THE ELECTRIC RELIABILITY COUNCIL OF TEXAS:

COAL PLANTS VS. MARKET CONDITIONS

by
Carolyn Mullen

A capstone submitted to Johns Hopkins University in conformity with the requirements for the degree of Master of Science in Energy Policy and Climate

Baltimore, Maryland
April 2018

© 2018 Carolyn Mullen

All Rights Reserved

Table of Contents

Figures, Tables, and Graphs

Figures

Tables

Graphs

Abstract

Coal-fired power plant retirements are important to understand as energy systems and energy markets evolve. Three base-load coal-fired power plants that were operational within the Electric Reliability Council of Texas (ERCOT) region were retired in the early months of 2018, which resulted in 4.2 GW of generating capacity being removed from the ERCOT grid. The purpose of this study is to analyze the driving factors behind these retirements. From shifts in electricity generation by fuel source, changing economic conditions, to various state and federal policies influencing the ERCOT wholesale electricity market, there is many influences that contribute to these retirements. To conduct this study an analysis of ERCOT's wholesale energy market was performed to understand shifts in utilized fuel sources to meet consumer demands, and how net generation by fuel source has evolved over a fifteen-year period. An in-depth analysis was conducted on net generation by fuel source data over the fifteen-month period of January 2017-March 2018 to analyze shifts in net generation leading up to these coal-fired power plant retirements in February 2018. After finalizing this analysis, one general observation can be made: multiple factors influenced these coal-fired power plants, including: [1] Inexpensive natural gas prices; [2] increased installation of renewable energy generating capacity; and [3] various EPA air quality regulations and policies. These factors have made it extremely difficult for these coal-fired power plants to compete within ERCOT's wholesale energy market. Understanding how these retirements were influenced by the variety of factors allows for a better assessment of how future coal-fired power plants within the ERCOT service region could be at risk for retirement.

Acknowledgements

Thank you to Dr. Peter Saundry for serving as my capstone advisor and providing assistance and feedback that helped further my analysis for this project. Thank you to Samir Nandy, my work colleague who is a great educator, mentor, and resource to discuss industry related questions that pertained to my research. My appreciation for your willingness to sit and talk to me about this topic, and other domestic coal related issues, is never ending. Lastly, thank you to my friends and family for listening to me and supporting me during my final stretch of my master's program. I know I was difficult at times, but the never-ending support, candor, and well wishes will forever be value.

Introduction

Numerous utilities across the United States have either announced or executed retirements of coal-fired power plants. A multitude of reasons drives these retirements, but above all, environmental concerns, aging power plants, and economics have accelerated plant shutdowns or conversions to natural gas. Coal-fired power plant retirements have occurred all over the United States, but significant retirements announced by Luminant, an electric power generator that operates within the Electric Reliability Council of Texas (ERCOT), were of note in the later months of 2017. Luminant, the "largest electricity generator in the state of Texas," announced the retirement of three of its largest coal-fired power plants.[1] In October of 2017, Luminant announced the planned 2018 retirements of Monticello, Big Brown, and Sandow.[2,3] Luminant's total capacity for all plants it owned and operated (nuclear, natural gas, and coal plants) in 2017 was 17,814 MW, and after these retirements were executed, Luminant's total capacity decreased to 13,647 MW in 2018.[4] With over 4,000 MW of capacity being retired in the early part of 2018, it is intriguing to see how energy demands of the consumers within ERCOT will be met, and how fuel sources used to generate electricity will change. With such a dynamic shift within ERCOT's energy profile, it is also essential to understand the driving factors behind or influencing these coal-fired plant retirements. This paper will use ERCOT as the focus of this study to analyze the factors that contributed to the retirement of these large capacity generators

---

[1] Luminant. "Powering Texas." Luminant. accessed December 13, 2017. https://www.luminant.com/powering-texas/.
[2] "Luminant Announces Decision to Retire Its Monticello Power Plant." *Luminant* (blog). October 6, 2017. https://www.luminant.com/luminant-announces-decision-retire-monticello-power-plant/.
[3] "Luminant to Close Two Texas Power Plants." *Luminant* (blog). October 13, 2017. https://www.luminant.com/luminant-close-two-texas-power-plants/.
[4] Luminant. "Generation Capacity and Energy Production." *Powering Texas- Generation, Capacity, and Energy Production* (blog). accessed April 30, 2018, https://www.luminant.com/powering-texas/generation-capacity-and-energy-production/.

in Texas. In is hypothesized that due to the wholesale energy market that operates within the ERCOT service region paired with the increase in installed renewable energy generation capacity and inexpensive natural gas prices, the three coal-fired power plants of focus in this study were unable to compete within the competitive wholesale energy market within the ERCOT region, consequently leading to their retirements.

The Electric Reliability Council of Texas (ERCOT)

The Electric Reliability Council of Texas (ERCOT) manages the flow of electric power to 24 million customers in the state of Texas, representing roughly 90% of the state's electrical load.[5] ERCOT serves as the independent system operator (ISO) for the region. As the ISO, ERCOT has four main responsibilities: system reliability, a wholesale market settlement for electricity production and delivery, retail switching process for customer choice, and open access to transmission[6]. Within the region, ERCOT's grid is comprised of more than 46,500 miles of transmission lines and over 610 generation units[7]. In ERCOT's Capacity, Demand, and Reserves (CDR) 2018-2027 report published in 2017, they estimated that in 2018 the grid would have 84,420 MW or 84.42 GW of installed capacity within the region.[8] ERCOT is a membership-based 501(c)(4) nonprofit corporation, governed by a board of directors and subject to oversight by the Public Utility Commission of Texas and the Texas Legislature.[9] Its members include consumers, cooperatives, generators, power marketers, retail electric providers, investor-owned

[5] "About ERCOT." accessed March 2, 2018. http://www.ercot.com/about.
[6] "ERCOT Quick Facts." April 2018. http://www.ercot.com/content/wcm/lists/144926/ERCOT_Quick_Facts_41018.pdf.
[7] Ibid
[8] Electric Reliability Council of Texas (ERCOT). "Report on the Capacity, Demand, and Reserves (CDR) in the ERCOT Region, 2018-2027." May 2, 2017. http://www.ercot.com/content/wcm/lists/114798/CapacityDemandandReserveReport-May2017.pdf.
[9] Ibid

electric utilities, transmission and distribution providers and municipally owned electric utilities[10].

When the Texas state legislature restructured the Texas electricity market in the late 1990s, the result was the current wholesale electricity market. Within the wholesale electricity market, distinct companies provide retail, transmission & distribution, and generation services to consumers in the ERCOT region. Having separate entities within ERCOT provide each aspect of electricity generation, transmission, and retail sales fosters a competitive market where consumers have multiple retail electric providers (REPs) to choose from. [11] Wholesale and retail prices are set by competitive market forces, while the public utility commission (PUC) sets transmission and distribution rates.[12] In the diagram below found in a presentation provided by the Association of Electric Companies of Texas, Inc. (AECT), a simple breakdown of how separate companies provide electricity services to consumers within the state can be seen.

[10] "ERCOT Quick Facts." April 2018. http://www.ercot.com/content/wcm/lists/144926/ERCOT_Quick_Facts_41018.pdf.

[11] Association of Electric Companies of Texas, Inc. "The Wholesale Electricity Market in ERCOT." 2017. http://aect.net/documents/2017/AECT%20Wholesale%202017.pdf.

[12]Ibid, Slide 5.

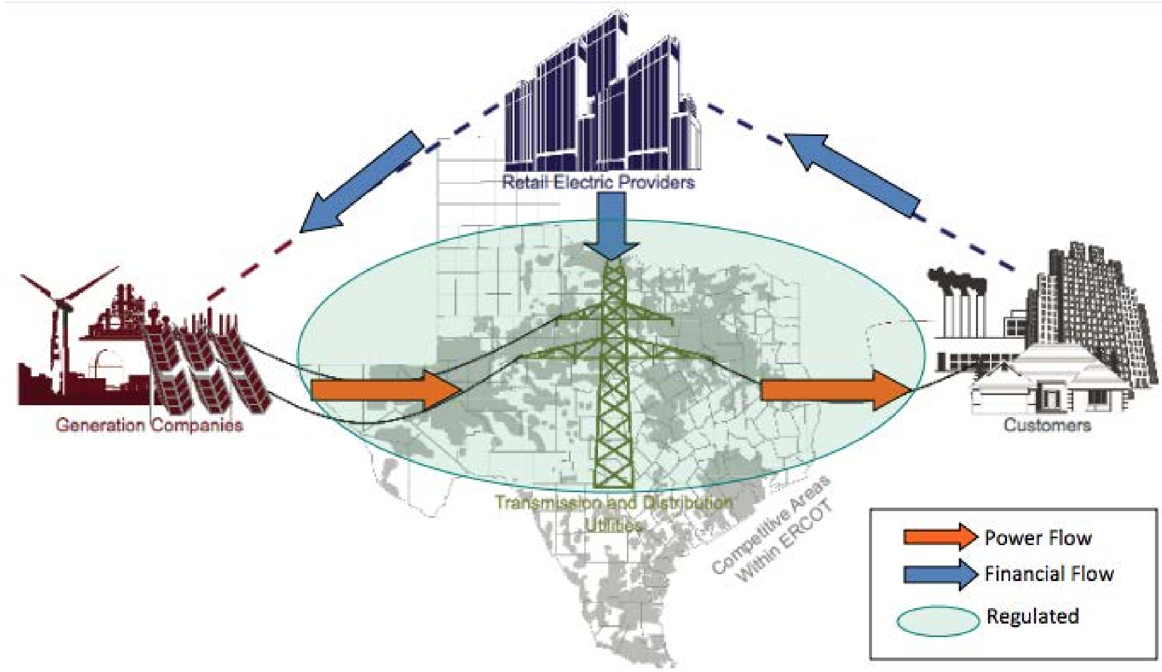


Figure 1: ERCOT Wholesale Energy Market Structure

In the diagram above, the orange arrows represent power flow between generation companies via transmission and distribution utilities which are regulated by the PUC. The blue arrows represent the financial flow between each group. The consumers pay the retail electric providers which in turn pay transmission and distribution utilities and generation companies[13].

Having three distinct groups within the electricity market in Texas has helped drive market competition and greater efficiency of generators to the wholesale market. Generation companies shoulder the most risk of building new power plants within ERCOT; this means that generation companies are less likely to invest in new generating capacity if they do not think it will be able to compete on the wholesale market. Generating companies shouldering the risks associated with adding new power plants to the grid has driven increased investments in more

[13] Association of Electric Companies of Texas, Inc. “The Wholesale Electricity Market in ERCOT.” 2017. http://aect.net/documents/2017/AECT%20Wholesale%202017.pdf.

efficient, cost-effective generation for consumers.[14] New power plants that have been constructed within the ERCOT grid produce more electricity per unit of fuel, and this increase in operational efficiency helps push wholesale prices downward.[15] To understand how the wholesale energy market is currently functioning within ERCOT's region, it is crucial to know the key state and federal policies influence the market.

State and Federal Policies at Play in the ERCOT Region

In 1970, the Texas Interconnected System (TIS) formed the Electric Reliability Council of Texas (ERCOT) to comply with the North American Electric Reliability Council (NERC) requirements[16]. After the formation of ERCOT, the Texas state legislature passed various policies that would alter the state's energy infrastructure. Federal legislation passed in 1992 helped lay the framework for state level legislation regarding wholesale energy markets. The Energy Policy Act (EPAct) encouraged the rise of inexpensive independent power producers by requiring utilities owning transmission lines to transmit wholesale power from other producers at the same rate as their own generated power.[17] In 1995, the Texas state legislature passed SB 373, which restructured and deregulated the current wholesale generation energy market functioning within the ERCOT region[18].

[14] Association of Electric Companies of Texas, Inc. "The Wholesale Electricity Market in ERCOT."
[15] Ibid, Slide 6.
[16] Tom Hunter. "History of Electric Deregulation in ERCOT." Presentation. Electric and Gas Reliability Workshop (Public Utility Commission, April 17, 2012). https://www.puc.texas.gov/agency/topic_files/101/PUC-History_Dereg_ERCOT.pdf.
[17] Philip Sharp. "H.R.776 - 102nd Congress (1991-1992): Energy Policy Act of 1992." Pub. L. No. H.R. 776, § 712 (1992). https://www.congress.gov/bill/102nd-congress/house-bill/776/text/enr.
[18] Armbrister. "SB 373." Pub. L. No. SB 373 (1995). 373. http://www.legis.state.tx.us/billlookup/History.aspx?LegSess=74R&Bill=SB373.

SB 373 did many things that influenced the future wholesale energy market. The main results of SB 373 were:

> "requiring utilities to provide independent generators with non-discriminatory, open access to transmission to support wholesale market competition in ERCOT, recognizing new unregulated participants in ERCOT's wholesale energy market, allowed non-utility wholesale energy market participants to offer market-based prices in ERCOT, and deregulated electric distribution rates that were once regulated by PUC"[19].

