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Impacts of renewables in ERCOT

Prepared for TXP

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Executive Summary

The purpose of this analysis is to estimate the impacts on water use, emissions, and wholesale electricity market prices from renewable (wind and solar) generation in ERCOT. Because renewable generation does not consume any water or produce emissions at the point of generation, any offset of other types of generation will reduce the water and emissions intensity of the grid, providing multiple benefits. Because renewable sources such as wind and solar have zero marginal fuel cost, they reduced wholesale clearing prices in ERCOT, which is economically beneficial to consumers, but reduces revenues and profits for producers.

In 2015, Texas power plants withdrew almost four trillion gallons of water for power plant cooling[1]. 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 economic sectors, such as agriculture and oil and gas extraction, can benefit from increased supply[3] that would occur from reduced water use in the power sector. Many thermal power plants share the same watersheds as growing cities that are eager to expand water resources, so increasing renewables can reduce water 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, the public health benefits are worth $12,000 per ton of avoided nitrogen oxides (NO_x) missions and $107,000 per ton of avoided sulfur oxide (SO_x) emissions[4]. These benefits are largely due to fewer Texans having to seek medical services due to environmentally-related respiratory problems. We also considered the benefits of carbon dioxide (CO_2) emissions at $10-$50/ton.

To quantify the water and emissions impacts from using renewables for Texans' electricity needs, this analysis simulated meeting total electricity demand from 2010 to 2017 with and without these resources available to ERCOT. Power plant specific data were taken from previous grid studies[5] [6] and utilized for this analysis. The difference (with and without renewables) in total yearly water withdrawals, water consumption, and emissions of NO_x and SO_x were calculated as the environmental impacts of having renewables on the grid.

In total between 2010 and 2017, we estimate The economic impacts of widespread adoption of renewables reduced wholesale energy expenditures by about $5.7B between 2010 and 2017 saving consumers significantly. Renewables contributed between $11B and $54B of benefits to Texans from reduced emissions, reduced water consumption, and lower wholesale electricity costs. Reduced emissions accounted for

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between $5.8B and $47.3B in benefits to human health. Avoiding 100B gallons of water consumption resulted in between $100M and $400M in value.

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 2017. Figure 1 though Figure 6 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.

Data

The model used historical system load data[7] and available wind generation data for computation. For years when actual wind and solar generation data were not available, typical ERCOT wind and solar profiles were normalized by installed capacities[8] to estimate their effect on the marginal bid stack. Each set of annual data were matched with their yearly average natural gas price[9]. The delivered price of coal was assumed to be $2.50/MMBTU for all years.

*Table 1: Model assumptions for each year. Capacities marked with a * indicate that installed capacities of wind and solar were multiplied by hourly capacity factors because measured data were not available.*

Year	Wind capacity (MW)	Solar capacity (MW)	Natural gas price ($/MMBTU)
2010	9,400*	15*	$5.08
2011	9,604*	42*	$4.72
2012	10,407*	82*	$3.41
2013	11,065*	93*	$4.33
2014	12,470*	193*	$5.00
2015	12,730 – 16,170	228*	$3.26
2016	16,246 – 18,923	556*	$2.88
2017	18,923 – 21,182	1,000*	$3.39

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.

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Model execution

For every hour, for 2010-2017, 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[10]. There are three major drivers that affect how prices are formed and which power plants are dispatched: 1) demand, 2) natural gas price, and 3) installed capacity of renewables online.

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 1 and Figure 2 show this difference. In Figure 1, early morning ERCOT demand is 40 GW and the resulting electricity price is about $31/MWh. In Figure 2, 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.

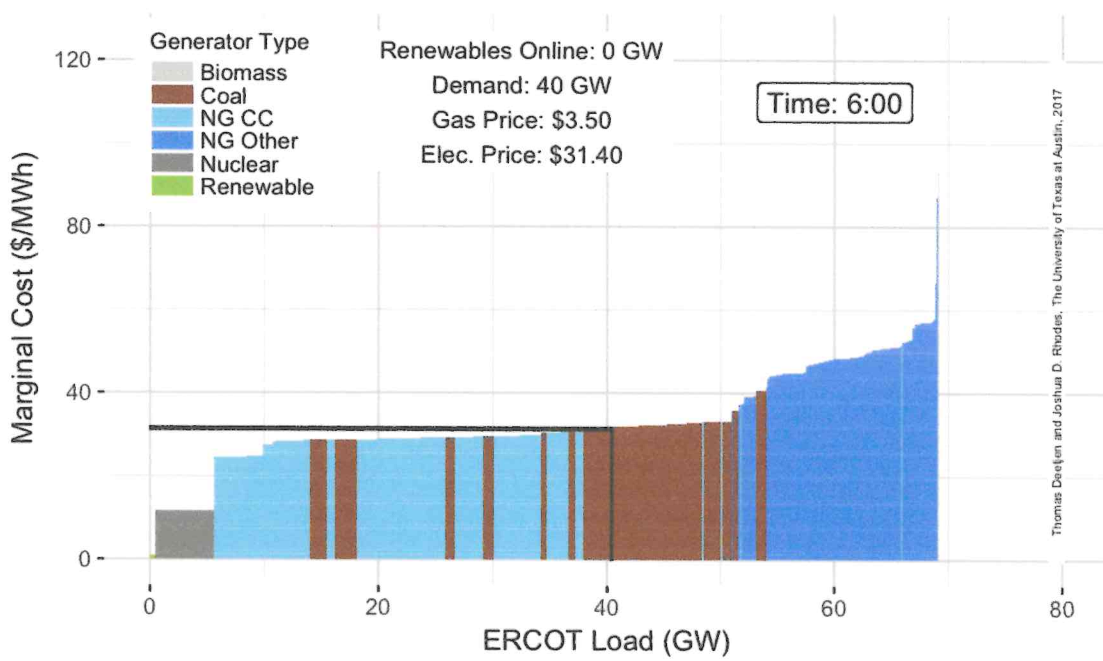

Figure 1: ERCOT bid stack and clearing price of $31.40/MWh at a load of 40 GW and natural gas price of $3.50/MMBTU.

