The Economic Value of Renewable Energy to Texas

Wind Solar Alliance (WSA)
American Wind Energy Association (AWEA)
Solar Energy Industries Association (SEIA)

Fall 2018

Prepared by

&

TXP, Inc.
1310 South 1st Street, Suite 105
Austin, Texas 78704
www.txp.com

Table of Contents

List of Figures

List of Tables

Executive Summary

With the advent of cost-competitive solar and wind generation, resources in high demand from modern economy sectors such as data centers and technology-driven manufacturing, Texas has become an energy leader and is positioned to continue this leadership well into the 21st Century. Moreover, as renewables assume an increasing role in Texas' energy portfolio, their economic value manifests itself in a variety of ways. Our research shows that renewable energy development in the state produced a nearly $1 billion direct injection into the Texas economy last year. The result was a total of about $1.5 billion in economic activity/output, just over $430 million in earnings, and more than 10,225 permanent jobs. Specifically, renewables have delivered economic value in six distinct ways:

1. ***Providing revenue to local governments***
   As a capital-intensive industry, renewables pay substantial property taxes, even after incentives are factored into the equation. Our research shows that total local government revenue associated with renewables reached $210.4 million last year, almost double the $115.4 million figure for 2013. These figures are net of incentives, and mask the outsized impact renewable projects can have in smaller, rural counties where they are typically located.

2. ***Providing revenue to landowners***
   TXP-IdeaSmiths modeling shows that in 2017 landowners hosting wind and solar energy projects received an estimated $90.4 million in lease payments.

3. ***Reducing energy costs to customers***
   TXP-IdeaSmiths modeling quantifies the impacts of renewables on wholesale electricity prices. These impacts have been substantial: customers in ERCOT saved a total of $5.7 billion in electricity costs from 2010 to 2017 compared to what they would have paid if renewables were not part of the portfolio, including $855.9 million in 2017.

4. ***Providing well-paying jobs***
   The renewable energy industry has grown to support 33,000 jobs in Texas, a threefold growth since 2013. Renewables directly account for at least $2 billion in annual Texas wages paid.

5. ***Stimulating economic development***
   As the nation's energy leader, Texas has seen continued economic development connected to the provision of power. Corporate and industrial customers are increasingly demanding renewable energy and looking to locate operations such as

data centers in areas with access to renewables. Renewables line up well with the needs of much of the modern economy, in terms of the low cost and predictability of longer-term renewable energy contracts, and the demands of customers/stakeholders. It is no accident that many of the leading firms in the with a strong presence in Texas are choosing to purchase renewable energy.

A key reason that renewables are attractive to large corporate energy users is because they provide hedging opportunities for those seeking to protect themselves against the impact of price shocks. Conditions are especially favorable in Texas, with a strong wind and growing solar presence, natural gas as the leading fossil fuel source, and a market that accommodates customer choice.

Renewables also provide opportunities for economic development officials to target companies for cluster development. A cluster is a group of companies sharing local resources, using similar technologies, and forming linkages and alliances. The Governor's Office has recognized the economic development potential of clustering renewable energy companies:

> *The Lone Star State's renewable energy potential is among the largest in the nation, with abundant wind, solar, and biomass resources found across the state's geographically diverse regions. In recent years, Texas has built upon its energy experience and trained workforce to take the lead in renewable energy production and services. As a result, Texas has become the top state in wind generation capacity and biodiesel production.*

6. ***Improving human health and the environment***
   While the focus of this report is on the economic benefits of renewables, environmental benefits also create significant tangible value for Texas. As demonstrated with the TXP-IdeaSmiths modeling described below, the combination of reduced emissions (which manifest themselves in improved health outcomes) and savings associated with avoided water consumption yields between $0.8 and $2.4 billion annually in environmental savings, with a total over the 2010-2017 period of $11.1 billion.[1]

In sum, renewable energy already provides a wide range of value to individuals, companies, communities, local governments, and the State of Texas. These benefits are expected to grow over time and proportionately rise as the world demands more energy produced from

[1] See the Appendix for details.

renewable sources. In the process, a strong renewables sector positions Texas to continue its global energy leadership role.

Background: Renewables in the Texas energy market

Since the first gusher of oil at Spindletop, Texas has been the energy capital of the US, if not the world. Throughout the 20th Century, a combination of private investment and state policies placed Texas as a global leader in the oil and gas supply chain. With the emergence of cost-competitive wind and solar generation, Texas has also become a leader in renewable energy is positioned to continue to be an energy leader well into the 21st Century.

The movement toward renewables has created a shift in market share. In 2007, coal and natural gas represented 82.9 percent of all electricity consumption in the ERCOT service territory; by last year, that share had fallen to 71.0 percent. See Table 1.

Table 1: Shares of Electricity Consumption by Energy Source

	2002	2007	2012	2017
Natural Gas	46.4%	45.5%	44.5%	38.8%
Coal	38.5%	37.4%	33.8%	32.2%
Nuclear	12.9%	13.4%	11.8%	10.8%
Wind	0.8%	2.9%	9.2%	17.4%
Solar/Biomass	NA	NA	NA	0.8%
Other	1.4%	0.8%	0.7%	NA

Source: ERCOT, TXP

The expanding role of renewables in Texas is no accident, as investments in key infrastructure have unlocked market demand. In 2005, the Texas legislature passed Texas Senate Bill 20, which ordered that the Public Utility Commission of Texas (PUC) – in consultation with ERCOT – designate competitive renewable energy zones (CREZ) and develop a transmission plan to deliver renewable power from CREZ to customers.

The designation of CREZ focused on large-scale wind resources that could be developed in sufficient quantities to warrant transmission system expansion and upgrades. Based on a transmission analysis and wind developer interest, the PUC identified five CREZs. ERCOT then began to develop a transmission optimization study. Transmission capacity for 18.5 GW of wind, stretching 3,600 miles, was built. The total project cost of $6.8 billion yielded an increase of about 50.0 percent in transmission capacity, three times as much as any other state.

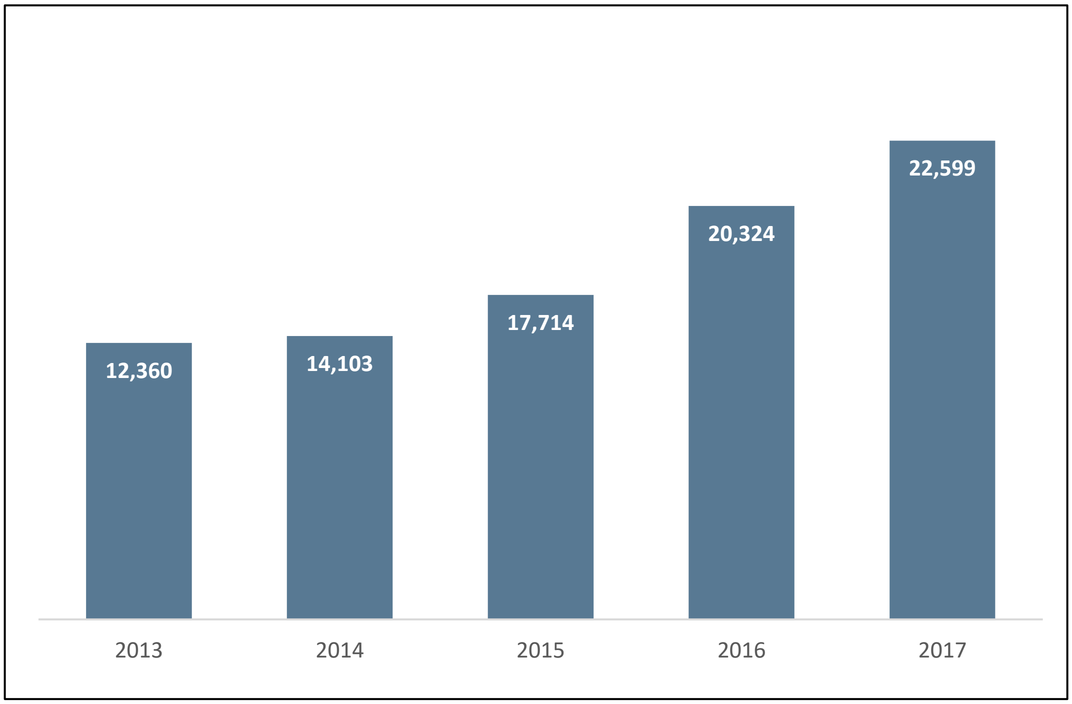
According to a speech[2] given in 2014 by Warren Lasher, Director of System Planning for ERCOT, a range of factors have contributed to the success of the effort including:

- *The ERCOT region has both world-class wind resources and large population (load) centers;*
- *There are few barriers to land development in west Texas;*
- *The CREZ project combined economic development, development of in-state energy resources, and development of green energy;*
- *Cost allocation formulas are settled;*
- *The overall risk of the project was controlled by taking small steps, and by maintaining the ability to change course if needed;*
- *The regulatory processes and technical planning analyses moved forward in tandem;*
- *Wind integration is facilitated in ERCOT by a large fleet of flexible natural gas, combined-cycle generation, and by system-wide dispatch at 5-minute intervals; and*
- *The geographic scope of the ERCOT system lends itself well to regional planning.*

The investments in capacity, connection, and market environment have come together in recent years. In 2017, Texas produced more wind power in a given amount of time than ever in history, reaching "peak wind" on October 27, when local wind farms produced 54.0 percent of the total electricity load of the state's main power grid. This peak as a share of electricity generated in a given day followed the absolute all-time high March 31, 2018 when wind electricity generation in Texas hit 16,141 MW. Meanwhile, the far western part of the state – which has the best solar resources – is now seeing multi-decade solar lease contracts appearing, indicating that transmission capacity will enable solar generation growth as well.

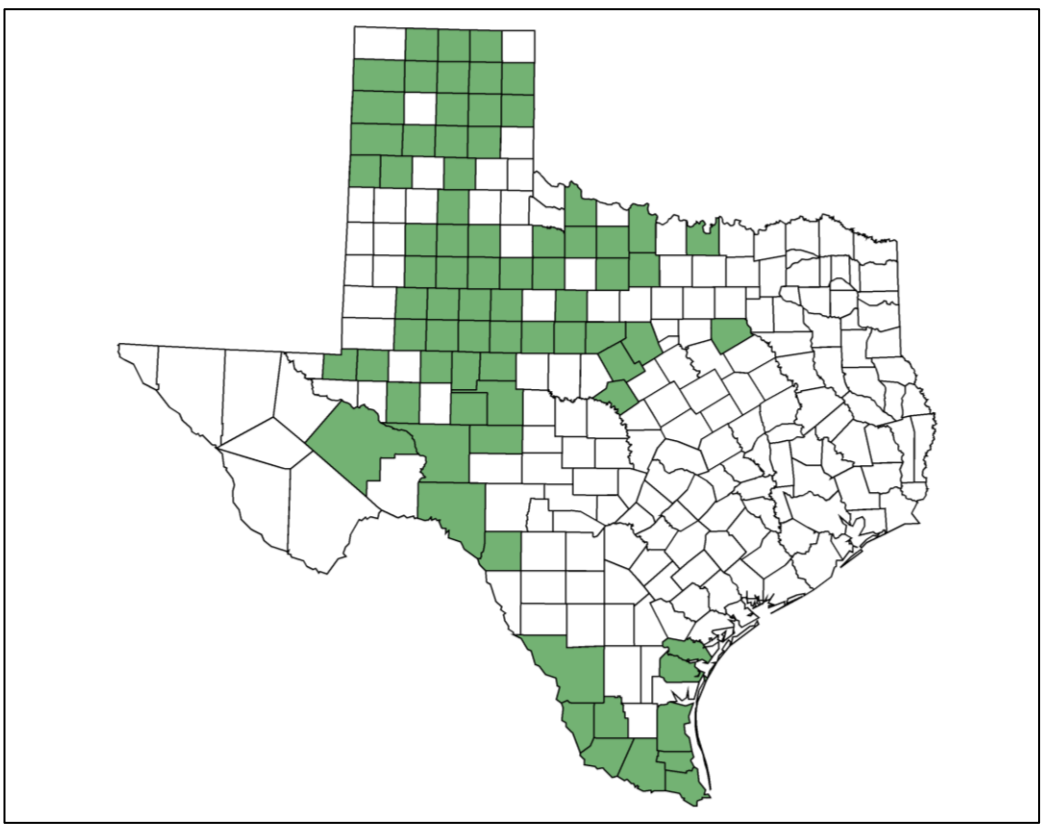
[2] https://www.energy.gov/sites/prod/files/2014/08/f18/c_lasher_qer_santafe_presentation.pdf.

