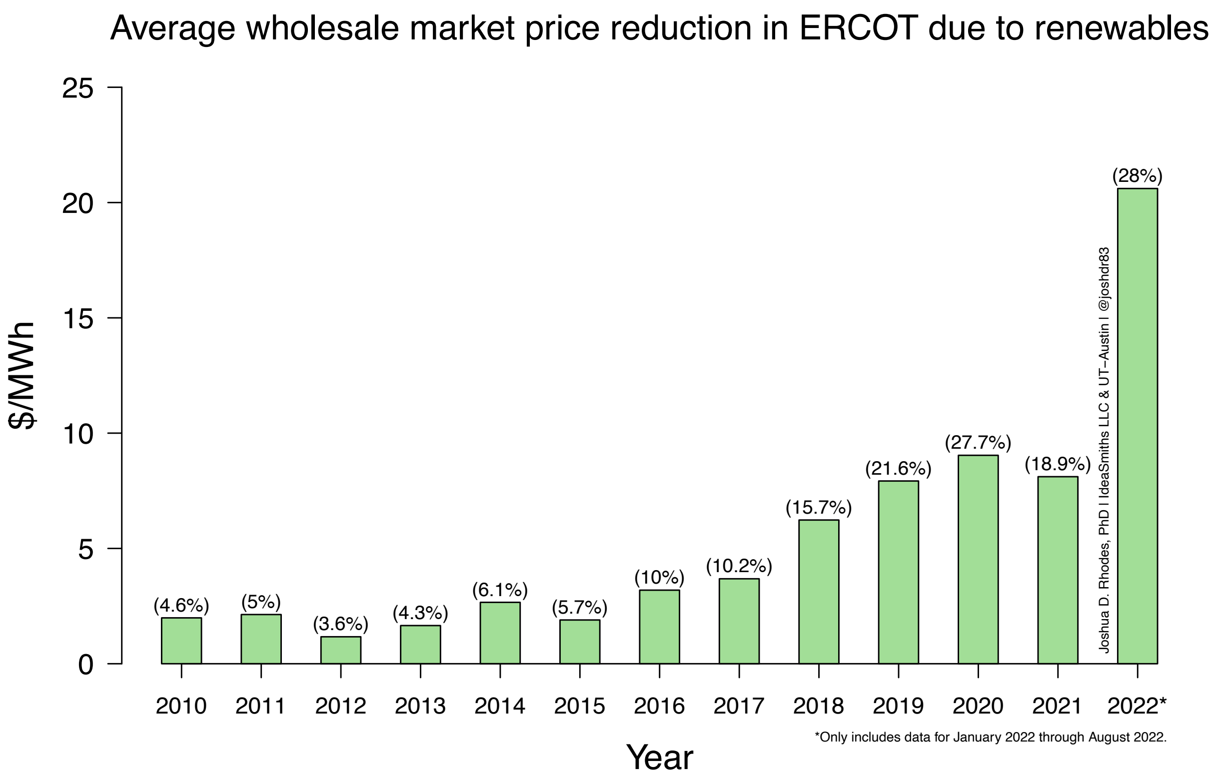

Figure 2: Modeled yearly average wholesale electricity market price reductions attributed to renewables for 2010 – August 2022 vary from less than 5% to approximately 28%. Percentages above each bar indicate relative reduction in average wholesale market costs due to renewables.

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[16] Joshua D. Rhodes, Carey King, Gürcan Gulen, Sheila M. Olmstead, James S. Dyer, Robert E. Hebner, Fred C. Beach, Thomas F. Edgar, Michael E. Webber, "A geographically resolved method to estimate levelized power plant costs with environmental externalities," *Energy Policy*, Volume 102, 2017, Pages 491-499, ISSN 0301-4215, https://doi.org/10.1016/j.enpol.2016.12.025.
[17] This range takes into account low and high values for other water uses as well as the value of each pollutant.

For example, Figure 2 shows that in the first eight months of 2022 wind and solar are estimated to have reduced the average wholesale electricity cost by about $20.60/MWh, or by about 28% compared to expected prices on a renewables free grid. Average market prices so far in 2022 are about $72/MWh, so our analysis implies costs would have been over $90/MWh without renewables acting as a hedge against higher fuel prices. We estimate that wind and solar reduced wholesale electricity market costs between $480M to $7.4B per year ($27.8B in total for 2010 through August 2022). Further, we estimate that renewables have reduced ERCOT wholesale market costs by about $925 million per month so far from January 2022 to August 2022.

Renewables as a hedge against high natural gas prices

Figure 3 shows the impact of renewables on wholesale electricity market prices as the price of natural gas changes. In this figure, the year (demand and renewable capacity) is held constant at 2021 values, but the price of natural gas fluctuates from $2 to $12/MMBTU. As expected, renewables reduce overall wholesale electricity market prices and have a greater impact at higher natural gas prices. This result indicates that renewables in ERCOT can provide a price hedge against the volatility of natural gas prices. Natural gas prices had ranged between $2-4/MMBTU for several preceding years before rising to $6-7/MMBTU as of mid-2022. Further, higher global demand for natural gas coupled with an increase in the LNG export capacity of the US likely puts upward pressure on prices as exports couple US prices with the global trading hubs, such as is the case with oil.

