Wind Energy Integration into Regional Markets:

Market Innovation in ERCOT and what can be learned by the SPP

by

April Christensen

Dr. Timothy Johnson, Advisor

April 29th, 2016

Masters project submitted in partial fulfillment of the requirements for the Master of Environmental Management degree in the Nicholas School of the Environment of Duke University

Executive Summary

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Generation, transmission, and distribution systems make up what we know as the entirety of the electricity system. In the generation stage, electricity is produced and then moved via transmission to then be distributed to end-users, also known as load. As renewable generation continues to grow within the electricity sector, operators of the electrical grid are having to take a fresh look at the capabilities of regional systems to handle these resources, as well as policies to encourage development. This is especially true for those regions that cover areas possessing high levels of wind, such as the central region of the United States. The benefits of wind generation are numerous: non-existent fuel cost, minimal environmental effects, and a resources for fuel that cannot be depleted. In addition to these benefits, we also encounter challenges with these same wind resources, namely the variability. Accompanying the variability comes the inability to "turn on" this form of generation in the way that a typical coal or natural gas fueled power plant can be.

This paper looks at multiple facets of wind integration into regional markets, specifically on the generation and transmission side of the electricity system. When looking at these wholesale markets, we focus on Regional Transmission Operators (RTOs) and/or Independent System Operators (ISOs), specifically the Electric Reliability Council of Texas (ERCOT) and the Southwest Power Pool (SPP). The Electric Reliability Council of Texas is one of the leading RTOs in pursuing innovative market policies and operational protocols for dealing with the variability of wind generation. The Southwest Power Pool (SPP) possesses similar wind resources, but until recently, has not integrated as much wind generation into their portfolio as ERCOT. With the recent SPP expansion into areas with additional wind resource potential, operational procedures and market policies are continuously being improved. This provides a unique opportunity to examine the parallels and lessons that can be drawn between these two regional organizations. During this analysis, we take a specific look at off-site corporate power purchase agreements in both regions, as this is of specific interest to our client, the Business Renewables Center (BRC).

When comparing these two markets, we focus on:

- **Wind speed and resource potential.** A very similar wind resource profile, with the SPP possessing somewhat stronger wind resources in specific areas of the territory.
- **Population and load gradient across service territories.** Similar population and load gradient from sparsely populated in the west to dense population centers on the eastern side of the service territory.
- **Current wind generation penetration, with a particular focus on Corporate PPAs.** Current wind generation penetration as compared to load is somewhat similar, as well as the installed capacity of the Corporate PPAs.
- **Market operational structure.** Market operational structures are similar, though ERCOT has more years of experience in operating their day ahead and real time markets.
- **Curtailment of wind generation.** ERCOT has experienced significant curtailment, while SPP has yet to experience a significant need for wind reduction.

After this comparison, we then look at the future of wind integration in these two areas, focusing specifically on how transmission investments are made and the interconnection queue for new generation. Within the conclusion, we discuss potential for future studies and efforts that can be made to continue to integrate wind generation into both ERCOT and SPP, given their similarities, but also their differences.

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Dr. (MP adviser name printed)

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Date

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INTRODUCTION

When distilled to its most basic components, the U.S. electrical system contains three different levels: generation, transmission, and distribution. In the generation stage, electricity is produced and then moved via transmission to then be distributed to end-users, also known as load.

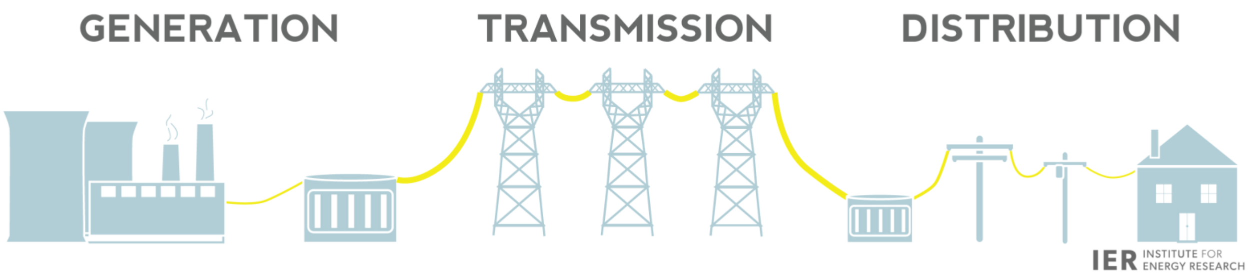

Figure 1. The three basic components of the U.S. electrical system: generation, transmission, and distribution (Institute for Energy Research, 2014).

This system delivers $400 billion of electricity services to United States consumers by utilizing 7 million miles of transmission and distribution lines (Martin, Wade, 2016). It represents a crucial part of the United States economy and also continues to improve the quality of life for citizens throughout the United States.

> "The U.S. electric grid is a vast physical and human network connecting thousands of electricity generators to millions of consumers—a linked system of public and private enterprises operating within a web of government institutions: federal, regional, state, and municipal" (Massachusetts Institute of Technology, 2011).

How the electricity system as a whole is regulated and managed has evolved over time. Different types of technology have been implemented, from solar to combined heat and power to smart thermostats. The infrastructure needed to not only generate, but transmit and then bring electricity to homes and businesses, is often termed the "biggest machine on Earth" (Martin, Wade, 2016). This machine is in a constant state of evolution and improvement, as better methods for regulation, operation, and integration emerge.

One of the most significant contributions towards a changing power grid is the integration of renewable generation. As additional renewable generation goes in and larger thermal units, such as coal, are retired, the electricity sector is having to take a fresh look at what the future electricity system may look like. Within this paper, we will focus on those regions that cover areas possessing high levels of wind, such as the central region of the United States. The benefits of generating electricity from wind are numerous: non-existent fuel cost, minimal environmental effects, and a resource for fuel that cannot be depleted. In addition to these benefits, we also encounter challenges with these same wind resources, namely the variability. Accompanying the variability comes the inability to “turn on” this form of generation in the way that a typical coal or natural gas fueled power plant can be.

Regional Transmission Organizations (RTO) and Independent System Operators (ISO)

In this paper, we will focus on renewable integration into the generation and transmission portions of the system. This portion of the electricity system is often termed the “wholesale market”, while the “retail market” sells to end users. Historically, electric utilities owned generation assets, transmission networks, and distribution wires, and came to be known as vertically-integrated utilities. The areas that were not vertically integrated and had separate ownership of different functions presented a challenge for regulation: who decides which electricity source gets to use the transmission? When looking at Figure 1, it becomes apparent that whichever entity controls transmission would have a great deal of influence on which generators could provide power to the distribution level of the electrical system.

Within the vertically integrated utilities, the ownership of all three components of the electrical system did not incentivize these utilities to provide access for other generators to utilize the transmission they owned. Even if there was separate ownership, it was difficult to determine if discrimination between generating sources was occurring. In 1978, the Federal Public Utility Regulatory Policies Act (PURPA) was passed as a way to address this issue (Purdue University, n.d.). This legislation designated a different type of generator, known as a Qualifying Facility (QF), that was entitled to use of the transmission system and required to be granted access by transmission owners and operators. But entities that were not considered Qualifying Facilities still encountered challenges in use of the transmission system. As a way to prevent discrimination of use of transmission within the wholesale markets, it became necessary for the Federal Energy Regulatory Commission (FERC) to take steps to regulate the use of the transmission network.