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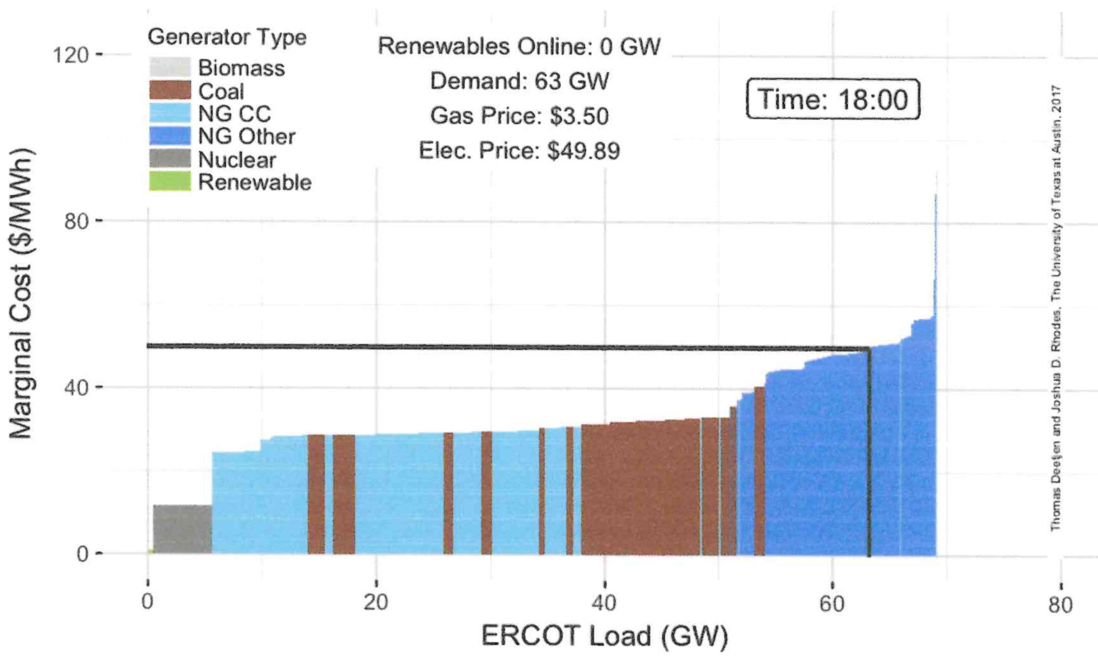

Figure 2: ERCOT bid stack and clearing price of $49.89/MWh at a load of 63 GW and natural gas price of $3.50/MMBTU.

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[11]. 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 3 and Figure 4 illustrate this point by holding demand constant at 40 GW and increasing the cost of natural gas from $2.50 to $7/MMBTU.

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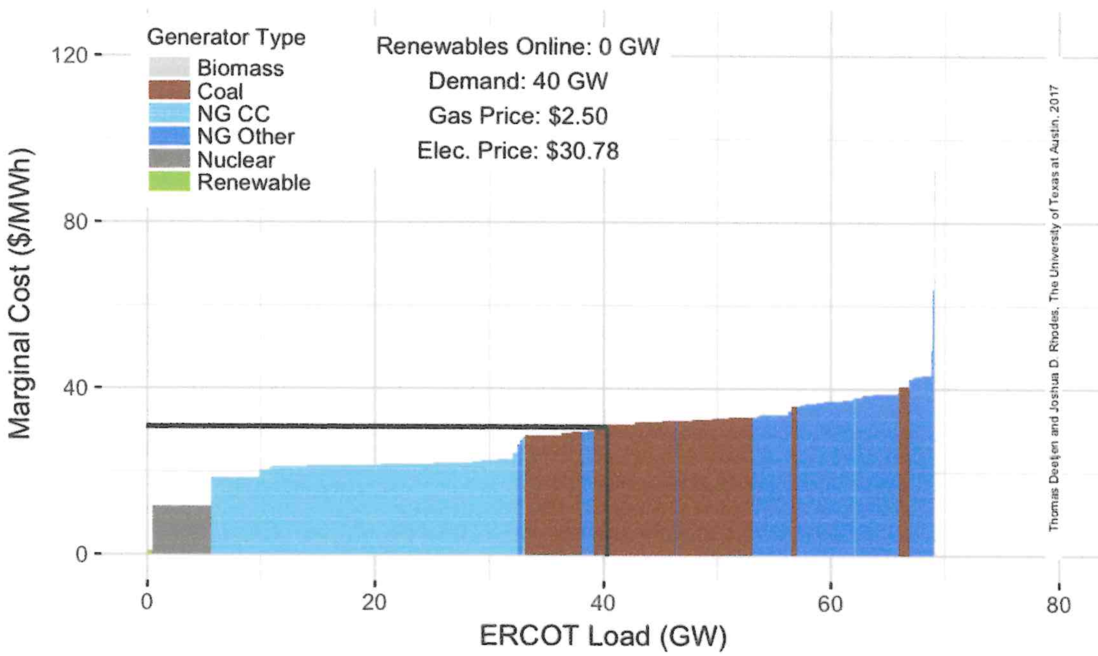

Figure 3: ERCOT bid stack and clearing price of $30.78/MWh at a load of 40 GW and natural gas price of $2.50/MMBTU.