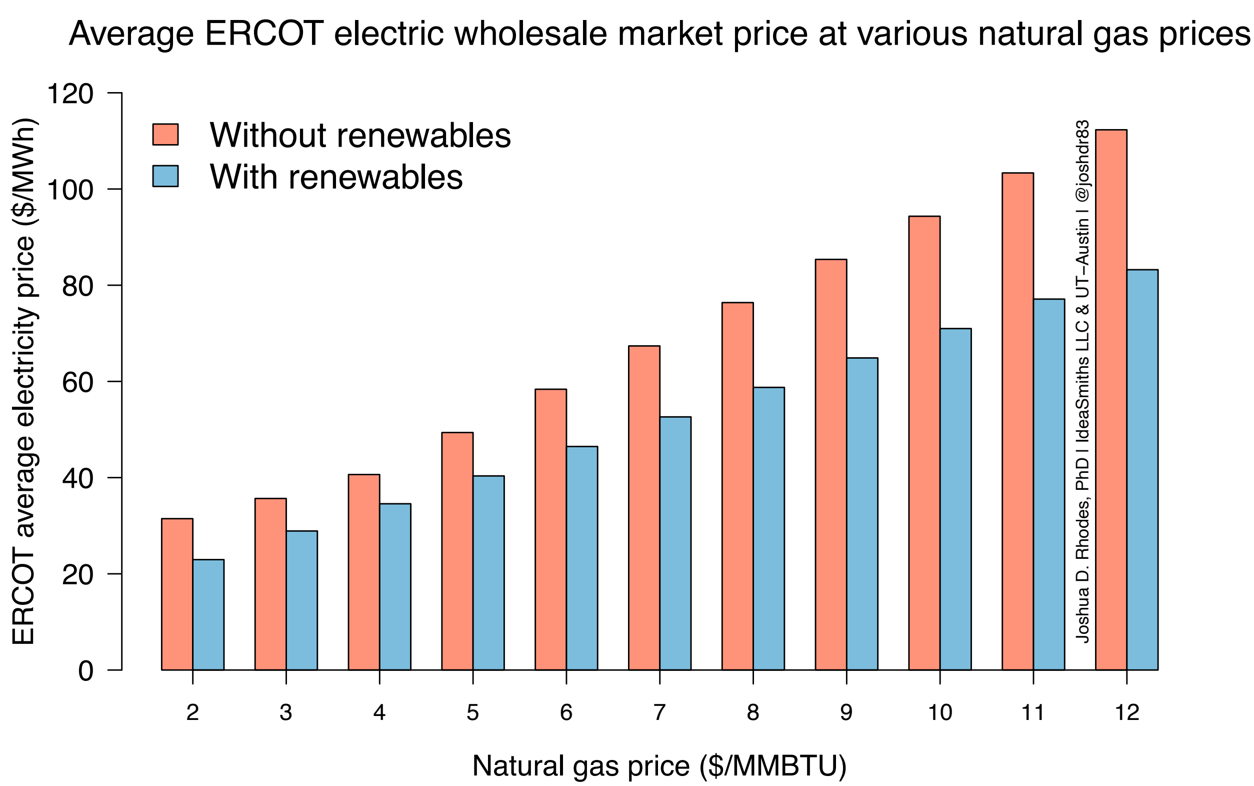

Figure 3: Natural gas prices are critical drivers of ERCOT's wholesale electricity market price and use of renewables avoids some of those costs. Note that all groups of bars are for 2021 generation and capacity, but with a range natural gas prices for

illustration purposes. Natural gas prices have historically ranged between $2-4/MMBTU range but rose to $6-7/MMBTU in mid-2022.

Combined impact of renewables on ERCOT

Figure 4 shows a stacked breakdown of the magnitudes of water, emissions, and reduced electric wholesale market cost benefits per year in ERCOT from renewables assuming median values for water and emissions.[18] The relative magnitudes of the benefits change each year depending on 1) the cost of natural gas and coal and 2) the amount of renewables online, but, in general, are increasing with time. We estimate that renewables have saved between $1.2B (in 2010) and $9.8B in (January – August 2022) per year, about $48.2B in total, using median values for water and emissions reductions.

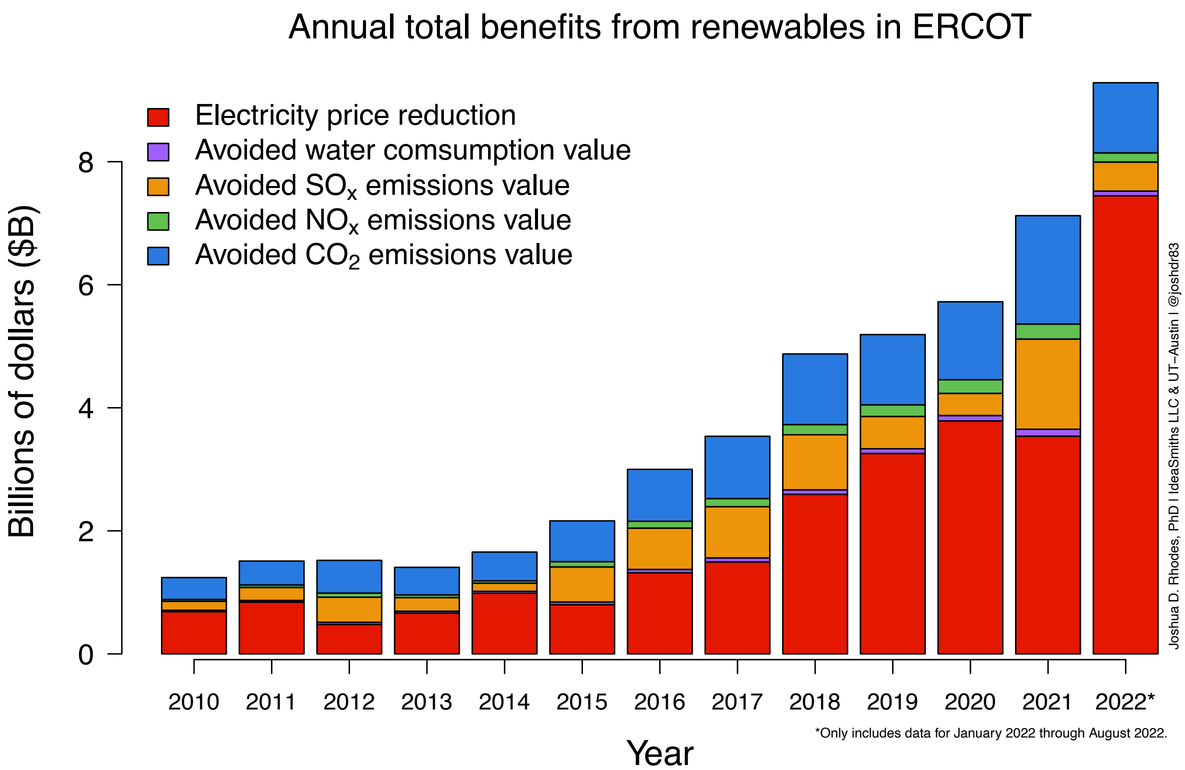

Figure 4: Cumulative annual benefits from renewables in ERCOT for 2010 – August 2022 vary from $1.2 to 9.8 billion. Median values (from all Texas counties) of damages were used to monetize the emissions reductions (SO_x: $16,600/ton, NO_x: $4,750/ton, CO_2: $20/ton, water: $3/thousand gallons).