Figure 1: Generation Capacity of Commercial Wind Projects 2013-2017 (MW)



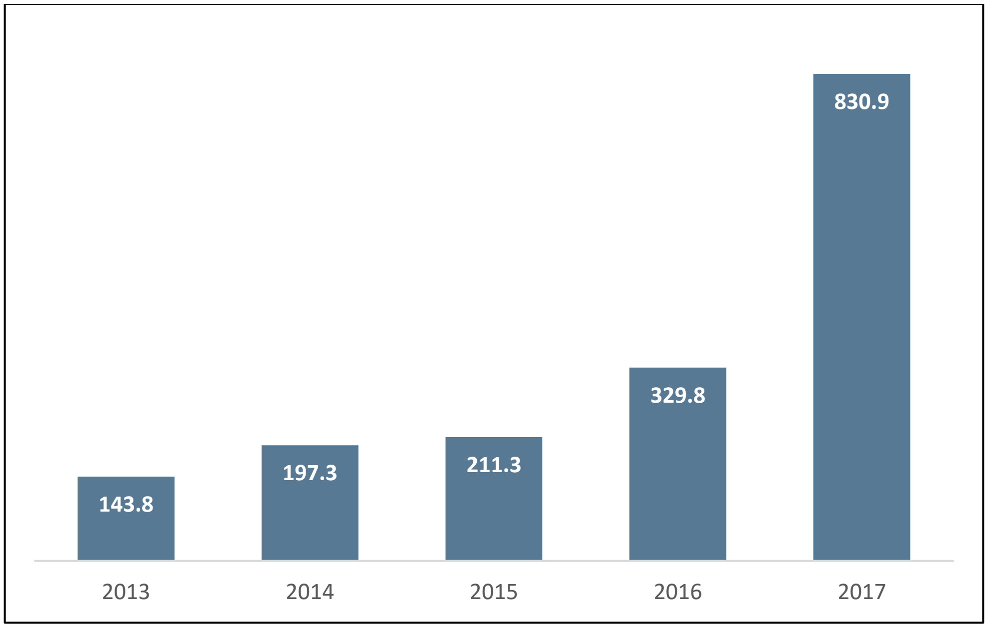
Sources: AWEA, TXP

Figure 2: Location of Wind Generation in Texas



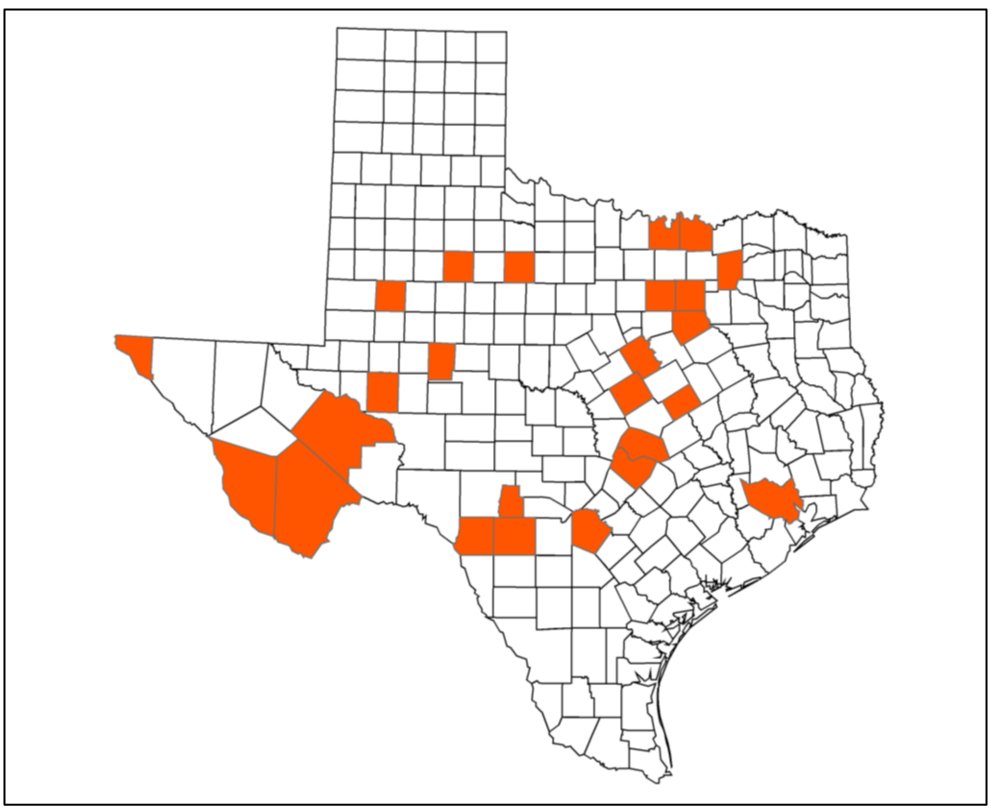
Sources: AWEA, TXP

Figure 3: Generation Capacity of Commercial Solar Projects 2013-2017 (MW)



Sources: The Solar Foundation, TXP

Figure 4: Location of Solar Generation in Texas



Sources: The Solar Foundation, TXP

Renewable Energy in Texas: Providing revenue to local governments

The growing presence of renewables in Texas also results in increasing tax revenues to counties, school districts, and other jurisdictions. Chapter 313 is the enabling legislation that allows a school district to offer a temporary, 10-year limit (ranging from $10 million to $100 million) on the taxable value of a new investment project in manufacturing, and certain renewable energy projects. The limitation applies only to school district taxes levied for maintenance and operations (M&O); taxes for debt service are not subject to the limitation, nor do business inventories qualify.

Before the school district can approve a limitation, the State Comptroller must issue a certificate of approval that finds the project will generate more tax revenue for the state than the amount of the benefit received by the taxpayer.

Through 2015, the State Comptroller reports that 311 projects have participated in the program, creating 12,321 operations jobs (plus an unreported number of construction and contract jobs), adding $12.1 billion to school M&O tax rolls and $31.7 billion to school debt tax rolls. Overall the Comptroller estimates the program has brought over $80 billion in new investment to the state, creating a total of 50,300 jobs and adding $2.0 billion in personal income

Of the 311 projects, renewable energy accounts for just over half—with 144 in wind and 22 in other types of renewable energy. Manufacturing accounts for almost all of the other projects and for 77 percent of the direct investment.

Taxable capacity in commercial wind and solar projects has been steadily growing over the past five years, with the total taxable value of renewables (wind and solar) almost doubling since 2014.[3] Net of incentives, renewables accounted for a total of $107 million in local government tax revenue last year; $59.7 million to school districts, $27.2 million to counties, and the balance spread among a range of other local jurisdictions (such as hospital districts).[4]

In addition to property tax payments, renewable energy projects oftentimes make PILOT (payments in lieu of taxes) and revenue protection payments under Chapter 313 agreements with local school districts. In 2017, renewables paid $103.4 million in these supplemental payments to school districts, for a total of $210.4 million paid to local governments overall.

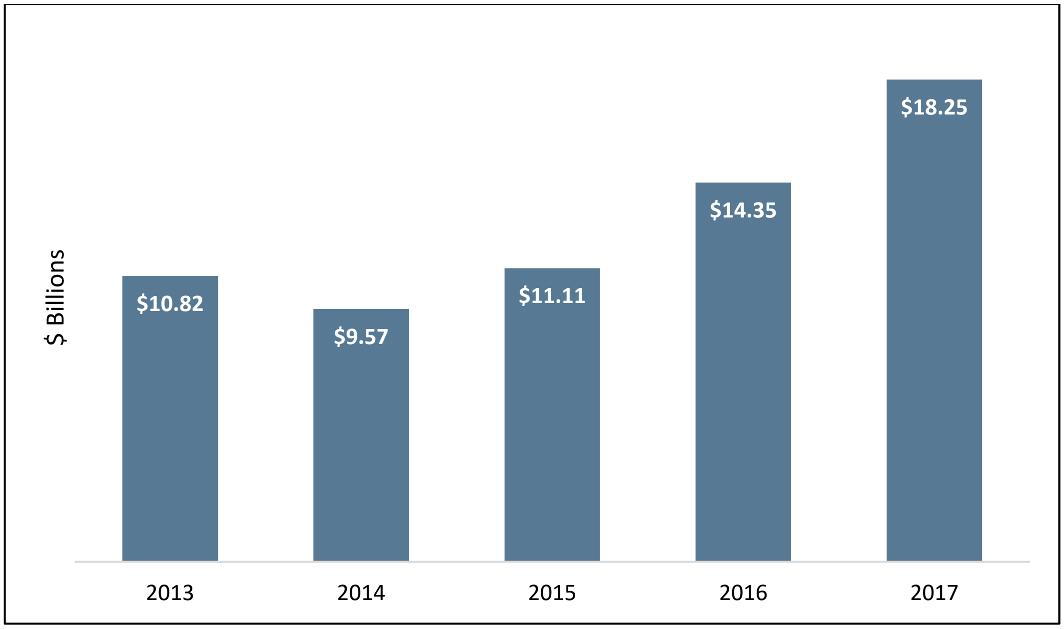
---

[3] Renewable projects often effectively enhance the value of property for initial valuation purposes, as much of was previously under agricultural exemption.

[4] Since renewable generation projects are primarily located in rural areas, there is very little municipal tax revenue collected.

The footprint of renewable generation continues to grow. In tax year 2017, there were 156 wind projects and 23 commercial solar projects. In addition, there are 10 wind projects and 26 solar projects projected to be completely online in the next two years.

Figure 4: Texas Major Renewables Taxable Value by Year



Source: various appraisal districts, TXP

Table 2: Taxes Paid to Local Jurisdictions by Wind, 2013-2017 ($Millions)

Wind	2013	2014	2015	2016	2017
School District Taxes	$48.5	$34.0	$53.5	$52.88	$54.5
County Taxes	$16.6	$17.2	$19.8	$22.7	$25.2
Other Local Taxes	$10.7	$8.8	$10.2	$13.8	$17.9
Supplemental Payments*	$35.3	$31.6	$30.3	$60.2	$79.9
Total Payments	$111.1	$91.6	$113.8	$149.6	$177.5

Sources: various appraisal districts, TXP

* Payments in lieu of taxes and revenue protection payments to school districts

Table 3: Taxes Paid to Local Jurisdictions by Solar Projects, 2013-2017 ($Millions)

Solar	2013	2014	2015	2016	2017
School District Taxes	$2.2	$2.5	$3.1	$6.5	$5.1
County Taxes	$0.8	$0.7	$1.0	$1.4	$2.0
Other Local Taxes	$1.2	$1.2	$1.3	$1.8	$2.4
Supplemental Payments*	$0.1	$0.2	$0.8	$2.2	$23.5
Total Payments	$4.3	$4.6	$6.2	$11.9	$33.0

Sources: various appraisal districts, TXP

* Payments in lieu of taxes and revenue protection payments to school districts

Table 4: Taxes Paid to Local Jurisdictions by Wind & Solar Projects, 2013-2017 ($Millions)

Combined	2013	2014	2015	2016	2017
School District Taxes	$50.7	$36.6	$56.6	$59.4	$59.6
County Taxes	$17.4	$17.9	$20.9	$24.2	$27.2
Other Local Taxes	$11.9	$10.0	$11.5	$15.6	$20.2
Supplemental Payments*	$35.4	$31.8	$31.0	$62.4	$103.4
Total Payments	$115.4	$96.3	$120.0	$161.5	$210.4

Sources: various appraisal districts, TXP

* Payments in lieu of taxes and revenue protection payments to school districts

Others have recognized the benefits of the State incentivizing the growth of renewables through facilitation of local incentives. In a report issued in May 2018, Moody's Investor Service (Moody's) describes the local government benefits of renewable generation.[5] The section on Texas is instructive:

> *With over 22,000 megawatts of installed generation capacity, Texas has more wind farms than any other state in the country and over 100 Texas school districts benefit. To promote new wind development, Texas allows school districts to offer property tax incentives to encourage large-scale capital investments. Referred to as "Chapter 313 agreements," individual school districts reduce the market value of a developer's property that is subject to their levy for up to 10 years. In exchange, the developer agrees to a minimum investment or the creation of a minimum number of jobs within the district. To date, these agreements have been used for over 140 wind farm projects and spurred more than $23 billion of investment.*

[5] Moody's Investor Service. *Wind Farms Bring Windfalls to Local Governments Across US.* May 7, 2018. Report #1123425

While a large share of a district's operating levy tends to be abated through the Chapter 313 agreement, a district's debt service levy is applied to the wind farm's full market value. As a result, the districts debt burden as a share of full value can fall significantly as each mill generates more revenue to service debt.

As an example, Webb Consolidated Independent School District used Chapter 313 agreements to attract four sizable wind farms with a combined market value of $596 million. Under the agreements, the district's debt service levy is applied to the full market value of the projects. Collectively, the four wind farms are paying over 40 percent of the district's annual debt service requirements, significantly reducing the burden on local taxpayers. Operating revenues also grow under the agreements, but not to the same extent because only $110 million (or 19 percent) of the wind farms market value is subject to the operating levy. With the significant abatement, the wind farms look to increase annual operating revenues by about 2.5 percent.

There are other examples of this type of local benefit. A similar story is found in Nolan County in central West Texas. Home to almost 1,300 wind turbines, the taxable value of renewables in 2016 was $929.4 million, equal to almost half of the County's total appraised value of property. Other counties in the region (such as Howard, Mitchell, and Upton) see a similar pattern, in that renewables account for the equivalent of between 10 and 22 percent of the appraised value of the local property tax base. At the same time, there are hundreds of firms engaged in some element of the renewable industry that are not subject to discrete taxes that can be attributed solely to renewables. This undoubtedly brings additional value to both local governments and the State.

Renewable Energy in Texas: Providing revenue to landowners

Direct Payments

Payments to landowners provide benefits to communities hosting wind and solar projects above and beyond the local government revenues discussed above. Industry sources indicate that $4,000/MW per year is an appropriate estimate of the average landowner payment; using this figure against the 22,599 MW of installed wind capacity yields a direct estimate of at least $90.4 million to Texas landowners last year.[6]

Additional Economic Impact Calculations

In an input-output analysis of new economic activity, the norm is to distinguish between three types of expenditure effects: direct, indirect, and induced. Direct effects are production changes associated with the immediate effects or final demand changes. The cost of installing a solar array is an example of a direct effect, as is the electricity customer savings associated with the presence of renewables in the Texas energy portfolio. Indirect effects are production changes in backward-linked industries cause by the changing input needs of directly affected industries – typically, additional purchases to produce additional output. A solar installer will have to purchase a range of technologies and services to create the array, while wind project developers must contract with equipment manufacturers and construction companies. These purchases affect the economic status of other local merchants and workers. Induced effects are the changes in regional household spending patterns caused by changes in household income generated by direct and indirect effects. Employees of the solar and wind firm experience increased income from these projects, for example, as do those who work for the turbine manufacturer and the construction company. Induced effects capture the way in which this increased income is in turn spent by them in the local economy.