SB 373 provided the framework for the wholesale energy market within the state of Texas. Shortly after EPAct and SB373, the Federal Energy Regulatory Commission (FERC) Order 888 was enacted in 1996. FERC Order 888 directed utilities to functionally unbundle transmission services applying to wholesale and retail sales.[20] Utilities under this order had to file tariffs with rates terms and conditions for generation services and they were required to allow other utilities to sell wholesale power in their service territory. FERC Order 888 also expanded transmission and ancillary services.[21] In 1996, ERCOT was named the regions Independent System Operator (ISO), thereby creating a third-party organization to oversee grid operations. These grid operations range from system reliability to facilitating the wholesale energy market for the region. When this occurred in 1996, ERCOT was the nation's first ISO, and was the only ISO created by state legislation instead of by FERC[22]. Following this, the Texas legislature passed

[19] Tom Hunter. "History of Electric Deregulation in ERCOT." April 2012. https://www.puc.texas.gov/agency/topic_files/101/PUC-History_Dereg_ERCOT.pdf.

[20] Marcel A Lamoureux. 2001. "FERC's Impact on Electric Utilities." IEEE Power Engineering Review. August. Accessed April 15, 2018. https://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=948252

[21] Ibid, Pg. 9

[22] Tom Hunter. "History of Electric Deregulation in ERCOT." April 2012. https://www.puc.texas.gov/agency/topic_files/101/PUC-History_Dereg_ERCOT.pdf.

Senate Bill 7 (SB 7), which restructured the retail electricity market and required the electric energy markets to be open to competition by 2002[23,24].

Senate Bill 7 (SB 7) also resulted in significant changes to the electricity market in ERCOT's region. First, incumbents were required to separate business activities by generation, transmission and distribution, and retail electric providers[25]. Unbundling these business activities by these three general classifications allowed for the formation of a competitive energy market structure. In addition to this significant change in structure, this bill has specific stipulations that restrict market power abuse. The most notable of these stipulations is Sec. 39. 154. "Limitation of Ownership of Installed Capacity" within SB 7, which limits the generation capacity that a power generation company may own and control. This section of the bill states that a "power generation company may not own and control more than 20% of the installed generation capacity located in, or capable of delivering electricity to, a power region"[26]. This portion of SB 7 facilitates the continuation of the competitive wholesale energy market by limiting a power generating company from exceeding this 20% share of generation capacity. Setting specific limits regarding a generating company's share of installed generating capacity creates the opportunity for growth and a diverse generating profile to meet consumer demands.

In addition to these state-level policies that transformed the Texan energy market, the renewable electricity production tax credit (PTC) provided a federal tax incentive for generating companies to expand renewable technology utilization in Texas. The renewable electricity

[23] Sibley. "SB 7" Pub. L. No. SB 7 (1999). http://www.legis.state.tx.us/billlookup/History.aspx?LegSess=76R&Bill=SB7.
[24] Tom Hunter. "History of Electric Deregulation in ERCOT." April 2012. https://www.puc.texas.gov/agency/topic_files/101/PUC-History_Dereg_ERCOT.pdf.
[25] Sibley. "SB 7" Pub. L. No. SB 7 Sec. 39.051. (1999). http://www.legis.state.tx.us/billlookup/History.aspx?LegSess=76R&Bill=SB7.
[26]Sibley. "SB 7" Pub. L. No. SB 7 Sec. 39.051. (1999). http://www.legis.state.tx.us/billlookup/History.aspx?LegSess=76R&Bill=SB7.

production tax credit (PTC) “is an inflation-adjusted per-kilowatt-hour (kWh) tax credit for electricity generated by qualified energy resources and sold by the taxpayer to an unrelated person during the taxable year.” The tax credit amount is $0.015/kWh in 1993 dollars and is adjusted each year by the inflation adjustment factor determined by the IRS.[27] The value of the PTC depends on the type of renewable technology being used, with wind power having a tax credit of $0.019/kWh in 2017.[28] Thus, federal tax credit allows for electricity generated by wind to be extremely cost effective and cost competitive in a wholesale energy market.

Texas Renewable Portfolio Standards (RPS)

Another important aspect of this study involves understanding the various policies enacted by the Texas state legislature that were favorable for renewable technologies. One of the first steps the Texas state legislation took was to establish the state’s renewable portfolio standard (RPS) in 1999.[29] Once the legislative framework was established for the state’s RPS, state representatives were strategic in linking the RPS with related issues that were deemed a priority, such as the competitive restructuring of the state’s electricity market.[30] Strategically connecting the state’s RPS to key state legislation regarding the restructuring of its electricity market allowed for the RPS to be successful and achieve the state legislator’s goals. These goals focused on increasing economically sustainable renewable energy, the promotion of economic efficiency, and demand for renewable energy within the competitive wholesale energy market. In his case study, Hurlbut states “an RPS is a system of renewable energy credits and green-power

---

[27] “Renewable Electricity Production Tax Credit (PTC).” Government Website. Department of Energy. Accessed March 21, 2018. https://www.energy.gov/savings/renewable-electricity-production-tax-credit-ptc.
[28] “Renewable Electricity Production Tax Credit (PTC).” Government Website. Department of Energy. Accessed March 21, 2018. https://www.energy.gov/savings/renewable-electricity-production-tax-credit-ptc.
[29] David Hurlbut. “A Look behind the Texas Renewable Portfolio Standard: A Case Study.” *NATURAL RESOURCES JOURNAL* 48 (Winter 2008): 34. Page 129.
[30] Ibid, Pg. 129.

policies that works best as an integrated package; the regime of rules needs to be stable, and an RPS goal need not be ambitious to succeed."[31] Once the RPS was put in place, the Public Utility Commission of Texas (PUCT) aimed to build a practical policy framework that would allow the increase of renewable energy generation capacity to be a response to both the mandated RPS and customer-driven demand within the wholesale electricity market. Typical RPS that are enacted are statutory requirements to achieve a renewable energy goal within a specific time frame. Texas's original RPS goals were to "install 400 MW of new renewable capacity by 2003 and increase capacity every two years after to reach the overall goal of 2,000 MW of renewable capacity by 2009."[32] When the RPS was established, the state only had about 880 MW of renewable capacity installed, which was mostly hydroelectric capacity.[33] Having the RPS goal of adding almost 1,120 MW of installed renewable capacity in a ten-year period was ambitious. However, the success of the RPS was due to the PUCT "promulgated rules governing the RPS, green power, and renewable energy tracking as an integrated package in the context of wholesale and retail electric competition."[34]

The original RPS goal of 2,000 MW of renewable capacity by 2009 was achieved four years ahead of schedule in 2005. A majority of the renewable energy generation that was installed between 1999-2005 was wind power. Details regarding the growth of wind can be seen in Graphs 4 and 5, and Tables 9 and 10. Due to the early achievement of the RPS, the Texas legislation updated the RPS goal from 2,000 MW of renewable generation capacity to 5,000 MW of renewable capacity by 2015.[35] In addition to the updated goal, the bill set a capacity target of

[31] David Hurlbut. "A Look behind the Texas Renewable Portfolio Standard: A Case Study." *NATURAL RESOURCES JOURNAL* 48 (Winter 2008): 34. Page 129.
[32] David Hurlbut. "A Look behind the Texas Renewable Portfolio Standard: A Case Study." *NATURAL RESOURCES JOURNAL* 48 (Winter 2008): 34. Page 130.
[33] Ibid, Pg. 132.
[34] Ibid, Pg. 132.
[35] Ibid, Pg. 132.

10,000 MW for 2025, with 500 MW coming from renewable energy sources other than wind.[36] A key provisional update to the RPS in 2005 was the proposed measure that formed the competitive renewable energy zones (CREZs) for new transmission. The formation of the CREZs bolstered new transmission projects that would be able to transmit electricity from wind projects and other renewable energy projects to areas of need within the grid to meet consumer demands. The development of CREZs allowed the PUCT to designate areas where transmission projects could be developed prior to renewable energy projects, particularly for wind development.[37] Having the authority to designate specific renewable energy zones resolved both the issues investors in renewable projects had and the issues utilities had with establishing reliable transmission infrastructure.

Currently, there is currently over 20,000 MW of wind generating capacity, and over 1,120 MW of utility-scale solar.[38] The ERCOT market and grid have been able to successfully reach each RPS goal set by the Texas legislation, with continued growth to continue well into the future.

---

[36]David Hurlbut. "A Look behind the Texas Renewable Portfolio Standard: A Case Study." *NATURAL RESOURCES JOURNAL* 48 (Winter 2008): 34. Page 132.

[37] Ibid, Pg. 136.

[38] "ERCOT 2017 Sate of the Grid Report" (Electricity Reliability Council of Texas (ERCOT)). accessed April 13, 2018. http://www.ercot.com/content/wcm/lists/144926/ERCOT_2017_State_of_the_Grid_Report.pdf.

ERCOT and its Wholesale Electricity Market

As stated earlier, ERCOT has a functioning wholesale electricity market. This means that electricity prices are competitive, and that "real-time wholesale prices in a functioning market tend to reflect the marginal cost of the marginal unit."[39] In simpler terms, the market operator (ERCOT) will select the least expensive generators first to meet consumer demand and will continue selecting generators to be dispatched based off of cost until consumer demand is met. The marginal costs associated to the generating unit determines if it will be selected to be dispatched in the day ahead market (DAM) or real-time market (RTM) to meet consumer demand. The marginal costs of wind and solar are $0 because their fuel costs are zero, however, due to the production tax credit (PTC), wind and solar resources are able to bid into the wholesale energy market at negative prices and still break even on operating costs. In a effective wholesale energy market, more significant amounts of electricity generation from renewable energy sources such as wind and solar tend to reduce wholesale power prices, which consequently impacts the revenues that fossil fuel generators, like coal-fired power plants, earn[40].

[39] David Hurlbut. "A Look behind the Texas Renewable Portfolio Standard: A Case Study." *NATURAL RESOURCES JOURNAL* 48 (Winter 2008): 34. Page 137.

[40] Ibid.

To understand changes in electricity prices in the ERCOT market, data was obtained via the Potomac Economics group for the average day ahead market (DAM) and average real-time market (RTM) prices between 2009-2017.[41,42,43,44] This data over this time period can be seen on the proceeding page. The most significant take away from this data is that over this time period, DAM and RTM prices have been declining. Even though there were the DAM and RTM prices were above $40, DAM and RTM prices have remained under $30 during 2015, 2016, and 2017.

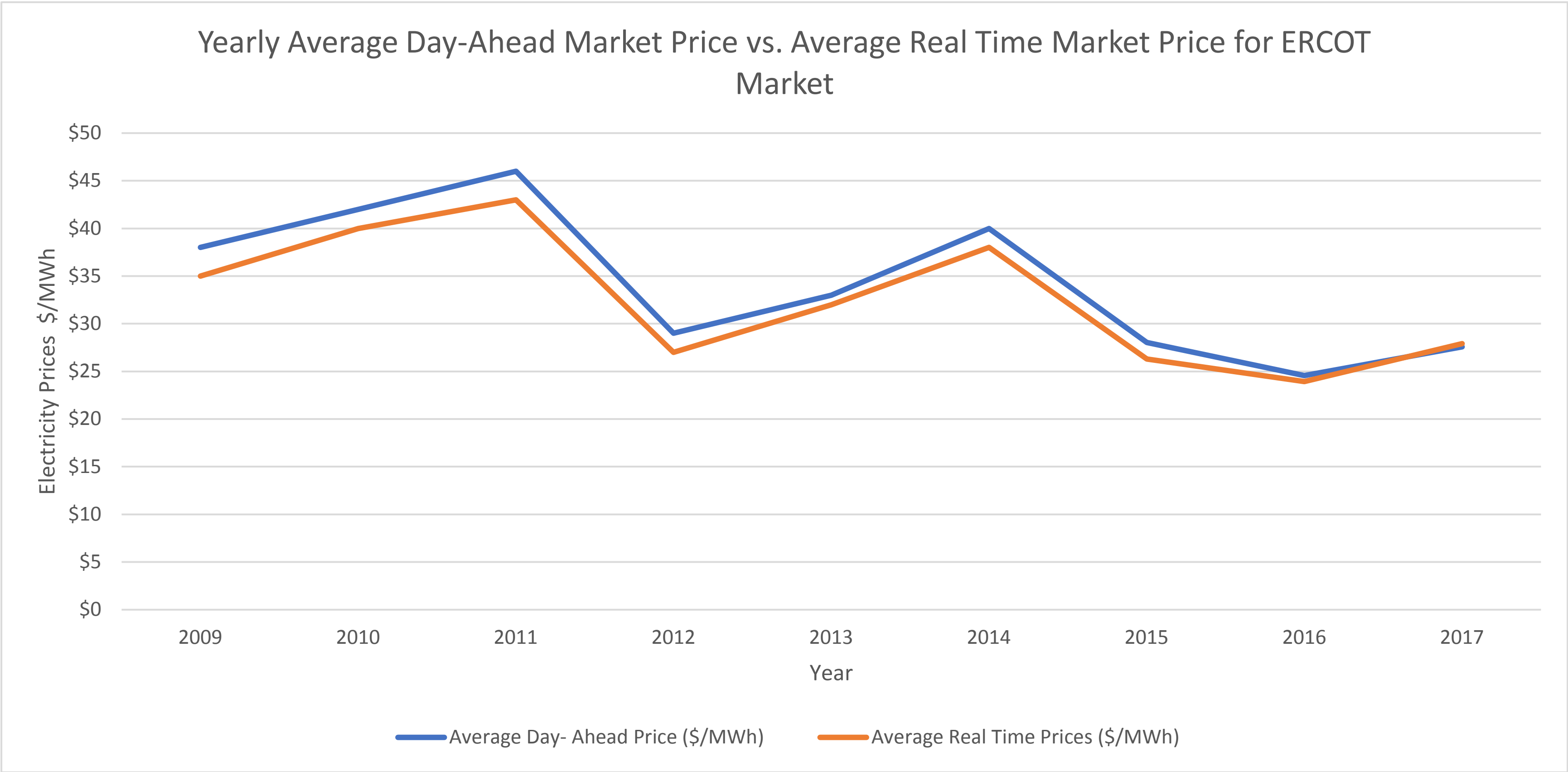
[41]Potomac Economics. *ERCOT Wholesale Electricity Market Monthly Report.* Report. January 10, 2018. Accessed April 20, 2018. https://www.potomaceconomics.com/wp-content/uploads/2018/01/Nodal_Monthly_Report_2017-12.pdf.