The next sections go into further detail on the water and emissions reduction benefits from renewables in ERCOT that are shown in Figure 4.

Impact of renewables on water and emissions

Figure 5 through Figure 9 show the impact of renewables on water and emissions.

[18] Median emissions and water values: SOx: $16,600/ton, NOx: $4,750/ton, CO2: $20/ton, water: $3/thousand gallons

Avoided water withdrawals

Figure 5 shows that, if there had not been any renewables on the ERCOT grid, power plants would have withdrawn between approximately 272 billion to 1,300 billion more gallons of water per year, or 8.6 trillion gallons total from 2010 to August 2022. For reference, 1,300 billion gallons is the annual use of about 14.2 million Texans[19].

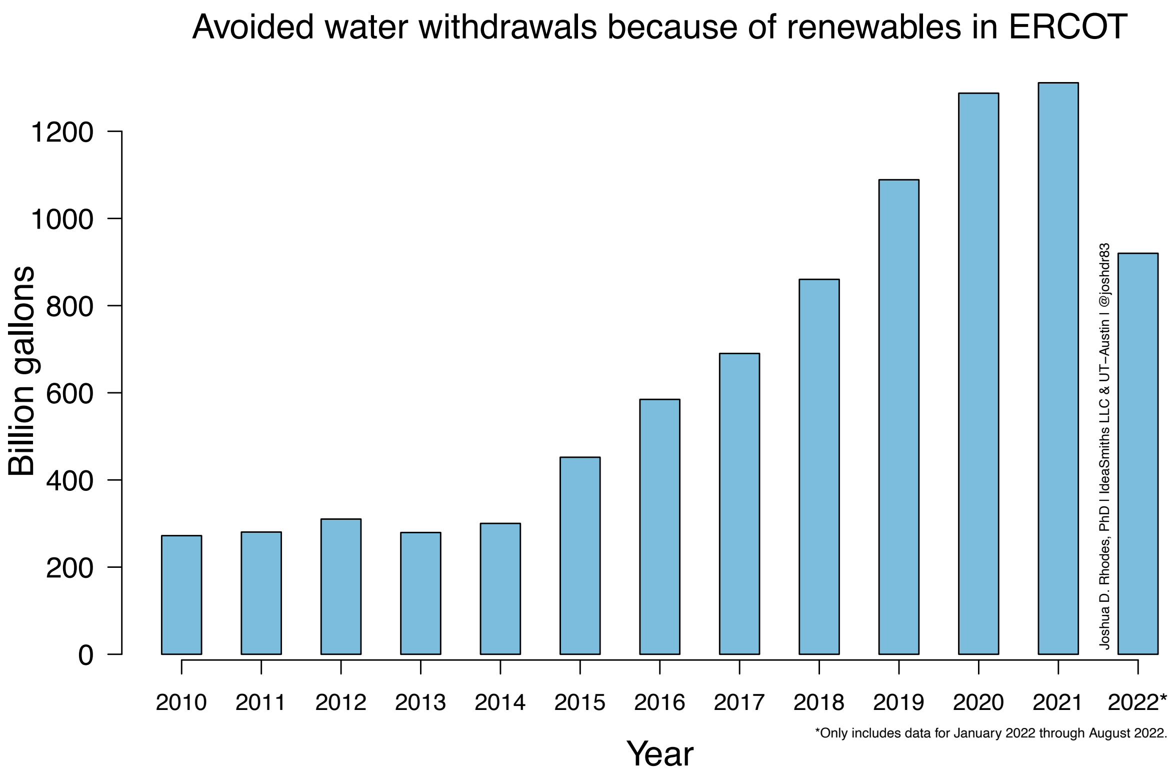

Figure 5: Modeled water withdrawal reductions attributed to renewables for 2010 – August 2022 varied from over 200 to over 1200 billion gallons per year. Water withdrawals refer to water that is used by a power plant for cooling, most of which is returned to the source, usually at a higher temperature.

Avoided water consumption

Figure 6 shows that, if there had not been any renewables on the ERCOT grid, power plants would have consumed between 8 and 38 billion gallons of additional water per year, or about 244 billion gallons from 2010 to August 2022. For reference, 244 billion gallons is enough to hydraulically fracture between 70,000 to 200,000 natural gas wells, depending on well type and formation[20]. At typical wholesale water rates of $3 to $7 per thousand gallons, 244 billion gallons of water is worth between $0.7B and $1.7B.

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[19] Assuming 250 gallons per capita daily: http://www.twdb.texas.gov/publications/reports/special_legislative_reports/doc/2014_WaterUseOfTexasWaterUtilities.pdf

[20] https://www.rrc.texas.gov/about-us/faqs/oil-gas-faqs/hydraulic-fracturing-faqs/