An economy can be described in a number of ways. Four of the most common measurements are "Output," which describes total economic activity, and is equivalent to a firm's gross sales, "Value-Added," which is the difference between revenue and cost of goods sold, "Earnings," which represents compensation paid, and "Employment," which refers to permanent jobs that have been created in the local economy. In order to provide an accurate basis of comparison, all dollar-denominated results are expressed in constant 2018 figures.

The interdependence between different sectors of the economy is reflected in the concept of a "multiplier." An output multiplier, for example, divides the total (direct, indirect and induced) effects of an initial spending injection by the value of that injection – i.e., the direct effect. The higher the multiplier, the greater the interdependence among different sectors of

[6] The $4,000 figure is on the lower end of estimates of the average annual payment per MW.

the economy. The results of running the increased spending levels through the RIMS System (RIMS II) developed and maintained by the Commerce Department of the Census Bureau are shown as follows.

Total Economic Impact of Landowner Payments

The direct payments of $90.4 million yield a 2017 total impact of $134.4 million in economic activity/output, $78.0 million in value-add, $40.0 million in earnings, and a total of 1,006 permanent jobs. Table 5 provides a detailed breakdown by sector of the economy.

Table 5: Total 2017 Impact of Landowner Payments ($Millions)

NAICS	Output	Value-Add	Earnings	Employment
Natural Resources	$1.1	$0.5	$0.2	11
Mining	$1.8	$1.2	$0.3	3
Utilities	$3.9	$2.1	$0.6	6
Construction	$1.6	$0.8	$0.6	10
Durable goods mfg.	$3.4	$1.3	$0.7	12
Nondurable goods mfg.	$11.0	$3.3	$1.8	29
Wholesale trade	$6.6	$4.5	$2.1	27
Retail trade	$13.1	$8.7	$4.8	162
Transportation & warehousing	$5.1	$2.5	$1.6	34
Information	$6.1	$3.5	$1.2	18
Finance & insurance	$14.2	$7.4	$3.8	70
Real estate/rental/leasing	$23.3	$16.3	$3.6	141
Prof, scientific, & technical services	$5.8	$3.7	$2.7	37
Management of companies	$1.6	$0.9	$0.7	8
Administrative and waste services management	$4.1	$2.7	$1.9	52
Educational services	$2.0	$1.2	$0.9	32
Health care & social assistance	$15.7	$9.4	$7.3	157
Arts, entertain., & recreation	$1.3	$0.7	$0.5	21
Accommodation	$1.3	$0.8	$0.4	11
Food services & drinking places	$5.2	$2.7	$1.7	81
Other services	$6.3	$3.5	$2.5	68
Households	$0.0	$0.2	$0.2	17
TOTALS	**$134.4**	**$78.0**	**$40.0**	**1,006**

Sources: industry sources, various appraisal districts, TXP

Renewable Energy in Texas: Reducing energy costs for customers

Since renewable sources such as wind and solar have zero marginal fuel cost, they historically have reduced wholesale clearing prices in ERCOT, which is economically beneficial to consumers. This cost savings will in turn have additional impacts, as more money in customer pockets will ripple through the Texas economy. By the same token, landowner payments also represent an injection in the state and local economies that will have secondary impacts.

IdeaSmiths LLC was engaged to quantify the impacts of renewables wholesale electricity prices and the environment in Texas, with TXP providing the economic impact portion associated with reduced wholesale electricity prices due to the presence of renewables and the impact of landowner payments. For this project, the overall approach was to model the impact of removing renewables from the Texas electricity generation portfolio as a means of illustrating their impact, for a period of sufficient duration to reflect substantial variance in the cost of fossil fuel feedstock. The results of their work are summarized in the main body of the report, with their full analysis (including citations) provided in the Appendix.

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, based on results for multiple scenarios of load, natural gas price, and installed capacity of renewables. 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 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 to estimate their effect on the marginal bid stack. Each set of annual data was matched with its yearly average natural gas price. The delivered price of coal was assumed to be $2.50/MMBTU for all years.

Table 6: Annual Model Assumptions

	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*	$3.36
2016	16,246-18,923	556*	$2.88
2017	18,923-21,182	1,000	$3.30

*Capacities marked with a * indicate that installed capacities of wind and solar were multiplied by hourly capacity factors because measured data were not available.*

Sources: Ideasmiths, TXP

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.

To quantify the 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 and utilized for this analysis.

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.[7] 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.

Model Results: Impact on the Wholesale Electricity Costs

Direct Effects

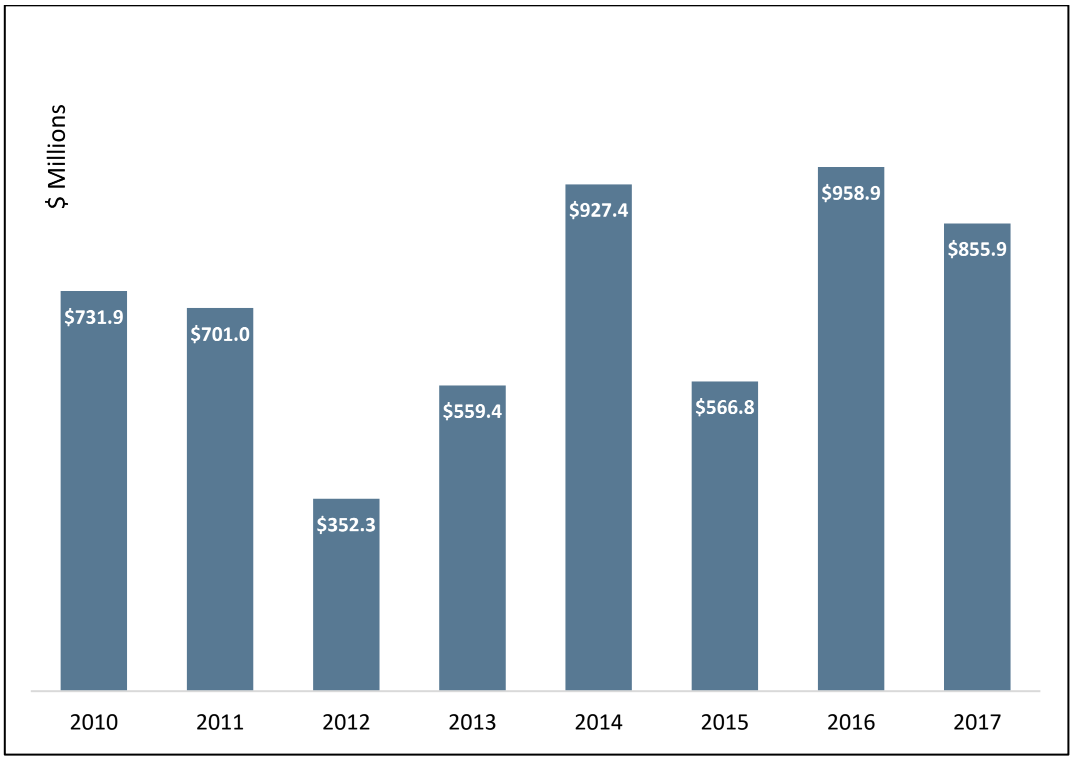
Renewables affect the average wholesale electricity market prices by providing energy at zero or negative prices. In the ERCOT market, this type of bidding behavior will yield lower market prices, with the result that renewables have reduced wholesale electricity market

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

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.

Figure 5 shows the annual customer direct savings attributable to the presence of renewables. As expected, the impact of renewables on wholesale electricity market prices is greater at higher natural gas prices. This result indicates that renewables in ERCOT can provide a price hedge against volatility of natural gas prices.

Figure 5: Wholesale Customer Savings Attributed to Renewables by Year



Source: Ideasmiths, TXP

Total Economic Impact of Wholesale Customer Savings

Customer savings during 2017 due to renewables amounted to $855.9 million. These savings give both residential and non-residential customers additional money to spend elsewhere in the economy, with the assumption that it matches typical applicable spending patterns. When the most recent year is run through the RIMS II system for Texas, the total average annual impact is $1,368.5 million in economic activity/output, $779.4 million in value-add,

$390.4 million in earnings, and a total of 9,223 permanent jobs. Table 7 provides a detailed breakdown by sector of the economy.

Table 7: Total 2017 Impact of Wholesale Customer Savings Due to Renewables ($Millions)

NAICS	Output	Value-Add	Earnings	Employment
Natural Resources	$14.5	$5.8	$3.1	137
Mining	$85.4	$59.1	$15.9	145
Utilities	$45.5	$24.3	$7.0	66
Construction	$39.1	$21.0	$15.3	251
Durable goods mfg.	$75.1	$29.5	$15.9	243
Nondurable goods mfg.	$140.7	$43.6	$22.5	335
Wholesale trade	$61.4	$41.7	$19.7	256
Retail trade	$111.0	$73.8	$40.3	1,370
Transportation & warehousing	$48.7	$23.9	$14.9	316
Information	$52.2	$30.2	$10.5	157
Finance & insurance	$122.1	$64.1	$32.7	605
Real estate/rental/leasing	$198.1	$138.3	$31.1	1,198
Prof, scientific, & technical services	$54.3	$34.1	$25.0	347
Management of companies	$16.5	$9.9	$7.0	81
Administrative and waste services management	$36.8	$23.8	$16.7	469
Educational services	$16.8	$10.2	$7.9	269
Health care & social assistance	$131.0	$78.4	$61.0	1,308
Arts, entertain., & recreation	$10.8	$6.3	$4.0	181
Accommodation	$11.1	$7.1	$3.2	92
Food services & drinking places	$43.7	$23.0	$14.4	679
Other services	$53.6	$29.7	$21.1	579
Households	$0.0	$1.5	$1.5	138
TOTALS	**$1,368.5**	**$779.4**	**$390.7**	**9,223**

Sources: Ideasmiths, TXP

It should be noted that these findings are consistent with similar recent work done by PA Consulting (PA)[8]. As part of a project examining the impact of marginal losses in Texas, PA modeled the impact of removing the CREZ transmission projects and associated renewable energy development made possible by the increased transmission capability due to CREZ. The PA analysis was conducted over the same time period (2010-2017) as this analysis, with findings of customer savings of $3.6 billion. Given the narrower geographic scope (elimination of the CREZ in the PA study compared to elimination of renewables entirely in this work), these findings are mutually supportive.

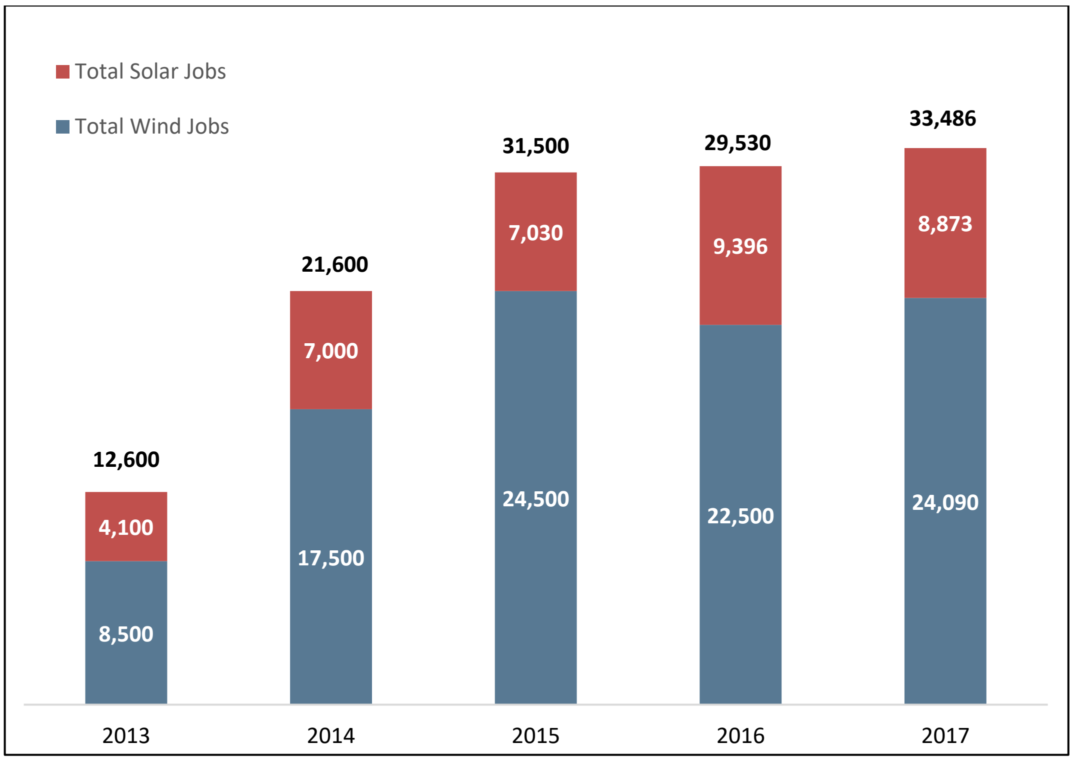
[8] *The Long-Term Impact of Marginal Losses on Texas Electric Retail Customers*. PA Consulting, April 2018. Texas PUC Project No. 47199.

