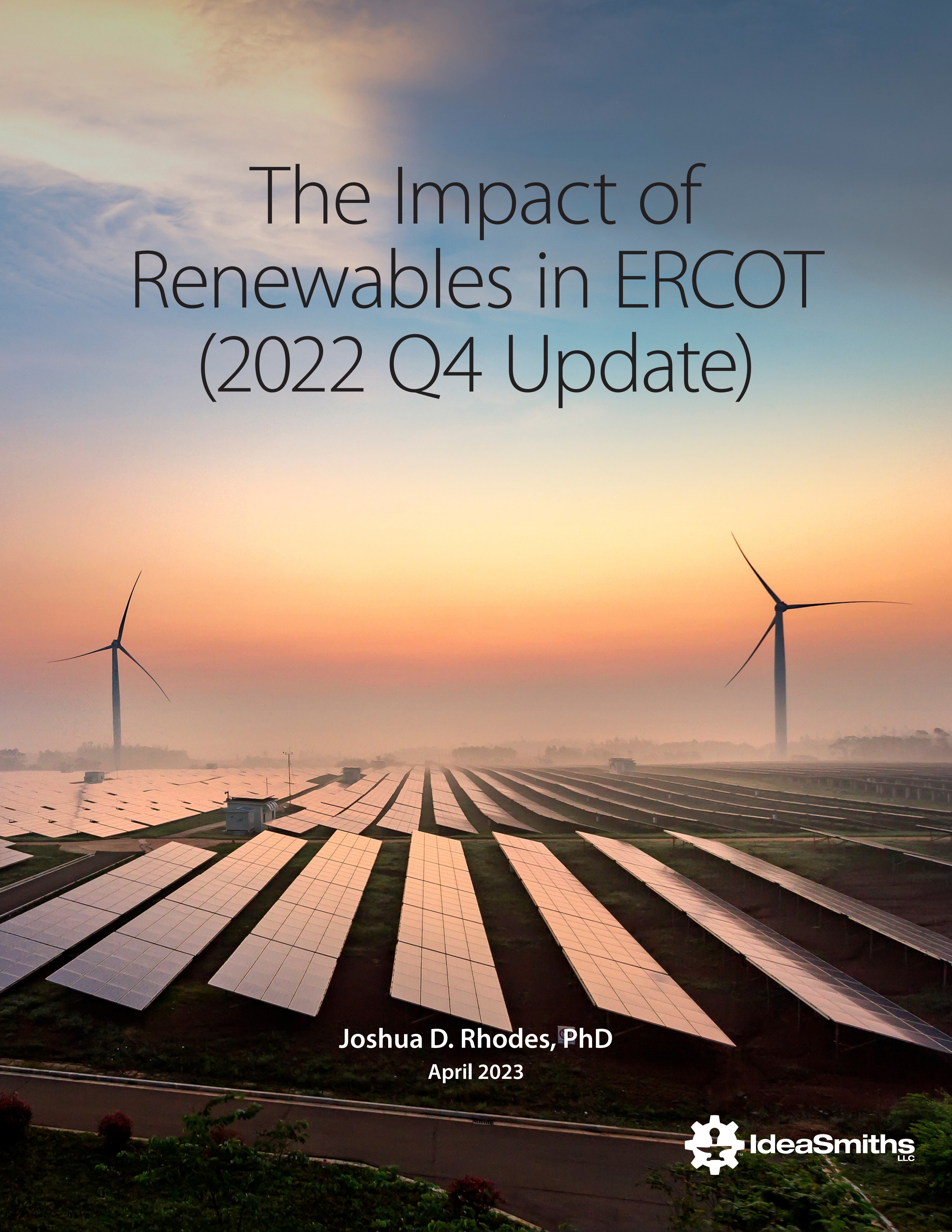
The Impact of Renewables in ERCOT (2022 Q4 Update)



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Executive Summary

This report quantifies the impacts of renewables in ERCOT on wholesale clearing prices, customer bills, water use, and emissions by comparing how the market would have performed with and without wind and solar from 2010 to 2022, as well as projecting wholesale electricity cost savings from 2023 to 2025. This analysis found that the rapid build out of renewable generation capacity since 2010 has yielded significant economic and environmental benefits for Texans in the ERCOT service area, cumulatively worth as much as $109 billion, with the potential for much more.

- The widespread adoption of renewables reduced wholesale electricity costs by about $31.5 billion between 2010 and 2022, saving consumers significantly from what they might otherwise have had to pay.
- In 2022 alone, due to high fuel prices and growth, renewables reduced ERCOT wholesale electricity market costs by about $11B (~$920M per month).
- This analysis estimates that renewables have saved the average residential household about $200 per year over the past five years.
- This analysis also projects that renewables will cumulatively reduce wholesale electricity costs by between $21B and $43B from 2023 to 2025, or between $6.1B and $15.2B per year, depending on the future price of natural gas.
- 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 and volatile in 2022 than the preceding years.
- Without renewables, power plants would have consumed an additional 252 billion gallons of water from 2010 to 2022, adding water stress to regions that are often in drought. At typical wholesale water rates of $3 to $7 per thousand gallons, 252 billion gallons of water is worth between $0.8B and $1.8B.
- Emissions reductions have cumulatively saved Texans between $10.4B and $77.6B from lower healthcare and environmental costs.
- Considering all these benefit streams, we estimate that between 2010 and 2022, renewables provided between $42B and $109B (about $52.1B 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 $11B in 2022 and about $31.5B cumulatively from 2010 to 2022, saving consumers significantly from what they might otherwise have had to pay (see Figure 1).**