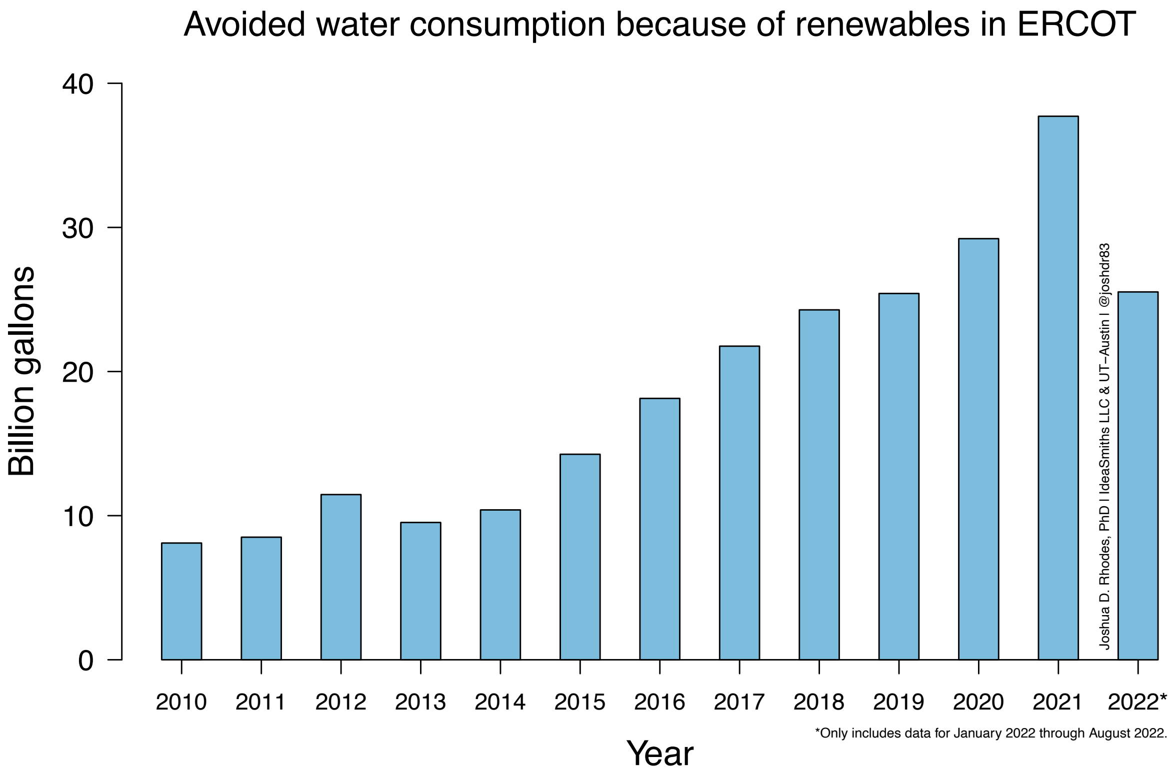

Figure 6: Modeled water consumption reductions attributed to renewables for 2010 – August 2022 varied from under 10 billion to nearly 40 billion gallons annually. Water consumption refers to water that is evaporated by a power plant's cooling system and is not available for other uses.

Avoided SO_2 emissions

Figure 7 shows that if there had not been any renewables on the ERCOT grid power plants would have emitted between 8 and 88 thousand tons more sulfur dioxide (SO_2) per year, or about 416 thousand cumulative tons since 2010. Avoided SO_2 emissions yielded Texans between $4.2B and $44.6B in human health benefits during this time. Other ecosystem benefits, such as reduced acid rain and its impacts on agriculture, would further increase this value but were not included in the analysis.

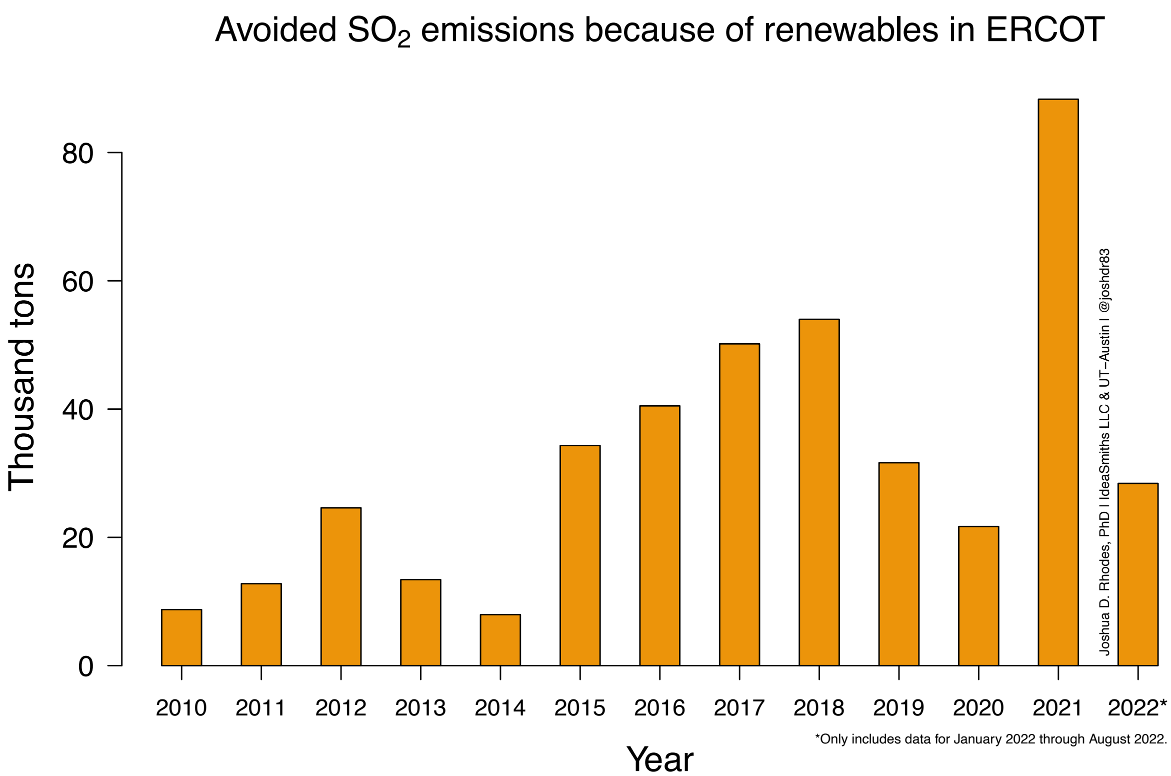

Figure 7: Modeled SO_2 emissions reductions attributed to renewables for 2010 – August 2022 varied between approximately 10 to more than 80 tons annually.

Avoided NO_x emissions

Figure 8 shows that if there had not been any renewables on the ERCOT grid power plants would have emitted between 6 and 51 thousand tons more nitrogen oxides (NO_x) per year, or 318 thousand cumulative tons from 2010 to August 2022. Not breathing these NO_x emissions saved Texans between $502M and $3.8B in health costs over this same period.