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.

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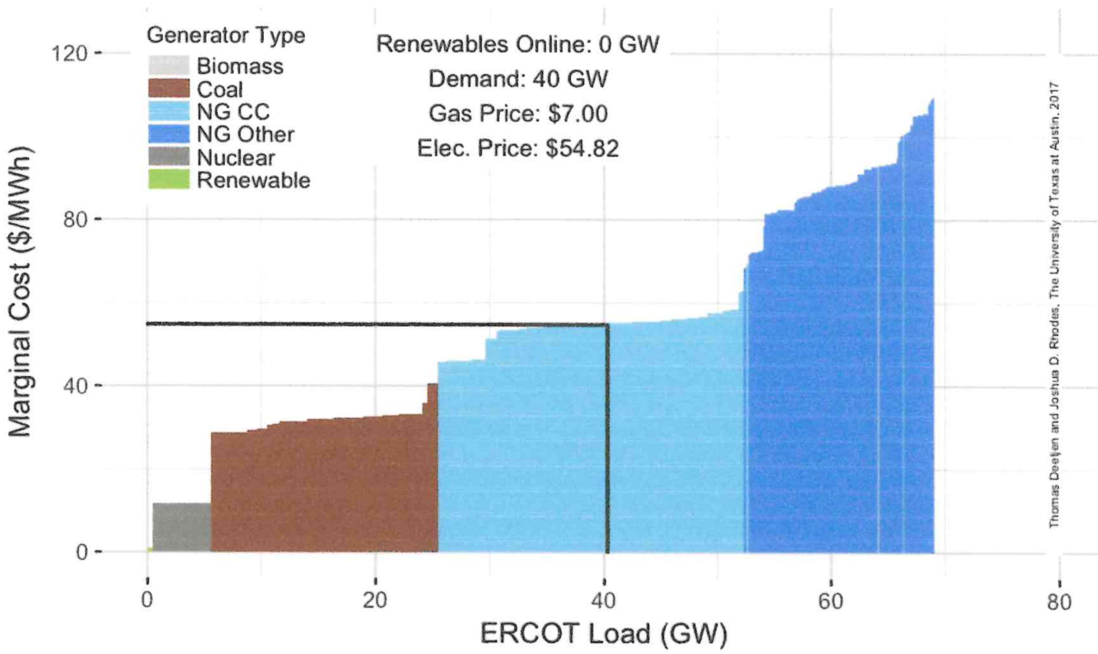

Figure 4: ERCOT bid stack and clearing price of $54.82/MWh at a load of 40 GW and natural gas price of $7.00/MMBTU.

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 (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 5 shows that with 2 GW of renewables online, the wholesale electricity price is about $31.24 and Figure 6 shows that, with 10 GW of renewables online, the wholesale electricity price is $29.61 (holding constant demand and natural gas prices).

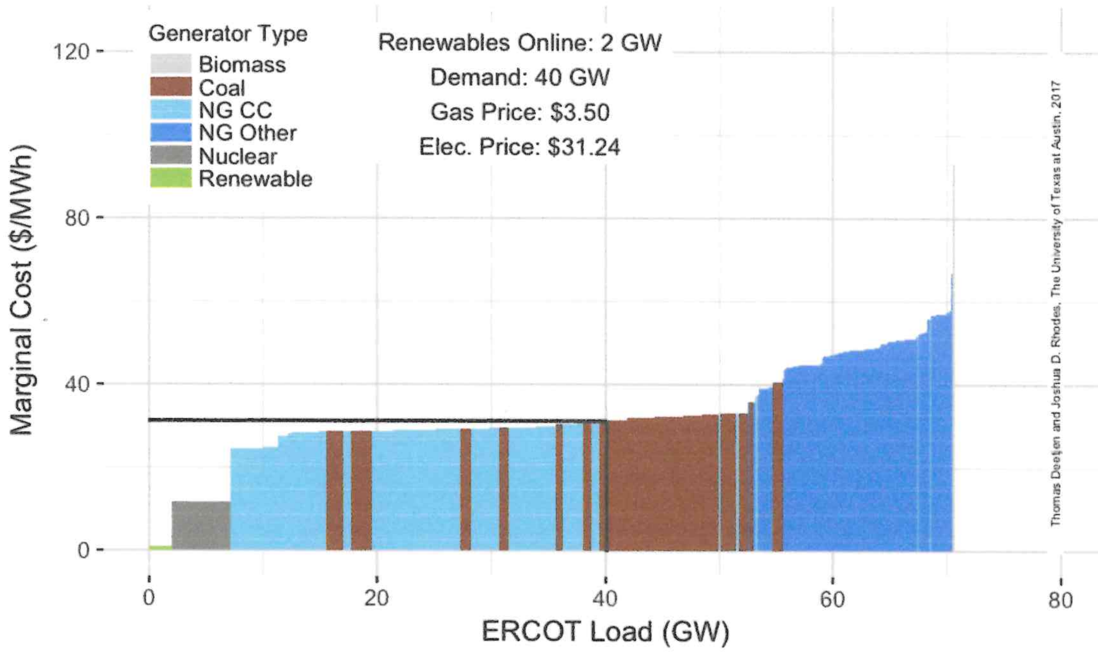

Figure 5: ERCOT bid stack with 2 GW of renewables online, a clearing price of $31.24/MWh at a load of 40 GW, and natural gas price of $3.50/MMBTU.