The Federal Energy Regulatory Commission (FERC) issued Orders 888 and 889 in 1996, which required all electric utilities to allow open access to the transmission system (Eisen, et al, 2015). The wholesale electricity markets were required to provide the marketplace with transparency for pricing and establish an Open Access Transmission Tariff (OATT). The OATT was established in order to require entities that owned transmission to allow use of their transmission in a non-discriminatory manner, with transparent pricing for all parties. Order 888 and 889 created the idea of an Independent System Operator (ISO) as a way to achieve these requirements. The ISO structure would provide an un-biased operator of the transmission system that could establish a market for bids from generators. Future planning for transmission needs was also placed as a responsibility upon these new ISOs.

In 1999, FERC expanded upon these goals by establishing Order 2000. Within this order, there were twelve characteristics and functions that were identified as qualifications for becoming a Regional Transmission Organization (RTO) (FERC, 2016). Though there are subtle differences between the RTOs and ISOs, the main purpose of both is to support and encourage state and regional wholesale markets. These wholesale markets serve as both the operator of the system, but also oversee financial markets for wholesale energy sales. The terms RTO and ISO will be used interchangeable throughout this paper.

There are currently seven ISO/RTO organizations in the United States:

- California ISO (CAISO)
- Electric Reliability Council of Texas (ERCOT)
- Midcontinent ISO (MISO)
- New England ISO (ISO-NE)
- New York ISO (NYISO)
- PJM
- Southwest Power Pool (SPP)

Looking at Figure 2, we can see the large area that is covered by these wholesale market operators.

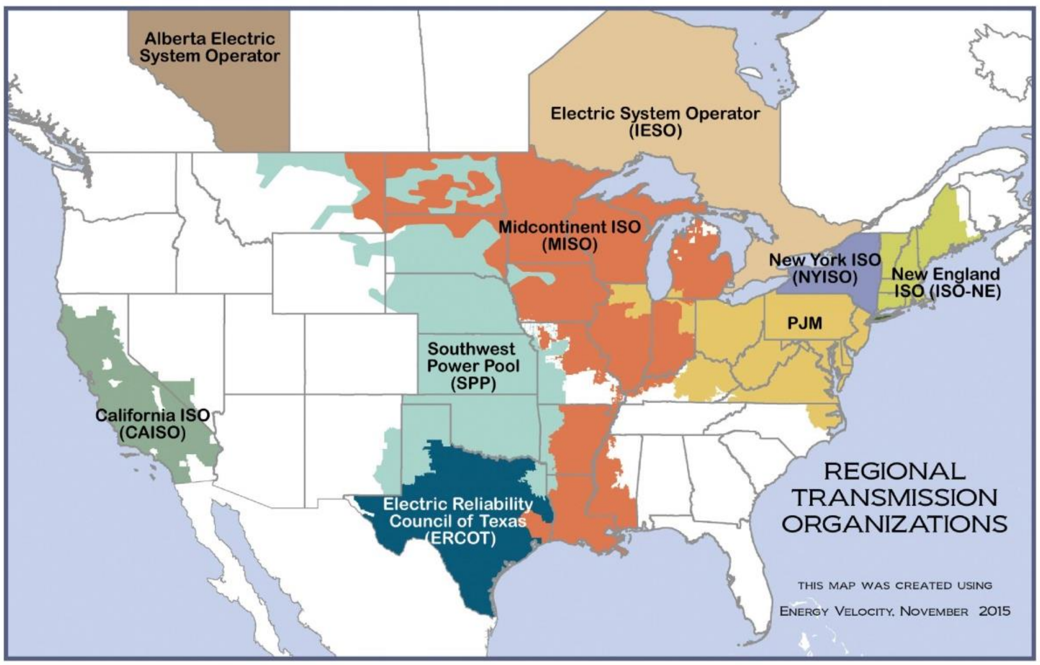

Figure 2. RTO/ISOs throughout North America. (FERC, 2016)

Wind Generation in Electricity Markets

Renewables possess two basic characteristics that differentiate themselves from other generation assets on the grid. The first is the non-existent fuel cost, which make these assets competitive when bidding into a wholesale market. The low fuel cost results in a low marginal cost which enables them to bid a low price into the wholesale market (See Market Structure Section). Wind generation commonly functions as a price-taker in the market, accepting the price that is settled on in the market by other generators, due to the other generators having higher marginal costs from fuel costs. Serving as a price-taker is often considered a valuable and low-risk approach for renewable generation, due to the absence of fuel cost and minimal, if any, marginal cost (Hurlbut, Zhou, Porter, Arent, 2015).

The second main characteristic that differentiates renewable generation is the variability of the resource utilized for generation. For example, both sun and wind resources are not available on command and may vary throughout the day. Though regional operators are used to dealing with the variability of demand on the system, renewables can add another level of variability that makes it even more complicated to manage. 'Net load' becomes of concern for regional operators, which is the electricity demand minus wind and solar production (Andersen, 2014). By adding wind and solar into the generation mix, other generation assets often have to adjust their output more quickly and more often.

In spite of the variability of the resource, regional operators have identified integration processes and management protocols to encourage increased renewable generation. Many consider the open access to transmission and transparency offered by the RTOs structure encourages the development of renewables in a region (EPSA, 2008). In wholesale markets, it is possible for a renewable generator to function as an Independent Power Producer (IPP), gaining profits from sales of electricity into the wholesale market. In a vertically integrated utility without an open wholesale market, it is more difficult for the IPP to gain access to the transmission, as they have to negotiate an off-take agreement with the regulated utility. An IPP is much more likely to install generation assets in an area that allows for open transmission access and therefore, access to the wholesale market. As is shown in Figure 3, significant amounts of wind capacity have been installed in the seven RTO/ISO regions within North America. Not only does open access to transmission spur renewable development, but the transparency of pricing in the market allows investors and developers to have a better idea of what their asset will be worth (EPSA, 2008).