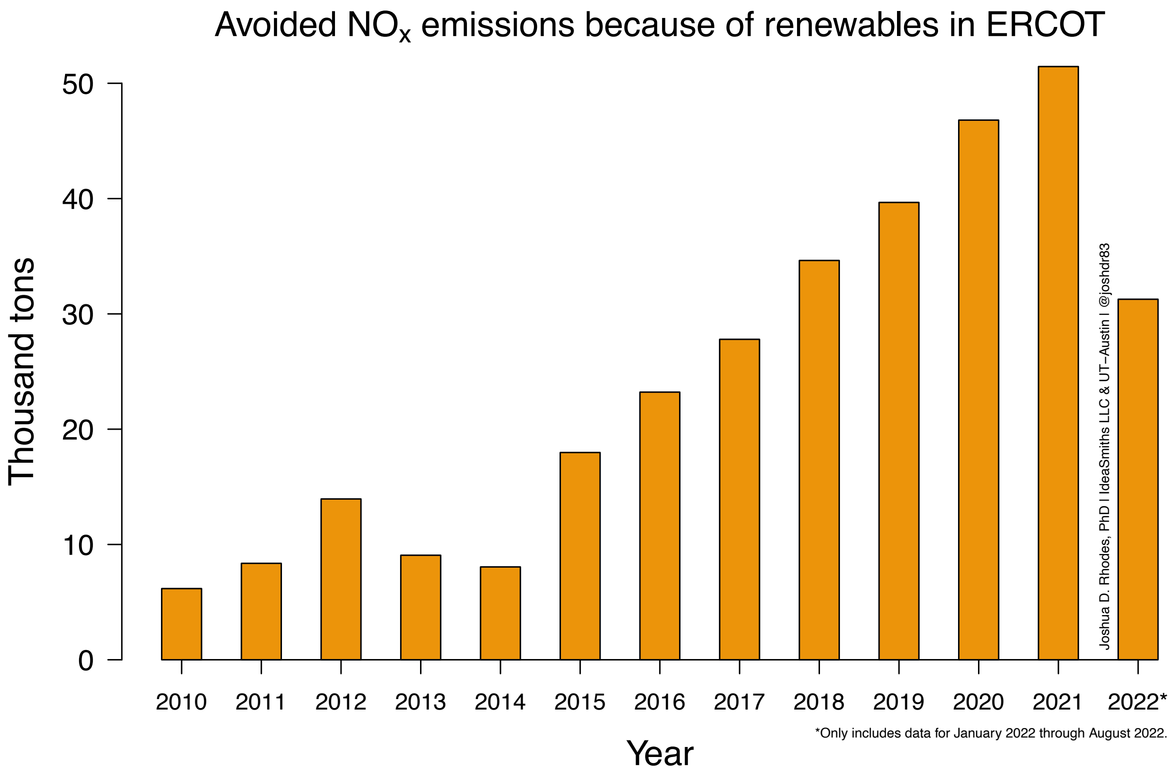

Figure 8: Modeled NO_x emissions reductions attributed to renewables for 2010 – August 2022 varied from over 5 to 50 thousand tons annually.

Avoided CO_2 emissions

Figure 9 shows that if there had not been any renewables on the ERCOT grid power plants would have emitted between 17.8 and 88 million tons more carbon dioxide (CO_2) depending on the year, or about 558 million cumulative tons between 2010 and August 2022. Not emitting this CO_2 is worth between $5.6B and $27.9B (at $10 and $50/ton of CO_2 respectively) in total since 2010.

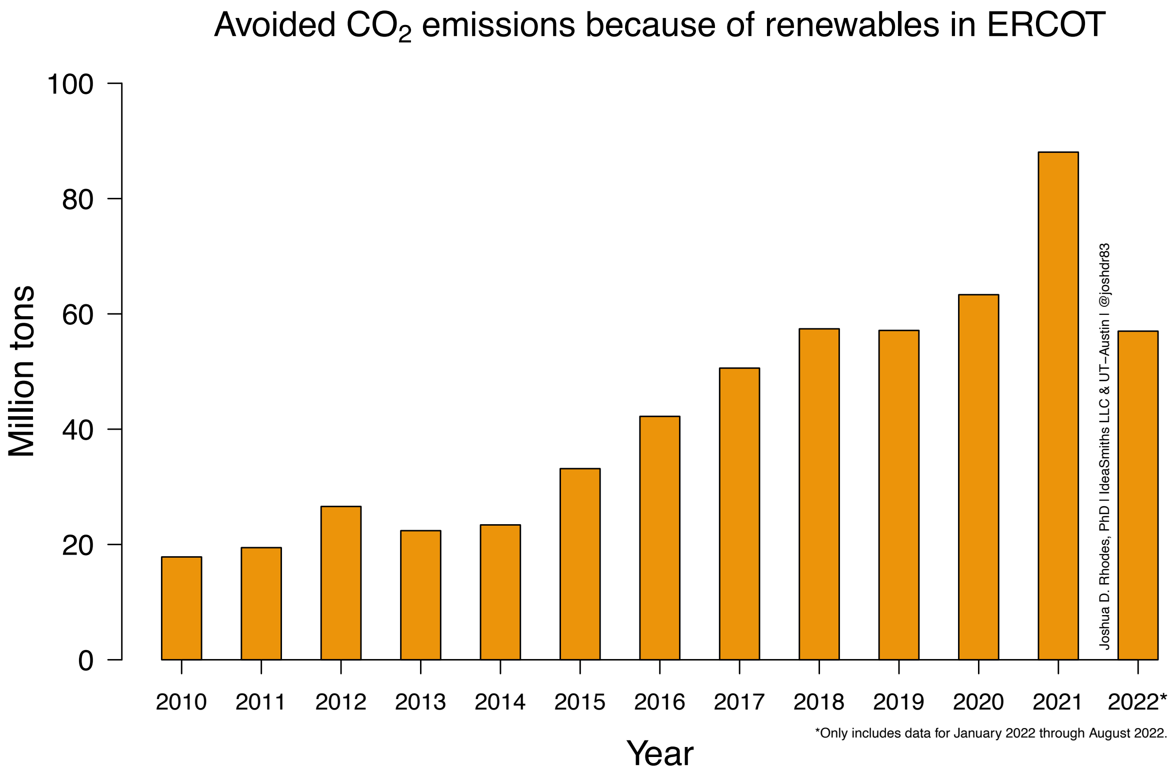

Figure 9: Modeled CO_2 emissions reductions attributed to renewables for 2010 – August 2022 vary from approximately 20 to 90 million tons annually.

Conclusions

This analysis indicates that renewables have 1) reduced ERCOT wholesale electricity market prices, 2) reduced the water intensity of the ERCOT grid, and 3) reduced the emissions of pollutants associated with power generation in ERCOT. The reductions vary depending on the year, but are, in general, increasing as more renewables are integrated into the ERCOT grid. Renewables' downward pressure on wholesale electricity market prices increases as natural gas and coal prices rise and act as a hedge against possible higher prices in the future. Quantifying these benefits between 2010 and August 2022, we estimate that renewables provided between $38.7B and $106B in total benefits to Texas residents in the ERCOT service territory.

Acknowledgements

This work is supported by Texas Consumer Association and funded by the Consumer Fund of Texas, a 501(c)(3) research organization.[21]

About Us

IdeaSmiths LLC[22] 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.