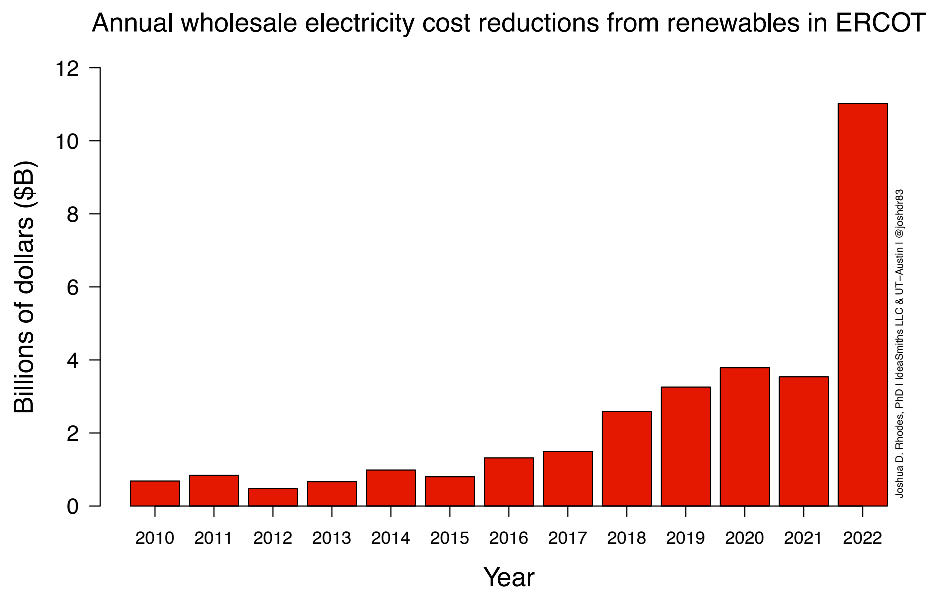

Figure 1: The estimated total annual reduction in ERCOT wholesale market costs due to wind and solar was approximately 1 to 11 billion dollars. Savings in 2022 are much higher than in previous years due to both historically higher natural gas and coal fuel costs as well as more renewables on the system.

Of the estimated $31.5 billion in savings, over one-third was realized in 2022 alone. The effect was 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.

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]. These withdrawals can increase water stress since 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

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

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

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 wind and solar, 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] and same-year wind and solar generation data for quantifying impacts. 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 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 shows a summary of the model characteristics and inputs for each year.

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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/

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	36,650	14,249	$7.52	$3.72

Table 1: The model of ERCOT depends on input parameters such as installed capacity (for wind and solar) and fuel prices (for natural gas and coal), both of which changed from year to year.

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. Table 2 shows a breakdown of the water and emissions ranges used.

Value	Low	High	Median
SO_2	$10,068/ton	$107,150/ton	$16,600/ton
NO_x	$1,578/ton	$11,956/ton	$4,750/ton
CO_2	$10/ton	$50/ton	$20/ton
Water	$3/thousand gallons	$7/thousand gallons	$3/thousand gallons

Table 2: Assumed value ranges for reduced water consumption and emissions.

Future Electricity model data

This analysis also made short-term projections of the impact of renewables on wholesale market costs for 2023 to 2025. Demand data were taken from 2022 and scaled by 2.1% per year to estimate demand profiles for 2023 to 2025 based on ERCOT's Long Term Load Forecast.[14] Power plant capacity additions for natural gas, wind, and solar were taken from ERCOT's Capacity Changes by Fuel

14 https://www.ercot.com/gridinfo/load/forecast

Type reports.[15,16] These reports indicated that about 2,100 MW of natural gas (combined cycle and open cycle), about 4,700 MW of wind, and about 31,500 MW of solar are expected to come online by the end of 2025 unless legislative action is taken by state government to prohibit these rural investments.[17]

The natural gas power plants were added to the list of power plants that the model could choose to dispatch in the year that they were expected to come online.[18] In each respective modeled future year, the 2022 wind and solar profiles were scaled based on the capacity available in 2022 and the assumed future additions and assumed that the additional capacity came online spread over the year similar to 2022.

Because fuel prices, in particular natural gas, have an outsized impact on the savings associated with renewables—that is, when natural gas prices are higher, the savings renewables provide are greater—we modeled a range of future possible natural gas prices (low, reference or mid, and high) based on the Energy Information Administration's 2023 Annual Energy Outlook[19,20] as well as a super low case of $3/MMBTU for all years. For future coal prices, we used projections from the EIA's Short Term Energy Outlook[21] except for the super low gas case where we assumed a constant low price of $2.50/MMBTU for all years. Table 2 shows a summary of the values used to create the future model runs.

Year	Wind capacity (MW)	Solar capacity (MW)	Natural gas price case	Natural gas price ($/MMBTU)	Coal price ($/MMBTU)
2023	39,079	21,231	Super low	3.00	2.50
			Low	5.44	2.61
			Mid	6.16	2.56
			High	7.34	2.51
2024	41,267	40,686	Super low	3.00	2.50
			Low	4.04	2.61
			Mid	4.76	2.56
			High	6.74	2.51
2025	41,618	45,727	Super low	3.00	2.50
			Low	3.42	2.61
			Mid	4.08	2.56
			High	6.40	2.51

Table 3: Table showing model input assumption values for each projected future year.

15 We used the February 2023 version: https://www.ercot.com/gridinfo/resource

16 While batteries are not modeled directly, it is assumed they help in the deployment of wind and solar by reducing curtailment of those resources.

17 We assumed that all projects with signed interconnection agreements will come online on time.

18 Because performance data (heat rate, water consumption, etc.) were not available for these power plants, we assumed that they were best in class and gave them the most efficient characteristics based on other similar types of power plants. This also is a conservative estimate given the relative uncertainty of what month these resources would enter service.

19 https://www.eia.gov/outlooks/aeo/data/browser/

20 The "mid" natural gas price forecast comes from the AEO "Reference Case", the "low" natural gas price forecast comes from the AEO "High Oil and Gas Supply" case, and the "high" natural gas price forecast comes from the AEO "Low Oil and Gas Supply" case.

21 Release date: March 7, 2023. https://www.eia.gov/outlooks/steo/

Results

The results of this analysis indicate that between 2010 and 2022, if there had been no solar or wind generation in ERCOT, the power sector would have withdrawn 8.8 trillion more gallons of water[22], consumed 252 billion more gallons of water[23], emitted 410 thousand tons more SO_2, emitted 324 thousand tons more NO_x, and emitted 577 million tons more CO_2. That magnitude of additional water consumption and emissions would have induced between $10.7B and $77.7B in environmental and public health costs[24] over this time period[25]. Also, if wind and solar had not existed during this time period, higher wholesale electricity market prices would have resulted in an additional $31.5B in systemwide 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 based on marginal-cost dispatch schemes, 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 2022) per year. The higher reductions in 2022 result from greater installed capacity of wind and solar offsetting historically high natural gas and coal prices.