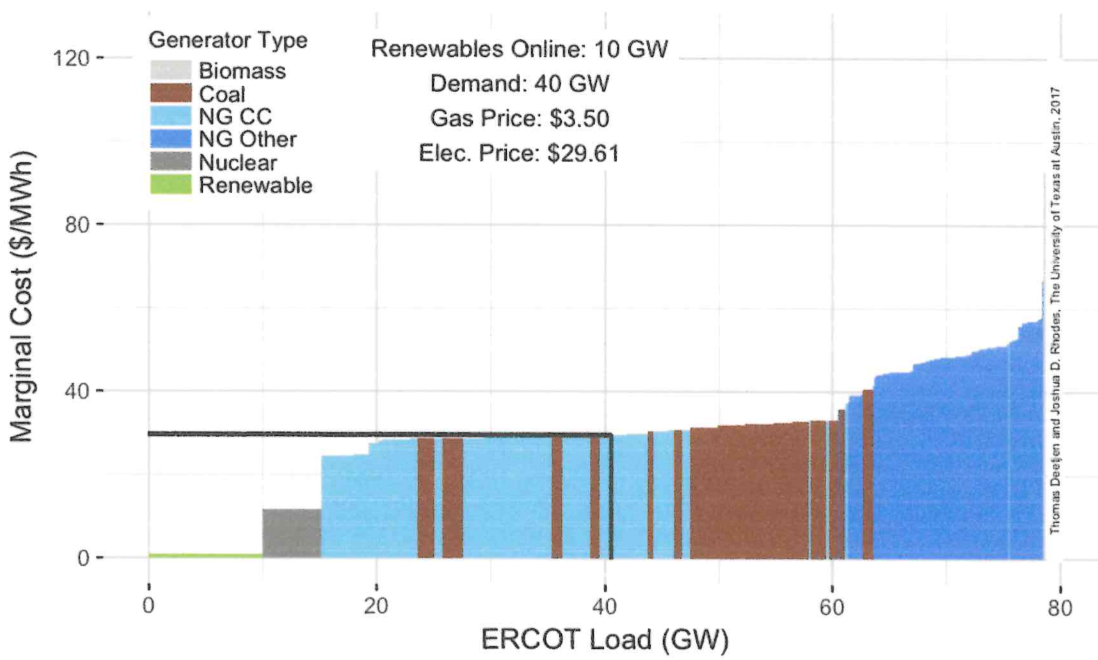

Figure 6: ERCOT bid stack with 10 GW of renewables online, a clearing price of $29.61/MWh at a load of 40 GW, and natural gas price of $3.50/MMBTU.

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Results

The results of this analysis indicate that between 2010 and 2017, if wind and solar generation did not exist in ERCOT, the wholesale electricity market would have borne an additional $5.7B in costs. Meanwhile, the power sector would have withdrawn 4 trillion more gallons of water, consumed 100 billion more gallons of water, emitted 310 thousand tons more SO_2, emitted 121 thousand tons more NO_x, and emitted 251 million tons more CO_2. This additional water consumption and emissions would have resulted in between $6B and $48B in environmentally-induced costs[12] over this time period[a].

Renewables such as wind and solar, which have zero marginal cost, can also act as a hedge against volatility in natural gas prices, which also has economic value.

Impact of renewables on average wholesale electricity market prices

Renewables affect the average wholesale electricity market prices by providing energy at zero or negative prices. In the ERCOT market, this type of bidding behavior will yield lower market prices. Figure 6 indicates that renewables have reduced wholesale electricity market prices on average between $1 and $2.50/MWh, depending on the year. ERCOT wholesale markets prices have averaged about $30/MWh, also depending on the year. Note, these reductions are relative to what the prices would have been in that year given the prevailing natural gas prices and demand. Wind and solar reduced wholesale electricity market costs between $350M to $960M per year ($5.7B total 2010-2017) out of the total energy dispatch cost of about $10 – $13B per year.

[a] This range takes into account low and high values for other water uses as well as the value of each pollutant.