[21] https://www.texasconsumer.org/

[22] https://www.ideasmiths.net/

Appendix A: 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 from 2010 to August 2022. Figure 10 though Figure 15 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 year (8,760 hours, + 24 for leap years), ERCOT demand[23] as well as year-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 each scenario.
- 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 year were summed for that year.
- The difference in the emissions and water consumption totals between the two scenarios was output as the value of having renewables in the system.

Model execution

For every hour, for 2010 – August 2022, 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[24]. 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 10 and Figure 11 show this difference. In Figure 10, early morning ERCOT demand is 40 GW and the resulting electricity price is about $31/MWh. In Figure 11, afternoon demand has increased to 63 GW and more power plants have been dispatched to meet that

[23] Total amount of electricity being consumed by all customers in ERCOT for that hour.
[24] https://theconversation.com/are-solar-and-wind-really-killing-coal-nuclear-and-grid-reliability-76741

demand. Because these extra power plants have higher marginal costs, the wholesale market cost has increased to the marginal generator, almost $50/MWh.

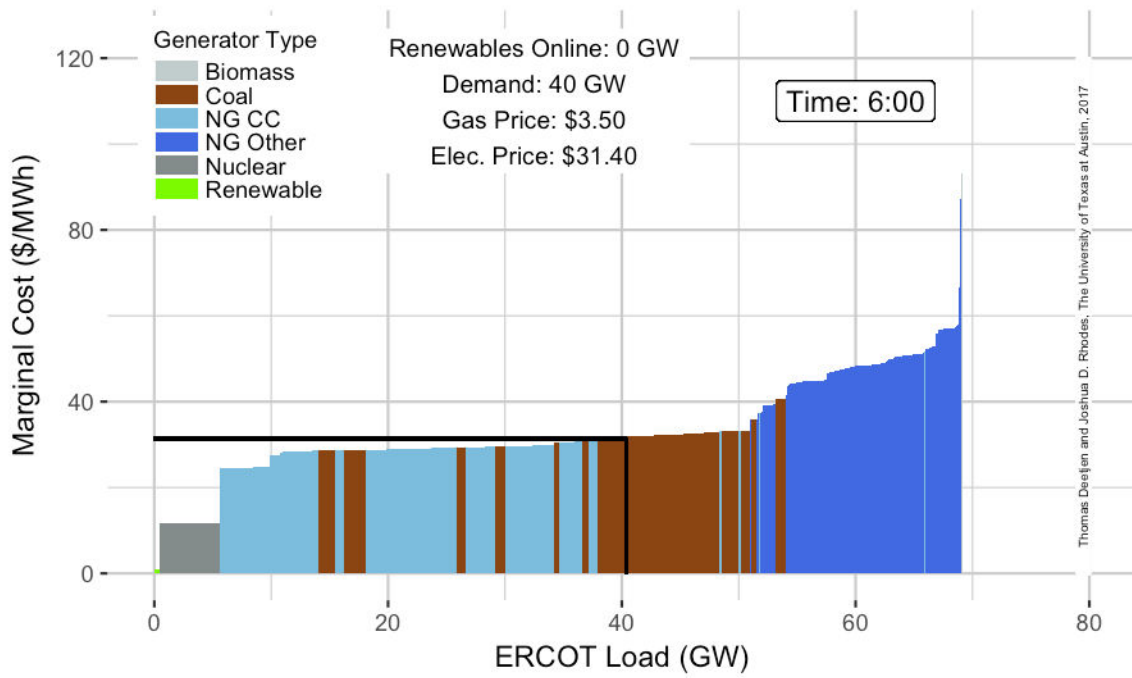

Figure 10: ERCOT bid stack and clearing price of $31.40/MWh at a load of 40 GW and natural gas price of $3.50/MMBTU.

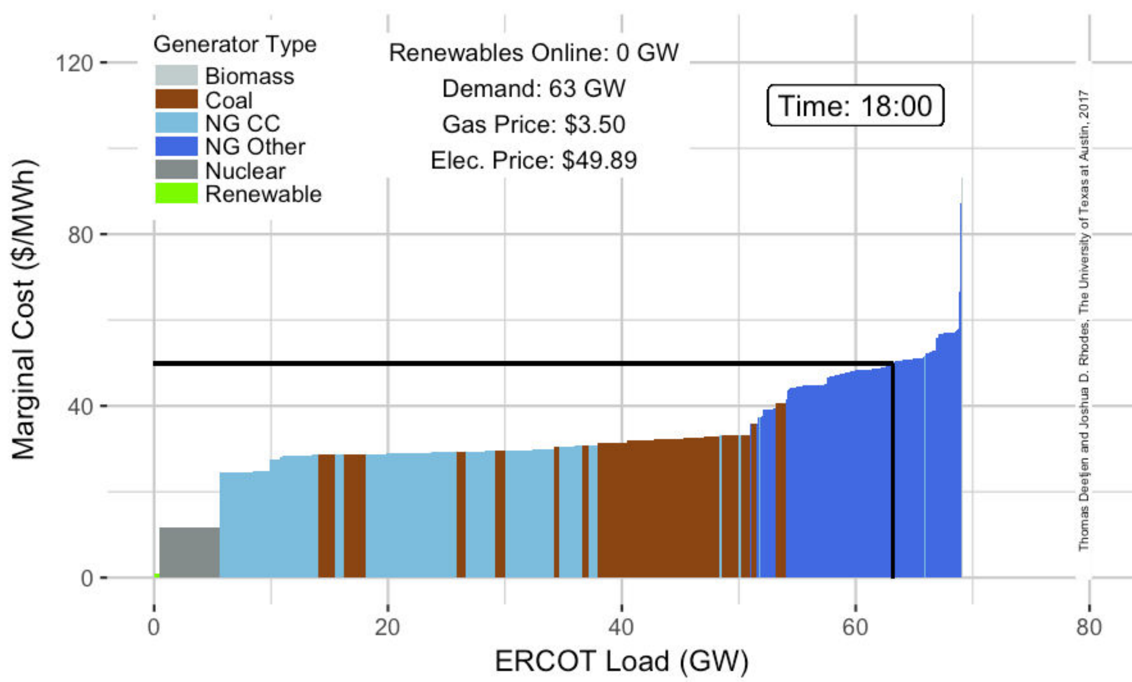

Figure 11: ERCOT bid stack and clearing price of $49.89/MWh at a load of 63 GW and natural gas price of $3.50/MMBTU.