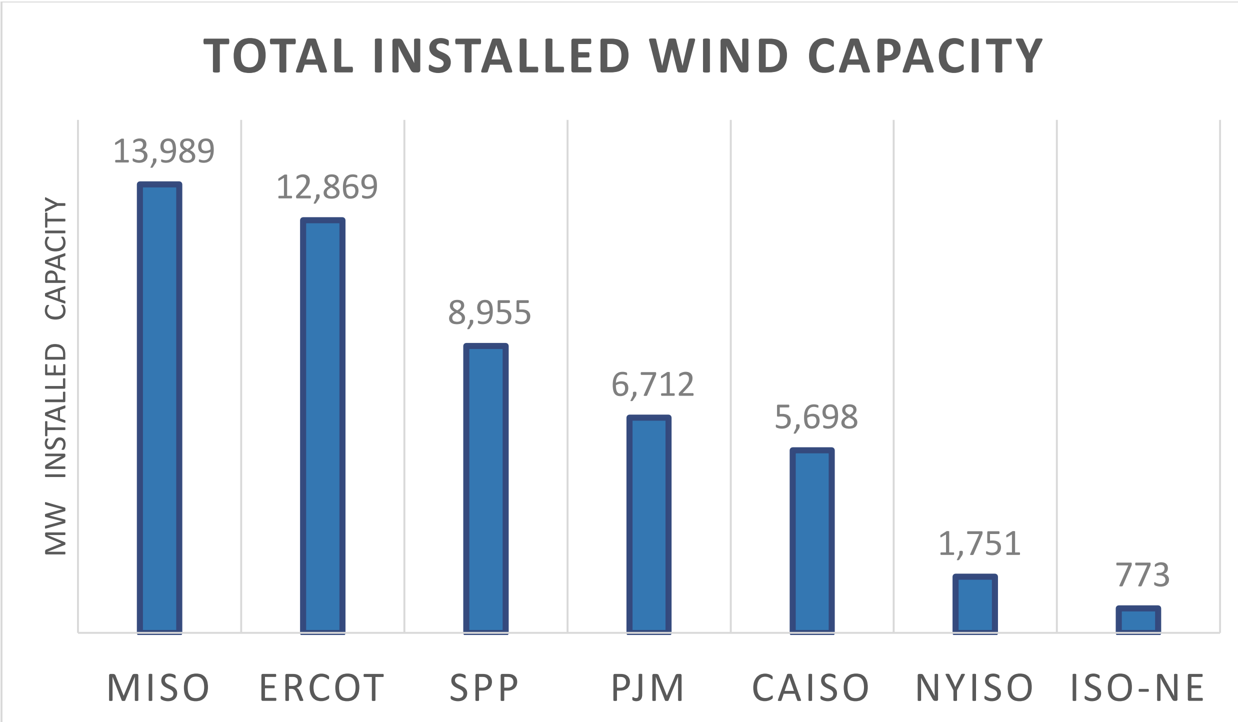

Figure 3. The total installed wind capacity throughout the seven RTO/ISO regions in the United States (Energy Information Administration, 2015).

Motivation

The Rocky Mountain Institute (RMI), and specifically, the Business Renewables Center (BRC) is the client for this project. The BRC is a "member-based platform that streamlines and accelerates corporate purchasing of off-site, large-scale wind and solar energy" (Business Renewables Center, 2016). These off-site corporate Power Purchase Agreements, or Corporate PPAs, have become a significant force within the renewable energy industry, as we will discuss in the next section. The mission of the BRC is to accelerate this trend, which prompted them to request a study looking at the leading market for Corporate PPAs paired against a growing market for Corporate PPAs. The audience for this report will be renewable energy developers and corporations that are members of the BRC and are interested in the opportunities for increased Corporate PPAs.

To identify which regions should be studied, we first took a look at the total amount of wind capacity installed in each RTO/ISO. As is shown in Figure 3, MISO, ERCOT, and SPP are leading other

Table 1. Corporate Power Purchase Agreement Capacity showing total, wind technology, and solar/biomass agreements through February 2016 (Business Renewables Center, 2016).

RTO/ISO	Total MW	Wind MW	Solar & Biomass MW
ERCOT	1756	1756	0
SPP	1264	1264	0
MISO	862	862	0
PJM	807.6	647.6	160
CAISO	451	86	365
NYISO	20	20	0

RTOs in the amount of wind capacity installed within their service territories. To achieve the goals of this market study, we then looked specifically at the quantity of Corporate PPAs within each market. As we can see in Table 1, corporate purchasing of large scale renewable energy is significant, with a large bias towards wind generation. As a result, my client requested a comparison of off-site Corporate PPAs utilizing wind generation between the leading two markets:

1. Electric Reliability Council of Texas (ERCOT)
2. Southwest Power Pool (SPP)

The BRC wanted to look at the SPP specifically due to their recent growth in installed wind capacity with corporate off-takers (PPAs). Also, the expansion of the Southwest Power Pool, which will be discussed in detail later in the study, offers a significant opportunity for increased wind generation and Corporate PPAs in the region. Within this paper, we will look at four principal questions:

1. Why is the comparison of the SPP and ERCOT valuable to the industry? What do these markets have in common that could provide valuable insight into future challenges and opportunities for these markets?
2. How does the current installed wind generation capacity compare between SPP and ERCOT? More specifically, is there a large difference in Corporate PPA agreements between the two markets?
3. What policies and operational procedures are notable differences between the two markets?
4. What does the future look like for wind generation and specifically, corporate PPAs in the SPP and ERCOT?

BACKGROUND AND MARKET ATTRIBUTES

Corporate Power Purchase Agreements

Power Purchase Agreements (PPAs) have been a tool utilized in the electricity industry for quite some time. At its most basic, a PPA is "…the agreement that governs the sale and purchase of power" (Badissy, 2014). Bilateral contract negotiation (between two parties) is often utilized to finalize these long-term PPAs for electric generation (Kreycik, Couture, & Cory, 2011).

> "A bilateral contract in an electricity market is an agreement between a willing buyer and a willing seller to exchange electricity, rights to generating capacity, or a related product under mutually agreeable terms for a specified period of time. Most economists agree that such arrangements are crucial to the functioning of electricity markets, because they allow both parties to have the price stability and certainty necessary to perform long-term planning and to make rational and socially optimal investments" (Hausman, Hornby, & Smith, 2008).

They are a fundamental way to provide certainty in a market for long term investments and are a large, or even the determining, factor considered when applying for project financing. PPA deal structure and financing are outside the scope of this project, but are a crucial consideration for any project developer and/or electricity buyer (off-taker). Naturally, as renewable energy has become more prominent in the electricity sector, the PPA structure has been utilized to integrate this new form of generation. Recently, though, there have been new stakeholders requesting more autonomy when it comes to procurement of the energy they utilize: corporations. Corporations negotiating bilateral agreements for PPA off-take is a relatively recent trend, which we will examine in the context of the SPP and ERCOT.

As noted by the AWEA U.S. Wind Industry Fourth Quarter 2015 Market Report, almost 75% of MW contracted through PPAs in the 4th quarter of 2015 possessed a non-utility off-taker. This AWEA U.S. Wind Industry Fourth Quarter 2015 Market Report also reveals that 52% of total 2015 PPA MW's were signed by non-utility off-takers. This percentage has been increasing since the first Corporate PPA was signed in 2012 by Google. These non-utility off-takers mainly consist of corporations, although

AWEA statistics include other entities such as universities. The BRC tracks all corporate specific off-take PPAs, with a clear representation of this shown in Figure 4.