[42]Potomac Economics. *ERCOT Wholesale Electricity Market Monthly Report.*Report. January 11, 2017. Accessed April 20, 2018. https://www.potomaceconomics.com/wp-content/uploads/2017/01/Nodal_Monthly_Report_2016-12-1.pdf.

[43] Potomac Economics. *2014 State of the Market Report for the ERCOT Wholesale Electricity Markets.*Report. July 2015. Accessed April 20, 2018. https://www.potomaceconomics.com/wp-content/uploads/2017/01/2014-ERCOT-State-of-the-Market-Report.pdf.

[44] Potomac Economics. *2012 State of the Market Report for the ERCOT Wholesale Electricity Markets.*Report. June 2013. Accessed April 20, 2018. https://www.potomaceconomics.com/wp-content/uploads/2017/01/2012_ERCOT_SOM_REPORT.pdf.

Graph 1: Historical Averaged DAM Prices and RTM Prices 2009-2017



Graph 1: In this graph, data obtained from various monthly and yearly reports published by Potomac Economics is combined to view yearly trends in averaged day ahead market prices and average real time market prices. Over the period of focus, the yearly average electricity price per megawatt hour has decreased. These price declines can be associated to many factors, but a main influence is the increased competitiveness from cost -efficient fuels like natural gas and renewable energy generation. Data and reports published by Potomac Economics, Ltd can be found online at https://www.potomaceconomics.com/document-library/?filtermarket=ERCOT .

In the graphic below, the typical dispatch order of generators by fuel type within the ERCOT market is detailed.[45] Wind and solar resources are dispatched first to meet consumer demands because of their negative-to low prices. Then, typically nuclear power plants are utilized to achieve baseload power demands because of the marginal costs being relatively low for a reliable energy source. In the proceeding dispatch order, marginal costs are crucial. Natural gas power plants are typically dispatched after coal-fired power plants. However, dispatch order is dependent on the price of natural gas per million BTU ($/mmbtu). When natural gas prices are around $2/mmbtu, natural gas plants are typically dispatched before coal power plants.

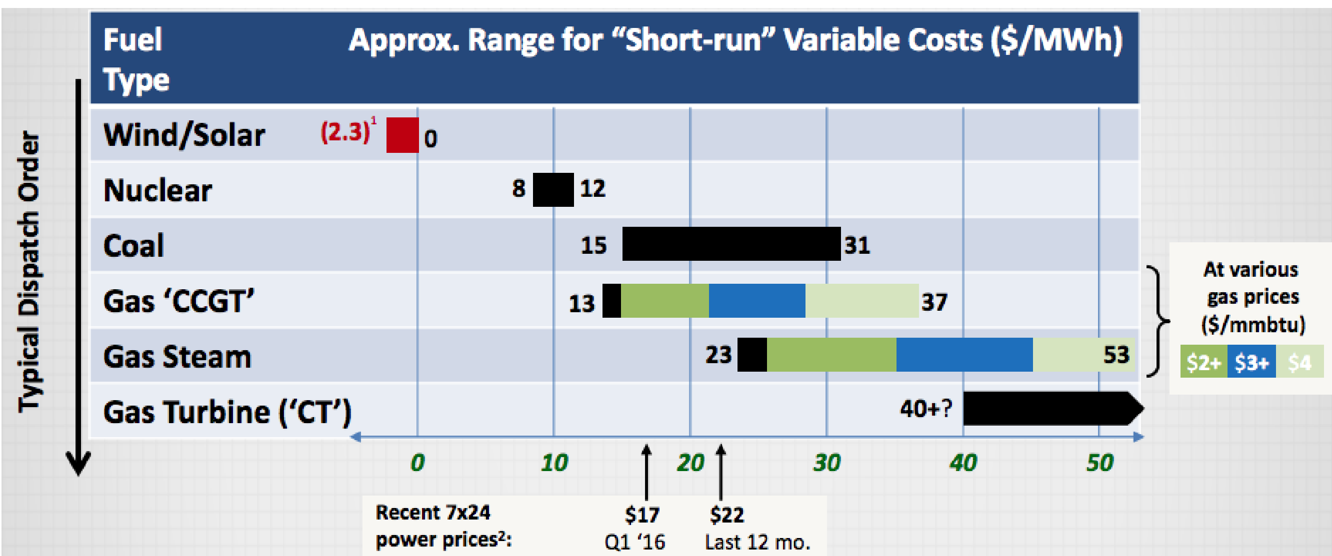


Figure 2: Typical Dispatch Order by Fuel Type for Generators operating in the ERCOT Wholesale Energy Market

[45] AECT. "The Wholesale Electric Market in ERCOT - 2017." January 2017. https://www.slideshare.net/aectnet/the-wholesale-electric-market-in-ercot-2017.

Potomac Economics, an independent market monitor for ERCOT, provides a yearly economic analysis for the ERCOT market. In its *2016 State of the Market Report for the ERCOT Electricity Markets*, Potomac Economics states that due to “lower natural gas prices and a surplus supply of natural gas, the average price for natural gas was 4.7 percent lower in 2016 than in 2015, decreasing from $2.57 per MMBTu in 2015 to $2.45 per MMBtu in 2016.”[46] In addition to this information regarding the slight reduction in average natural gas prices per MMBtu, Potomac Economics also states:

> “The largest component of the all-in price is the energy cost. …Natural gas prices continued to be a primary driver of electricity prices. This correlation is expected in a well-functioning, competitive market because fuel costs represent the majority of most suppliers’ marginal production costs. Since suppliers in a competitive market have an incentive to offer supply at marginal costs and natural gas is the most widely-used fuel in ERCOT, changes in natural gas prices should translate to comparable changes in offer prices. Hence, the reduction in natural gas prices of almost 5 percent contributed to an 8 percent reduction in ERCOT’s average real-time energy prices.”[47]

Natural gas prices have also fluctuated over the fifteen-year period the ERCOT wholesale electricity market has been functioning within the region. Historical data obtained via the U.S. Energy Information Administration (EIA) shows the monthly fluctuations in the Henry Hub natural gas spot prices.[48] Over the historical period, natural gas prices were highest at two different incidences. First, in 2005, natural gas prices peaked between September-December, and prices ranged between $10.30/MMBTU to $13.42/MMBTU.[49] The second peak in natural gas

[46] Potomac Economics. “2016 State of the Market Report for the ERCOT Electricity Markets.” May 2017. https://www.potomaceconomics.com/wp-content/uploads/2017/06/2016-ERCOT-State-of-the-Market-Report.pdf. Page i.

[47] Ibid,iii.

[48] US Energy Information Administration. “Henry Hub Natural Gas Spot Price (Dollars per Million Btu).” Government Website. Natural Gas. April 25, 2018. https://www.eia.gov/dnav/ng/hist/rngwhhdm.htm.

[49]Ibid.

spot price occurred between April-July in 2008. Spot prices over this period ranged between $10.18/MMBTU to $12.69/MMBTU.[50] Starting in 2009, natural gas prices began staying below $6.00/MMBTU.[51] Since January 2015, natural gas prices have stayed under $4.00/MMBTU, typically ranging between $2.00/MMBTU-$3.00/MMBTU.[52] In the graph on the proceeding page, data regarding the Henry Hub natural gas spot prices can be seen. In this graph, the overall trend of lower natural gas prices can be seen over the period of 2012-2018.

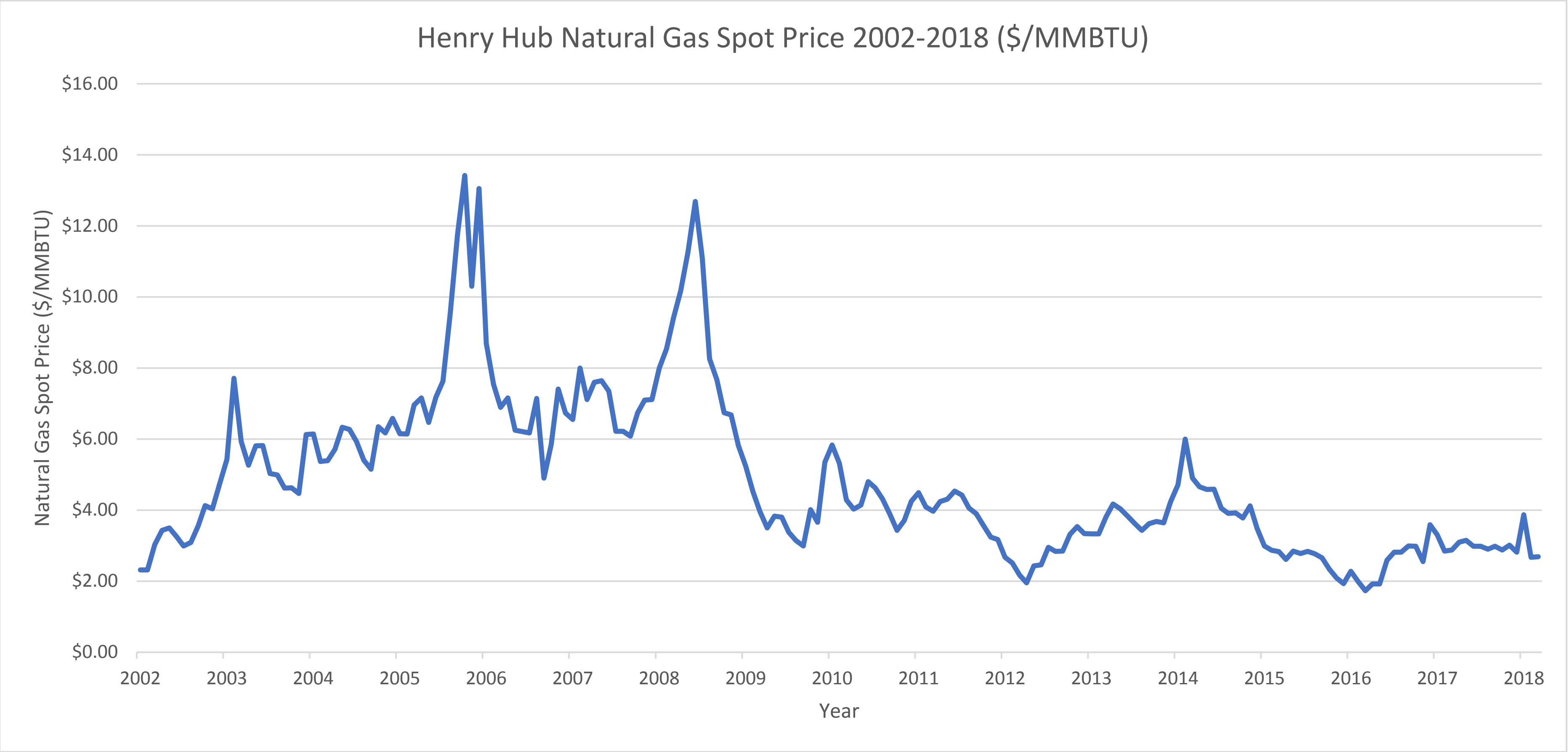
With natural gas prices projected to remain between $2/MMBtu- $3/MMBtu, the trend of natural gas prices driving electricity prices will continue well into the future. With the price of natural gas remaining relatively low, consumers will benefit within the ERCOT region, as natural gas fired plants will be chosen to meet demand over coal-fired power plants. The lower prices per MMBTU experienced within the region will lead to increased competitiveness from natural gas power plants within the wholesale electricity market. However, even though natural gas prices have been a significant driver of electricity price within the ERCOT region over the last few years, lignite coal production of local deposits and consumption at mine-mouth coal-fired power plants dominated the electricity market in previous years.

[50] US Energy Information Administration. “Henry Hub Natural Gas Spot Price (Dollars per Million Btu).” Government Website. Natural Gas. April 25, 2018. https://www.eia.gov/dnav/ng/hist/rngwhhdm.htm.

[51] Ibid.

[52] Ibid.

Graph 2: Historical Henry Hub Natural Gas Spot Prices 2002-2018 ($/MMBTU)



Graph 2: This graph shows the fluctuations of natural gas spot prices over the historical period of 2002-2017, with available 2018 data included. Understanding the fluctuations in spot prices for natural gas aids in the analysis of the competitiveness of natural gas as a fuel source within the ERCOT region.[53]

[53] US Energy Information Administration. "Henry Hub Natural Gas Spot Price (Dollars per Million Btu)," Government Website. Natural Gas. April 25, 2018. https://www.eia.gov/dnav/ng/hist/rngwhhdm.htm.