Renewable Energy in Texas: Providing well-paying jobs

Industry-Related Employment

The growth of renewable energy production in Texas has inevitably led to rising levels of related employment in the state. AWEA has tracked the number of jobs related to wind energy for some time, reporting just over 24,000 jobs during 2017, compared to less than 10,000 as recently as 2013. The Solar Foundation, meanwhile, conducts the Solar Census on an annual basis. Texas' 2017 employment across the solar industry is given at just under 8,900. Collectively, industry-related employment is just short of 33,500, a figure consistent with a recent Department of Energy (DOE) estimate of about 36,100.[9]

Figure 6: Texas Major Renewable Energy Employment by Year



Sources: The Solar Foundation, AWEA, TXP

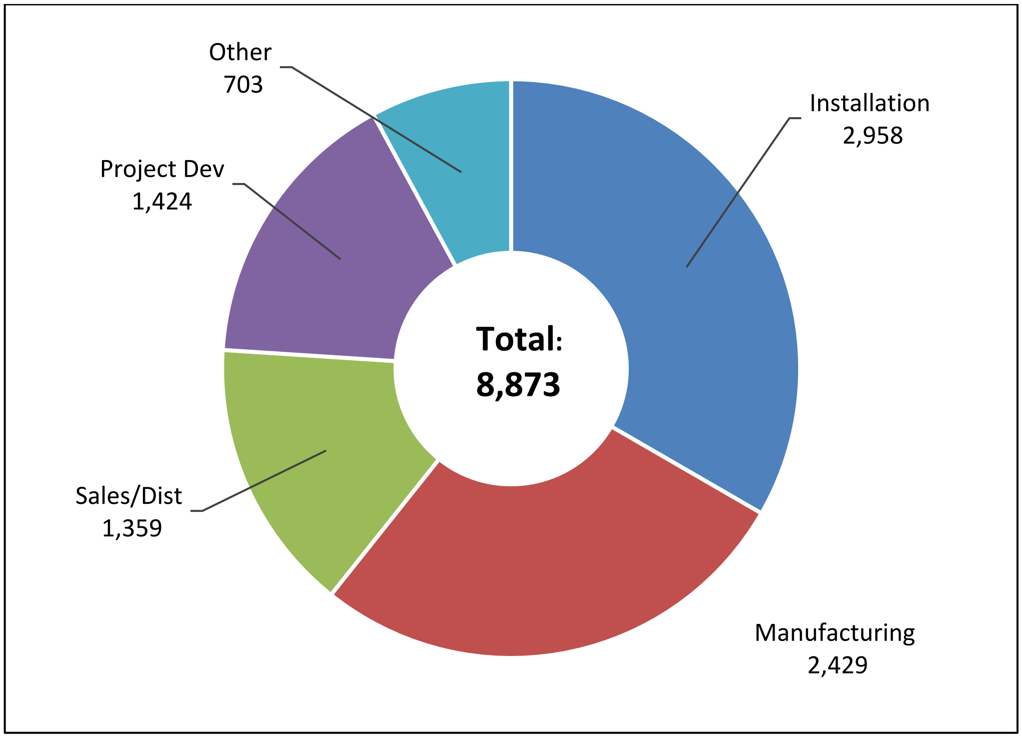
Backward & Forward Linkages/Supply Chain

A number of sectors and companies are engaged in renewable-related activity, in terms of manufacturing the products used to create/capture/transport energy, installing and servicing the technologies and the supporting infrastructure, and in the development of projects

[9] U.S. Department of Energy, https://www.energy.gov/sites/prod/files/2017/01/f34/2017%20US%20Energy%20and%20Jobs%20Report%20State%20Charts%202_0.pdf.

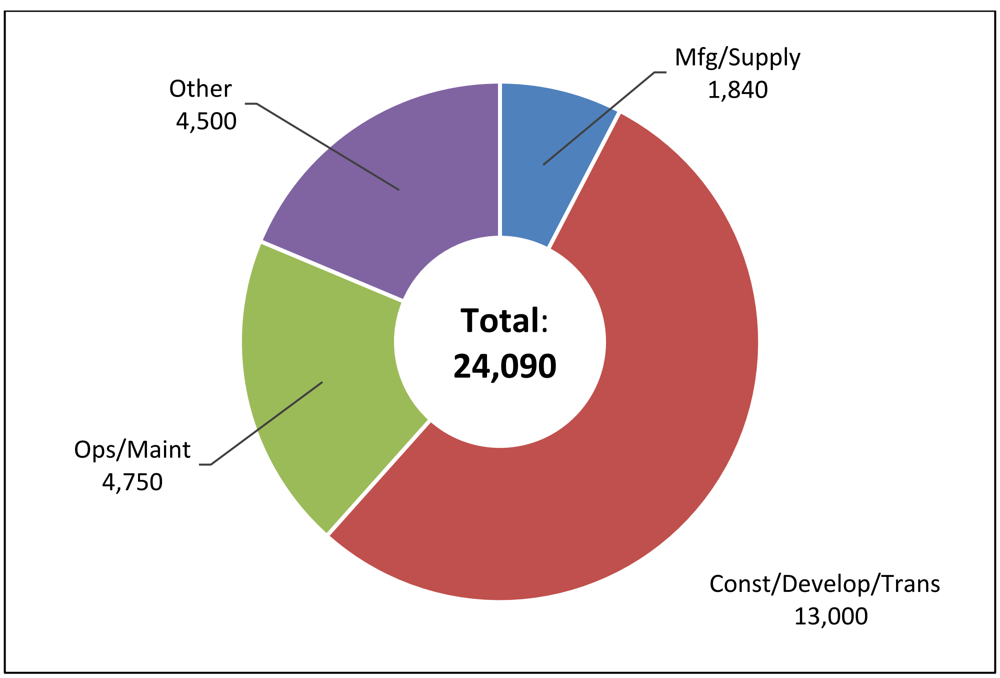
themselves. The following chart provides the breakdown by activity within the solar and wind segments, as provided by industry sources.

Figure 7: Texas 2017 Major Solar-Related Employment by Category



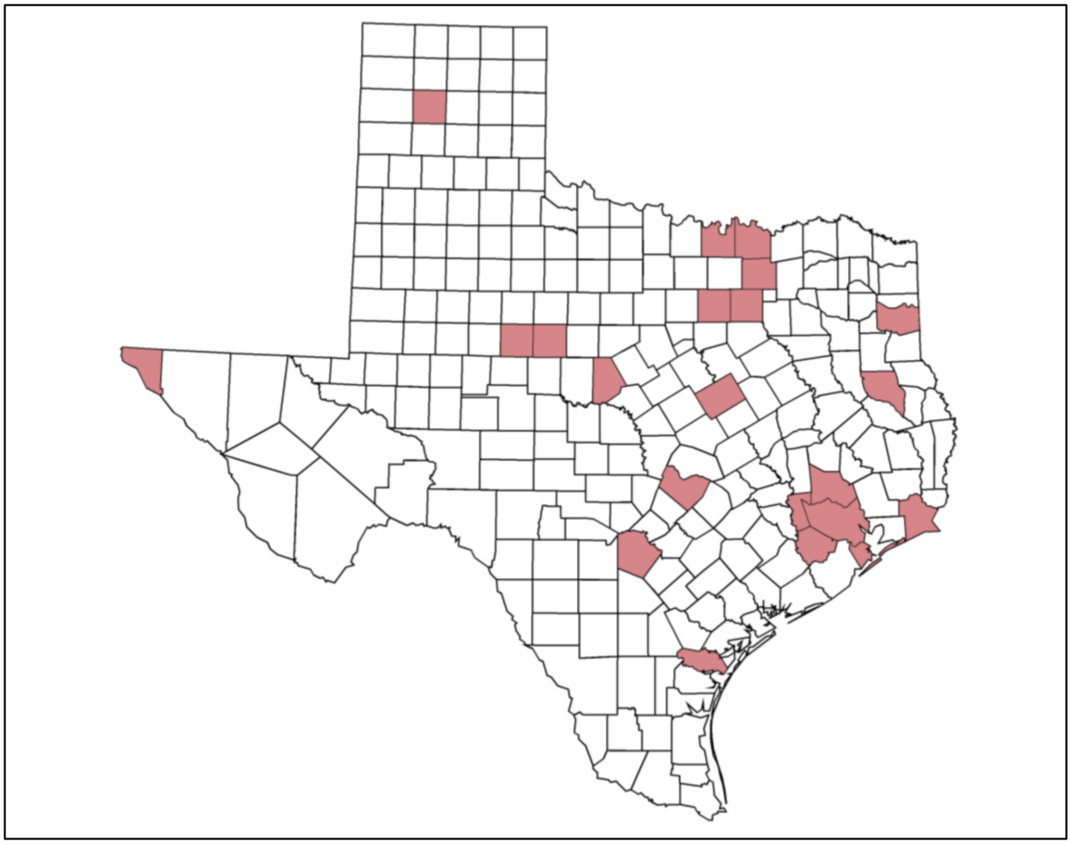
Sources: The Solar Foundation, TXP

Figure 8: Texas 2017 Major Wind-Related Employment by Category



The benefits are distributed across Texas, as most major urban areas contain firms engaged in some aspect of renewable-related production. The following figure depicts the geographic distribution.

Figure 9: Location of Wind & Solar Industry Manufacturers & Suppliers in Texas



Sources: AWEA, The Solar Foundation, TXP

Renewable Energy in Texas: Stimulating economic development

Corporate Relocation & Expansion

The availability of large-scale renewable energy increasingly is a factor in corporate relocation and expansion, especially for modern-economy industries that rely heavily on high volumes of reliable electric supply with stable long term-prices. Data centers are a prime example. Highlights from a recent report on the role of renewables in the data center industry by *IHS Markit* are as follows:[10]

- *Between 2 percent and 3 percent of developed countries' electricity consumption is currently attributed to data centers. For most data centers, the largest operational cost is the electricity used for cooling.*
- *The two most popular renewable energy methods are solar and wind power, due to their high-energy production and relative ease of implementation.*
- *Utility-scale renewable energy sources are the most cost-competitive way for data centers to obtain renewable energy. Long-term power purchase contracts remove risk and the large upfront capital expenses required to produce onsite renewable energy and the geographical limitations of renewable energy production methods.*

The report highlights the fact that both internal and external forces motivate data center operators to seek renewable energy sources. Internally, they are driven by energy cost savings, long-term price certainty, and corporate sustainability policies. Externally, data centers are motivated by customer and shareholder preferences for sustainable corporate practices, low-cost electricity, demonstrable economic development impacts, and customer sustainability goals.

Texas is well-positioned to respond to the trends described above, as the conditions on both the supply and demand side are in place for the state to be a leader in non-residential renewable energy. It is not a surprise, therefore, that Texas has such a strong presence on the Environmental Protection Agency (EPA)'s Green Power Partner List.[11] Based on the list released in July 2018, 19 of the top 25 national companies (and 9 of the top 10), representing 88 percent of the annual renewable power usage among that group, have a significant presence in Texas. This impact extends across of range of industries and regions within the state.

---

[10] https://technology.ihs.com/Categories/450457/datacenter-cloud

[11] https://www.epa.gov/greenpower/green-power-partnership-national-top-100

Table 8: Top Twenty-Five EPA Private Green Partners with a Significant Texas Presence

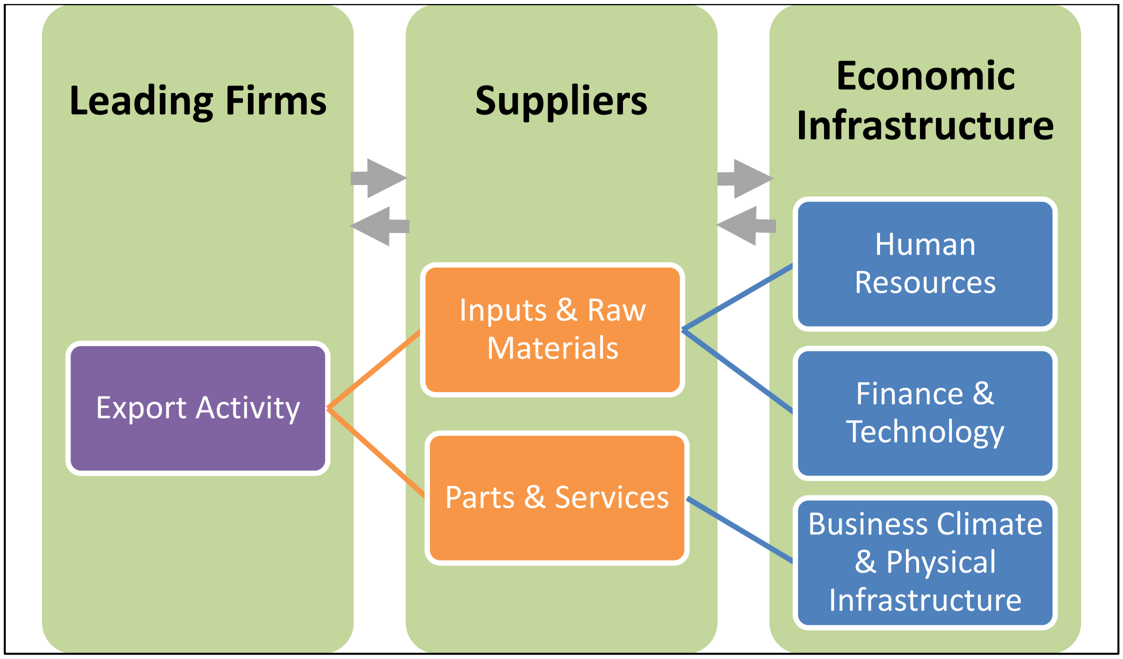
Company Name & Rank	Annual Renewables Usage (millions of kWh)	Renewables % of Power Consumed	Company Industry
1. Microsoft	4,557.3	100%	Technology & Telecom
2. Intel	4,152.0	100%	Technology & Telecom
3. Google	2,409.1	53%	Technology & Telecom
4. Apple	1,650.4	107%	Technology & Telecom
5. Bank of America	1,619.5	89%	Banking & Finance
6. Equinix	1,475.5	105%	Technology & Telecom
7. Cisco Systems	1,107.0	100%	Technology & Telecom
10. Starbucks*	1,056.8	103%	Restaurants & Cafes
12. IKEA	776.1	310%	Retail
13. Wal-Mart Stores	747.6	4%	Retail
14. Procter & Gamble	743.1	20%	Consumer Products
15. Anheuser-Busch	727.0	55%	Wineries & Breweries
16. Digital Realty	719.8	25%	Technology & Telecom
18. Mars, Inc.	662.3	70%	Food & Beverage
19. T-Mobile	625.6	27%	Technology & Telecom
23. Capital One	467.6	114%	Banking & Finance.
29. Boeing	326.7	15%	Aerospace
30. Johnson & Johnson	326.0	48%	Health Care
31. Lockheed Martin	303.8	20%	Health Care

* Company-owned cafes & retail stores
Sources: EPA, TXP

Cluster Development

The impact of the rising role of renewables in corporate recruitment and retention feeds into the possibility of a renewable energy cluster, a second area of opportunity related to economic development. First articulated by Michael Porter almost 40 years ago, the idea of economic clusters has become a key element of regional economic development strategy. Broadly defined, a cluster is a group of companies sharing local resources, using similar technologies, and forming linkages and alliances. These linkages can take the form of buyer-supplier relationships, fluid labor markets, joint marketing, training, or research initiatives, associations, and collective government interaction. Different regions are known for different clusters; finance in New York, entertainment in Los Angeles, and auto production in Detroit are just a few examples. Figure 9 illustrates the concept.