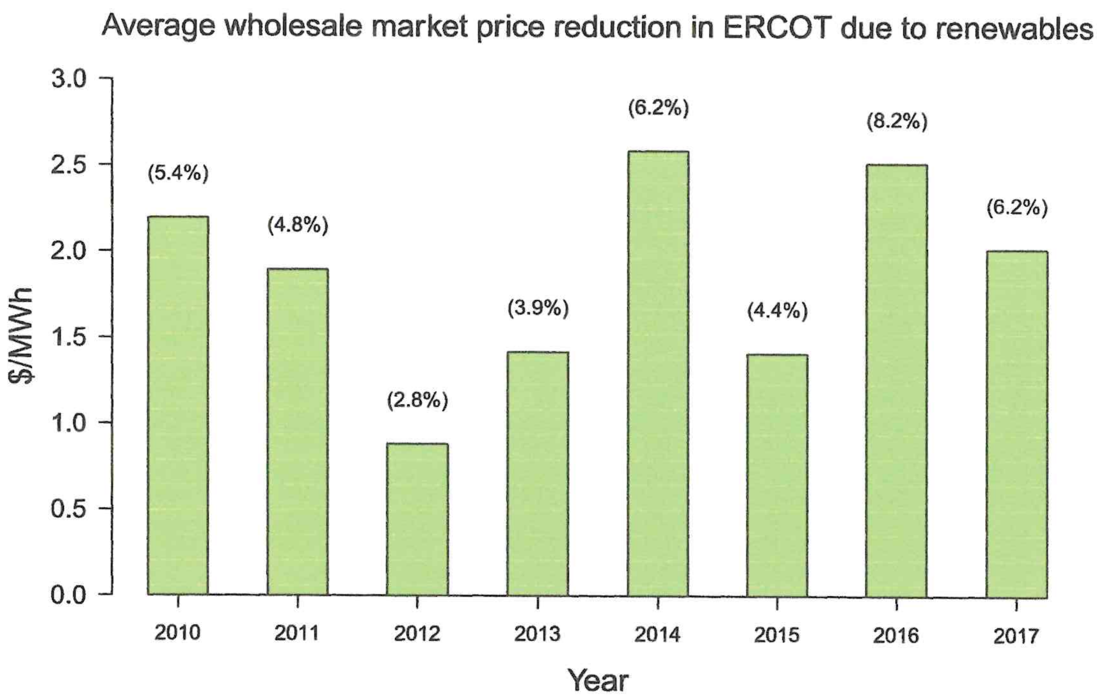

Figure 7: Figure showing modeled yearly average wholesale electricity market price reductions attributed to renewables for 2010-2017. Percentages above each bar indicate percentage reduction in average wholesale market costs due to renewables.

Figure 7 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 2017 values, but the price of natural gas fluctuates from $2 to $12/MMBTU. As expected, renewables mildly reduce overall wholesale electricity market prices, but they have a greater impact at higher natural gas prices. This result indicates that renewables in ERCOT can provide a price hedge against the possible volatility of natural gas prices.

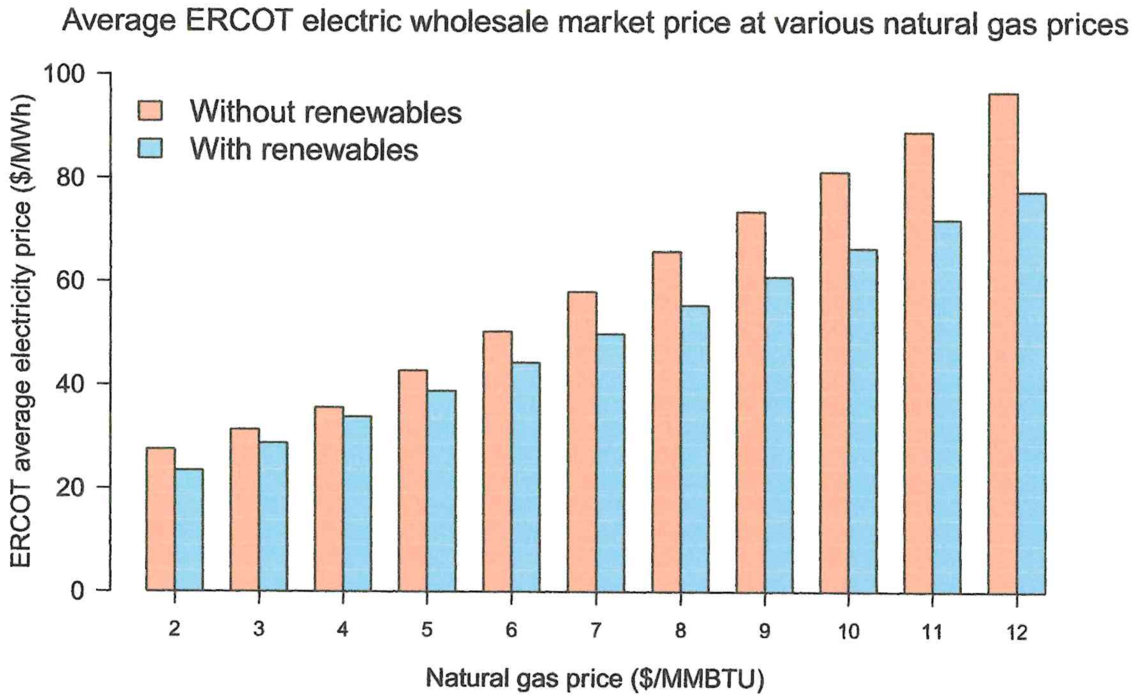

Figure 8: Figure showing the modeled impact of natural gas prices on ERCOT's wholesale electricity market price. Note that all groups of bars are for 2017, but with different natural gas prices.

The effect of renewables on water and emissions

Figure 9 through Figure 13 show the impact of renewables made for water and emissions. Each year was simulated with the amount of renewable generation installed and that year's average natural gas price.

Figure 9 shows that, if there had not been any renewables on the ERCOT grid, power plants would have withdrawn between 300 and 700 billion gallons more water per year. Water withdrawals refer to water that used by a power plant for cooling, but returned to the source. For reference, 700 billion gallons is the annual use of about 783,000 Texans[13].