Effect of changing natural gas price on bid stack and market price

The price of natural gas has fallen significantly in the past few years. Recent studies indicate that the decline in natural gas has been responsible for 85-90% of the decline in wholesale electricity prices over that span[25]. Because the ERCOT grid has significant installed capacity of natural gas generation, an increase in the cost of natural gas will affect the marginal cost of those plants, raising wholesale market electricity prices. Figure 12 and Figure 13 illustrate this point by holding demand constant at 40 GW and increasing the cost of natural gas from $2.50 to $7/MMBTU.

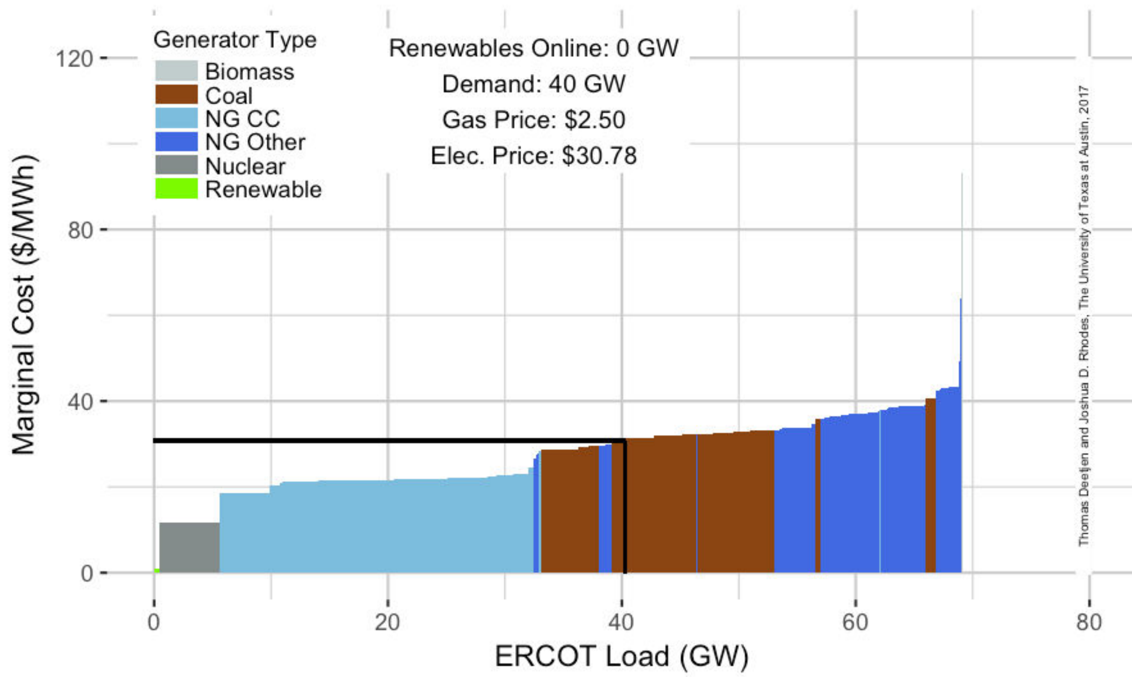

Figure 12: ERCOT bid stack and clearing price of $30.78/MWh at a load of 40 GW and natural gas price of $2.50/MMBTU.

When the price of natural gas increases from $2.50 to $7/MMBTU two impacts can be seen in the ERCOT bid stack. First, the marginal cost of natural gas plants increases. Second, those plants switch order with the coal generators such that the gas plants are later in the merit order for dispatch. Thus, at higher gas prices we use coal power plants more often, and those plants tend to consume more water and emit more air pollution than natural gas-fired plants.

[25] https://emp.lbl.gov/sites/default/files/lbnl_anl_impacts_of_variable_renewable_energy_final.pdf

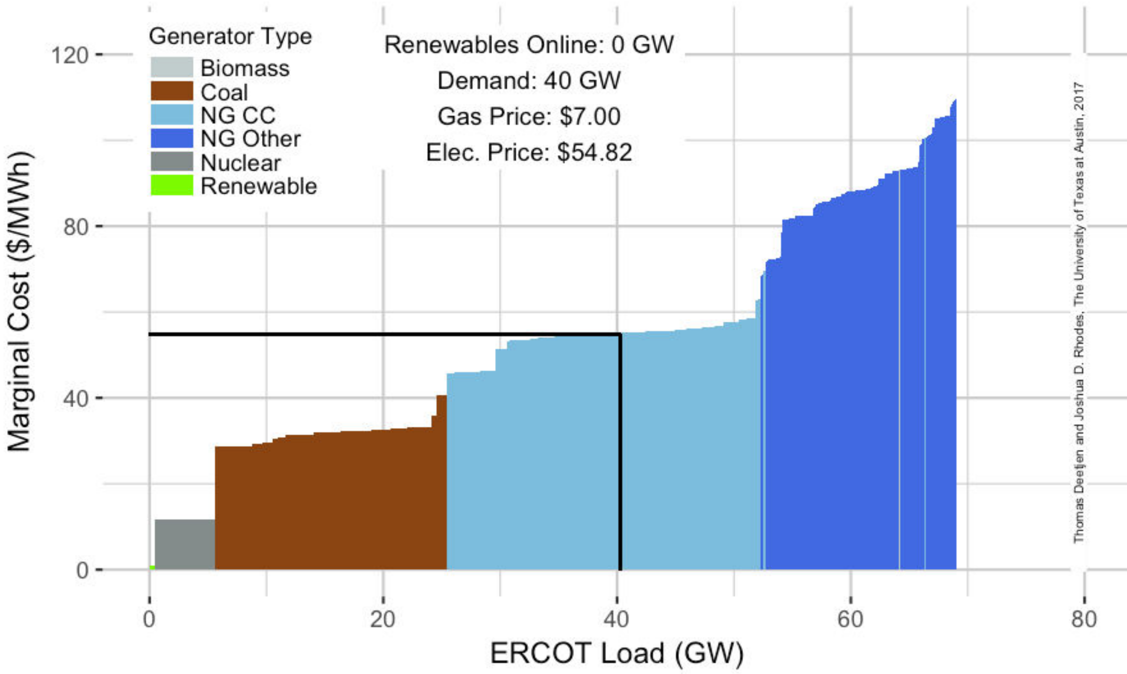

Figure 13: ERCOT bid stack and clearing price of $54.82/MWh at a load of 40 GW and natural gas price of $7.00/MMBTU.