Figure 9: Cluster Development Illustration



Sources: ecgroup,TXP

The goal of cluster development is to create a level of scale that enables the region to capture an enhanced level of "market share" in that industry over time. As part of that effort, clusters can be "seeded" via government investment, university/non-for-profit support, and/or commitments from local buyers. Much of that work has been done around renewables in Texas; in combination with strength in all of the factors shown as being the necessary elements of cluster development, it would not be surprising if a renewables cluster emerges as a major factor in Texas' economic development success in the near future. The Governor's Office has recognized the potential, identifying Energy, including Renewable Energy, as one of seven Target Industry Clusters:

> *The Lone Star State's renewable energy potential is among the largest in the nation, with abundant wind, solar, and biomass resources found across the state's geographically diverse regions. In recent years, Texas has built upon its energy experience and trained workforce to take the lead in renewable energy production and services. As a result, Texas has become the top state in wind generation capacity and biodiesel production.*[12]

[12] https://gov.texas.gov/business/page/target-industries

Fuel Cost Hedging

An additional area of benefit is that renewables can serve as a hedge against high feedstock costs in the production of electricity. The concept that adding renewables to diversify an electricity generating portfolio is not new, with a fairly thorough summary included as part of *The Use of Solar and Wind as a Physical Hedge against Price Variability within a Generation Portfolio*, by National Renewable Energy Laboratory (NREL).[13] The basic concept behind the value of energy diversification is fairly simple. It is conventional wisdom in finance that a diversified portfolio is more "efficient," in that returns over time will exceed those of portfolios that are not diversified. The application in electricity relates to costs, as fluctuations in feedstock prices can create both scarcity and the opportunity for rent seeking, both of which mean higher prices for customers. The modeling done for this analysis tends to bear this out, as does the work reported by NREL. Three key findings from their work that are especially germane in Texas:

- *Solar and wind generation significantly reduce the exposure of electricity costs to natural gas price uncertainty in fossil-based generation portfolios on a multi-year to multi-decade time horizon.*
- *The reduction in volatility of electricity costs with increased (renewables) penetration is greater for natural gas-dominated portfolios than for coal-dominated portfolios.*
- *Market structure choices are important. Adding renewables reduces uncertainty in cost to consumers much more in restructured markets than in regulated markets*.

A second related value of renewables is that they are more amenable to long-term contracts than fossil-fuel alternatives. NREL also addresses this issue:

> *Of particular relevance to renewables is the fact that it is difficult and rare to be able to lock in financial or physical supply contracts of 10 years or more for natural gas. Such contracts may include premiums that reflect lack of liquidity and counterparty risk. Because of these and other issues, in the longer term solar and wind may be able to provide a physical hedge that is not easily replicated in the financial and physical commodity markets. It also provides insurance value against rising electricity prices in futures where natural gas prices rise or carbon emissions are priced via a tax or some other mechanism.*

Overall, renewables expand the hedging opportunities for those seeking to protect themselves against the impact of price shocks. Per NREL, the conditions are especially favorable in Texas, with a strong wind and growing solar presence, natural gas as the leading fossil fuel source, and a market that accommodates customer choice.

---

[13] See NREL whitepaper at http://www.nrel.gov/docs/fy13osti/59065.pdf.

Renewable Energy in Texas: Improving human health and the environment

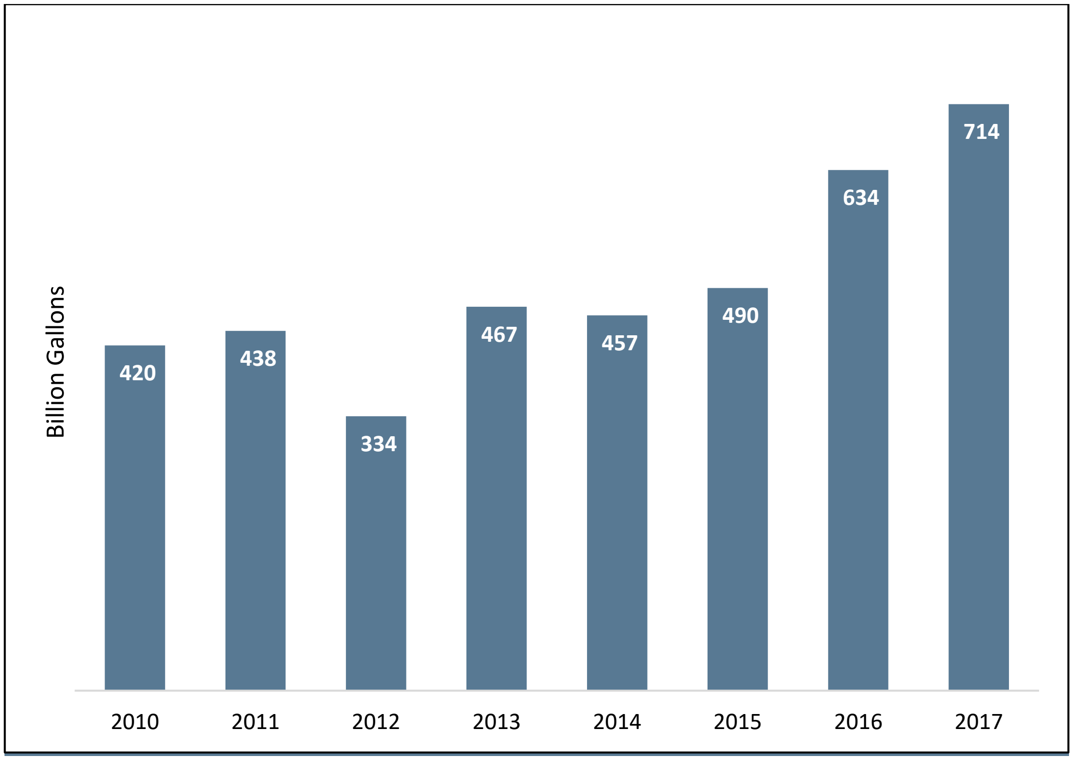
In addition to the impact on wholesale electricity costs, Ideasmiths also modeled the impacts on human health and the environment if renewables were not present. Renewable sources such as wind and solar do not involve combustion (hence no emissions) and do not require as much net water as part of the production process as many other forms of electricity production. Figures 10 through 12 illustrate the impact of renewables on water use and emissions. Each year was simulated with the amount of renewable generation installed and that year's average natural gas price.

Figure 10 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.

Figure 11 shows that under the same conditions 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. At average wholesale water rates, 100 billion gallons of water is worth about $309M.

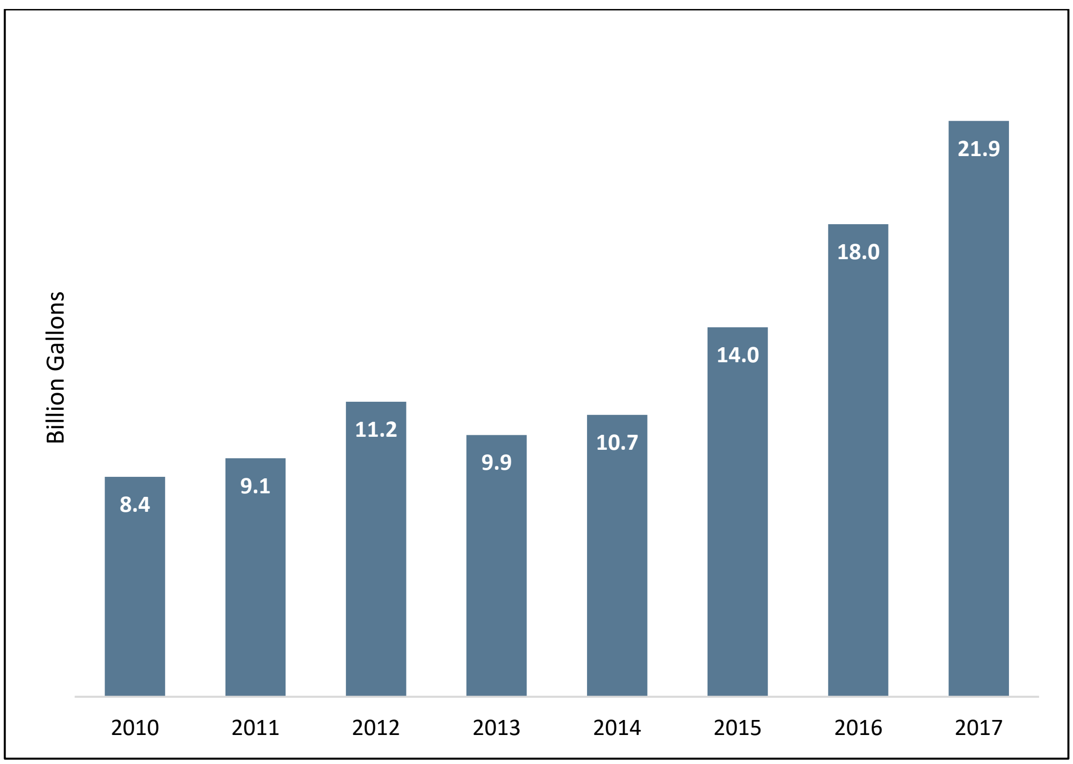
Table 9 indicates that, absent renewables, power plants would have emitted between 20 and 70 thousand tons more sulfur dioxide (SO_2), between 7 and 28 thousand tons more nitrogen oxides (NO_x) and between 20 and 52 million tons more carbon dioxide (CO_2) per year. In combination with savings associated with avoided water consumption, Texans realize between $0.8 and $2.4 billion annually in environmental savings, which is detailed in Table 10.

Figure 10: Water Withdrawal Saved by Year



Source: Ideasmiths, TXP

Figure 11: Water Consumption Avoided by Year



Sources: Ideasmiths, TXP

Table 9: CO_2, NOx, and SO_2 Emissions Avoided by Year

Year	Avoided SO_x Value (000s of tons)	Avoided NO_x Value (000s of tons)	Avoided CO_2 Value (millions of tons)
2010	20.6	7.6	19.9
2011	31.6	10.7	22.9
2012	32.3	13.8	27.2
2013	36.0	11.8	26.3
2014	19.1	8.9	25.1
2015	46.1	17.9	34.2
2016	55.0	23.0	43.7
2017	69.8	27.9	52.2
Total	**310.5**	**121.6**	**251.5**

Sources: Ideasmiths, TXP

Table 10: Environmental Savings in Water Consumption, SO_x, NO_x, and CO_2, by Year ($Bil.)

Year	Water Consumption Savings	Avoided SO_x Value	Avoided NO_x Value	Avoided CO_2 Value	Total Environmental Value
2010	$0.03	$0.34	$0.04	$0.40	$0.80
2011	$0.03	$0.53	$0.05	$0.46	$1.06
2012	$0.03	$0.54	$0.07	$0.54	$1.18
2013	$0.03	$0.60	$0.06	$0.53	$1.21
2014	$0.03	$0.32	$0.04	$0.50	$0.89
2015	$0.04	$0.77	$0.09	$0.68	$1.58
2016	$0.05	$0.91	$0.11	$0.87	$1.95
2017	$0.07	$1.16	$0.13	$1.04	$2.40
Total	**$0.31**	**$5.17**	**$0.59**	**$5.02**	**$11.07**

Sources: Ideasmiths, TXP

Conclusion

The rise of renewables in Texas' energy market has accelerated in recent years, as the combination of market demand, scale, incentives, enabling infrastructure, technology advances, and intermittent high costs for electricity produced from other feedstocks has come together the make the State arguably one of the leading consumers and producers of renewable energy in the country. Renewable energy already provides a wide range of value to individuals, companies, communities, local governments, and the State of Texas. These benefits are expected to grow over time and proportionately rise as the world demands more energy produced from renewable sources. In the process, a strong renewables sector positions Texas to continue its global energy leadership role.

Legal Disclaimer

TXP, Inc. and Ideasmiths (the Project Team) reserves the right to make changes, corrections, and/or improvements at any time and without notice. In addition, the Project Team disclaims any and all liability for damages incurred directly or indirectly as a result of errors, omissions, or discrepancies. the Project Team disclaims any liability due to errors, omissions, or discrepancies made by third parties whose material the Project Team relied on in good faith to produce the report.

Any statements involving matters of opinion or estimates, whether or not so expressly stated, are set forth as such and not as representations of fact, and no representation is made that such opinions or estimates will be realized. The information and expressions of opinion contained herein are subject to change without notice, and shall not, under any circumstances, create any implications that there has been no change or updates.

About TXP, Inc. & Ideasmiths

TXP is an economic analysis and public policy consulting firm founded in 1987 in Austin, Texas. Since then, TXP has grown into a team of professionals whose diverse backgrounds allow us to craft customized solutions to client problems. Our clients have discovered that TXP is the firm to hire when there is not an immediate, obvious, or simple solution to their economic or public policy challenge. Our reputation for having the right people to analyze issues from a variety of perspectives has made TXP the firm to call first for professionals in the public sector and business arenas.