Lignite Coal Production and Coal-Fired Plants in Texas

The coal produced in the state of Texas is lignite coal. The Energy Information Administration (EIA) estimated that in 2016, the state of Texas produced 39 million short tons of coal and was the sixth largest coal producing state in 2016.[54] The EIA also estimates that the state of Texas has an economically feasible recoverable reserve base of 582 million short tons, most of which is lignite coal at reporting mines.[55] In the map of the United States published by the U.S. Geological Society below, coal ranks are colored to match their geologic locations by state[56]. Yellow and orange indicates lignite Coal.

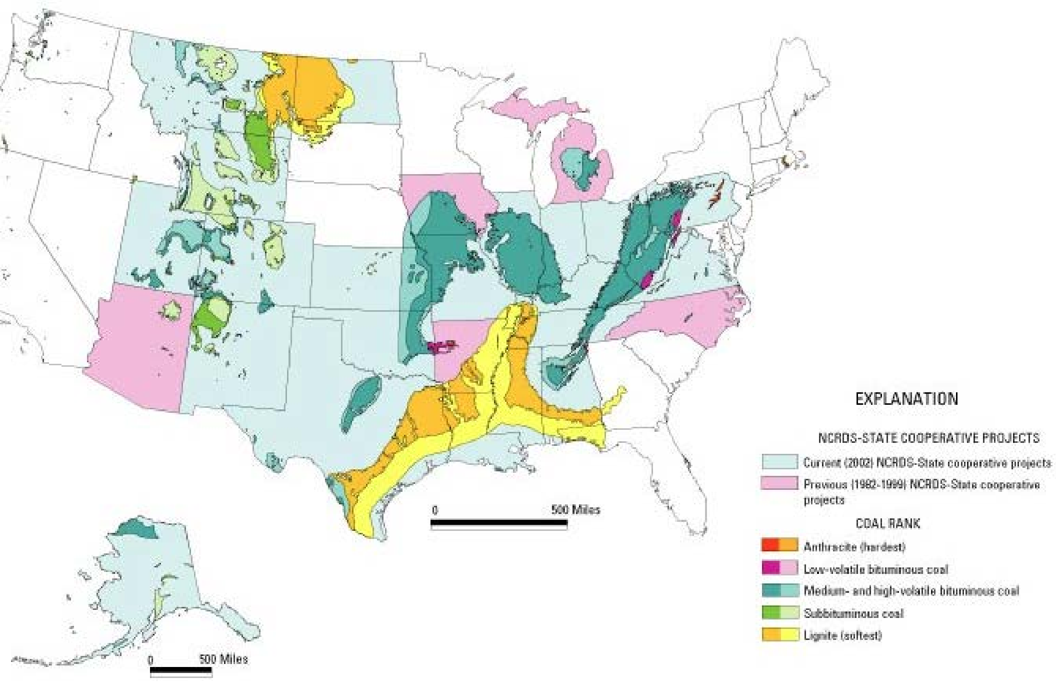


Figure 3: A map showing the United States Coal Reserves by Coal Rank

[54] US Energy Information Administration. "Rankings: Coal Production 2016." Government Website. Texas State Profile and State Estimates. accessed March 30, 2018. https://www.eia.gov/state/rankings/?sid=TX#series/48.
[55] "Annual Coal Report." Government Publication (US Energy Information Administration, November 2017). https://www.eia.gov/coal/annual/pdf/acr.pdf.
[56] Stanley Schweinfurth. "Figure 4: Coal Fields of the U.S. Classified by Coal Rank and Areas of Cooperative Study of Coal Resources and Quality." US Geological Survey (USGS). November 23, 2016. https://pubs.usgs.gov/circ/c1143/html/fig4.html.

As seen in the map on the previous page, lignite deposits can be found in many southeastern states such as Texas, Louisiana, Mississippi, Alabama, and Arkansas. There are also some lignite deposits in the northern interior plains region in North Dakota and Montana.

Of the four coal ranks found within the United States, lignite coal is the lowest rank of coal found in geologic formations. Lignite coal has a low carbon concentration, low BTU ranges and high moisture values. In the graph below, the rank of coal is mapped by comparing gross caloric value (heat content or BTU) to percent of fixed carbon.[57] Lignite can be seen in the bottom right corner in yellow with a max fixed carbon value of about 40-62%, and a BTU range of 5,000-8,300[58]. Lignite is highly flammable and cannot be transported far distances by rail due to the risk of sparks from the rail car igniting the coal. Most of the coal generators that consumed lignite coal were constructed in close proximity to the mine, where coal can be transported to the plant via conveyor belt or truck. These mine-mouth coal-fired power plants resulted in low marginal costs, and the ability to generate electricity at low prices to consumers.

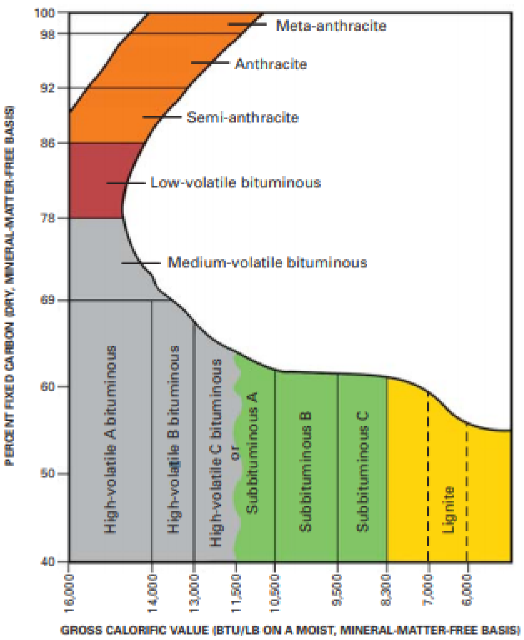


Figure 4: Heat Content vs. Percent of Fixed Carbon by Coal Rank

Even though most of the coal consumed in Texas in the past was exclusively lignite coal due to its close proximity and low cost as a fuel source, some plants import sub-bituminous coal from Powder River Basin (PRB). Sub-bituminous coal is easily accessible within the PRB

[57] Stanley Schweinfurth. "Coal-A Complex Natural Resource." Government Publication (U.S. Geological Survey. April 5, 2002). Page 25. https://pubs.usgs.gov/circ/c1143/c1143.pdf.

region, with large deposits close to the surface for easy mining, which, in turn, means low prices. Sub-bituminous coal from PRB also has lower sulfur and mercury contents and a slightly higher BTU rating when compared to lignite coal. The slight differences in chemical composition and the comparable fuel price between these two coal ranks makes sub-bituminous coal more favorable for use in coal-fired power plants than lignite.

Many coal plants in the United States consume sub-bituminous coal, and Texas coal-fired plants are no exception. There are coal-fired plants in Texas that have either transitioned from burning lignite to sub-bituminous coal, or the plant consumes both lignite and sub-bituminous coal. This transition occurred mainly because of the negative environmental impacts of lignite coal. As stated previously, lignite coal has slightly higher sulfur and mercury content when compared to sub-bituminous coal. The higher sulfur and mercury content of lignite coal results in higher air pollutants being emitted by coal-fired plants when they are consumed to generate electricity. The Environmental Protection Agency (EPA) has many policies related to air pollution from power plants. Some of these polices are the Mercury and Air Toxics Standards (MATS), Cross-State Air Pollution Rule (CSAPR), the National Ambient Air Quality Standards (NAAQS), and the Regional Haze Program. Details regarding these environmental regulations can be found in the Table 1 on the following page.

Table 1: Environmental Protection Agency Air Quality Regulations

Regulation Name	Regulation Acronym	Year Proposed	Year Enacted or Compliance Year	Regulation Summary
Mercury and Air Toxics Standards	MATS	2011	2016	MATS limits emissions of mercury and other toxic substances from power plants that can pollute water and soil sources.[59,60]
Cross-State Air Pollution Rule	CSAPR	2011	2015	CSAPR requires power plants to reduce emissions that cross state lines and contribute to smog and soot in downwind states.[61]
National Ambient Air Quality Standards	NAAQS	1990	1990	In the amended clean air act of 1990, the EPA is required to set NAAQs for pollutants considered harmful to the public. Currently, NAAQS are set for six pollutants: Carbon Monoxide, Ozone, Lead, Nitrogen Dioxide, Sulfur Dioxide, and Particle Pollution.[62]
Regional Haze Program	n/a	1999	2016	The Regional Haze Program was a program created by the EPA to reduce regional haze to improve visibility and air quality at National Parks and wilderness areas.[63]

[59] U.S. Environmental Protection Agency. "Mercury and Air Toxics Standards." United States Environmental Protection Agency. June 8, 2017. https://www.epa.gov/mats/regulatory-actions-proposed-mercury-and-air-toxics-standards-mats-power-plants.
[60] "Mercury and Air Toxics Standards (MATS)." Harvard Environmental Law Program. September 27, 2017. http://environment.law.harvard.edu/2017/09/mercury-air-toxics-standards-mats/.
[61] U.S. Environmental Protection Agency. "Overview of the Cross-State Air Pollution Rule (CSAPR)." Overviews and Factsheets. September 19, 2017. https://www.epa.gov/csapr/overview-cross-state-air-pollution-rule-csapr.
[62] U.S. Environmental Protection Agency. "NAAQS Table." Policies and Guidance. United States Environmental Protection Agency. December 20, 2016. https://www.epa.gov/criteria-air-pollutants/naaqs-table.
[63] U.S. Environmental Protection Agency. "Regional Haze Program." Policies and Guidance. United States Environmental Protection Agency. April 25, 2017. https://www.epa.gov/visibility/regional-haze-program.

To comply with these regulations set forth by the Environmental Protection Agency, coal plants needed to invest in special equipment to retrofit the power plants to reduce their emissions of the targeted air pollutants. Upgrades to scrubbers, baghouses, precipitators, and other control technologies were needed at these coal-fired plants so that these sites could still be operational. To fulfill the requirements of the EPA's Regional Haze rule, Monticello and Big Brown would need to abide by the Best Available Retrofit Technology (BART) rule, which would require new scrubbers and scrubber retrofit at these sites to reduce air pollutants and nitrogen oxide emissions from these sites.[64] Monticello and Big Brown would also need to install "reasonably available control technology" which include new scrubbers or scrubber upgrades to the plants to reduce sulfur dioxide emissions to comply with NAAQS.[65] This is because the EPA proposed to designate the counties surrounding these plants as being in a nonattainment for the sulfur dioxide NAAQS.[66] The various technologies that Luminant would need to install to these plants to comply with EPA's regulations would be a significant economic burden for these plants. Luminant estimated that it would cost over $1 billion to install new scrubbers at Big Brown and Monticello, and about $61 million dollars a year in additional operating and maintenance costs.[67] These additional costs pose a significant cost burden onto the coal-fired power plants. As the wholesale electricity market becomes more competitive and coal fired power plants being selected less to meet consumer demands, the potential for Luminant to recover the investments needed to comply with EPA's regulations would be slim. The additional compliance measures

[64] David Schlissel. "The Beginning of the End: Fundamental Changes in Energy Markets Are Undermining the Financial Viability of Coal-Fired Power Plants in Texas" (Institute for Energy Economics and Financial Analysis. September 2016). Page 25. http://ieefa.org/wp-content/uploads/2016/09/The-Beginning-of-the-End_September-2016.pdf.

[65] Ibid, Page 25.

[66] Ibid, Page 25.

[67] Ibid, Page 26.

would make these plants no longer profitable and competitive within the ERCOT wholesale electricity market. Retiring these plants was a cost-effective decision Luminant made given the conditions of the wholesale electricity market in conjunction with the substantial compliance investments required to keep these plants operational. Even though these investments were considerable, before Luminant needed to invest significant amounts of money into these plants to comply, there were other temporary cost-effective methods these plants implemented to reduce their air pollutant emissions. Switching their fuel type from lignite to sub-bituminous coal.

Transitioning from lignite coal to sub-bituminous coal was a solution for the Texas coal-fired power plants to do in conjunction with other mitigation methods to reduce their air pollution emissions. As operations at the three coal-fired plants of focus in this paper changed to comply with various EPA emission rules and policies, mining patterns also changed. There was a decrease in lignite coal mined and consumed within the state, and this pattern will continue now that these power plants are retired. The lignite mines that supported these three plants were: Big Brown Strip, Three Oaks Mine, Sulphur Springs, and Winfield South Strip. The production values for these mines can be found in Table 2, and Graph 3.