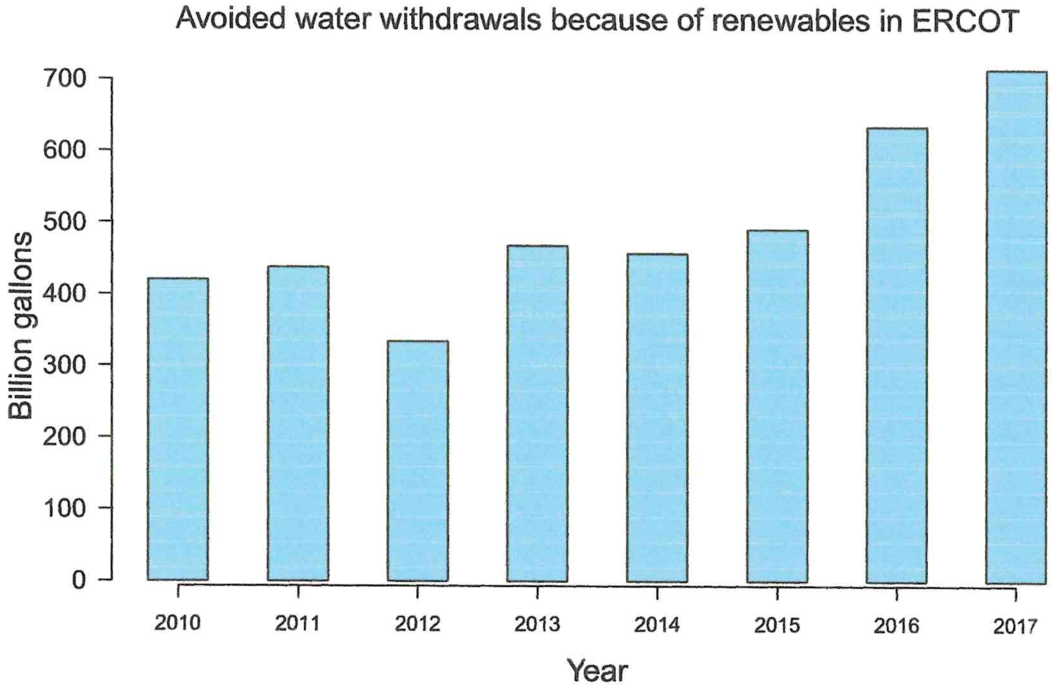

Figure 9: Figure showing modeled water withdrawal reductions attributed to renewables for 2010-2017. Water withdrawals refer to water that is used by a power plant for cooling, but is returned to the source, but at a higher temperature.

Figure 10 shows that, if there had not been any renewables on the ERCOT grid, power plants would have consumed between 8 and 22 billion gallons more water per year. Water consumption refers to water that is evaporated by a power plant's cooling system and is not available for other uses. For reference, 22 billion gallons is enough to hydraulically fracture between 6,000 to 18,000 natural gas wells, depending on well type and formation[14]. At average wholesale water rates, 100 billion gallons of water is worth about $309M.

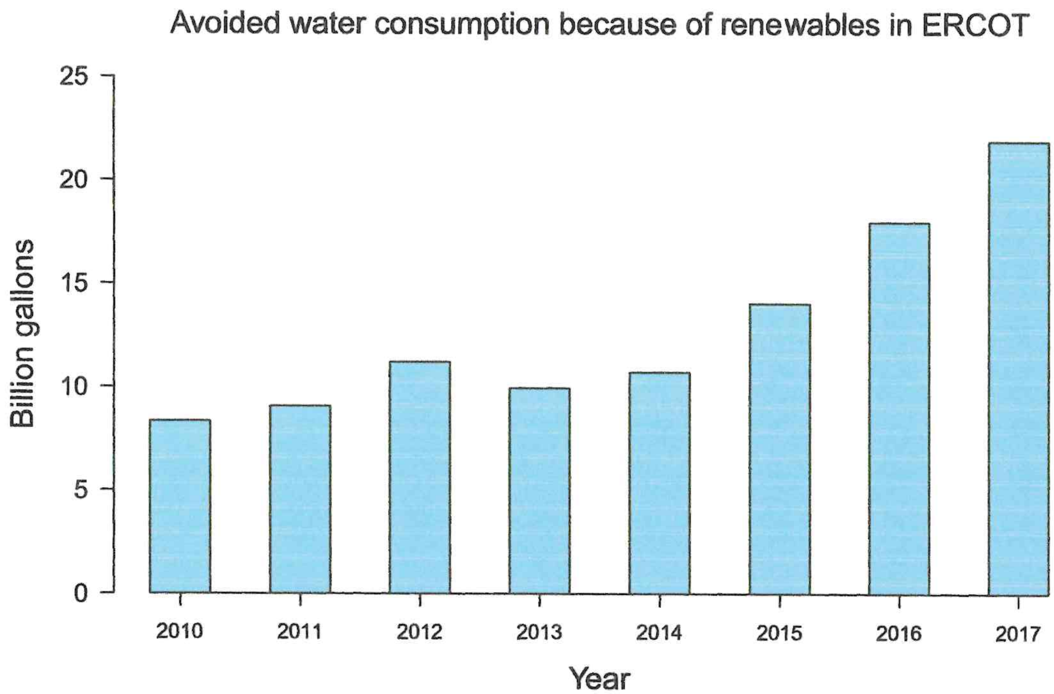

Figure 10: Figure showing modeled water consumption reductions attributed to renewables for 2010-2017. Water consumption refers to water that is evaporated by a power plant's cooling system and is not available for other uses.

Figure 11 indicates that, if there had not been any renewables on the ERCOT grid, power plants would have emitted between 20 and 70 thousand tons more sulfur dioxide (SO_2). Not emitting this SO_2 saved Texans between $3B and $33B from human health benefits. Other ecosystem benefits, such as reduced acid rain would increase that tally.