TXP has worked with a wide range of not-for-profits and private sector clients to provide illumination through analytical support, always with a strategic view of the big picture. Members of TXP are involved in the community and understand the challenges faced by an increasingly complex world, as heightened media attention and an ever more diverse set of stakeholders shine a brighter spotlight on public decision-making and public policy.

IdeaSmiths LLC 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.

Appendix - Impacts of Renewables in ERCOT Report

The following report was prepared by Joshua D. Rhodes, PhD of IdeaSmiths LLC.

Joshua D. Rhodes
Rhodes@IdeaSmiths.net
(512) 658-2965

Mailing address:
5714 Chesterfield Ave
Austin, TX 78752

Impacts of renewables in ERCOT

Prepared for TXP

by Joshua D. Rhodes, PhD

IdeaSmiths LLC

Table of Contents

Joshua D. Rhodes
Rhodes@IdeaSmiths.net
(512) 658-2965

Mailing address:
5714 Chesterfield Ave
Austin, TX 78752

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

Joshua D. Rhodes
Rhodes@IdeaSmiths.net
(512) 658-2965

Mailing address:
5714 Chesterfield Ave
Austin, TX 78752

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.

Joshua D. Rhodes
Rhodes@IdeaSmiths.net
(512) 658-2965

Mailing address:
5714 Chesterfield Ave
Austin, TX 78752

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.

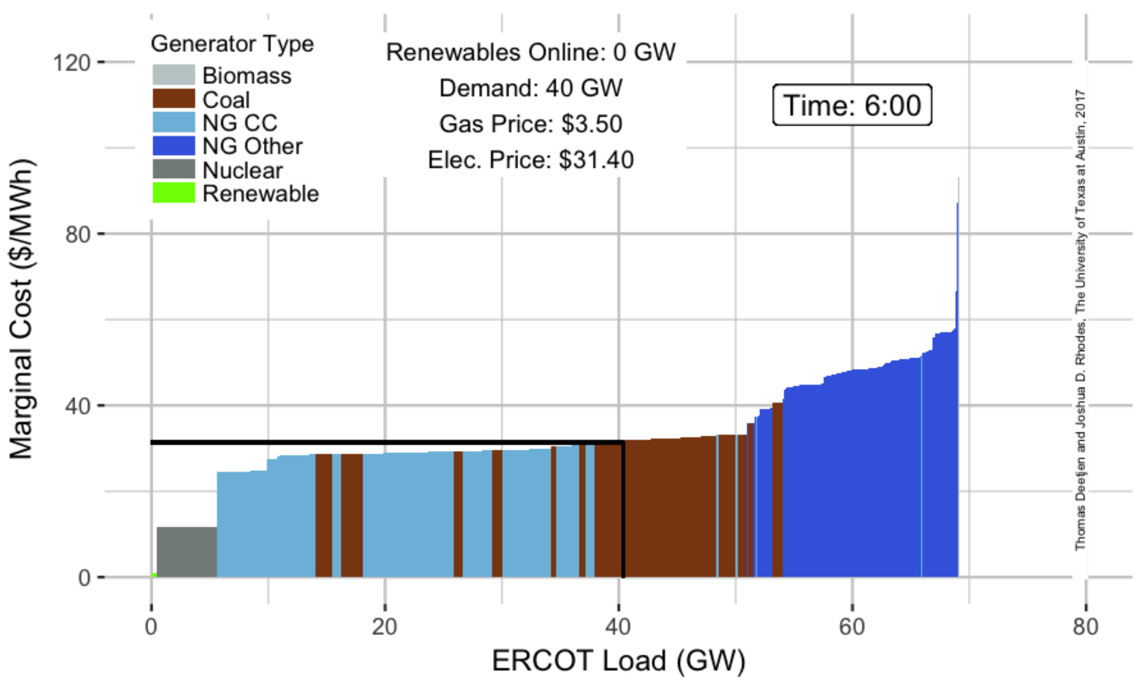


Figure 1: ERCOT bid stack and clearing price of $31.40/MWh at a load of 40 GW and natural gas price of $3.50/MMBTU.

Joshua D. Rhodes
Rhodes@IdeaSmiths.net
(512) 658-2965

Mailing address:
5714 Chesterfield Ave
Austin, TX 78752

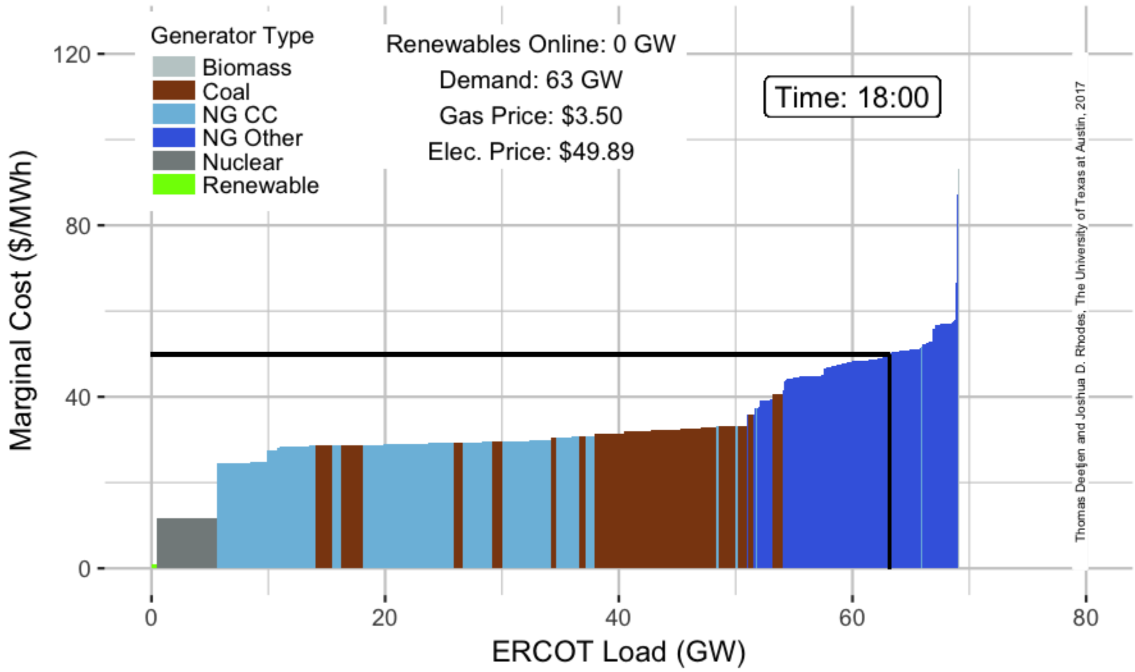


Figure 2: ERCOT bid stack and clearing price of $49.89/MWh at a load of 63 GW and natural gas price of $3.50/MMBTU.

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.

Joshua D. Rhodes
Rhodes@IdeaSmiths.net
(512) 658-2965

Mailing address:
5714 Chesterfield Ave
Austin, TX 78752

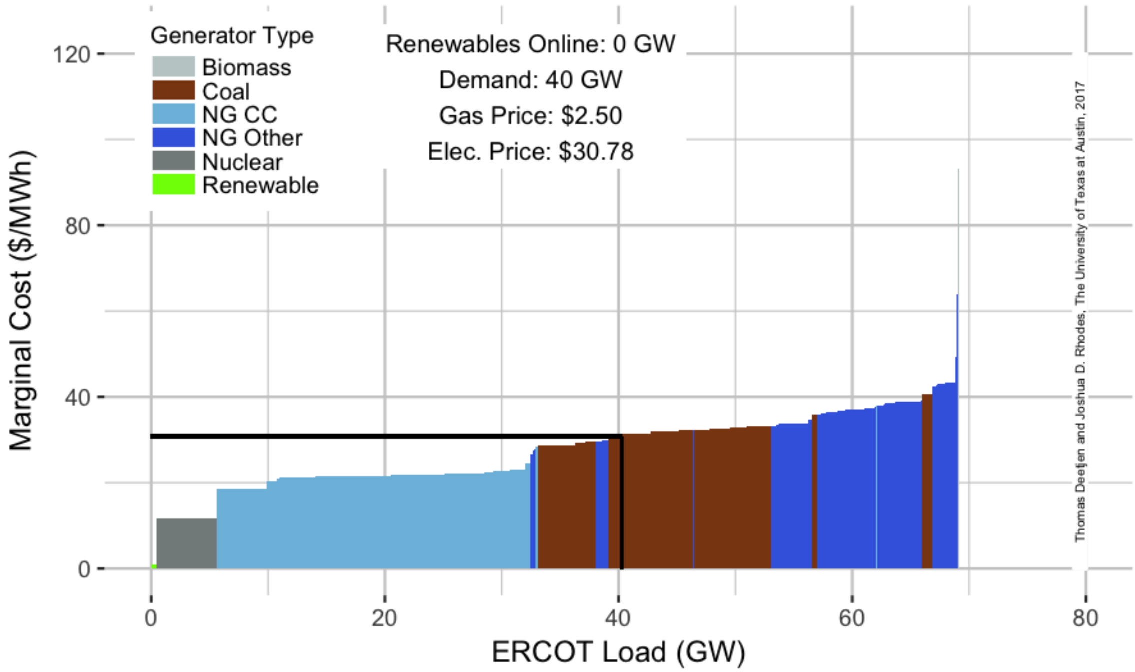


Figure 3: ERCOT bid stack and clearing price of $30.78/MWh at a load of 40 GW and natural gas price of $2.50/MMBTU.

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.

Joshua D. Rhodes
Rhodes@IdeaSmiths.net
(512) 658-2965

Mailing address:
5714 Chesterfield Ave
Austin, TX 78752

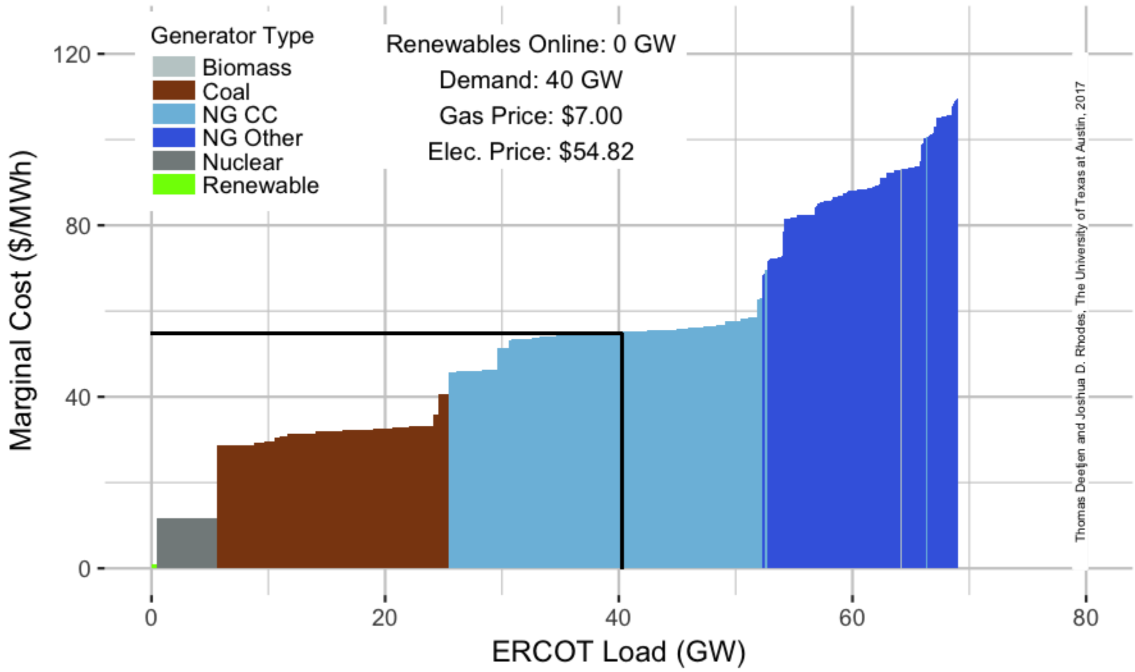


Figure 4: ERCOT bid stack and clearing price of $54.82/MWh at a load of 40 GW and natural gas price of $7.00/MMBTU.

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).

Joshua D. Rhodes
Rhodes@IdeaSmiths.net
(512) 658-2965

Mailing address:
5714 Chesterfield Ave
Austin, TX 78752

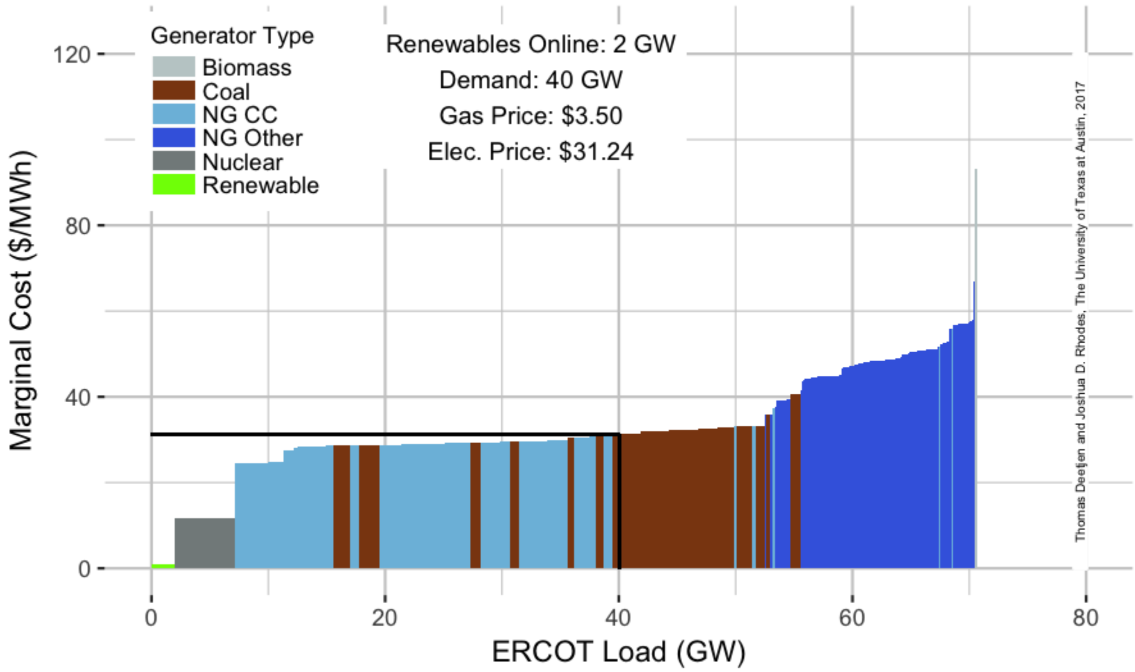


Figure 5: ERCOT bid stack with 2 GW of renewables online, a clearing price of $31.24/MWh at a load of 40 GW, and natural gas price of $3.50/MMBTU.