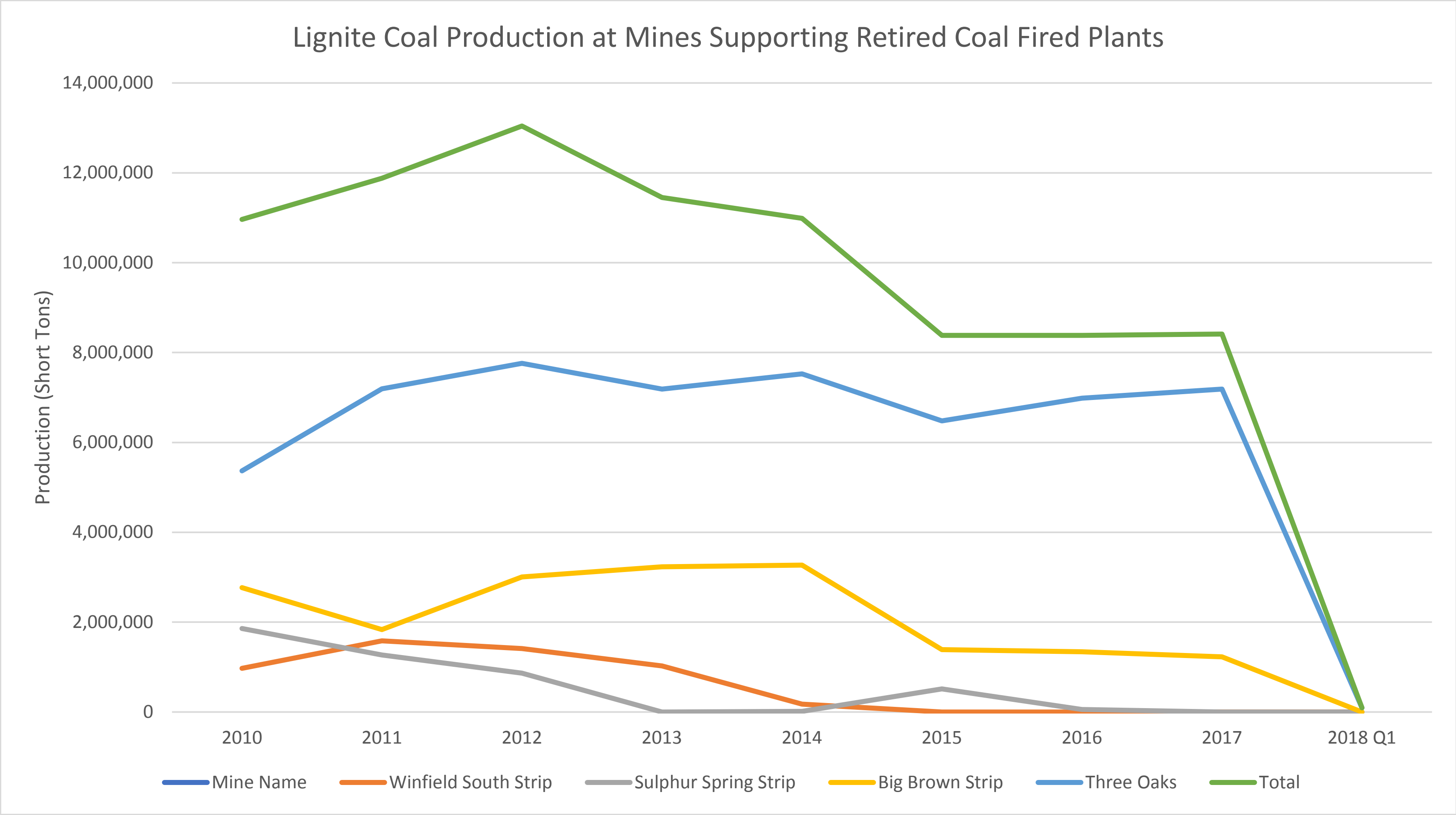
Table 2: Lignite Coal Production between 2010-2018 Q1

			2010 Production (Short Tons)	2011 Production (Short Tons)	2012 Production (Short Tons)	2013 Production (Short Tons)	2014 Production (Short Tons)	2015 Production (Short Tons)	2016 Production (Short Tons)	2017 Production (Short Tons)	2018 Q1 Production (Short Tons)
Plant Name	**MSHA ID**	**Mine Name**									
Monticello	4103658	Winfield South Strip	971,476	1,584,019	1,413,200	1,027,817	172,770	0	0	0	0
Monticello	4102776	Sulphur Spring Strip	1,858,244	1,267,357	863,143	0	15,022	511,938	59,120	0	0
Big Brown	4101192	Big Brown Strip	2,768,958	1,837,202	3,005,616	3,232,521	3,269,584	1,387,041	1,341,856	1,226,441	0
Sandow	4104085	Three Oaks	5,364,236	7,192,404	7,760,301	7,189,178	7,527,358	6,482,152	6,983,347	7,186,478	93, 632
		Total:	**10,962,914**	**11,880,982**	**13,042,260**	**11,449,516**	**10,984,734**	**8,381,131**	**8,384,323**	**8,412,919**	**93,632**

Table 2: This table shows lignite coal production at four mines that provided lignite coal to the coal-fired plants that were retired in early 2018. Data was obtained via the MSHA Mine Data Retrieval System by searching each mine's MSHA ID.[68] Over the period of 2010-2018 Q1, production at these sites saw periods of relative stability, followed by a sharp decline in production until these sites became nonproducing. Winfield South Strip and Sulphur Spring Strip were the first two mines to either become nonproducing or see significant decreases in production because of Monticello transitioning from lignite coal consumption to subbituminous coal consumption in its generators. Big Brown strip saw an 80.8% decrease in production between 2014 and 2015 when more subbituminous coal was burned in the generators at Big Brown. Big Brown retired in February of 2018, which means mining activities at Big Brown strip have ceased. The lignite coal consumed at Sandow was mined at Three Oaks mine, which had comparable production rates between 2010-2017, with less than 100,000 short tons being produced at this site in 2018. On the following page, a line graph with the same production values is portrayed to visually represent the data to more easily see the trends between years.

[68] "MSHA - Mine Data Retrieval System (as Developed by PEIR) Home Page." accessed April 15, 2018. https://arlweb.msha.gov/drs/drshome.htm.

Graph 3: Lignite Coal Production at Mines Supporting Retired Coal-Fired Plants



Graph 3: Lignite production trends at Three Oaks Strip, Sulphur Springs Strip, Winfield South Strip, and Big Brown Strip between 2010-2018 Q1. By 2018 Q1, all these sites that once produced over a million short tons of coal either were non-producing or no longer produced a significant amount of coal. This is because of the changes in fuel type from lignite to sub-bituminous coal, and plant retirement announcements.

Coal-Fired Plant Retirements in ERCOT

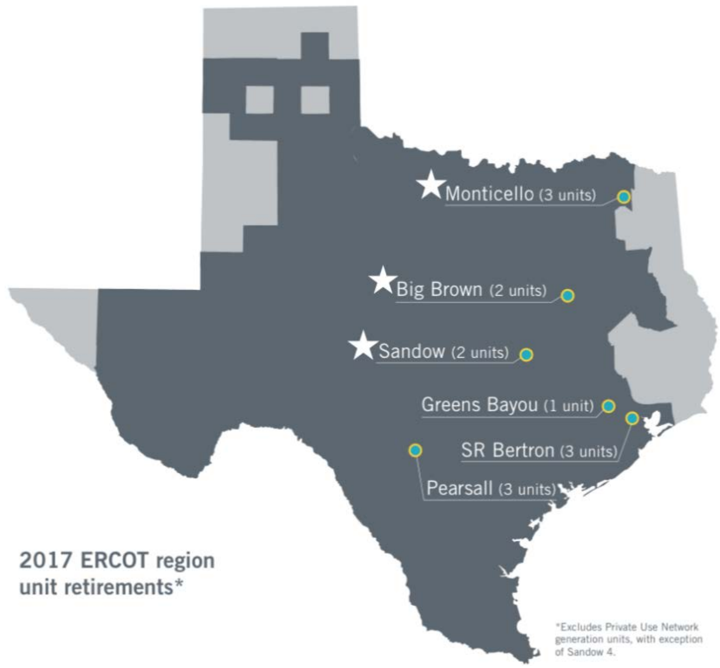


Figure 5: 2017 ERCOT Region Plant Retirement Locations

Even though there were a handful of plants that announced retirements within the ERCOT region in 2017, three coal-fired plants that were planned to be retired in early 2018 are of high significance. These three coal-fired power plants are Big Brown, Sandow, and Monticello. The map to the right shows the locations of these plants within the ERCOT region.[69] The combined total summer capacity of these three plants was 4,273 MW. Details of these three plants can be found in the tables on the following pages.

Big Brown, located in Freestone County, Texas, was the oldest of the three sites to be retired in early 2018. The two generators at this site were operational in December of 1971 and 1972, with a combined capacity of 1,208 MW[70]. At roughly 46 years old, these coal-fired generators were some of the earliest generators within Texas. Details regarding the fuel sources and net generation can be found in Table 5.

Monticello, located in Titus County, Texas, was the second oldest of the three sites with three generators that came online in 1974, 1975, and 1995. The combined summer capacity of

[69] "ERCOT 2017 Sate of the Grid Report" (Electricity Reliability Council of Texas (ERCOT)). accessed April 13, 2018. http://www.ercot.com/content/wcm/lists/144926/ERCOT_2017_State_of_the_Grid_Report.pdf.
[70] "Annual Electric Generator Data - EIA-860 Data File." Government Website. U.S. Energy Information Administration. November 9, 2017. https://www.eia.gov/electricity/data/eia860/.

the three generators at Monticello was 1,865 MW.[71] Monticello's three coal-fired generators produced the highest amount of net generation during 2017, which was provided to consumers within the ERCOT region. Expanded details about Monticello can be found in Table 6.

Sandow, located in Milam County, Texas, had two coal generators that were retired in early 2018. Sandow No. 4 and Sandow No. 5 were two generators at this site that consumed lignite coal in 2017. Sandow No.4 and Sandow No. 5 had a combined summer capacity of 1,200 MW.[72] Sandow No. 5 was the youngest generator within this group that was retired in early 2018, having a total lifespan of about seven years. The retirement of Sandow No. 5 is important because this plant was nowhere near the end of its lifecycle. Retiring this generator after it only being operational for seven years supports the idea that these coal-fired power plants were retired because of economic conditions within the wholesale energy market. Additional details regarding Sandow can be found in Table 7.

Therefore, with these three coal-fired plants retired from the generating fleet in the ERCOT region, there will be a decrease in lignite coal mined and consumed within the state. Even though there are significant lignite coal reserves remaining that could support these coal-fired plants for many years into the future, the wholesale electricity market and costs associated to complying with various EPA regulations make these plants, and supporting coal mines, uneconomical. The lignite mines that supported these three generators are Big Brown Strip, Three Oaks Mine, Sulphur Springs, and Winfield South Strip. As seen in Table 2 and Graph 3, lignite production has steadily decreased nearing no production between 2010- 2018 Q1 as these coal-fired power plants began consuming more sub-bituminous coal rather than lignite coal.

---

[71] Annual Electric Generator Data - EIA-860 Data File." Government Website. U.S. Energy Information Administration. November 9, 2017.

[72] Ibid

Table 3: Plant Specific Data for Big Brown, Monticello, and Sandow.

Plant Name	State	County	Generator ID	Operating Month	Operating Year	Planned Retirement Month	Planned Retirement Year	Technology	Nameplate Capacity (MW)	Summer Capacity (MW)	Winter Capacity (MW)	Minimum Load (MW)
Big Brown	TX	Freestone	1	December	1971	February	2018	Conventional Steam Coal	593.4	606	606	220
Big Brown	TX	Freestone	2	December	1972	February	2018	Conventional Steam Coal	593.4	602	602	220
Monticello	TX	Titus	1	December	1974	January	2018	Conventional Steam Coal	593.4	535	580	210
Monticello	TX	Titus	2	December	1975	January	2018	Conventional Steam Coal	593.4	535	580	210
Monticello	TX	Titus	3	June	1995	January	2018	Conventional Steam Coal	793.2	795	795	320
Sandow No. 4	TX	Milam	4	May	1981	January	2018	Conventional Steam Coal	590.6	600	600	310
Sandow No. 5	TX	Milam	5	April	2010	January	2018	Conventional Steam Coal	661.5	600	600	480

Table 3: This table includes plant specific data such as: the year and month the generators at these sites were operational, the retirement month and year of these generators, the technology used, and the capacity. The data in this table was obtained via the EIA-860 annual generator data file published online by the U.S. Energy Information Administration on November 9th, 2017[73]. The retirement data was added to this table by the author. The referenced total capacity of these sites was calculated using the summer capacity of each of the generators, totaling 4,273 MW.

[73] "Annual Electric Generator Data - EIA-860 Data File." Government Website. U.S. Energy Information Administration. November 9, 2017. https://www.eia.gov/electricity/data/eia860/.

Table 4: Energy Sources Used by Generator

Plant Name	State	County	Generator ID	Energy Source 1	Energy Source 2	Energy Source 3	Start Up Source 1
Big Brown	TX	Freestone	1	SUB	LIG	NG	NG
Big Brown	TX	Freestone	2	SUB	LIG	NG	NG
Monticello	TX	Titus	1	SUB	LIG	DFO	DFO
Monticello	TX	Titus	2	SUB	LIG	DFO	DFO
Monticello	TX	Titus	3	SUB	LIG	DFO	DFO
Sandow No. 4	TX	Milam	4	LIG	DFO		DFO
Sandow No. 5	TX	Milam	5	LIG	DFO		DFO

Table 4: In this table the primary, secondary, and tertiary fuel sources (if applicable) are detailed by generator at each plant that was retired in early 2018. Also, the startup fuel source is included in this table. This data was published by the U.S. Energy Information Administration in the EIA-860 annual generator data file published in November.[74] The acronym codes are as follows: SUB represents subbituminous coal, LIG represents lignite coal, NG represents natural gas, and DFO represents distillate fuel oil. The data in this table shows that the generators at these plants consumed subbituminous and lignite coal, natural gas, and distillate fuel oil to generate electricity.