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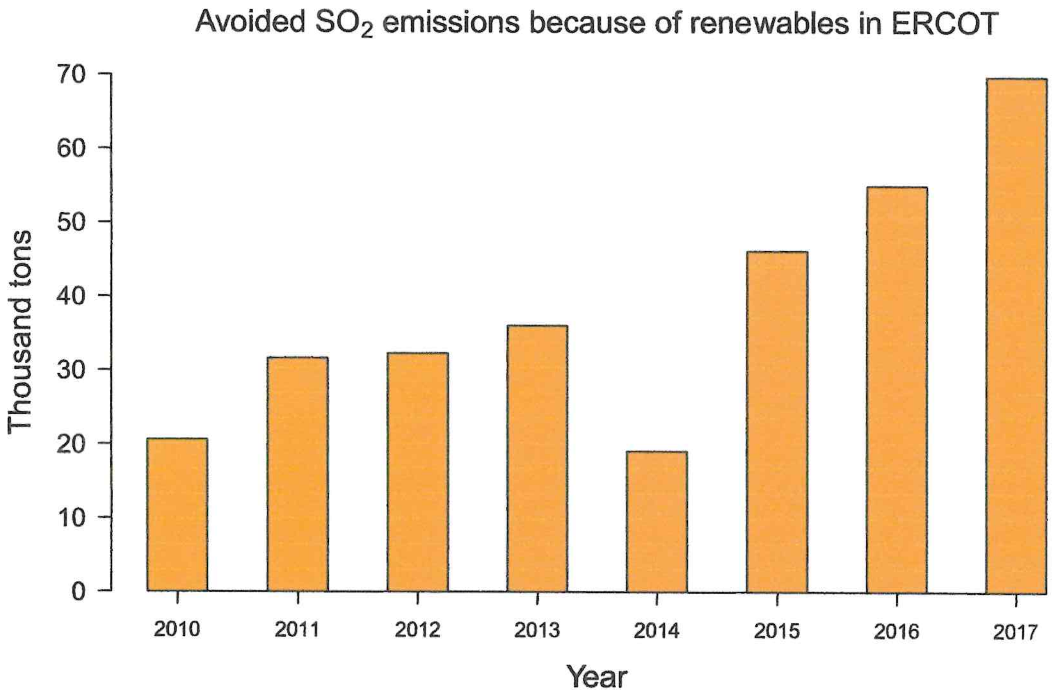

Figure 11: Figure showing modeled SO_2 emissions reductions attributed to renewables for 2010-2017.

Figure 12 indicates that, if there had not been any renewables on the ERCOT grid, power plants would have emitted between 7 and 28 thousand tons more nitrogen oxides (NO_x). Not emitting this NO_x saved Texans between $190M and $1.4B.

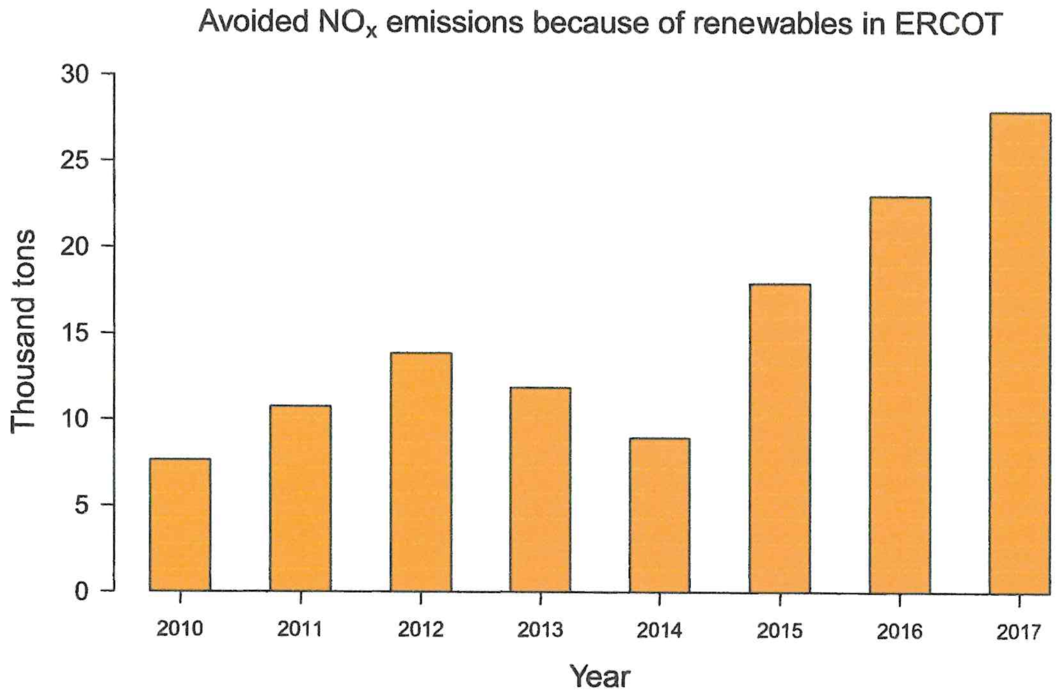

Figure 12: Figure showing modeled NO_x emissions reductions attributed to renewables for 2010-2017.

Figure 13 indicates that, if there had not been any renewables on the ERCOT grid, power plants would have emitted between 20 and 52 million tons more carbon dioxide (CO_2) per year, 251 million tons total between 2010 and 2017. Not emitting this CO_2 is worth between $2.5B and $12.5B (at $10 and $50/ton of CO_2).