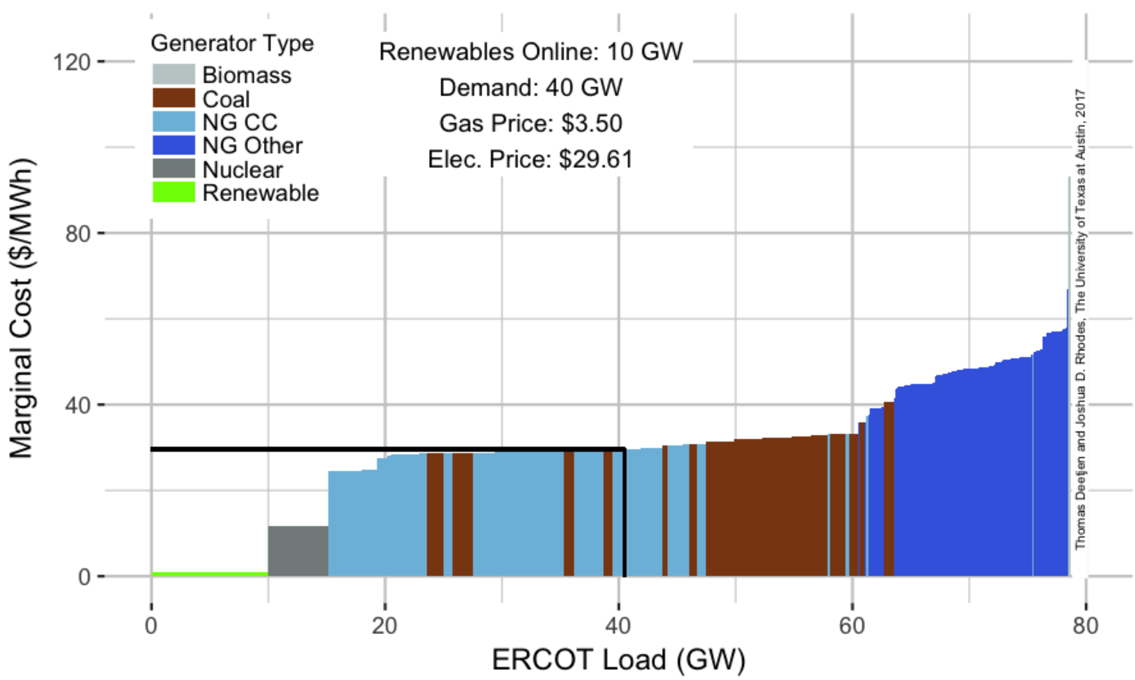


Figure 6: ERCOT bid stack with 10 GW of renewables online, a clearing price of $29.61/MWh at a load of 40 GW, and natural gas price of $3.50/MMBTU.

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.

Joshua D. Rhodes
Rhodes@IdeaSmiths.net
(512) 658-2965

Mailing address:
5714 Chesterfield Ave
Austin, TX 78752

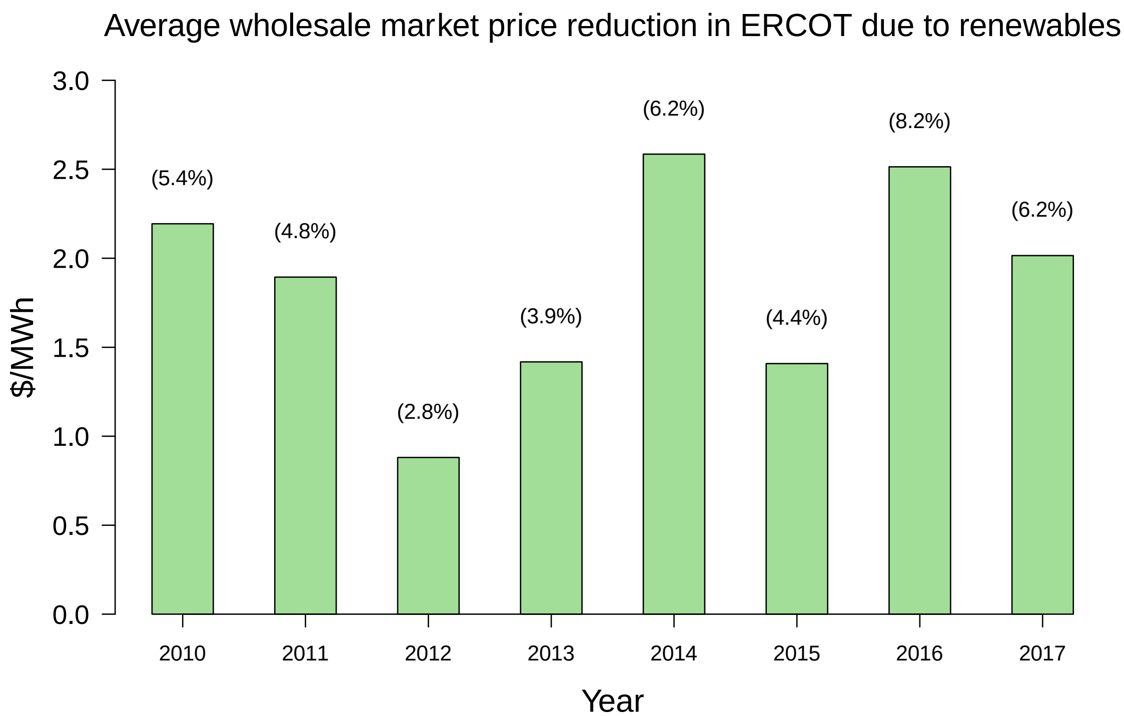


Figure 7: Figure showing modeled yearly average wholesale electricity market price reductions attributed to renewables for 2010-2017. Percentages above each bar indicate percentage reduction in average wholesale market costs due to renewables.

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.

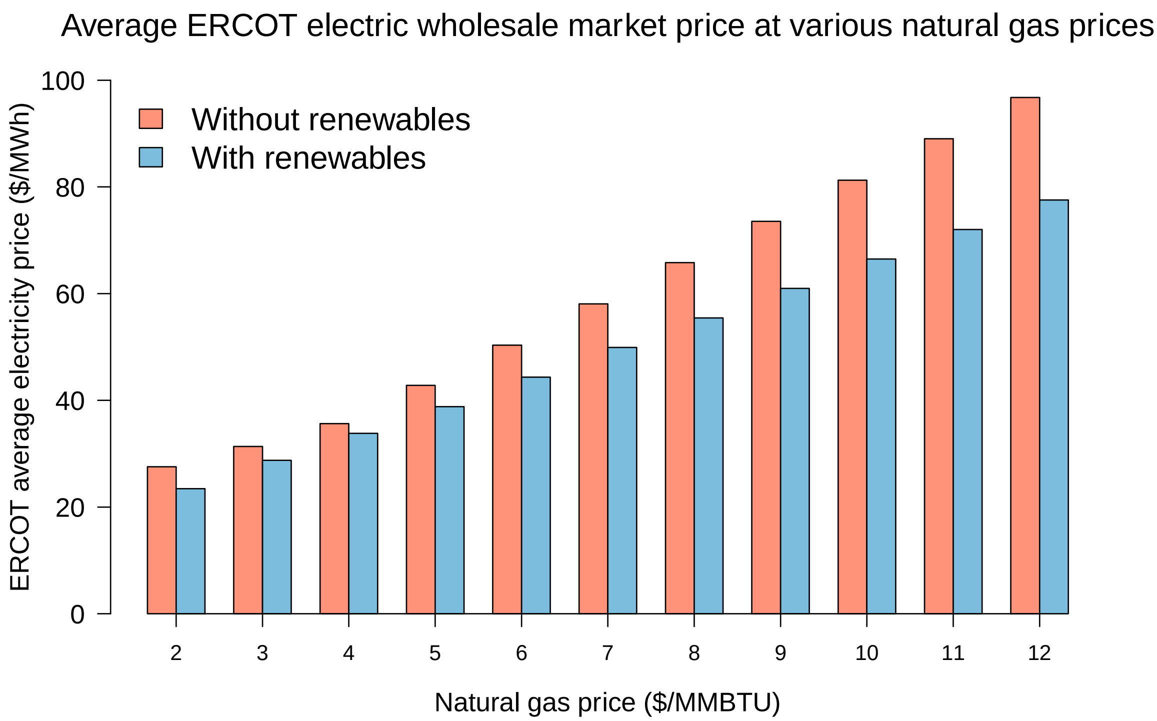


Figure 8: Figure showing the modeled impact of natural gas prices on ERCOT's wholesale electricity market price. Note that all groups of bars are for 2017, but with different natural gas prices.

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].

Joshua D. Rhodes
Rhodes@IdeaSmiths.net
(512) 658-2965

Mailing address:
5714 Chesterfield Ave
Austin, TX 78752

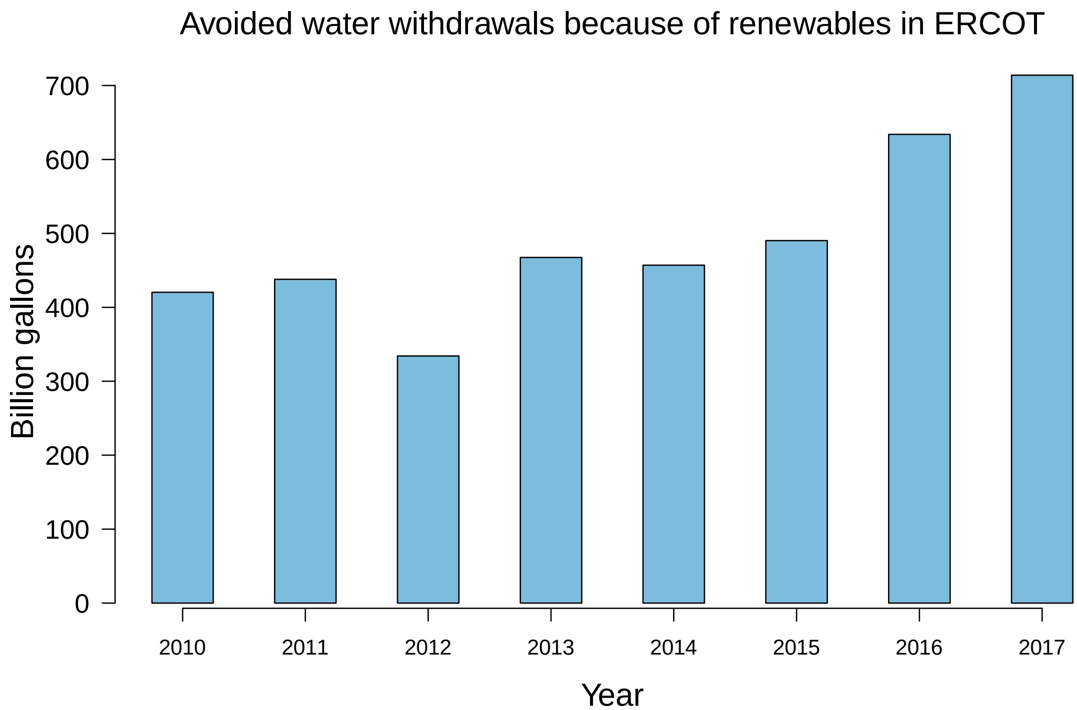


Figure 9: Figure showing modeled water withdrawal reductions attributed to renewables for 2010-2017. Water withdrawals refer to water that is used by a power plant for cooling, but is returned to the source, but at a higher temperature.

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.