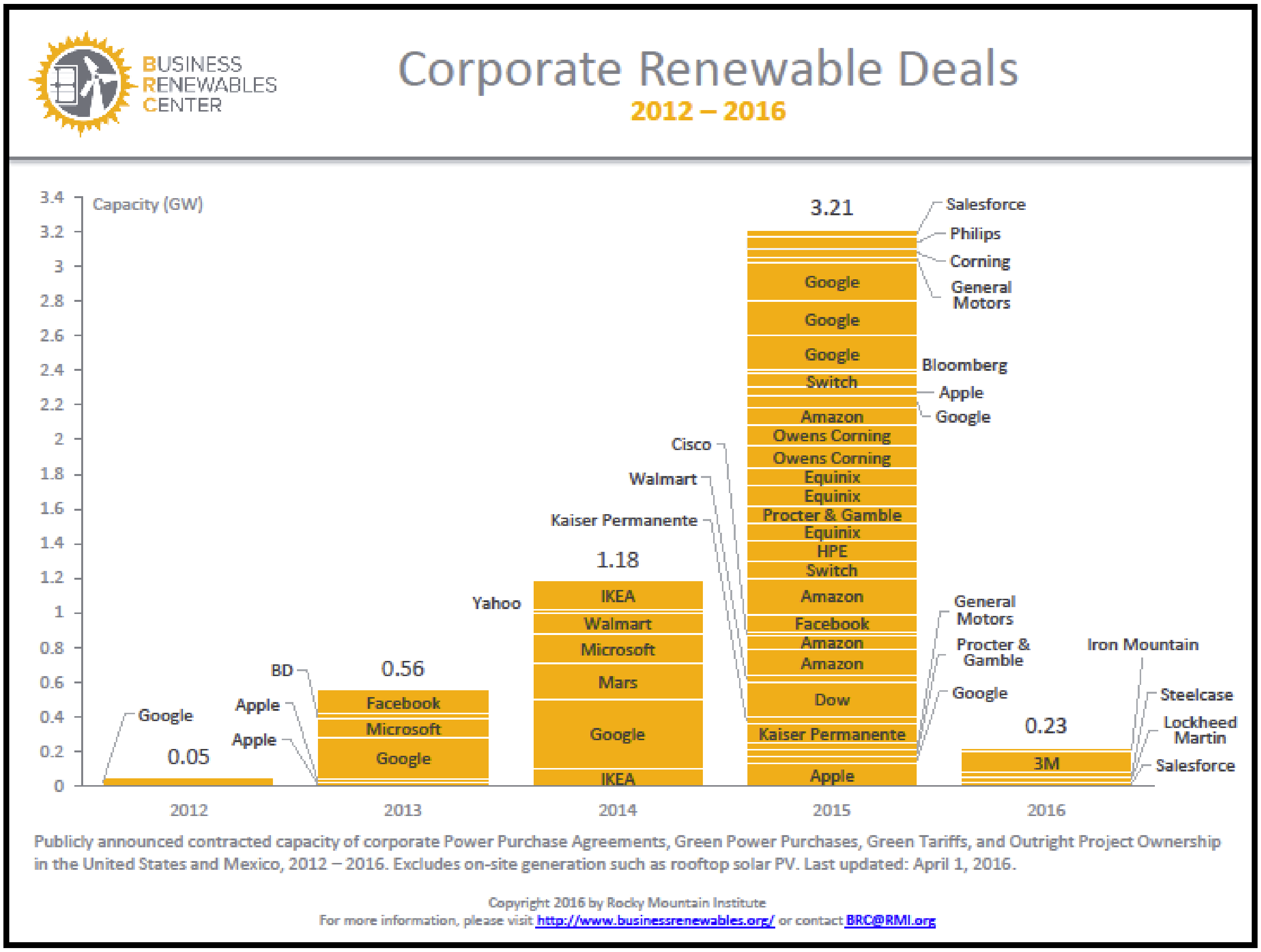

Figure 4. Corporate Renewable Deals from 2012-2016, as tracked by the Business Renewables Center (Business Renewables Center, 2016).

When we look at Corporate PPA statistics in Table 1, we can see that ERCOT, SPP, and MISO are the three leaders across technologies (solar, wind, biomass, etc.). When we narrow the query down to only Wind Corporate PPAs, we see that solar and biomass PPAs only exist in PJM and CAISO. As we can see in Figure 5, ERCOT, SPP, and MISO are the leaders in installed MW of wind capacity, which provided the motivation to pursue analysis of these specific markets.

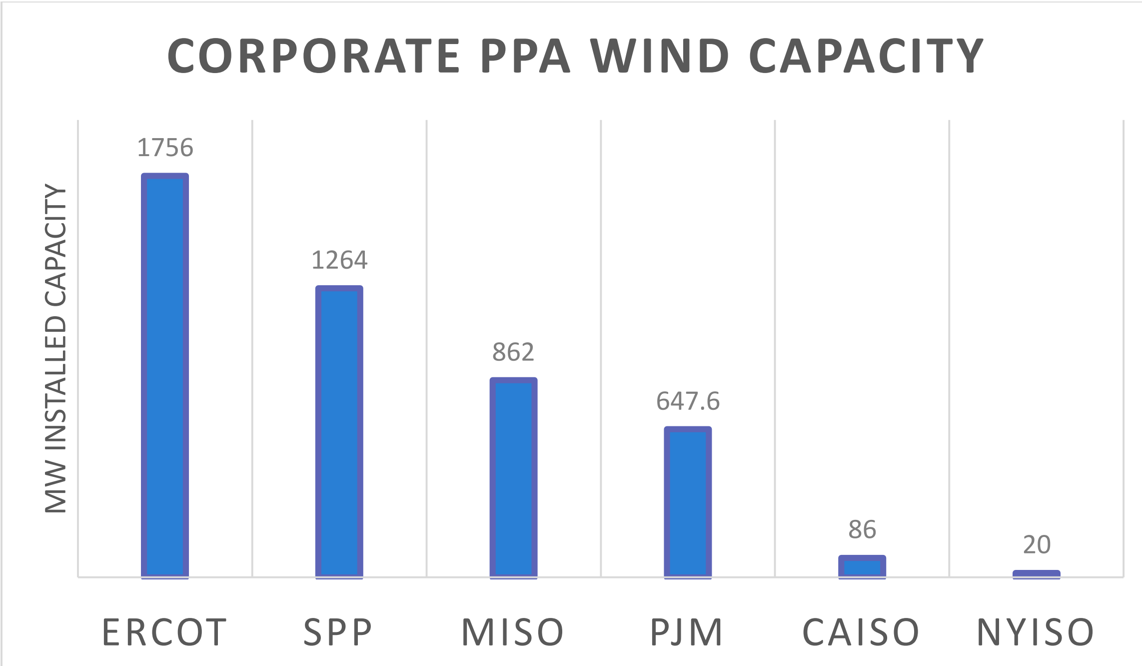

Figure 5. Corporate PPA Wind Capacity throughout all United States RTOs/ISOs. ISO-NE did not have any Corporate PPA Wind Capacity, and as such, was not included in this figure. This figure contains data up until February 2016 (Business Renewables Center, 2016).

Not only does SPP possess significant levels of installed Corporate PPA generation, but it also provides an interesting regional market for additional analysis due to its recent expansion. The region has grown in wind generation, but also in the size of its footprint.

Expansion of the Southwest Power Pool

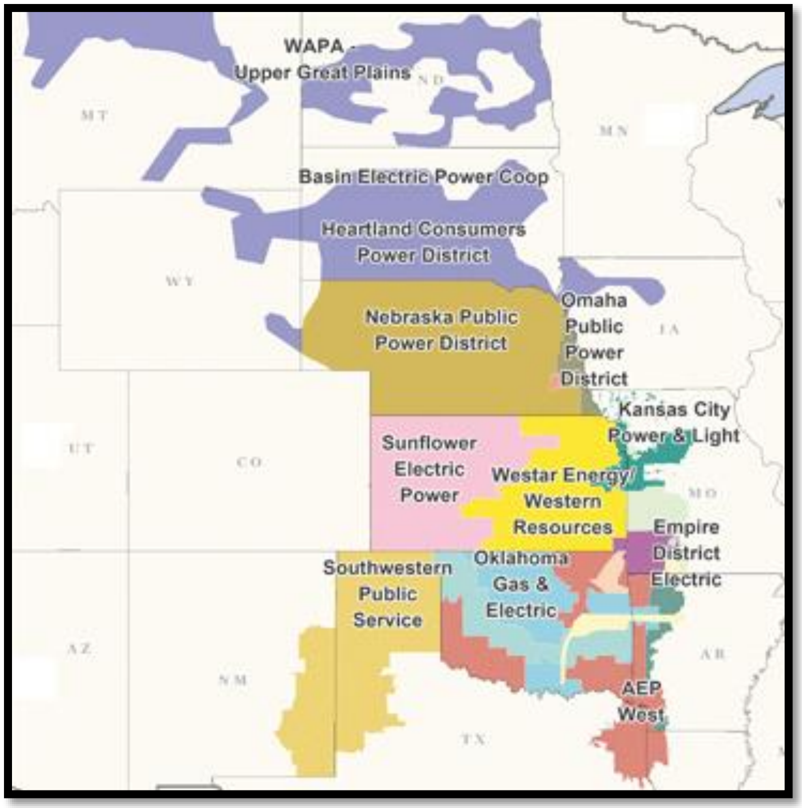

Figure 6. The entities included in the Southwest Power Pool, with the Integrated System shown above in purple (FERC: Electric Power Markets – Southwest Power Pool (SPP), 2015).