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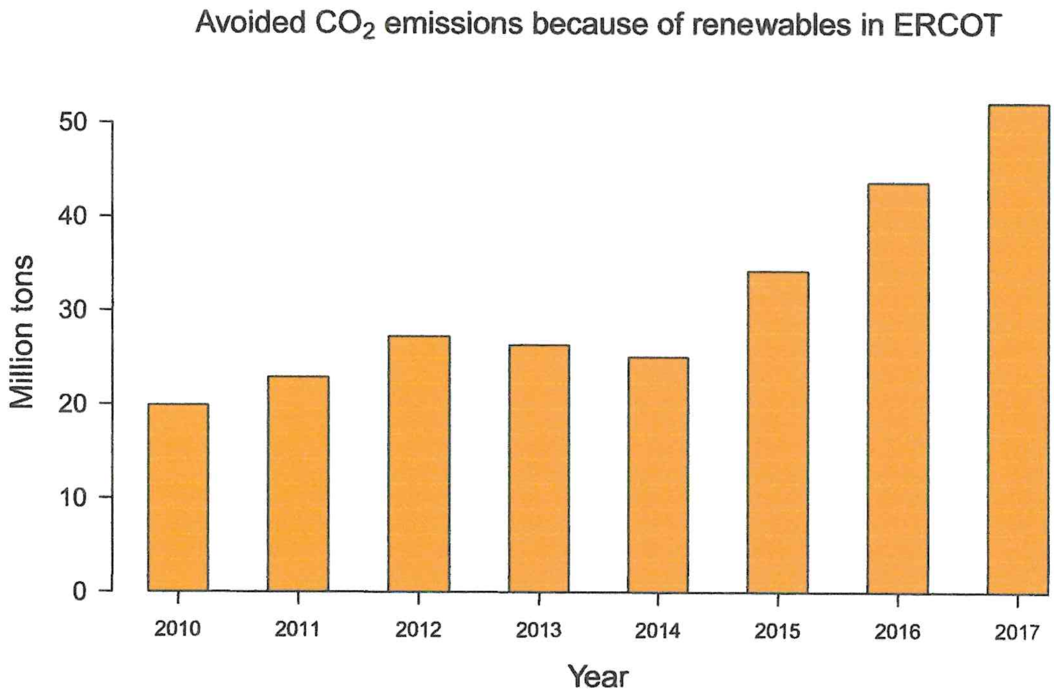

Figure 13: Figure showing modeled CO_2 emissions reductions attributed to renewables for 2010-2017.

Figure 14 shows a breakdown of the magnitudes of water, emissions, and reduced electric wholesale market cost benefits per year in ERCOT from renewables. The relative magnitudes of the benefits change each year depending on the cost of natural gas and the amount of renewables installed, but, in general, are increasing with time.

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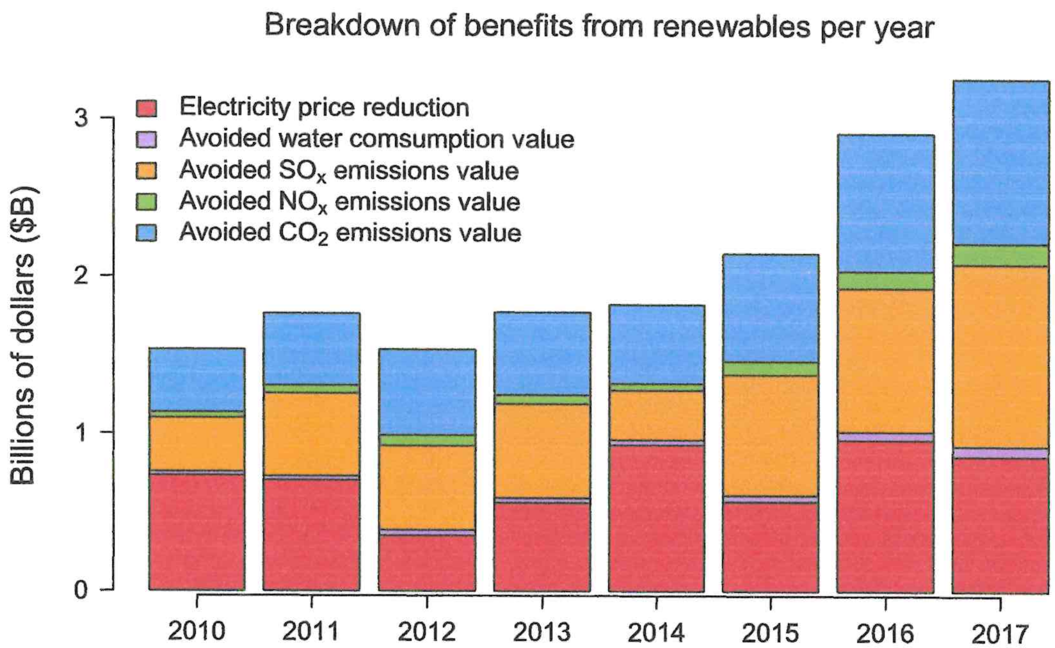

Figure 7: Figure showing breakdown of benefits from renewables for 2010 – 2017. Median values (from all Texas counties) of damages were used to monetize the emissions reductions (SO_x: \$16,600/ton, NO_x: \$4,750/ton, CO_2: \$20/ton, water: \$3/thousand gallons).

Conclusions

This analysis indicates that renewables have 1) have 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 year, but are, in general, increasing as more renewables are integrated into the ERCOT grid. Renewables' downward pressure on wholesale electricity market prices are modest at low natural gas prices, but can act as a hedge against possible higher prices in the future. Between 2010 and 2017, we estimate that renewables provided between $11B and $54B in benefits to Texas residents by 1) reducing the amount of water consumed by the power sector, 2) reducing the amount of pollution emitted by the power sector, and 3) reducing wholesale electricity costs.

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[15].

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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[16] [17]. 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[18].

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

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[1] https://owi.usgs.gov/vizlab/water-use-15/#view=TX&category=thermoelectric
[2] http://droughtmonitor.unl.edu/CurrentMap/StateDroughtMonitor.aspx?TXs
[3] https://ascelibrary.org/doi/abs/10.1061/9780784412947.279
[4] https://www.aeaweb.org/articles?id=10.1257/aer.101.5.1649
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[6] http://proceedings.asmedigitalcollection.asme.org/proceeding.aspx?articleid=1626445
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