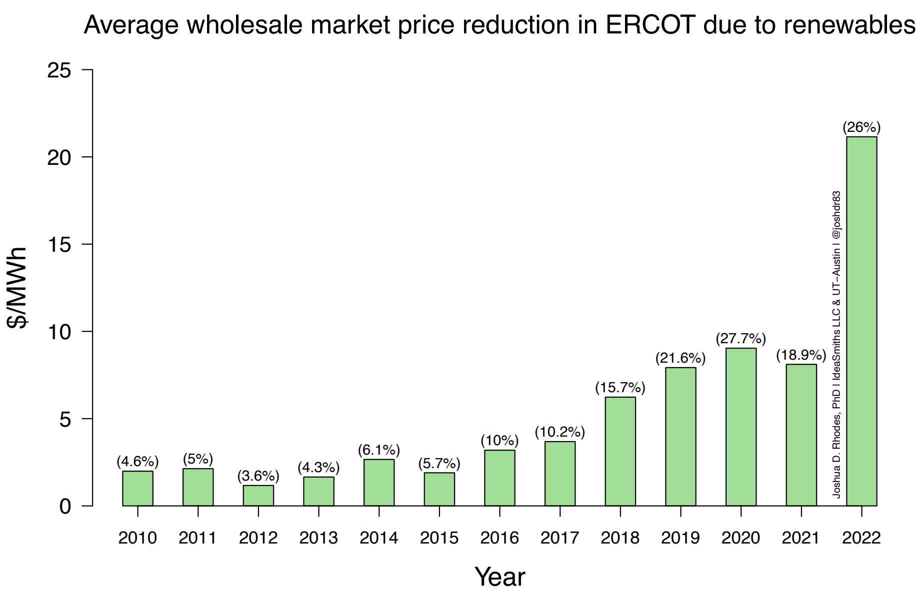

Figure 2: Modeled yearly average wholesale electricity market price reductions attributed to renewables for 2010 to 2022 vary from less than 5% to approximately 26%. Percentages above each bar indicate relative reduction in average wholesale market costs due to renewables.

22 Water withdrawals refer to water that used by a power plant for cooling but returned to a watershed.

23 Water consumption refers to water that is consumed (evaporated) by a power plant's cooling system and is not available for other uses

24 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.

25 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 2022, wind and solar are estimated to have reduced the average wholesale electricity cost by about $21.15/MWh, or by about 26% compared to expected prices on a renewables free grid. Average market prices in 2022 were about $62/MWh, so our analysis implies costs would have been over $84/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 $11B per year ($31.5B in total for 2010 through 2022). Further, we estimate that renewables have reduced ERCOT wholesale market costs by about $920 million per month in 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 2022 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 over $7/MMBTU in 2022 and falling back close to $2/MMBTU in early 2023. Further, higher global demand for natural gas coupled with an increase in the LNG export capacity of the US could put upward pressure on domestic natural gas prices (as is the case with oil). Higher natural gas prices would then lead to higher electricity costs as over 40% of the Texas electricity fleet uses natural gas.

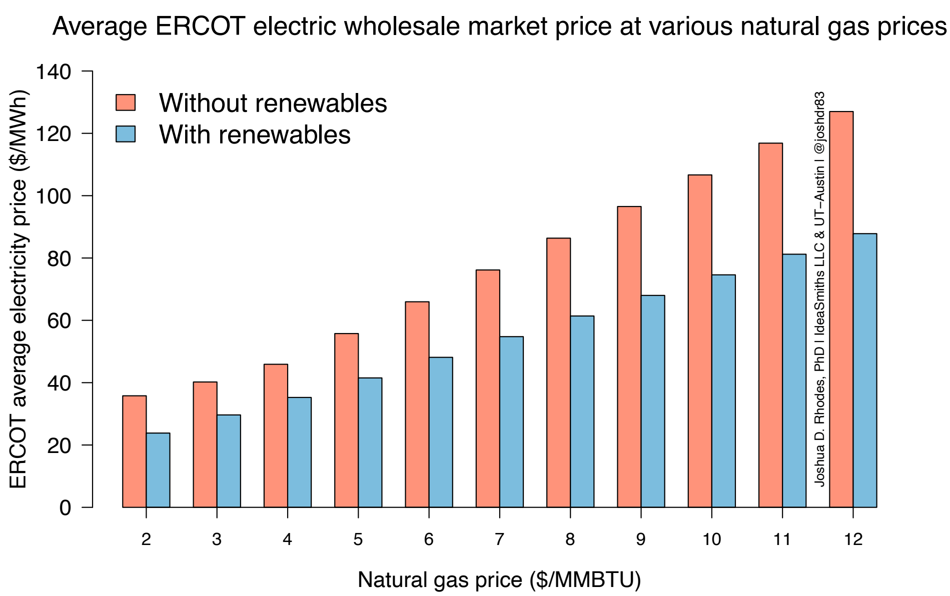

Figure 3: Natural gas prices are critical drivers of ERCOT's wholesale electricity market price and use of renewables avoids some of those costs. Note that all groups of bars are for 2022 generation and capacity, but with a range natural gas prices for illustration purposes. Natural gas prices have historically ranged between $2-4/MMBTU range but rose to over $7/MMBTU on average in 2022.

Combined impact of renewables on ERCOT

Figure 4 shows the combined benefits of water savings, avoided emissions, and reduced electric wholesale market cost per year in ERCOT from renewables assuming median values for water and emissions.[26] 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 have been increasing with time. We estimate that renewables have saved between $1.2B (in 2010) and $13.2B in (in 2022) per year, about $52.1B in total, using median values for water and emissions reductions.