The Southwest Power Pool (SPP) was founded in 1941 as a partnership of eleven regional power companies in the Arkansas region (FERC, 2015). The eleven power companies structured themselves as a reliability council, as the Jones Mill in Arkansas was producing aluminum for use in the war effort and it was imperative to provide reliable power to this facility.

In 1968, the SPP and twelve other entities became the North American Electric Reliability Corporation (NERC). In 1991, the SPP began to utilize a reserve sharing system among its members (Avery, 2016). In 1994, SPP was established as a non-profit organization. In 2004, FERC approved SPP as a Regional Transmission Organization (RTO), subsequently approving the SPP as a Regional Entity in 2007.

The SPP is based in Little Rock, Arkansas and serves all or parts of 14 states. As an approved RTO, the SPP has the responsibility to maintain reliability in the region, evaluate and improve transmission resources, and establish a market that enables competitive wholesale electricity prices.

The Southwest Power Pool recently expanded to include the area in Figure 6 that is shown in purple, making the addition of states including Iowa, Wyoming, South Dakota, North Dakota, and Montana. This expansion area originally united in 1998 to form the Integrated Transmission System (also known as the Integrated System or IS). The original Integrated System (IS) included the Western Area Power Administration – Upper Great Plains Region (Western-UGP), Heartland Consumers Power District, and Basin Electric Power Cooperative. As a result of the combination of these entities, the IS transmission now included approximately 9,848 miles of transmission lines. The Western Area Power Administration (WAPA) Open Access Transmission Tariff was utilized, with Western-UGP serving as the tariff administrator.

Over 50% of Western-UGP's electricity load that utilized Western-UGP generation was outside of the IS territory (Western Area Power Administration, 2013). This resulted in Western-UGP delivering their electricity across 3rd party transmission lines, mainly in the MISO and SPP regions, increasing costs and providing a great deal of uncertainty for reliability concerns. The North American Electric Reliability Corporation (NERC) started to get involved due to reliability concerns, as these 3rd party transmission lines had limited capacity to include electricity that had not secured transmission reservations for those lines. This type of involvement by NERC is termed the Transmission Loading Relief (TLR) Procedure. Also, because other entities were joining MISO and SPP, the IS started to see less opportunities to have bi-lateral short-term energy trading to fill in gaps in generation. With all of these challenges, the IS realized that it needed to have access to generation that could offset the variability of their generation, while still allowing them to pursue the lowest cost resources.

The IS considered multiple scenarios that could alleviate these issues, focusing on the IS that was located in the eastern electrical interconnected system (Western Area Power Administration, 2013). The scenarios considered included “Stand Alone”, “Join MISO”, or “Join SPP”. The IS performed a Cost/Benefit Analysis for quantitative analysis and a Multi-Criteria Decision Analysis tool for qualitative analysis.

The Cost/Benefit Analysis showed that the “Join SPP” option provided the most benefits. The risk score produced by the Multi-Criteria Decision Analysis tool showed the “Join SPP” option with the lowest risk score, making it the most favorable option (Western Area Power Administration, 2013). As a result, the Integrated System decided to enter into membership negotiations with the SPP, filing an official notice with the Federal Register stating this on November 1, 2013 (“Recommendation from the Western Area Power Administration to Pursue Regional Transmission Organization Membership”, 2013).

The SPP Board of Directors approved the Integrated System membership in June of 2014 (Caddell, 2015). The SPP filed with FERC on August 1st, 2014, to request the inclusion of the Integrated System in the Southwest Power Pool. SPP stated in its filings in regards to the expansion that this effort will: “(1) provide significant benefits to SPP members and customers; (2) provide the Integrated System Parties’ customers access to organized markets; and (3) increase efficiency and reliability for the newly combined portion of the bulk electric system” (FERC, 2014b). FERC accepted the filing and integration efforts between the two entities began.

SPP took over the reliability coordination service for the IS in June of 2015, followed by a full integration of markets in October of 2015 (SPP Communications Department, 2015). When SPP expanded to include Western-UGP, Basin Electric Power Cooperative, and the Heartlands Consumer Power District, it nearly doubled the square miles covered by the SPP footprint. In addition, it added more than 5,000 MW of peak demand, 7,000 MW of generating capacity and 9,500 miles of transmission lines (Caddell, 2015). In addition, this expansion included a portion of a federal Power Marketing Administration. There are four federal Power Marketing Administrations across the United States that operate hydroelectric dams in 33 states (Energy Information Administration, 2013). The Western-UGP portion of the Western Area Power Administration will be the first federal Power Marketing Administration to join an RTO.

"The expansion will 'enhance our ability to deliver value through transmission,'" SPP CEO Nick Brown said. "The Integrated System's footprint is well connected to SPP's existing service territory and provides a logical expansion from a network configuration standpoint (Caddell, 2015)." As you can see in Figure 6, this expansion increases the SPP footprint from 8 to 14 states.

> The expansion is expected to add stakeholder net benefits of about $334 million and increase SPP's peak load an estimated 10% to 12% ... It also will increase the ability to commit and dispatch generation into and out of Nebraska, and the availability of low-priced hydro generation out of Wester-UGP." (Trabish, 2015).

Wind Resource Potential

As we can see in Figure 2, ERCOT, SPP, and MISO all occupy area within the central regions of the United States. These central regions also tend to have significant amounts of wind resources, as can be seen in the NREL and AWS Truepower wind potential map of the United States in Figure 7. This map shows the predicted mean wind speed at an 80-meter height. The map utilizes a resolution of 2.5 kilometers, with the areas in between interposed from this data. The typical minimum threshold for wind generation utilization is 6.5 meters per second at an 80-meter wind turbine height (Department of Energy, 2014). As such, the 80-meter wind turbine resource map offers a look at the minimum potential for the United States, as many newer wind generation installations are exceeding 100 meters and above, as stated by the Department of Energy.

The National Renewable Energy Laboratory reviewed and confirmed AWS Truepower's 80-meter height map by looking at the data for 19 states and confirming they were within 10% of the value NREL predicted (Department of Energy, 2014). With this said, these average wind speeds are projections gained from a model, and specific locations may not observe exact replications of that wind speed.