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 14 shows that with 2 GW of renewables online, the wholesale electricity price is about $31.24 and Figure 15 shows that, with 10 GW of renewables online, the wholesale electricity price is $29.61 (holding constant demand and natural gas prices).

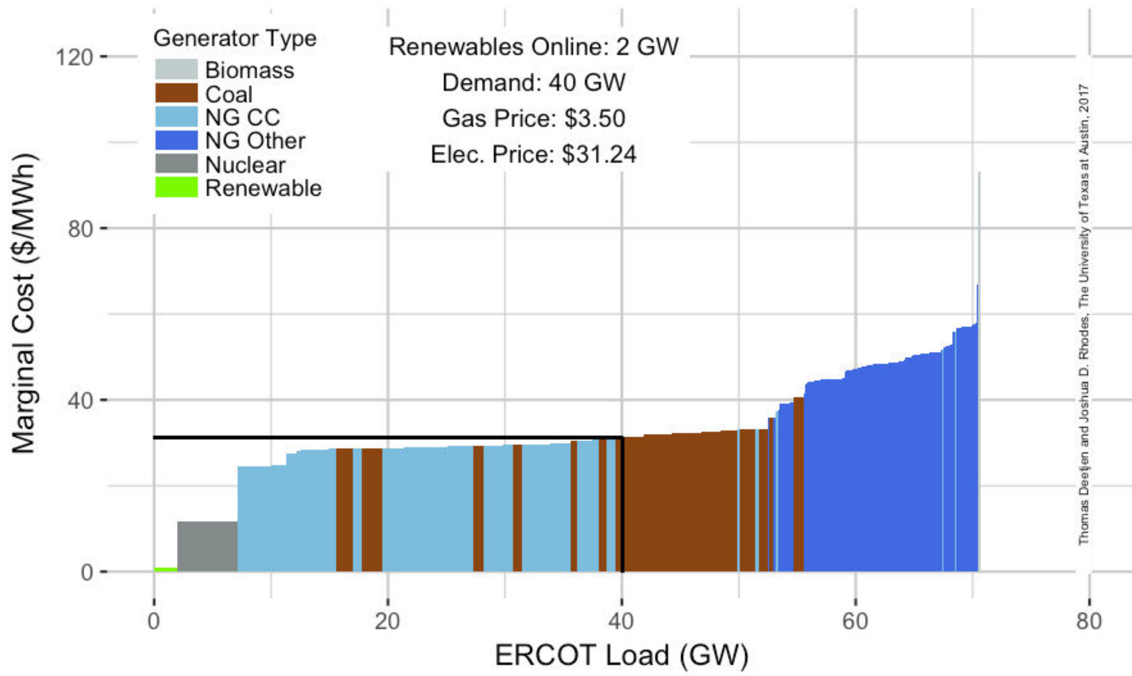

Figure 14: ERCOT bid stack with 2 GW of renewables online, a clearing price of $31.24/MWh at a load of 40 GW, and natural gas price of $3.50/MMBTU.

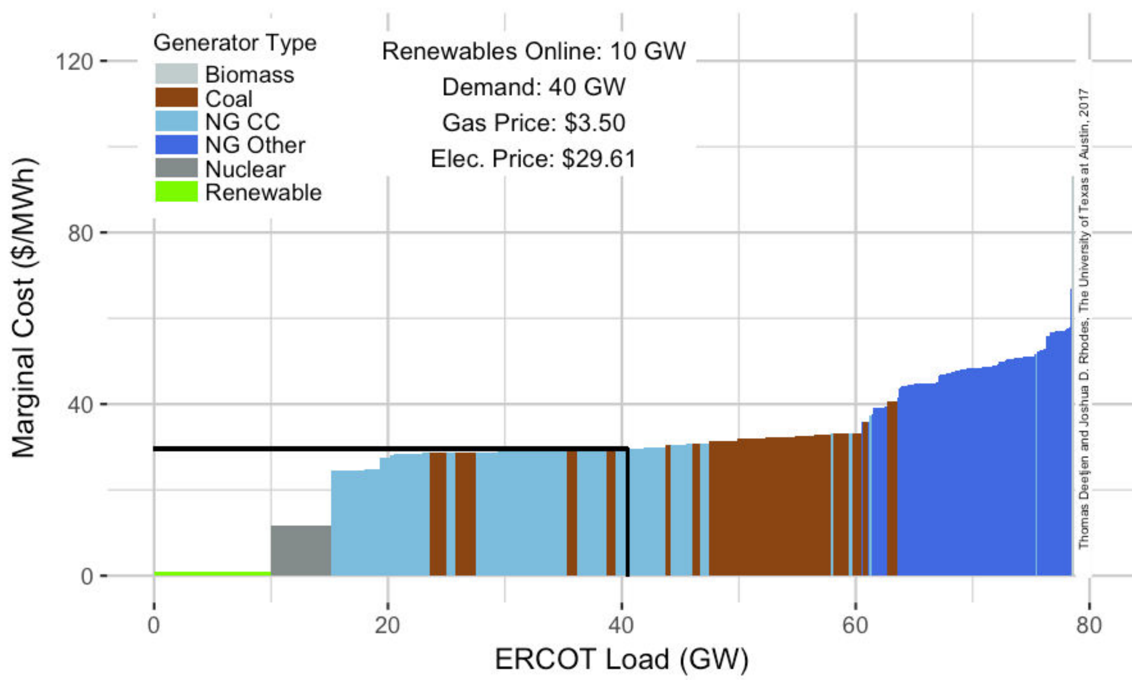

Figure 15: ERCOT bid stack with 10 GW of renewables online, a clearing price of $29.61/MWh at a load of 40 GW, and natural gas price of $3.50/MMBTU.

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[26]. However, in later years that include higher levels of renewables, 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[27,28]. 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[29].

While the impacts of renewables in ERCOT were calculated based on running yearly grid simulations with and without them in the dispatch, it is possible that generation investment decisions in a fully non-renewable world would have yielded a different thermal grid mix. However, it is likely that that generator mix would have been heavily dependent on natural gas. An analysis of such second-order effects is beyond the scope of this study.

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