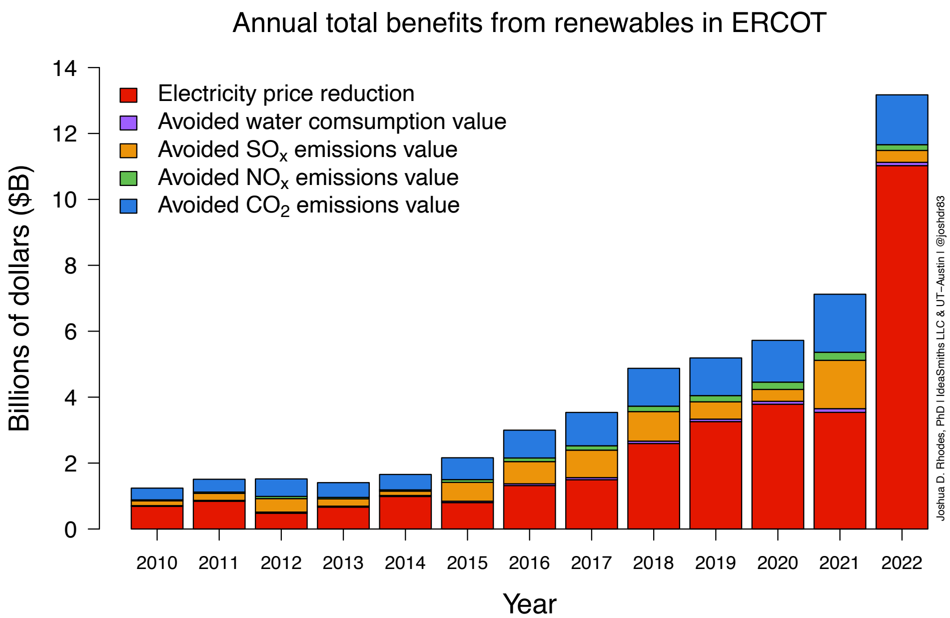

Figure 4: Annual benefits from renewables in ERCOT for 2010 to 2022 vary from $1.2 to 13.2 billion and cumulatively sum to about $52.1 billion. Median values (from all Texas counties) of damages were used to monetize the emissions reductions (SOx: $16,600/ton, NOx: $4,750/ton, CO2: $20/ton, water: $3/thousand gallons).

26 Median emissions and water values: SO_x: $16,600/ton, NO_x: $4,750/ton, CO_2: $20/ton, water: $3/thousand gallons

Impact of renewables on water and emissions

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

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 8.8 trillion gallons total from 2010 to 2022. For reference, 1,300 billion gallons is the annual use of about 14.2 million Texans[27].

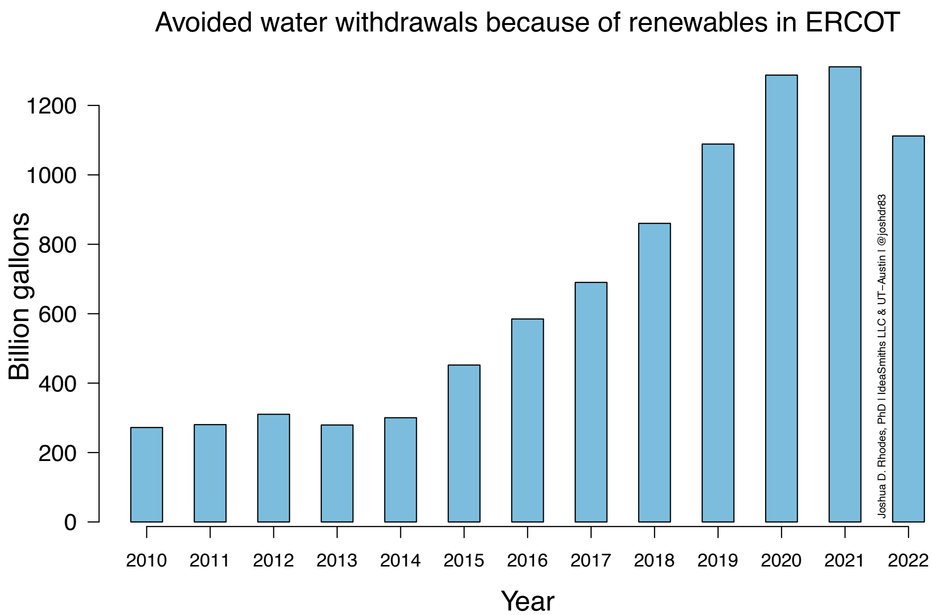

Figure 5: Modeled water withdrawal reductions attributed to renewables for 2010 to 2022 varied from over 200 to over 1200 billion gallons per year. Water withdrawals refer to water that is used by a power plant for cooling, most of which is returned to the source, usually at a higher temperature.

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

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 252 billion gallons between 2010 and 2022. For reference, 252 billion gallons is about the twice the annual consumption of Dallas, TX[28] or enough to hydraulically fracture between 72,000 to 210,000 natural gas wells, depending on well type and formation[29]. At typical wholesale water rates of $3 to $7 per thousand gallons, 252 billion gallons of water is worth between $0.8B and $1.8B.

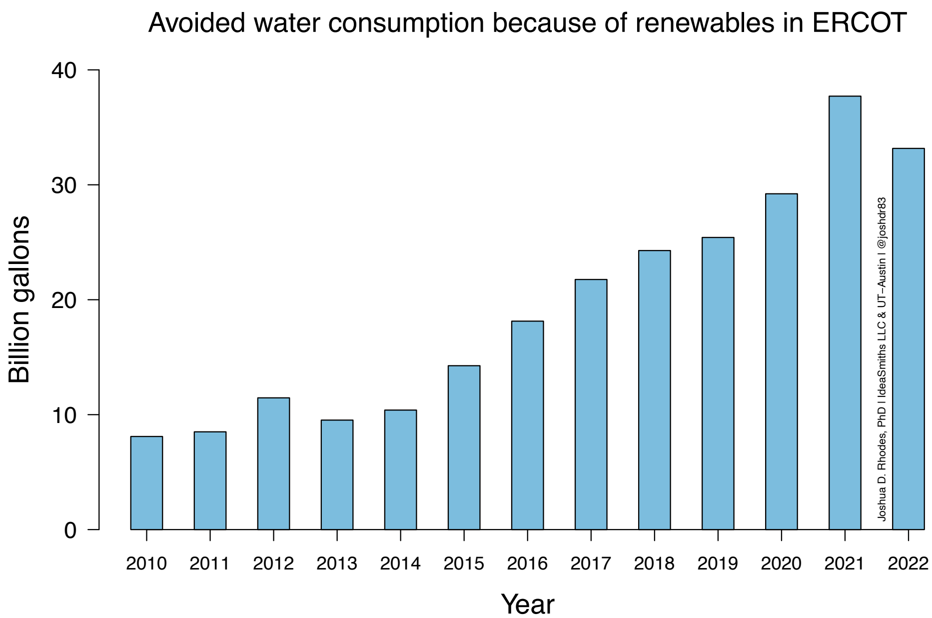

Figure 6: Modeled water consumption reductions attributed to renewables for 2010 to 2022 varied from under 10 billion to nearly 40 billion gallons annually. Water consumption refers to water that is evaporated by a power plant's cooling system and is not available for other uses.

28 https://www.cbsnews.com/texas/news/city-of-dallas-asks-residents-businesses-to-conserve-water-as-demand-increases/

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

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 410 thousand cumulative tons since 2010. Avoided SO_2 emissions yielded Texans between $4.1B and $43.9B 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.