[74] "Annual Electric Generator Data - EIA-860 Data File." Government Website. U.S. Energy Information Administration. November 9, 2017. https://www.eia.gov/electricity/data/eia860/.

Table 5: Quantity of Fuel Consumed for Electricity Generation at Big Brown Plant

Fuel Source	Quantity of Fuel Consumed for Electricity Generation in 2017	Units	Origin	Supplier	Mine Name	MSHA ID	Net Generation (MWh) by Fuel Receipt	Percent of Net Generation by Fuel Source
LIG	1,267,255	Short Tons	TX	Luminant Energy	Big Brown Strip	4101192	1,537,427	19.62%
SUB	4,284,127	Short Tons	WY	Luminant Energy	Rawhide Mine	4800993	6,286,448	80.21%
NG	144,639	mcf	various	Luminant Energy	n/a	n/a	13,114	0.17%

Table 5: This table details the quantity of fuel consumed for electricity generation by fuel type, specifically, lignite coal, sub-bituminous coal, and natural gas at Big Brown Plant during 2017. The U.S. Energy Information Administration preliminary data for 2017 shows that Big Brown's net generation was 7,837,019 MWh in 2017[75].

Table 6: Quantity of Fuel Consumed for Electricity Generation at Monticello Plant

Fuel Source	The quantity of Fuel Consumed for Electricity Generation in 2017	Units	Origin	Supplier	Mine Name	MSHA ID	Net Generation (MWh) by Fuel Receipt	Percent of Net Generation by Fuel Source
SUB	6,248,302	Short Tons	WY	Luminant Energy	Rawhide Mine	4800993	9,021,824	99.82%
DFO	31,854	barrels	various	Luminant Trading	n/a	n/a	15,997	0.18%

Table 6: This table details the quantity of fuel consumed for electricity generation by fuel type for Monticello Plant during 2017. During this year no lignite coal was consumed for electricity generation at this site, only sub-bituminous coal that originated in Wyoming was consumed in conjunction with DFO. These data are preliminary 2017 values published by the U.S. Energy Information Administration.[76]

[75] "Annual Electric Utility Data – EIA-906/920/923 Data File." Government Website. U.S. Energy Information Administration. March 9, 2018. https://www.eia.gov/electricity/data/eia923/.

[76] Ibid

Table 7: Quantity of Fuel Consumed for Electricity Generation at Sandow Plant

Fuel Source	Quantity of Fuel Consumed for Electricity Generation in 2017	Units	Origin	Supplier	Mine Name	MSHA ID	Net Generation (MWh) by Fuel Receipt	Percent of Net Generation by Fuel Source
LIG	7,316,224	Short Tons	TX	Luminant Energy	Three Oaks	4104085	8,512,890	99.91%
DFO	14,334	barrels	various	Luminant Trading	n/a	n/a	7,992	0.09%

Table 7: In this table, details regarding the fuel consumed for electricity generation at Sandow Plant. Sandow consumed lignite coal during 2017, accounting for 99.91% of net generation being sourced from lignite. These data are preliminary 2017 values published by the U.S. Energy Information Administration[77].

[77] "Annual Electric Utility Data – EIA-906/920/923 Data File." Government Website. U.S. Energy Information Administration. March 9, 2018. https://www.eia.gov/electricity/data/eia923/.

Methods

The hypothesis behind this study is that due to the wholesale electricity market that operates within the ERCOT service region paired with the increase in installed renewable energy generation capacity, the three coal-fired power plants of focus in this study were unable to compete within the competitive wholesale electricity market within the ERCOT region, thus leading to their retirements. To test this hypotheis, four main groups of data were used to understand the conditions driving these retirements. These four groups of data focused on: state and federal policies, net generation from electricity providers within the ERCOT region, plant specific data, and lignite production within the state. Focusing on these four groups of data allowed for a detailed understanding of the cause and effect impact of these plant retirements from the ERCOT grid, and how generating companies and retail electric providers are able to fill the gap and meet consumer demands even with the retirement of 4.2 GW of generating capacity from the region.

Net Generation from Electricity Providers within the ERCOT Region

Understanding net generation within the ERCOT region allows for a stronger analysis when reviewing trends in generation patterns by fuel source over the periods selected. For this analysis, two-time periods were of focus: historical net generation by fuel source between 2002-2017, and then monthly net generation by fuel source starting January 2017 through March 2018. The first-time period focuses on historical trends in net production within ERCOT. The starting year of 2002 for this period is of significance because Texas state legislation SB 7 restructured the retail electricity market and required the electric energy markets to be open to competition in this year. Reviewing annual data between 2002- 2017 gives a greater scope of growth or decline in fuel sources used to meet consumer demands over the fifteen-year period. Historical data was obtained via ERCOT's reports and presentations website, under the operations and system planning section, where a file titled "Energy by Fuel Type 2002-2016" is published electronically[78]. The second time period of focus for this analysis was January 2017- March 2018. Monthly net generation data by fuel source over this fifteen-month data allowed for a comparison between the first three months of 2017 to the first three months of 2018. Including this comparison allowed for an analysis focusing on the retirements of Big Brown, Sandow, and Monticello, and what fuel sources were utilized to meet consumer demands once these plants were offline. The data for 2017 and 2018 were obtained from files also published on ERCOT's reports and presentation website under operations and system planning titled, "2017 Demand and Energy Report" and "2018 Demand and Energy Report" where the electricity consumption by fuel type by month is published, with the most recent month of available 2018 data being March[79].

Plant Specific Details for the Retired Coal-Fired Plants

Plant specific details for Big Brown, Monticello, and Sandow plants was obtained from the U.S. Energy Information Administration (EIA) via numerous published files with data collected on the EIA-860[80] and EIA-923[81]. The data obtained from EIA is a combination of preliminary 2017 data and final 2016 data. Combining these two data sources allowed for specific plant level information regarding net generation, fuel consumption, and plant

[78] "Reports and Presentations," ERCOT Reports and Presentations, accessed January 20, 2018, http://www.ercot.com/news/presentations.

[79] Ibid

[80] "Annual Electric Generator Data - EIA-860 Data File." Government Website. U.S. Energy Information Administration. November 9, 2017. https://www.eia.gov/electricity/data/eia860/.

[81] "Annual Electric Utility Data – EIA-906/920/923 Data File." Government Website. U.S. Energy Information Administration. March 9, 2018. https://www.eia.gov/electricity/data/eia923/.

characteristics to be utilized within this study to understand plant age, generation capacity, fuel consumption, and net generation by fuel type.

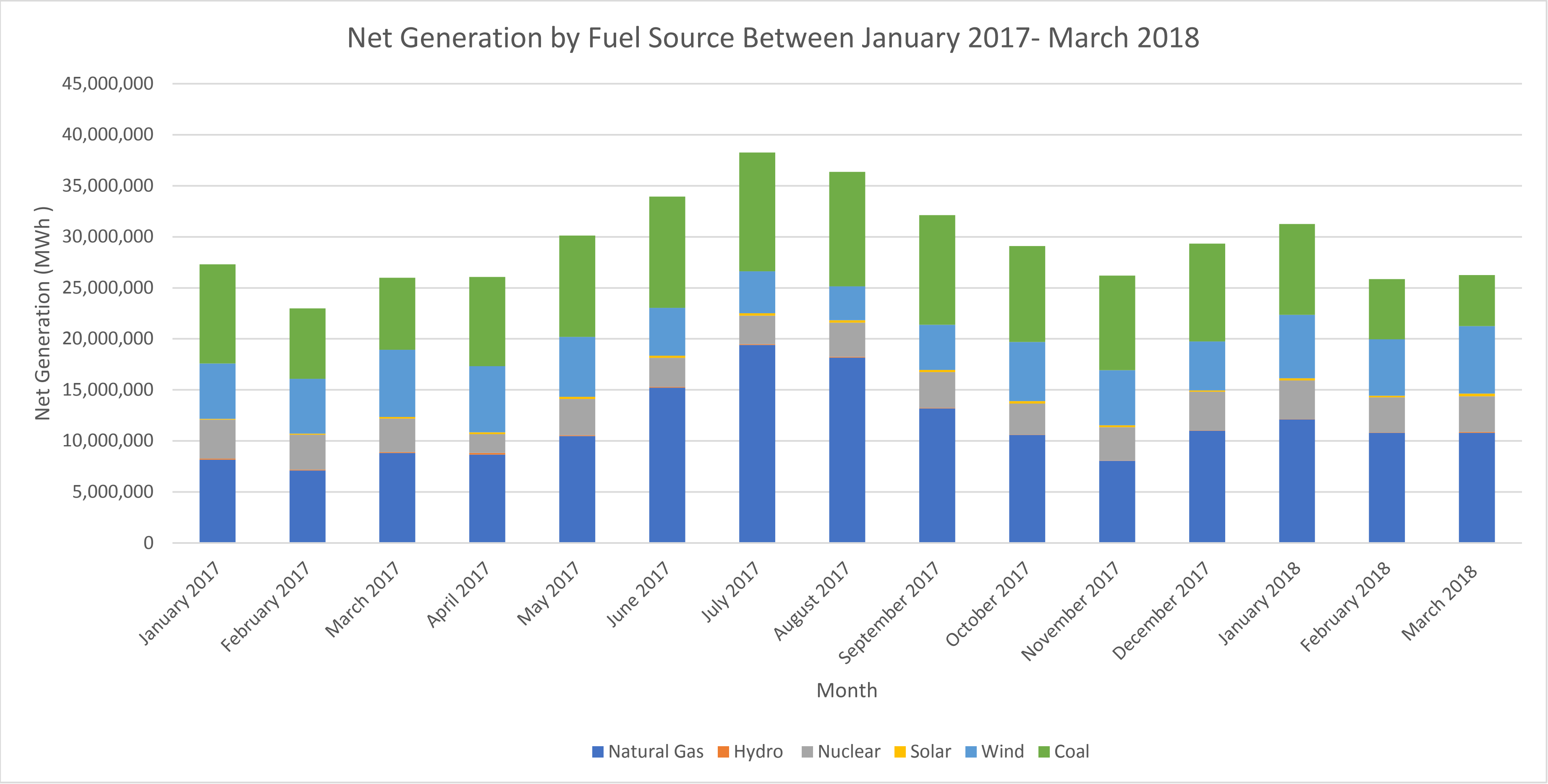
Lignite Production

Lignite production values for the mines that supported these retired coal-fired power plants was also included in this analysis. The reason behind this was to view trends in production, and to see when these mines transitioned from producing to nonproducing status, or when there was a significant decrease in production which indicates when sub-bituminous coal from PRB was brought to the plants to burn instead of lignite. Understanding the production of lignite coal at these sites help comprehend coal consumption patterns at the plants of focus. When more sub-bituminous coal from Powder River Basin was consumed at these plants to comply with various EPA policies, lignite production decreased. An important note here is that even though lower lignite production is expected, the reduction in lignite production did not influence the plant closures. The fuel resource is abundant, however is uneconomical to consume due to the environmental impacts. The plant modifications to comply with EPA regulations and retirements influenced the lignite production within Texas. The data outlined earlier in Table 2 regarding the lignite production was obtained from the Mine Safety and Health Administration (MSHA)'s Mine Data Retrieval System by searching each MSHA ID and generating reports over the period of 2010-2018 Q1[82].

[82] "MSHA - Mine Data Retrieval System (as Developed by PEIR) Home Page." Accessed April 10, 2018. https://arlweb.msha.gov/drs/drshome.htm.

Data

Graph 4: Net Generation by Fuel Source between January 2017 and March 2018.