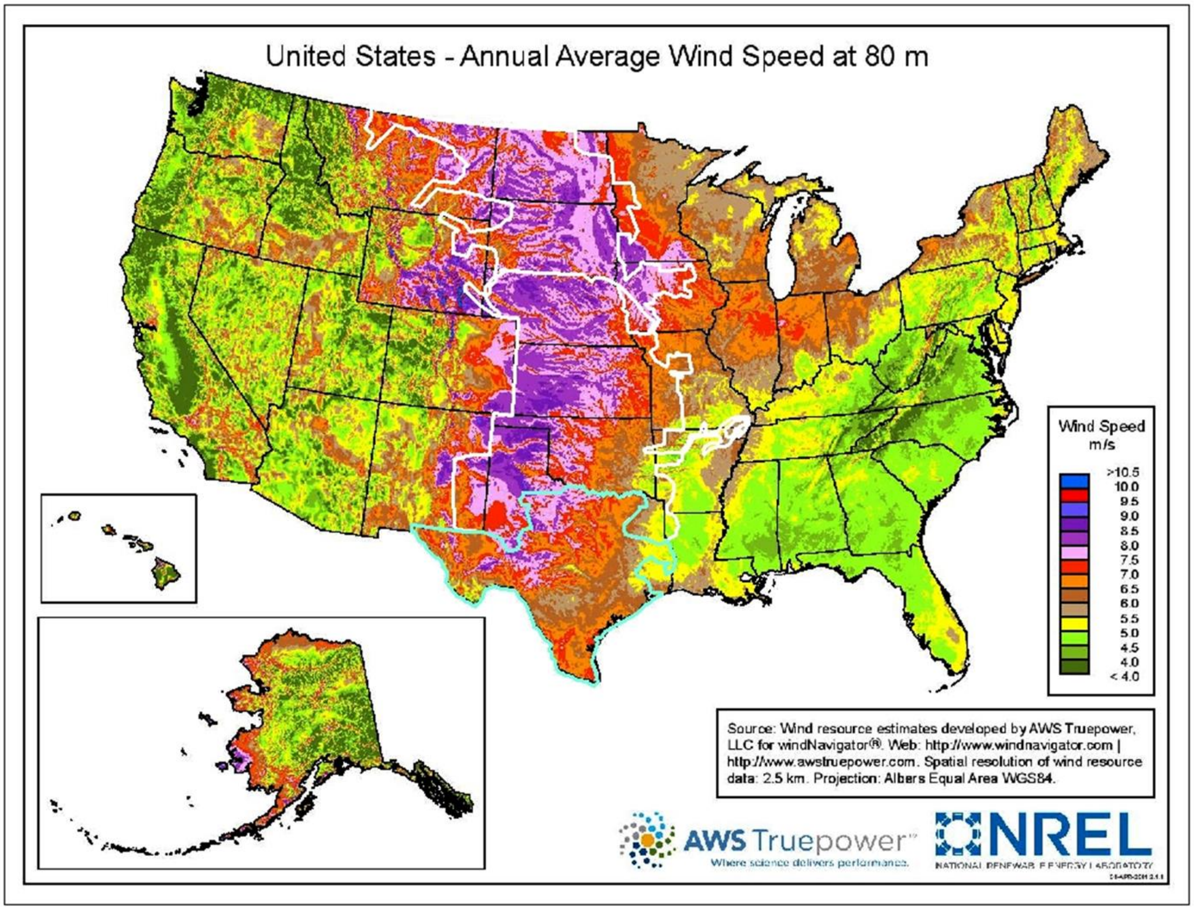

Figure 7. The underlying wind resource map by NREL and AWS TruePower provides wind resources estimates for typical 80 m turbines across the United States. The teal outline on the bottom outlines the ERCOT territory. The two white outlines represent the SPP and the SPP Expansion region on the top most part of the map (National Renewable Energy Laboratory, & AWS Truepower, 2011; Meiman, L., Avery, D., Blowers, A., & Hyland, A., 2015; Electric Reliability Council of Texas, 2015).

Figure 7 was utilized to demonstrate the regional wind potential possessed by the ERCOT, SPP, and SPP expansion regions. Utilizing the geo-referencing capabilities of ArcGIS with multiple regional maps overlaid on the wind resource map, we can see the wind resource possessed by the various RTO regions. Specifically, we can see the central area of the U.S. possesses the highest areas of wind potential, with much of this area covered by ERCOT (teal) and SPP (white). The SPP has two outlines, with the one closest to ERCOT being the original SPP, and the white outline farthest from ERCOT being the recent expansion area of the SPP. With the expansion in 2015, the SPP now encompasses a region that covers the majority of the wind speed areas in the range of 7.5-9 meters/second that exist in the United States. Yet, ERCOT still leads the nation in the MW of installed capacity for Corporate Power Purchase Agreements, as we demonstrated in Figure 5. In comparison to ERCOT, we can see in Table 2 that SPP has a larger land area in combination with greater wind resources, which signifies great potential for this market to grow in the near future.

Population Gradient

As we can see in Table 2, ERCOT possesses a population approximately 5 million people greater than the SPP region. The SPP spreads a lesser amount of population across more than twice as much area as ERCOT, which led us to look at a visual representation of the population gradient in these markets. Similar to our approach with ArcGIS geo-referencing in Figure 7, we also utilized the population density graph to show population gradients across the RTO regions. The population density graph is derived from the 2010 Census Results, showing population density by county.

Table 2. Comparison of the peak demand, % of load served by wind generation, and the wind peak record between SPP and ERCOT. Dates are associated, as the record peak demand for SPP is the seasonal projection, due to no historical data available that would include the Integrated System expansion (Electric Reliability Council of Texas, 2016; Micek & Jackson, 2016; Trabish, 2016; ISO/RTO Council, 2015).

	SPP	ERCOT
Population	~18 million	~23 million
Area	575,000 mi^2	200,000 mi^2
Miles of Transmission	60,944 miles	40,530 miles
Installed Generation	83,465 MW	84,000 MW
Record peak demand	42,000 MW	69,877 MW
Record % of load served by wind	43.3%	45%
Wind Peak Record	10,439 MW	14,023 MW