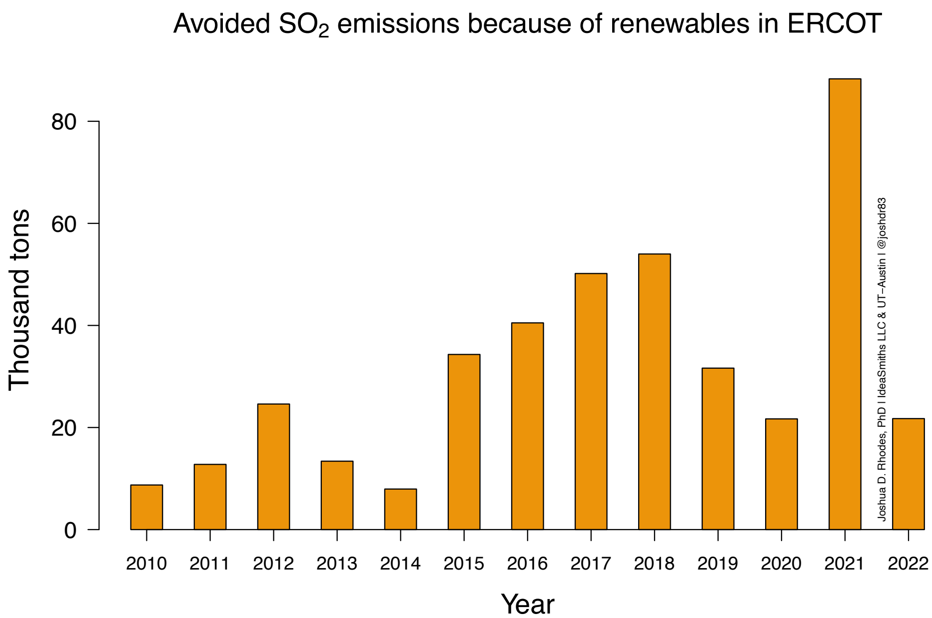

Figure 7: Modeled SO_2 emissions reductions attributed to renewables for 2010 to 2022 varied between approximately 10 to more than 80 tons annually.

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 324 thousand cumulative tons from 2010 to 2022. Not breathing these NO_x emissions saved Texans between $511M and $3.9B in health costs over this same period.

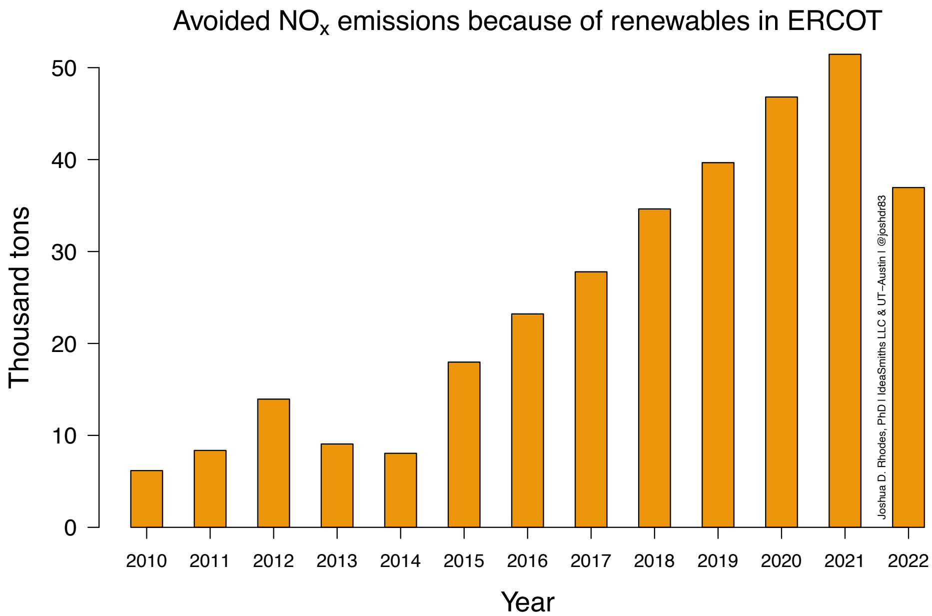

Figure 8: Modeled NO_x emissions reductions attributed to renewables for 2010 to 2022 varied from over 5 to 50 thousand tons annually.

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 577 million cumulative tons between 2010 and 2022. Not emitting this CO_2 is worth between $5.7B and $28.9B (at $10 and $50/ton of CO_2 respectively) in total since 2010.

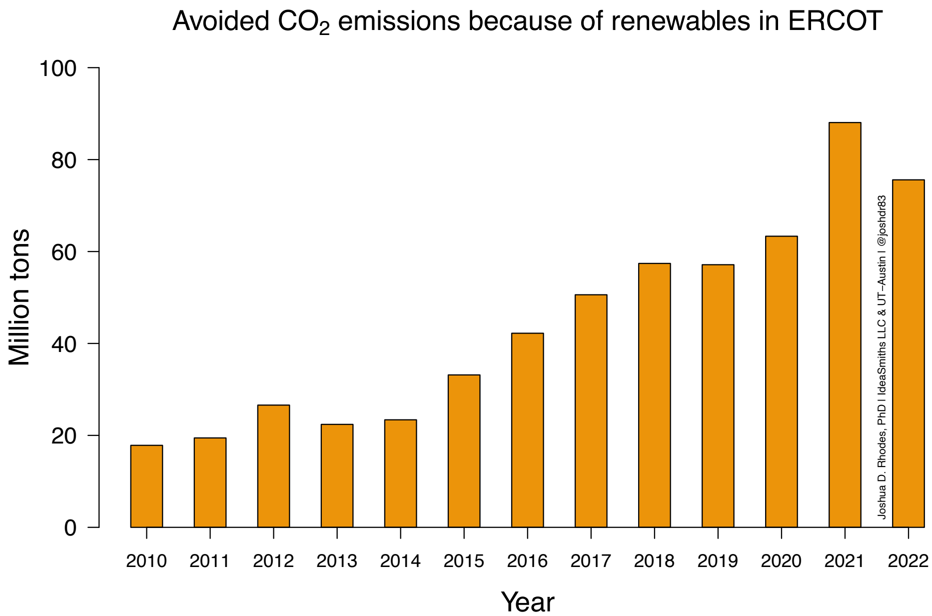

Figure 9: Modeled CO_2 emissions reductions attributed to renewables for 2010 to 2022 vary from approximately 20 to 90 million tons annually.