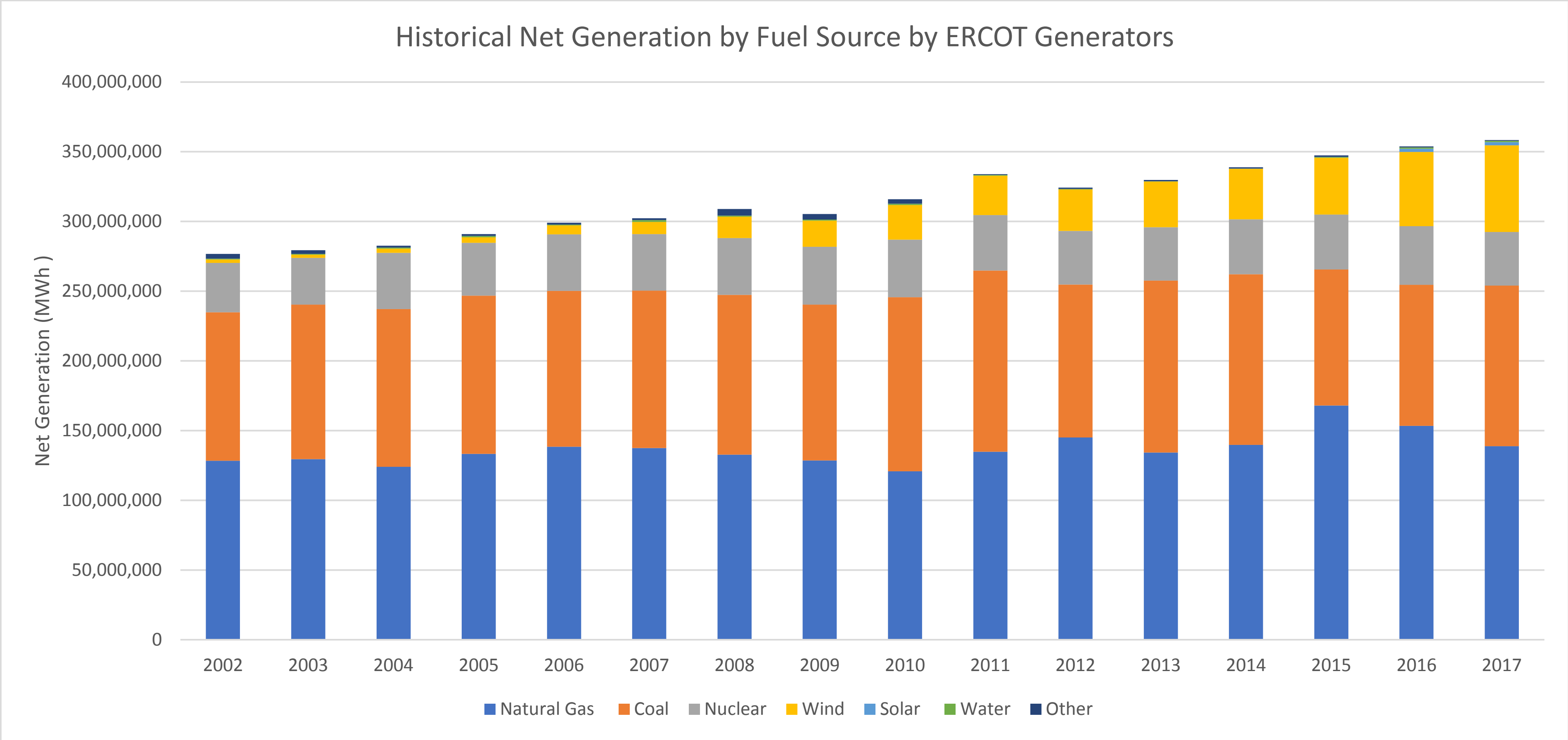
Graph 4: This graph shows net generation by fuel source for electricity generated within the ERCOT region between January 2017 and March 2018.

Table 8: Comparison of Net Generation by Fuel Type

Fuel Types	Jan-17 Net Generation (MWh)	Feb-17 Net Generation (MWh)	Mar-17 Net Generation (MWh)	Jan-18 Net Generation (MWh)	Feb-18 Net Generation (MWh)	Mar-18 Net Generation (MWh)	% Difference January 17/ January 18	% Difference February 17 / February 18	% Difference March 17/ March 18
Natural Gas	8,171,845	7,106,490	8,806,882	12,100,403	10,794,418	10,806,935	**48.07%**	**51.90%**	**22.71%**
Hydro	97,413	74,195	80,471	31,577	32,280	53,299	**-67.58%**	**-56.49%**	**-33.77%**
Nuclear	3,803,974	3,423,295	3,290,730	3,809,488	3,433,187	3,527,968	**0.14%**	**0.29%**	**7.21%**
Solar	96,253	121,820	165,158	189,510	164,655	241,224	**96.89%**	**35.16%**	**46.06%**
Wind	5,413,472	5,358,676	6,582,749	6,236,586	5,534,307	6,624,847	**15.20%**	**3.28%**	**0.64%**
Coal	9,731,896	6,901,994	7,068,925	8,890,869	5,898,589	4,990,092	**-8.64%**	**-14.54%**	**-29.41%**

Table 8: This table shows percent difference of net generation by fuel type, comparing the first three months of 2017 to the first three months of 2018. Notable increases in natural gas, wind, and solar are seen in this table with decreases in both hydropower and coal. By March of 2018, all three coal-fired power plants of focus were retired and not generating electricity.

Graph 5: Historical Net Generation Data for the ERCOT Region



Graph 5: Historical net generation data by fuel source for electricity generated within the ERCOT Market between 2002- 2017.[83] Details regarding the percent share of each fuel type can be seen in Tables 9 and 10.

[83] "Reports and Presentations," ERCOT Reports and Presentations, accessed January 20, 2018, http://www.ercot.com/news/presentations.

Table 9: Energy by Fuel Source 2002-2009

Fuel Source	2002	2003	2004	2005	2006	2007	2008	2009
Natural Gas	46.41%	46.35%	43.9%	45.8%	46.3%	45.5%	43.0%	42.1%
Coal	38.45%	39.72%	40.0%	39.0%	37.4%	37.4%	37.1%	36.6%
Nuclear	12.85%	11.95%	14.3%	13.0%	13.6%	13.4%	13.2%	13.6%
Wind	0.83%	0.83%	1.1%	1.4%	2.1%	2.9%	4.9%	6.2%
Water	0.26%	0.21%	0.3%	0.3%	0.2%	0.4%	0.2%	0.2%
Net DC/BLT	0%	0%	0%	0%	0%	0%	0%	0%
Other	1.2%	0.93%	0.5%	0.4%	0.5%	0.4%	1.6%	1.3%
Total	100%	100%	100%	100%	100%	100%	100%	100%

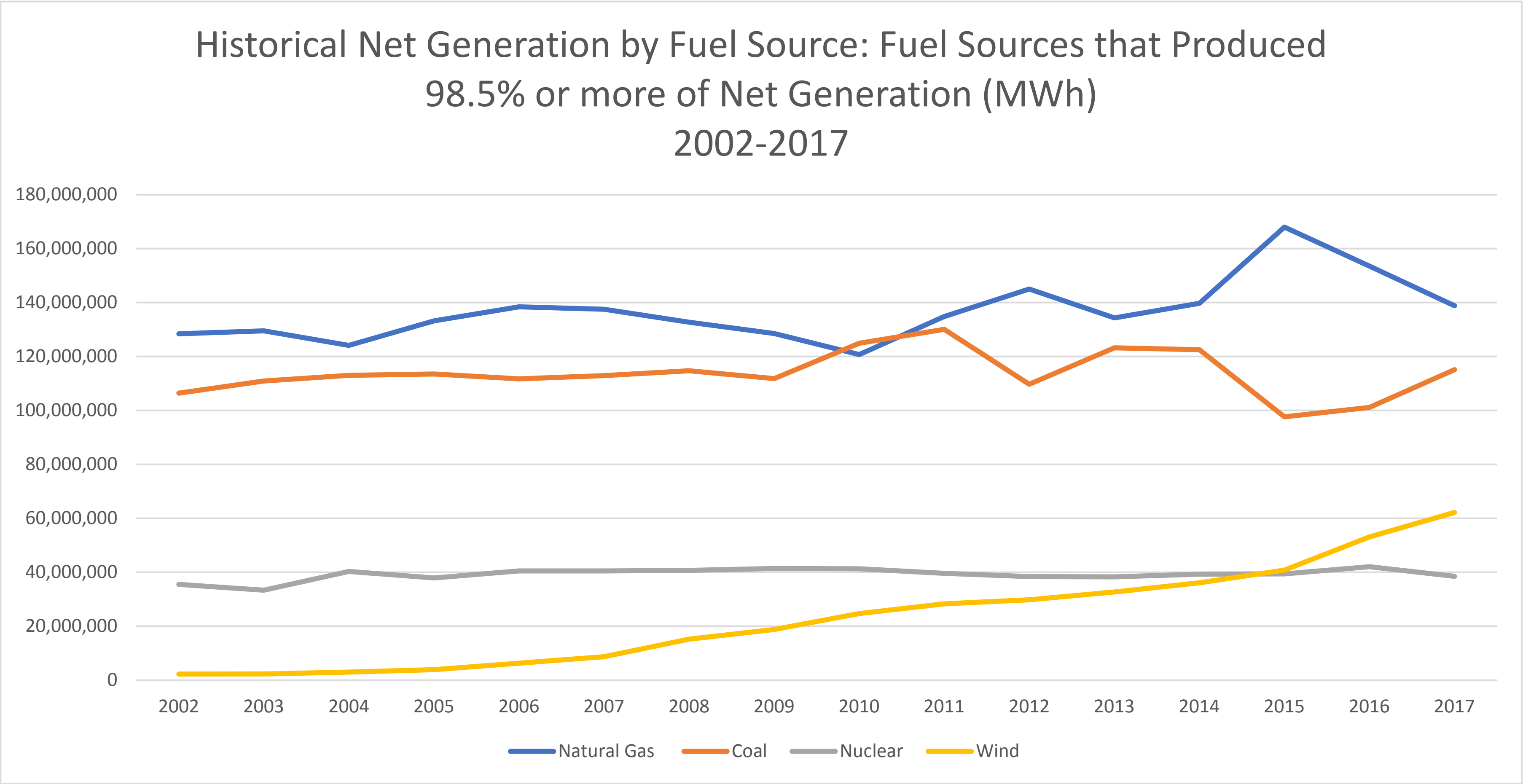
Table 9: In this table, energy by fuel source is expressed as a percent of total net generation. The ‘Other’ category includes petroleum coke, landfill gas, biomass, and solar. ERCOT did not provide a breakout of solar net generation until 2016. Also, there is no Net DC/BLT data provided by ERCOT until 2012.

Table 10: Energy by Fuel Source 2010-2017

Fuel Source	2010	2011	2012	2013	2014	2015	2016	2017
Natural Gas	38.2%	40.4%	44.6%	40.5%	41.1%	48.3%	43.7%	38.8%
Coal	39.5%	39.0%	33.8%	37.2%	36%	28.1%	28.8%	32.2%
Nuclear	13.1%	11.9%	11.8%	11.6%	11.6%	11.3%	12.0%	10.8%
Wind	7.8%	8.5%	9.2%	9.9%	10.6%	11.7%	15.1%	17.4%
Water	0.3%	0.2%	0.1%	0.1%	0.1%	0.2%	0.3%	0.2%
Net DC/BLT	0%	0%	0.2%	0.5%	0.4%	0.1%	-0.2%	-0.3%
Other	1.1%	0.2%	0.3%	0.3%	0.3%	0.3%	0.4%	0.8%
Total	100%	100%	100%	100%	100%	100%	100%	100%

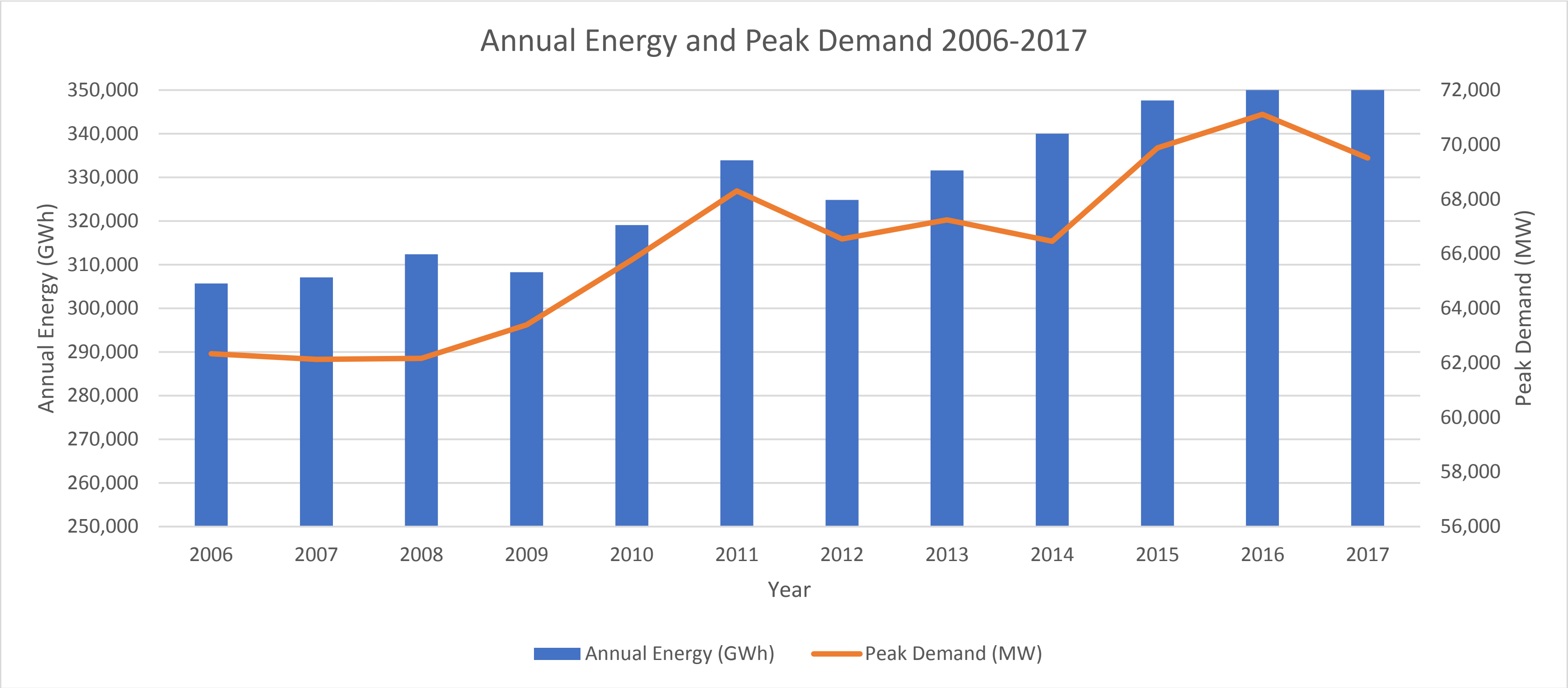
Table 10: In this table, continued data for energy by fuel source is expressed as a percent of total net generation is expressed. ‘Other’ includes petroleum coke, landfill gas, biomass, and solar. ERCOT did not provide a breakout of solar net generation until 2016, and biomass was not provided as a breakout of net production until 2017. For consistency, solar and biomass were combined with the other fuel source data.