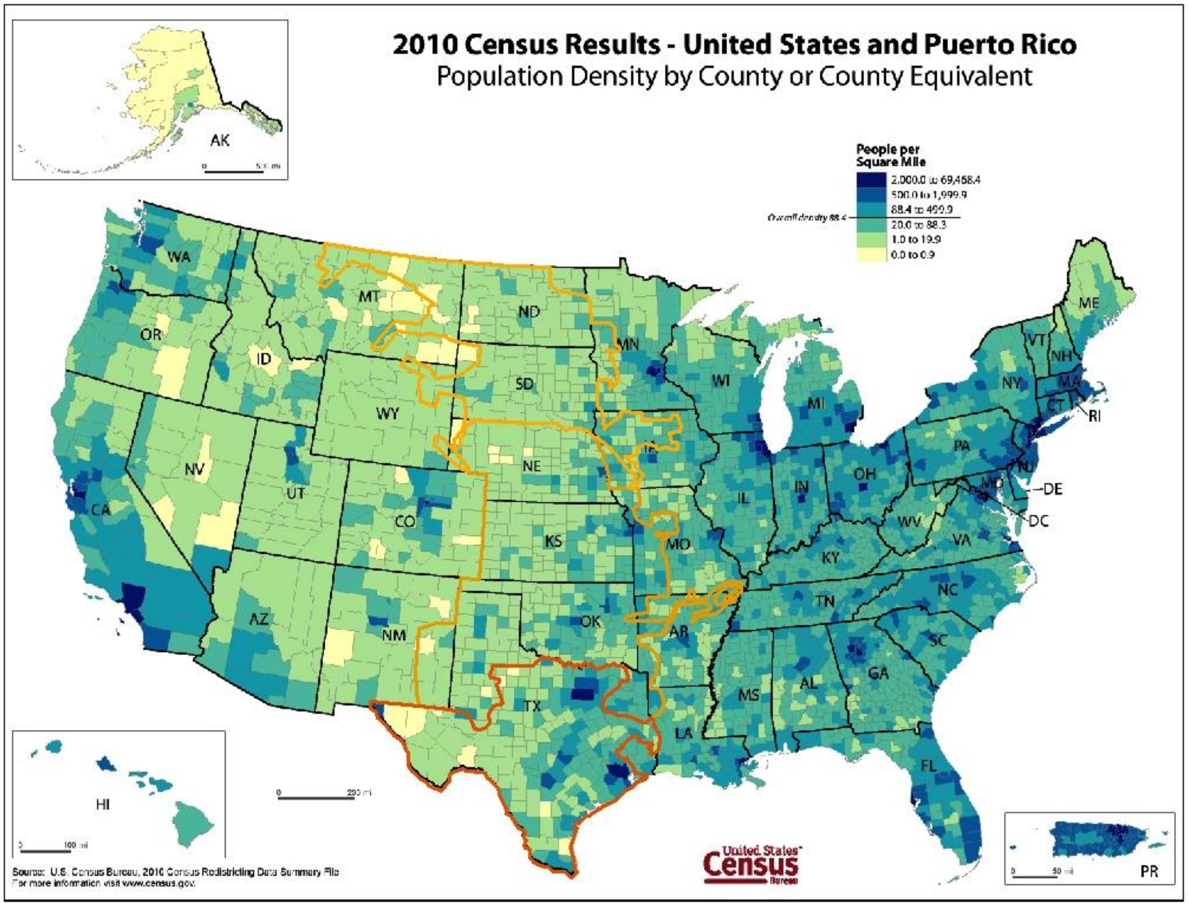

Figure 8. Population density across counties in the United States from the 2010 Census. The red outline on the bottom outlines the ERCOT territory. The two orange outlines represent the SPP and the SPP Expansion region on the top most part of the map (U.S. Census Bureau, 2010; Meiman, L., Avery, D., Blowers, A., & Hyland, A., 2015; Electric Reliability Council of Texas, 2015).

The population gradient across the territory of ERCOT is quite similar to the SPP and SPP expansion population gradient, with population centers in the eastern area of the region. This can present problems when considering much of the wind generation potential exists in the western side of these RTOs. Transmission constraints have historically been an issue for wind energy utilization in the ERCOT region due to this population gradient. The increasing significance of these effects encouraged the state of Texas to enact Competitive Renewable Energy Zones to alleviate this congestion, as will be discussed in a later section. Transmission constraints produced by wind integration are not unique to ERCOT or to wind resources in general. One of the crucial responsibilities of RTO and ISO entities is to maintain an understanding of the existing transmission infrastructure, as well as develop plans for investment in new infrastructure that may be needed. Population density and changes to that density are two significant drivers of the energy load or demand for a region and thus, play a large role in the successful integration of wind generation resources.

CURRENT INSTALLED WIND CAPACITY

Electric Reliability Council of Texas (ERCOT)

The first Renewable Portfolio Standard (RPS) was passed by the Texas Legislature in 1999, setting a goal for the addition of 2000 MW of renewable generation by January 1, 2009. This is often considered the starting point for the wind industry thriving in the ERCOT region. The RPS compliance was measured by utilizing Renewable Energy Credits (RECs), which represent 1 MWh of renewable energy generation. ERCOT was assigned the responsibility of tracking the generation and retirement of these RECs. The RPS created the demand, the low barrier to entry for Independent Power Producers created accessibility, and the wind resource throughout Texas created the resource to be capitalized upon.

Table 3. Showing the average wind generation as percentage of total generation in ERCOT (ERCOT, 2016b).

Year	Avg Wind Generation as a Percent of Load
2007	n/a
2008	4.9%
2009	6.2%
2010	7.8%
2011	8.4%
2012	9.2%
2013	9.9%
2014	10.6%
2015	11.7%

Southwest Power Pool (SPP)

Wind generation plays an increasingly large role in the generation portfolio of the Southwest Power Pool. The southwestern and north central areas of the SPP footprint have historically produced the majority of wind power (Avery, 2016), but now the Integrated System expansion has the potential to contribute additional wind power. As Avery states in the *SPP Wind Integration Study* in 2016, “Wind energy has grown over the last several years as additional bulk transmission has been added to the footprint and represented approximately 14% of total system capacity at the end of 2015” (Avery, 2016). The Southwest Power Pool experienced record wind generation levels on Feburary 17th, 2016 with 10,439 MW of wind online at that time. This represents a penetration level of 43.3% (Micek & Jackson, 2016).

Table 4. Wind Generation as a Percent of Load in the Southwest Power Pool. It should be noted that all numbers are prior to the expansion of the SPP (SPP Market Monitoring Unit, 2015).

Year	Avg Wind Generation as a Percent of Load	Max Wind Generation as a Percent of Load
2007	2.7%	9.0%
2008	3.6%	11.3%
2009	4.6%	15.4%
2010	5.1%	16.0%
2011	6.5%	20.1%
2012	8.3%	27.3%
2013	11.6%	33.6%
2014	12.0%	32.6%

The first wind integration report for their service territory was conducted in 2009. With the addition of the Integrated System, SPP decided another wind integration study would be beneficial to not only look at effects of wind, but set a baseline for years moving ahead. The evolution of the market structure in SPP, to be discussed in the Market Structure section of this paper, also necessitates a more recent wind integration study. The Southwest Power Pool recently published their 2015 Wind Integration Study, which analyzes scenarios looking at two seasons combined with three penetration levels of wind: 30%, 45%, and 60% (Avery, 2016). This report identifies particular areas of the service territory that may experience constraints at these high levels of wind generation.

Corporate PPAs in ERCOT and SPP

As we can see in Figure 9, Corporate PPAs installations on an annual basis have been somewhat similar, though 2014 was a significantly larger year for the ERCOT region. What is of most importance, though, is the cumulative MW value over time of both regions, which can be observed in Figure 10. During 2014, this is when the cumulative amount of installed wind capacity became a clear leader between the two RTOs. The data utilized to produce these graphs comes from the Business Renewables Center deal tracker, which details each recent corporate PPA, its size, and location.