Wholesale market cost impacts on residential electricity bills

Electricity rates differ from wholesale electricity market costs in that they also contain additional costs associated with the transmission and distribution of electricity. Some customer classes, such as residential consumers, generally pay a volumetric rate for electricity that includes these fixed costs on a per kWh basis.[30] In Texas, electricity rates have been volatile[31] in the past few years due to economic recovery in the electricity sector after the February 2021 winter storm.

Electricity rates have generally been calculated based on two main components; 1) what the utility must pay to generate or buy the electricity and 2) the costs associated with moving the electricity to the end user (transmission and distribution, T&D). Historically, electricity rates are about 60% energy and 40% T&D.[32,33]

30 Commercial and industrial electricity users have a wider variety of rate structures that vary depending on their size and might include non-volumetric charges, such as demand and 4CP charges that are beyond the scope of this analysis.

31 https://www.puc.texas.gov/industry/electric/rates/resrate.aspx

32 https://www.eia.gov/todayinenergy/detail.php?id=32812

33 https://www.eia.gov/outlooks/aeo/section_issue_renewables.php

According to the EIA, Texas residential retail rates averaged about 11.6 cents per kilowatt-hour (¢/kWh) from 2010 to 2022.[34] Assuming that about 60% of this rate is influenced by wholesale electricity costs (and using values from Figure 2) we estimate that, without renewables, average electricity rates in Texas over the same period would have been about 12.47 ¢/kWh, or about 8% higher. Even if we assumed that T&D costs increased at the same rate that energy costs decreased to support the integration of renewables, we still estimate that rates would be about 2% higher without the integration of renewables in ERCOT.

The past five years (2018-2022) have seen the fastest growth in renewables in the state. Using just these years and the same methodology as above, we estimate that renewables have reduced overall residential electricity rates by about 1.6 ¢/kWh, or about 13%. The average Texas household consumes about 1,100 kWh per month, or about 13,200 kWh per year.[35] For 2018 to 2022, the average residential electricity rate in Texas was about 12.1 ¢/kWh which indicates that the average Texas household paid about $1,600 per year for electricity. Without renewables, this analysis estimates that that rate would have been closer to about 13.7 ¢/kWh (for 2018-2022) which would put the average annual residential electricity bill at about $1,800. Thus, over the past five years, this analysis estimates that renewables have saved Texas households about $200 per year on electricity.

Starting from the top, we estimate that renewables have reduced wholesale market costs by about $24.2B from 2018-2022. There are about 10.26 million households in Texas.[36] If 90% of these households are in ERCOT[37] and residential customers consume about 36%[38] of Texas electricity indicates that renewables (from 2018-2022) have saved the average Texas household about $189 per year on electricity, which very closely aligns with our bottom-up estimate above.

34 https://www.eia.gov/electricity/data/browser/#/topic/7?agg=0,1&geo=vvvvvvvvvvvvo&endsec=vg&linechart=ELEC.PRICE.TX-RES.A~~~~ELEC.PRICE.US-RES.A&columnchart=ELEC.PRICE.TX-ALL.A~ELEC.PRICE.TX-RES.A~ELEC.PRICE.TX-COM.A~ELEC.PRICE.TX-IND.A&map=ELEC.PRICE.US-ALL.A&freq=A&start=2001&end=2022&ctype=linechart&ltype=pin&rtype=s&pin=&rse=0&maptype=0

35 https://www.eia.gov/electricity/sales_revenue_price/pdf/table5_a.pdf

36 https://www.eia.gov/consumption/residential/data/2020/index.php?view=state

37 https://www.ercot.com/files/docs/2022/02/08/ERCOT_Fact_Sheet.pdf

38 https://www.eia.gov/electricity/sales_revenue_price/pdf/table2.pdf

Potential future costs savings from renewables in ERCOT

This analysis also sought to estimate the potential wholesale market cost savings in the near-term under a range of possible future conditions. The same methods that were used to calculate historical savings were also used to calculate potential future savings given the growth of renewables and forecast ranges for fuel prices (see Table 2). Figure 10 shows estimates for 2023, 2024, and 2025 under a super low, low, mid, and high natural gas price future.

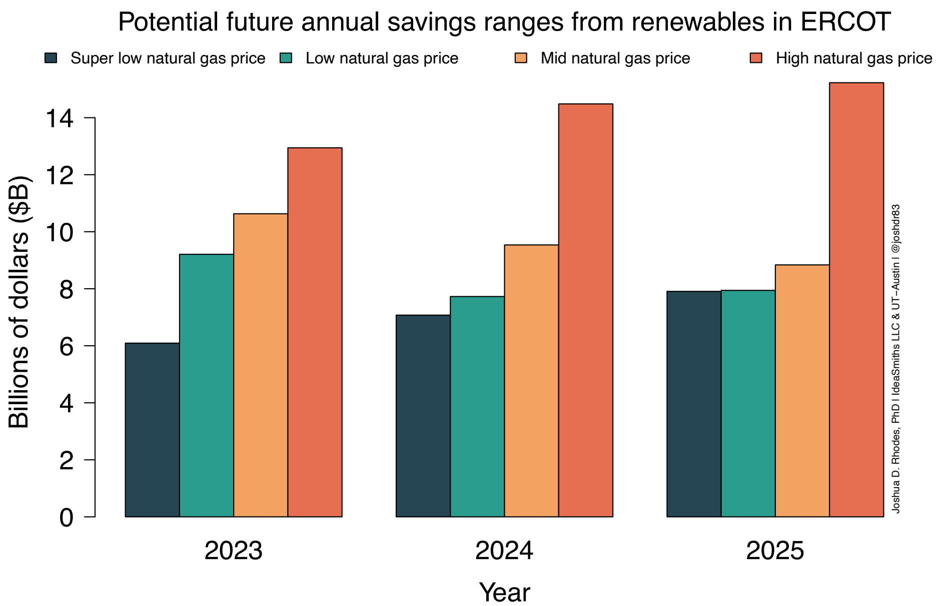

Figure 10: Figure showing potential annual wholesale market cost savings from renewables in ERCOT under super low, low, mid, and high natural gas price assumptions, based on EIA short-term natural gas price forecasts. Future years demand was based on 2022 demand, scaled by 2.1% per year and future capacity additions (wind, solar, and natural gas) were based on ERCOT's February 2023 CDR report.