Joshua D. Rhodes
Rhodes@IdeaSmiths.net
(512) 658-2965

Mailing address:
5714 Chesterfield Ave
Austin, TX 78752

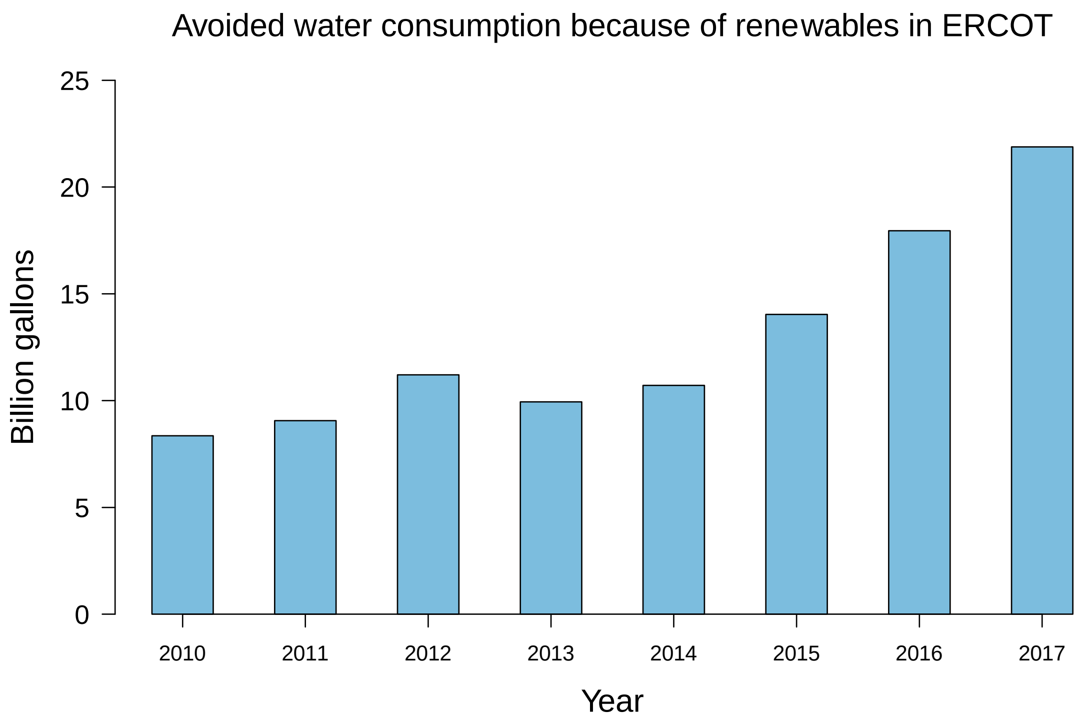


Figure 10: Figure showing modeled water consumption reductions attributed to renewables for 2010-2017. Water consumption refers to water that is evaporated by a power plant's cooling system and is not available for other uses.

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.

Joshua D. Rhodes
Rhodes@IdeaSmiths.net
(512) 658-2965

Mailing address:
5714 Chesterfield Ave
Austin, TX 78752

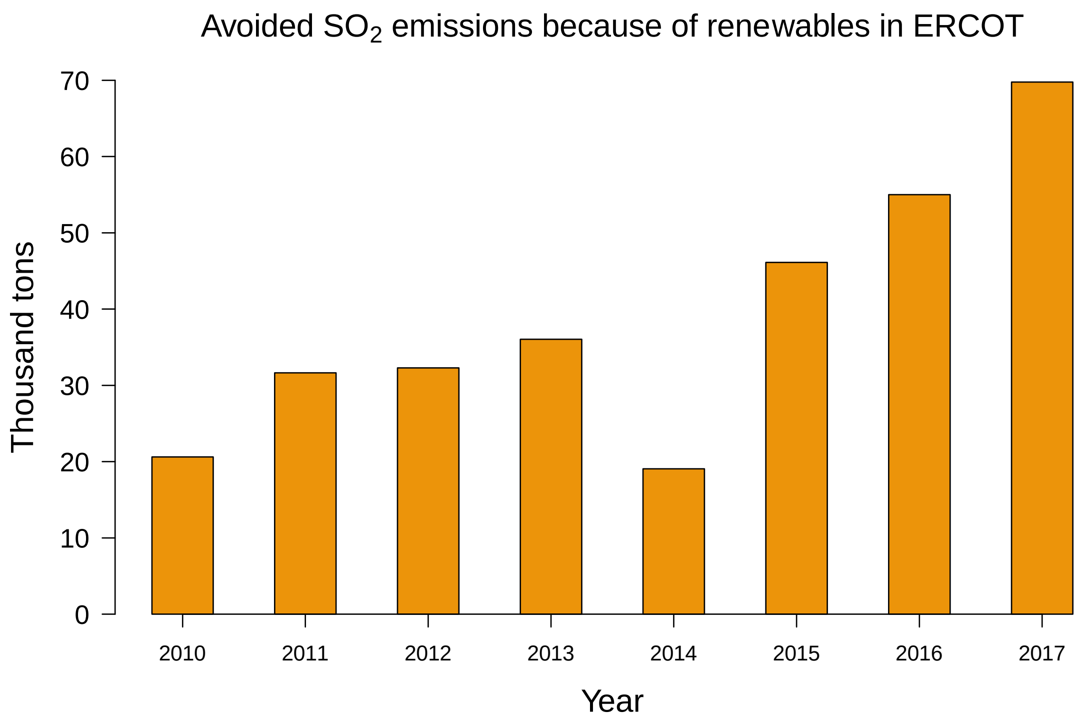


Figure 11: Figure showing modeled SO_2 emissions reductions attributed to renewables for 2010-2017.

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.

Joshua D. Rhodes
Rhodes@IdeaSmiths.net
(512) 658-2965

Mailing address:
5714 Chesterfield Ave
Austin, TX 78752

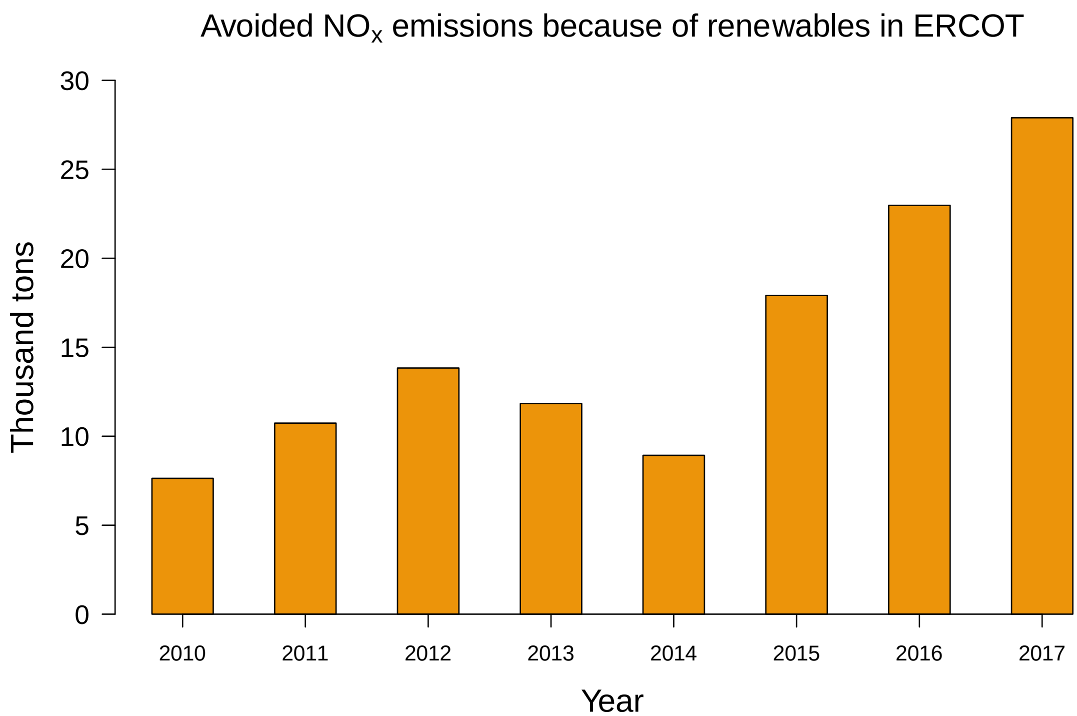


Figure 12: Figure showing modeled NO_x emissions reductions attributed to renewables for 2010-2017.

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).

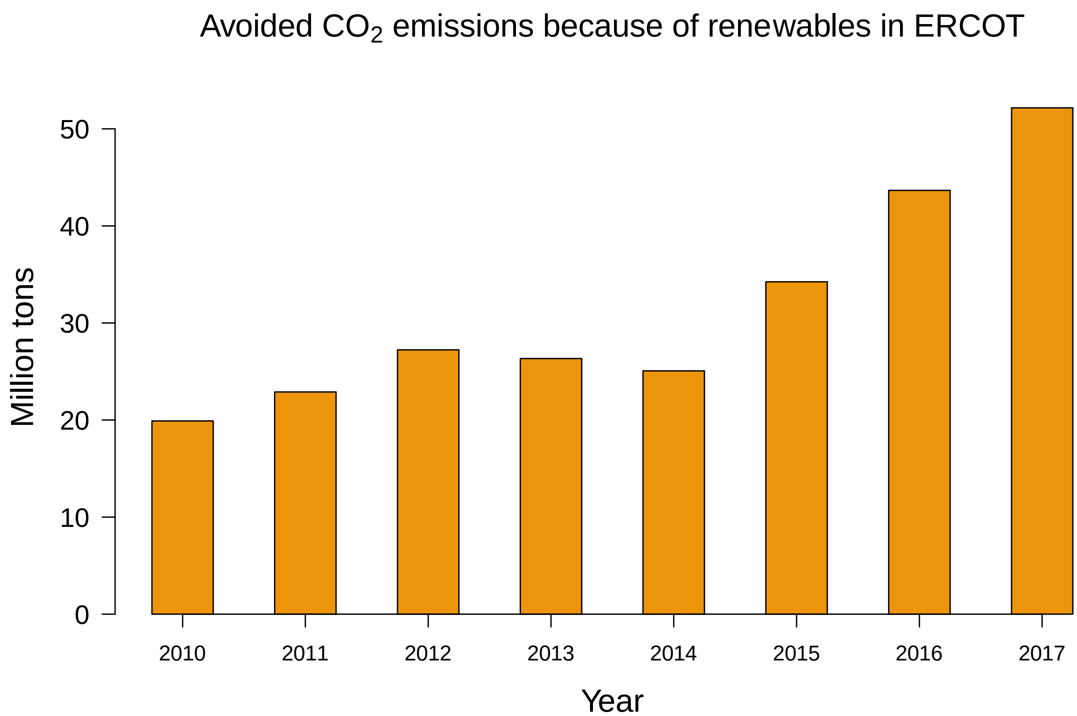


Figure 13: Figure showing modeled CO_2 emissions reductions attributed to renewables for 2010-2017.

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.

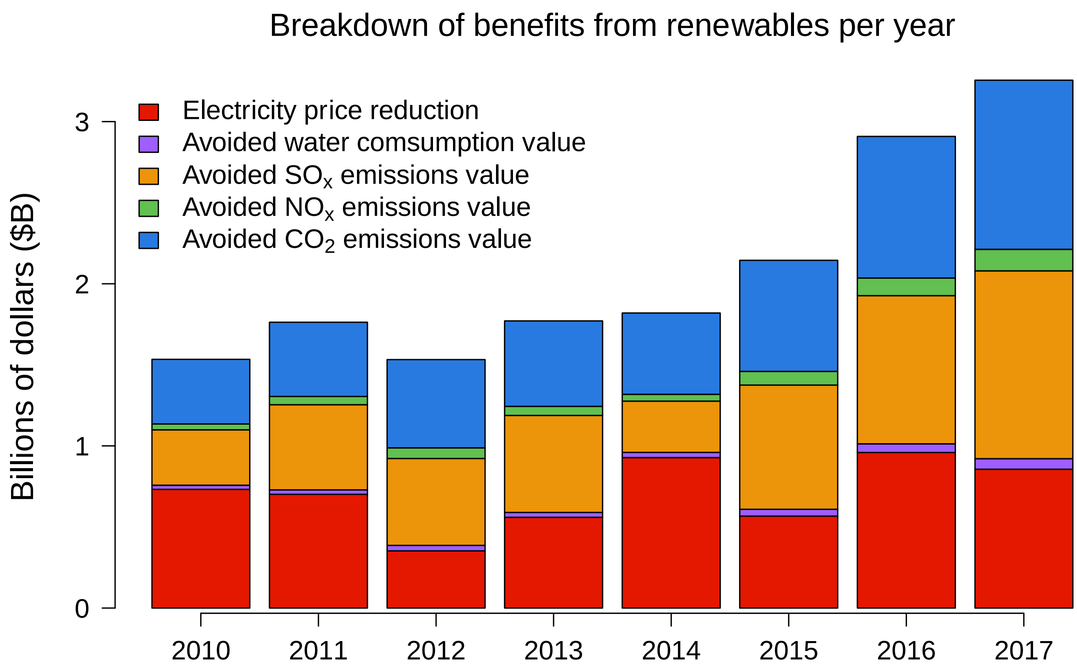


Figure 7: Figure showing breakdown of benefits from renewables for 2010 – 2017. Median values (from all Texas counties) of damages were used to monetize the emissions reductions (SO_x: $16,600/ton, NO_x: $4,750/ton, CO_2: $20/ton, water: $3/thousand gallons).

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].

Joshua D. Rhodes
Rhodes@IdeaSmiths.net
(512) 658-2965

Mailing address:
5714 Chesterfield Ave
Austin, TX 78752

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.

---

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
5 https://www.sciencedirect.com/science/article/pii/S0306261916310984
6 http://proceedings.asmedigitalcollection.asme.org/proceeding.aspx?articleid=1626445
7 http://www.ercot.com/gridinfo/generation
8 http://www.ercot.com/gridinfo/resource
9 https://www.eia.gov/dnav/ng/hist/n3045us3a.htm
10 https://theconversation.com/are-solar-and-wind-really-killing-coal-nuclear-and-grid-reliability-76741
11 https://emp.lbl.gov/sites/default/files/lbnl_anl_impacts_of_variable_renewable_energy_final.pdf
12 https://www.sciencedirect.com/science/article/pii/S0301421516306875
13 http://www.twdb.texas.gov/publications/reports/special_legislative_reports/doc/2014_WaterUseOfTexasWaterUtilities.pdf
14 http://www.rrc.state.tx.us/about-us/resource-center/faqs/oil-gas-faqs/faq-hydraulic-fracturing/
15 https://www.energy.gov/eere/analysis/downloads/2016-renewable-energy-grid-integration-data-book
16 http://proceedings.asmedigitalcollection.asme.org/proceeding.aspx?articleid=1719607
17 https://repositories.lib.utexas.edu/bitstream/handle/2152/23624/MEEHAN-THESIS-2013.pdf?sequence=1
18 https://www.sciencedirect.com/science/article/pii/S0306261916310984