Graph 6: Historical Net Generation by Fuel Source: Highlighted Net Generation by Fuel Source 2002-2017



Graph 6: This graph shows historical net generation by fuel source, focusing on net generation of natural gas, coal, nuclear, and wind power. These four fuel sources generated, at minimum, 98.5% of net generation between 2002 and 2017. Key years in this graph are 2010 and 2015. In 2010, net generation sourced from natural gas surpassed net generation sourced from coal. In 2015, net generation sourced from wind power exceeded net production from nuclear power.

Graph 7: ERCOT Annual Energy and Peak Demand



Graph 7: This graph depicts annual energy and peak demand for the ERCOT region between 2006- 2017. This graph was recreated using data provided in the ERCOT 2017 State of the Grid Report.[84] This graph is important because it shows the overall increase in annual energy and peak demand over an eleven-year period leading up to the coal-fired power plant retirements of focus. This graph supports the fact that even though energy generation and demand have continuously grown within the service region, ERCOT's operators are capable to meet consumer demands year after year effectively with cost and energy efficient technologies.

[84] "ERCOT 2017 Sate of the Grid Report" (Electricity Reliability Council of Texas (ERCOT)). accessed April 13, 2018. http://www.ercot.com/content/wcm/lists/144926/ERCOT_2017_State_of_the_Grid_Report.pdf.

Analysis

In the proceeding graphs and tables, data utilized in this study is presented. Analysis of key graphs and tables is detailed below.

Graph 4: Net Generation by Fuel Source between January 2017 and March 2018

In this graph, net generation by fuel source during the time period of January 2017 and March 2018 is displayed via a bar graph. This graph is significant and aids in the assessment of the hypothesis because it helps depict changes in net generation by fuel source between months, and even a comparison in net generation by fuel source between the first three months of 2017, and the first three months of 2018. This graph visually illustrates fluctuations in chosen fuel sources between months. For example, during the summer months when energy generation is at its highest to meet consumer demands, natural gas is the highest consumed fuel source. This is because as temperatures increase in the summer months, consumer demand for air conditioning increases, and the power sector utilizes natural gas to meet demands.[85] Wind generation typically decreases during the summer months because of warmer air temperatures, which in turn causes a decrease in air speeds. Wind generation is higher in cooler months due to colder temperatures and increased air speeds. Also, in this graph, monthly net generation by coal can be seen. By March 2018, net generation by coal decreased 29.4% when compared to March 2017, indicating that the three coal-fired power plants are retired and nonoperational. Even with very similar total net generation in each March month (2017 and 2018), consumer demands are met even without these base-load power plants.

[85] US Energy Information Administration. "Natural Gas Explained- Factors Affecting Natural Gas Prices." EIA-U.S. Energy Information Administration. August 23, 2017. https://www.eia.gov/energyexplained/index.cfm?page=natural_gas_factors_affecting_prices.

Table 8: Comparison of Net Generation by Fuel Source

In this table, a percent difference calculation was conducted to view shifts in net generation between the first three months of 2017 and the first three months of 2018. This analysis allowed for a greater understanding of how net generation by fuel source shifted between early 2017 when these base-load generators were operational and bidding into ERCOT's wholesale energy market, and early 2018 when these plants were shuttered down and retired. Notable changes can be seen in net generation fueled by natural gas, wind, and solar. Solar net generation had significant increases in January, February, and March of 2018 when compared to the same months of 2017. This is because of the additional installed utility-scaled solar projects that became operational in 2017. January of 2018 was particularly interesting because net generation sourced from solar resources increased by 96.89%, which is a significant indicator of growth from this fuel source. Net generation fueled from coal decreased in each month of comparison between 2017 and 2018. Overall, as these three coal-fired power plants were retired, ERCOT was still able to meet comparable consumer demands between years with energy produced by natural gas, wind, solar. This indicates that sufficient installed generating capacity exists within the region, and that the risks associated to reliability issues are low. Even though this analysis shows early indicators as to how the grid is reacting to these retired plants, this analysis needs to be expanded to include summer net generating data. Including the summer net generation data will lead to a stronger understanding and conclusions regarding how the ERCOT market is meeting consumer demands by shifts in net generation by fuel source.

Tables 9 and 10: Historical Energy by Fuel Source Data 2002-2017

In these two tables, historical data regarding the energy by fuel source is detailed. Natural gas as a fuel source peaked as ERCOT's highest energy fuel source in 2015, producing 48.3% of the energy during that year. Overall, natural gas as a fuel source has provided between 38%-48.3% of ERCOT's energy needs over the historical period of 2002-2017. Wind as an energy resource has seen significant growth over the historical period and is projected to continue to increase into the future. At the beginning of this time series in 2002, wind energy produced 0.83% of ERCOT's energy needs. In 2017, wind produced 17.4% of ERCOT's energy needs. This is a significant increase in the short fifteen-year time period for the ERCOT region. Coal as an energy source has an interesting history within the ERCOT region. Coal peaked as an energy source in 2003, when 40% of energy produced in the ERCOT region was from coal. Since 2004, coal produced between 36.6%-40% of energy within the region. Between 2011 and 2012, the first significant decrease in energy from coal sources can be seen after years of relative growth. Between 2002-2011, energy produced from coal stayed between 36-40% of total energy produced within the region. In 2012, energy produced from coal dropped to 33.8% of ERCOT's total energy. Even though there was a slight rebound in energy produced from coal between 2013 and 2014, by 2015 energy produced from coal dropped below 30% for the first time during the historical period. Even though in 2017 32.2% of energy was produced by coal, the 2018 numbers will be significantly different now that these three generators of focus are retired. Once the final 2018 data is published, it will be imperative to collect and analyze data for the entire year and compare to the historical period to see the areas of growth and decline for energy produced by fuel source within the ERCOT region.

Discussion

Coal-fired power plant retirements have occurred in the United States in high frequency over the last ten years and will continue to occur well into the future. Even though each coal-fired power plant retirement is dependent on the energy grid it is operating in, the common factors driving these retirements are the same. Competition from inexpensive natural gas prices, environmental concerns and regulations, increased installation of efficient and cost-effective generators, and coal-fired power plants near the end of their life-cycles are all contributing factors forcing utilities and generating companies around the country to consider the economic viability of the coal-fired power plants they operate.

Luminant, a generating company operating within the ERCOT and providing electricity to the wholesale energy market, decided to retire three important baseload coal-fired power plants in the later months of 2017. Big Brown, Monticello, and Sandow power plants were shuttered down and retired in the early months of 2018 and were fully offline and nonoperational by March of 2018. A variety of factors caused these retirements. First, regulations and policies set by the Environmental Protection Agency regarding air pollution and air quality put an increased economic burden on these plants at the very end of their life-cycle. The additional investments needed to retrofit these power plants to reduce their emissions to comply with these regulations and air quality standards was an unforeseen cost in operations. The investments needed to implement the additional technologies and practices would increase the price per unit of electricity generated at these sites, making the plants unable to compete with other energy sources such as wind, solar, nuclear, and natural gas on the wholesale energy market within the ERCOT service region.

Next, in conjunction with the increase in investment needed to comply with environmental regulations, the additional costs associated with switching from lignite coal to sub-bituminous coal were an additional economic burden on these plants. Luminant owned both the power plant and the lignite coal reserves within the vicinity of the plant. The lignite coal reserves were mined and transferred directly to the plant for consumption, leading to low marginal costs for Luminant. The numerous lignite coal-fired power plants that provided electricity to the ERCOT wholesale electricity market capitalized on the ability to provide cheap electricity by utilizing this low-grade and dirty fossil fuel. When these plants started purchasing subbituminous coal from the Powder River Basin, the associated fuel costs for these plants also increased.

Even though the economics associated with plant operations played a significant factor in these plant retirements, what is unique about these retirements is that they provided electricity in the ERCOT wholesale electricity market. This wholesale electricity is highly competitive due to renewable resources typically bidding into the day-ahead market (DAM) and real-time market (RTM) at negative prices. These negative prices are the result of the production tax credit these renewable energy sources receive, low operational costs, and zero fuel costs. The steady increase in installed renewable energy sources, particularly wind, within the service region has shifted the dispatch order of generators away from coal-fired plants. Another important aspect to ERCOT's wholesale electricity market is the relatively inexpensive natural gas prices. Texas has vast natural gas resources, and the ability to transport natural gas within the state to natural gas fueled power plants. Natural gas power plants are more efficient generators than traditional coal- fired power plants and generate more electricity per unit of fuel when compared to coal-fired power plant. Some natural gas fired plants, known as peakers, can quickly respond to consumer demands if needed than coal-fired power plants. This is due to the lower response time natural gas power plants have when compared to coal-fired power plants. Quicker response times, increased efficiency, and lower fuel costs make natural gas fired power plants more favorable and dispatched before coal-fired power plants to meet consumer demands. Since coal-fired power plants were being dispatched less to meet consumer demands, the investments needed to comply with environmental regulation in addition to the increase in fuel costs made these power plants no longer viable within the wholesale electricity market.

Another aspect to these retirements that is important to this study is analyzing the shifts in net generation over the lifespan of ERCOT's wholesale energy market. Analyzing the shift in net production by fuel source allows for a greater understanding of how ERCOT can meet consumer demand as populations within the service region increase. Since the establishment of the CREZs in 2005, it is easier for transmission projects to be constructed within the service region. Increasing the successful addition of transmission lines from the CREZs to consumers within the region also increased the usage of utility-scale solar and wind farms. The growth in renewable energy installed capacity within ERCOT has increased significantly over the last 15 years and is projected to increase well into the future.

An important piece to this analysis is reviewing how consumer demands are being met within the ERCOT region now that three major coal-fired power plants have been retired. To do this analysis, net generation by fuel source data was collected from ERCOT. Reviewing net generation by fuel source allowed for a better view into which fuel sources are dispatched to meet consumer demands within the service region. As seen in Table 8, increases in wind, solar, and natural gas as fuel sources for net generation increased over the period of focus. By March 2018, all three coal-fired power plants that were the focus of this study were retired and nonoperational. Even though this study focuses on the contributing factors that led to these retirements, it is important to analyze how the net generation gap created by these coal-fired power plants is filled, and how the ERCOT wholesale electricity market is able to remain reliable to consumers. Even though this study used data from the first three months of 2018, it is important to revisit this study in the later months of 2018 when more net generation data is made available by ERCOT, especially net generation data for the summer months. It is imperative to build on this current study because during the summer months demand for electricity increases, meaning that the available generation capacity will be put to the test without the 4.2 GW of baseload capacity the three coal-fired power plants provided to the ERCOT grid. As the grid is tested to meet consumer demand during the warm summer months, it will be interesting to see how generating companies bid into the wholesale energy market, and which fuel sources end up being the sources of net generation within ERCOT.

In addition to seeing how the various generating companies react to fill the gaps of these retirements to meet consumer needs, it will be particularly interesting to see how Luminant, the generating company that owned the retired coal- plants of focus will react. Where will they now be investing their resources now that 4.2 GW of capacity from their fleet is retired? In a news article posted by The University of Texas at Austin, the author, Brooke Holleman made an interesting point regarding Luminant's new need for generating capacity, and the large, flat coal mines they own. These sites would be perfect for utility-scale solar installations. The land that holds the lignite coal seams that once fed their power plants now sits unusable with no potential future of economic gain for Luminant. Brooke Holleman states in her article that the land Luminant owns "has been flattened and re-vegetated with grass, but it has little potential for any future use without costly cleanup efforts… [the land] is unencumbered by trees or other brush that often would need to be cleared to install a solar farm."[86] If no coal-fired power plants are operating, the mines that supported them are no longer needed. However, the transmission lines necessary to transfer the electricity generated in these areas already exist. Simply updating the existing transmission lines to connect utility-scale solar projects into the grid could give Luminant a second wind in its sails in making the land they own in eastern Texas profitable once again.

All in all, the various factors contributing to the coal-fired power plant retirements in ERCOT can be attributed to the wholesale electricity market, environmental policies and regulations, inexpensive natural gas, and an increase in renewable energy sources like wind and utility-scale solar. The rise of renewable energy sources has been gradual over the last fifteen years, and, this combined with low natural gas prices, leads to market conditions where operating coal-fired power plants is not ideal. These conditions have been influencing coal-fired power plants across the country, and Texas is no exception. Even though retirements of coal-fired power plants aren't a new phenomenon, having three large capacity baseload power plants retired in such a short period of time is significant, and understanding the driving factors can allow for a greater understanding of how other coal-fired power plants may be at risk of retiring in the future.

[86] Brooke Holleman. "Coal Belt to Sun Belt? Texas Has a Golden Opportunity for Clean Energy." UT News | The University of Texas at Austin. December 11, 2017. https://news.utexas.edu/2017/12/11/texas-has-a-golden-opportunity-for-clean-energy.