This analysis estimates that renewables will save between $21B and $43B in total from 2023 to 2025, or between $6.1B and $15.2B per year if all natural gas, wind, and solar projects that currently outlined in ERCOT's Capacity Changes by Fuel Type reports come online by their stated start dates[39] and natural gas prices are between $3.42/MMBTU and $7.34/MMBTU as projected by the EIA, or $3/MMBTU for a super low case. While not directly calculated here, we estimate that renewables will save billions more gallons of water and result in lower emissions, just as they have in the past.

39 We used the February 2023 version: https://www.ercot.com/gridinfo/resource

Conclusions

This analysis indicates that renewables have 1) reduced ERCOT wholesale electricity market prices, 2) reduced customer bills, 3) reduced the water intensity of the ERCOT grid, and 4) reduced the emissions 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 2022, we estimate that renewables provided between $42B and $109B in total benefits to Texas residents in the ERCOT service territory. We also estimate that renewables have saved the average Texas household about $200 per year in Texas and that the next few years could see similar savings.

Acknowledgements

This work is supported by Texas Consumer Association and funded by the Consumer Fund of Texas, a 501(c)(3) research organization.[40]

About Us

IdeaSmiths LLC[41] 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.

40 https://www.texasconsumer.org/

41 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 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[42] 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 to 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[43]. 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

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

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

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.

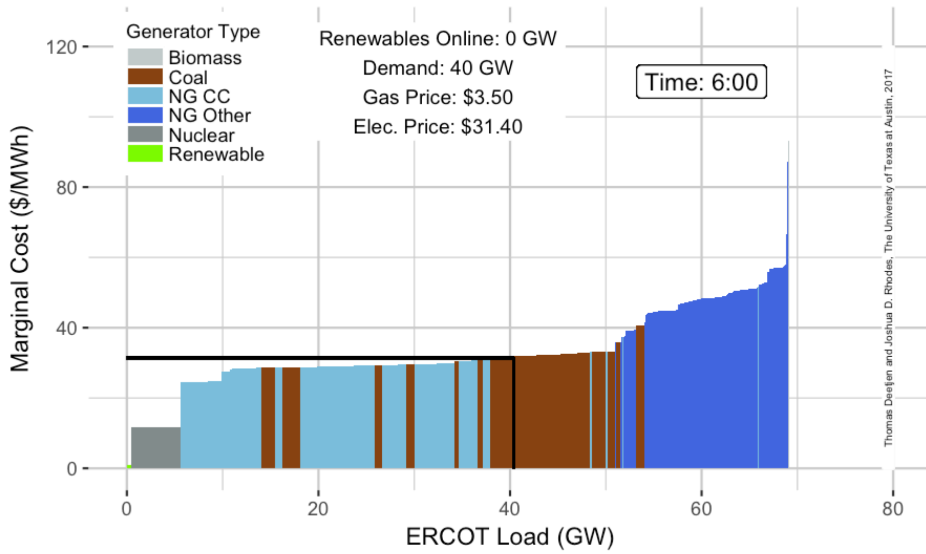

Figure 11: ERCOT bid stack and clearing price of $31.40/MWh at a load of 40 GW and natural gas price of $3.50/MMBTU.

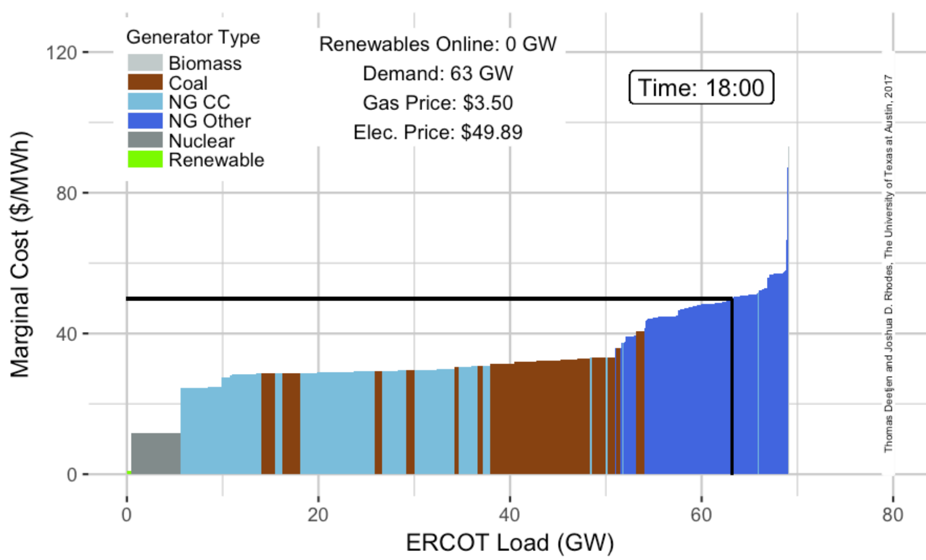

Figure 12: ERCOT bid stack and clearing price of $49.89/MWh at a load of 63 GW and natural gas price of $3.50/MMBTU.

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[44]. 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

44 https://emp.lbl.gov/sites/default/files/lbnl_anl_impacts_of_variable_renewable_energy_final.pdf

by holding demand constant at 40 GW and increasing the cost of natural gas from $2.50 to $7/MMBTU.

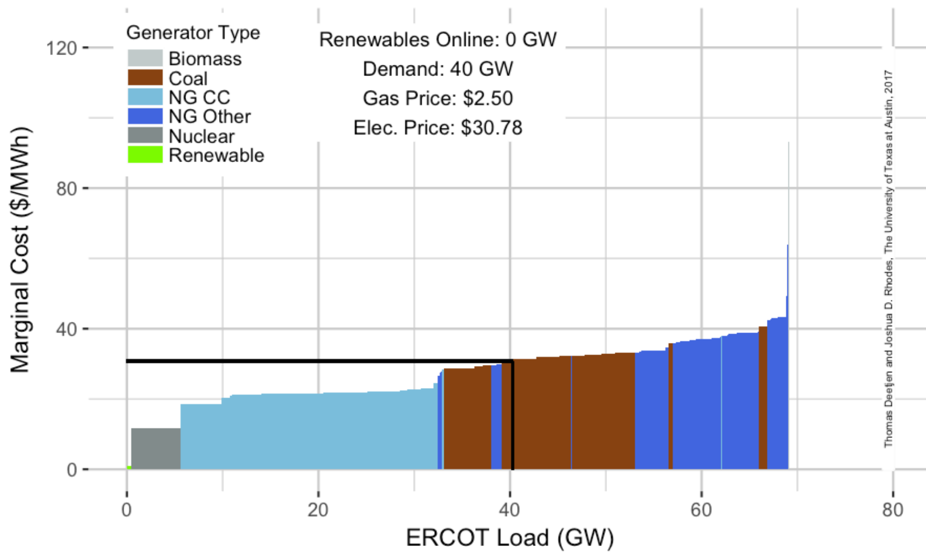

Figure 13: ERCOT bid stack and clearing price of $30.78/MWh at a load of 40 GW and natural gas price of $2.50/MMBTU.

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.

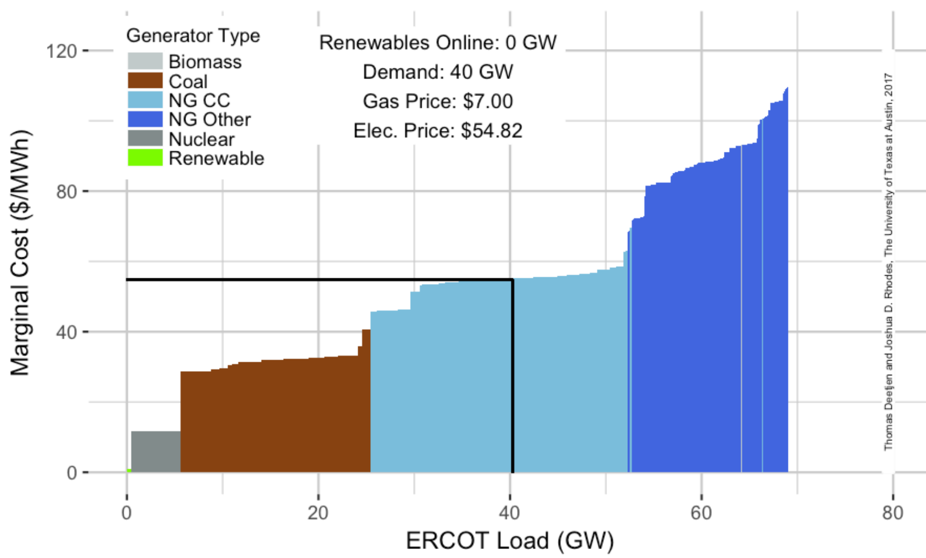

Figure 14: ERCOT bid stack and clearing price of $54.82/MWh at a load of 40 GW and natural gas price of $7.00/MMBTU.

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).

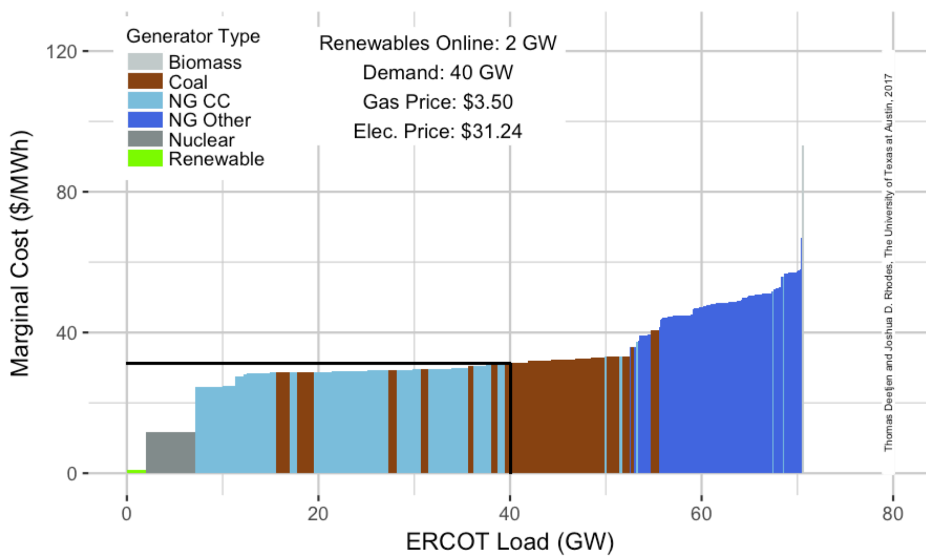

Figure 15: ERCOT bid stack with 2 GW of renewables online, a clearing price of $31.24/MWh at a load of 40 GW, and natural gas price of $3.50/MMBTU.

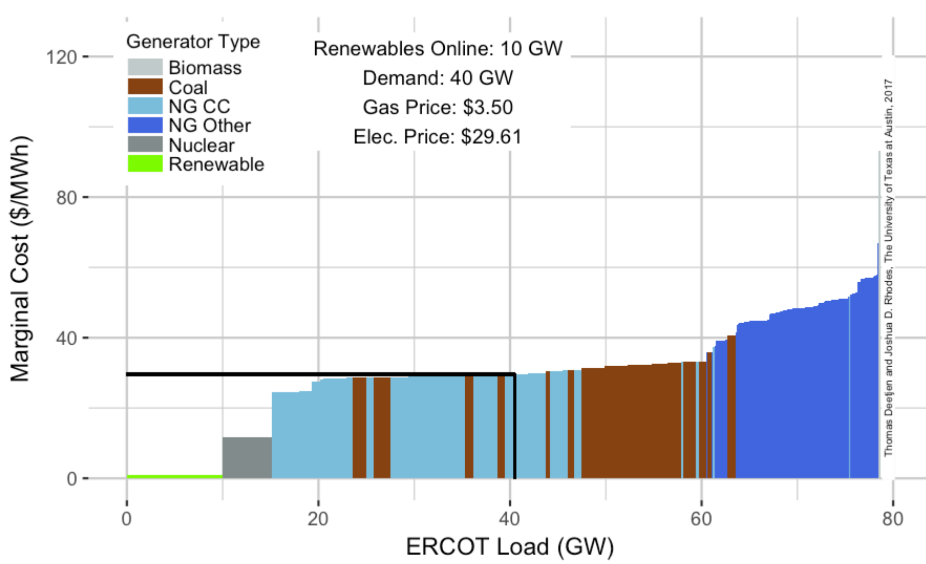

Figure 16: ERCOT bid stack with 10 GW of renewables online, a clearing price of $29.61/MWh at a load of 40 GW, and natural gas price of $3.50/MMBTU.

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[45]. 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[46,47]. 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[48].

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.

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

46 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.

47 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

48 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.