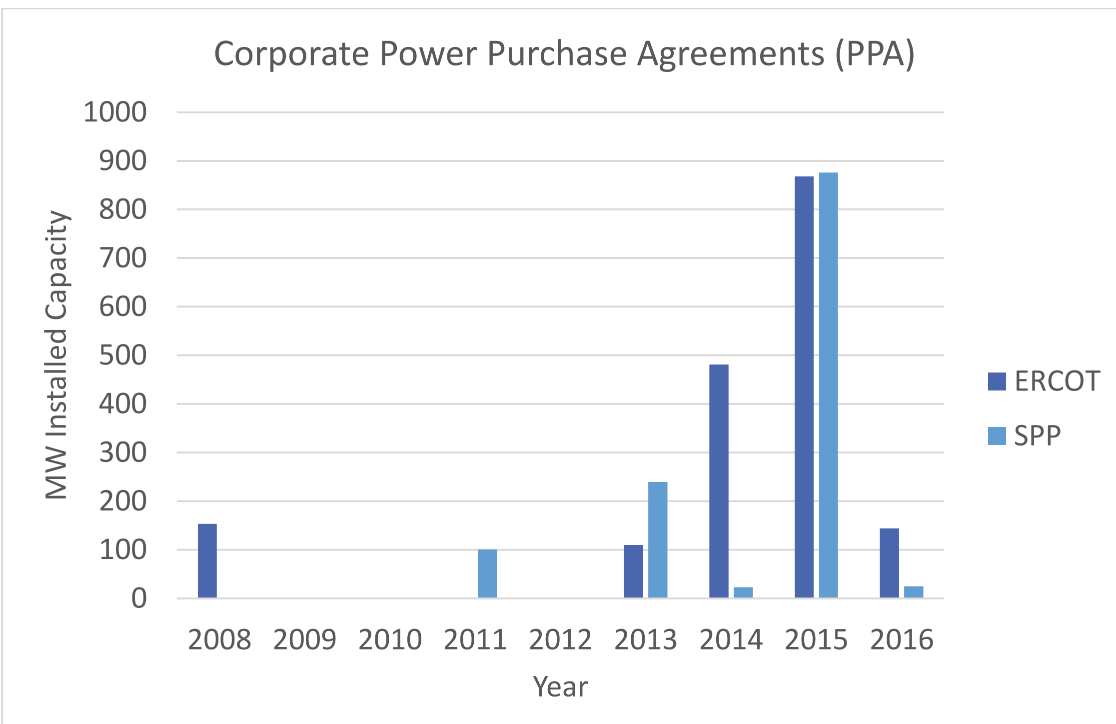

Figure 9. The megawatts (MW) of installed capacity across years of the ERCOT and SPP regions for Corporate Power Purchase Agreements (PPA) (Business Renewables Center, 2016).

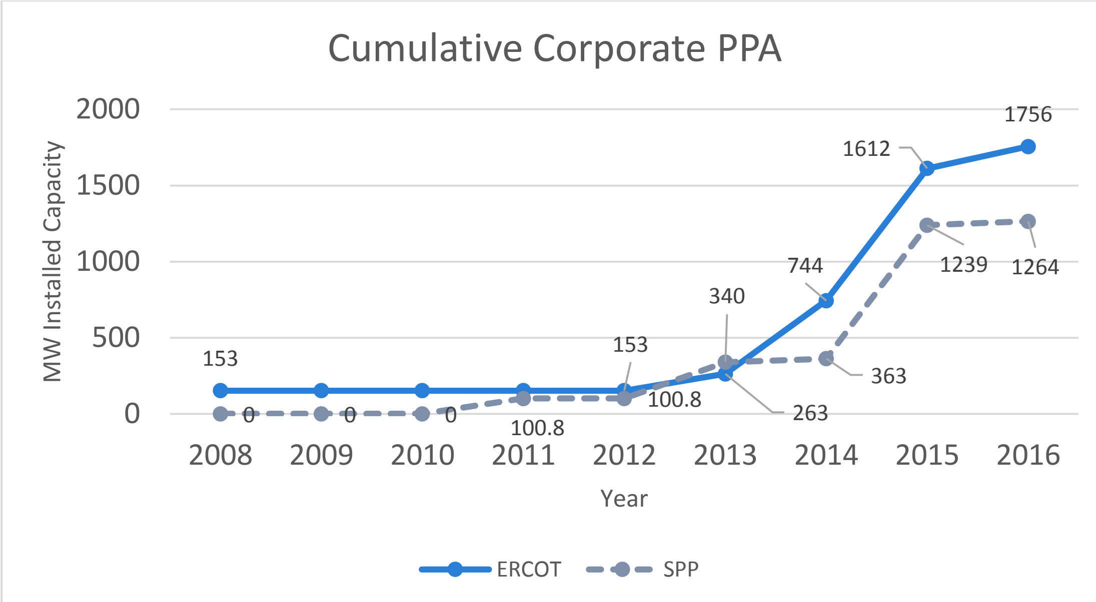

Figure 10. Cumulative Corporate PPA from 2008 until 2016 of the ERCOT and SPP regions (Business Renewables Center, 2016).

MARKET STRUCTURE

ERCOT and SPP have somewhat similar market structures, with both utilizing a nodal market structure. A nodal market structure is based on the utilization of Locational Marginal Prices (LMPs) associated with nodes across the region. In a nodal market, auctions establish everything, enabling the LMPs to vary across the thousands of nodes in a service territory. In this way, areas that have less transmission constraints can be incentivized for investment.

Both ERCOT and SPP utilize a day-ahead auction that allocates generation for each hour in the upcoming day. They also manage a real time market of smaller time increments that account for differences between the Day Ahead market and what is being produced or demanded in the next increment of time. The bid that generators would put into the day ahead or real time markets would incorporate the price and quantity of energy. The bid would be their marginal cost, which is defined as the cost from producing the next unit of energy. For fossil fuel generation, this is often the operation and fuel cost. For renewable generation, this marginal cost can be significantly lower due to the non-existent fuel cost. LMPs "…reflect the marginal costs of energy, congestion, and losses at any given pricing location in the market" (SPP Market Monitoring Unit, 2015).

Electric Reliability Council of Texas (ERCOT)

ERCOT transitioned from a zonal market to a nodal market in 2010, implementing a day-ahead and real time auction. A Congestion Revenue Rights auction is operated on an annual and monthly basis to allow stakeholders to hedge against congestion costs. ERCOT does not possess a capacity market, but functions purely as an energy marketplace. As a result, there is no incentive for energy suppliers to invest in reserve capacity to avoid generation shortages. Due to operating solely as an energy marketplace, wholesale market energy prices reach high levels during generation scarcity (Aniti, 2015). This operational approach is designed to motivate consumers to decrease demand during system emergencies, and in the long-term, encourage investment in additional generation. Unlike other markets, the cap on LMP prices is much higher in ERCOT at $9,000/MWh (Anderson, 2015).

Southwest Power Pool (SPP)

SPP implemented their "Integrated Marketplace" on March 1, 2014. Prior to the Integrated Marketplace, a real time market was in place that consisted of 16 balancing authorities in the RTO footprint (SPP Market Monitoring Unit, 2015). The new Integrated Marketplace combined these 16 balancing authorities into one SPP balancing authority. It also included a day-ahead market with transmission congestion rights, a real-time balancing market, congestion-hedging market, and reliability unit commitment.

> "This market expansion is the latest and most complex incremental step in SPP's evolutionary approach to adding market functionality that will coordinate next-day generation across the region to maximize cost-effectiveness, provide participants with greater access to reserve energy, improve regional balancing of electricity supply and demand and facilitate the integration of renewable resources" (SPP, 2015).

Phase II of the Integrated Marketplace, termed Project Pinnacle, was scheduled to go live in March of 2015. This project adds long-term congestion rights, market-to-market dispatch, and regulation compensation. The end goal for SPP with these market upgrades is to optimize the economics and reliability of the grid. As the SPP Market Monitoring Unit's (MMU) Annual State of the Market reports, "…the MMU emphasizes that economics and reliability are inseparable and that an efficient wholesale electricity market provides the greatest benefit to the end user both presently and in the years to come" (SPP Market Monitoring Unit, 2015). Similar to ERCOT, SPP does not possess a capacity market (Kuckro, 2014). A maximum LMP limitation could not be located for SPP, though should be researched in future studies.

Comparison and Implications

As we can see, both markets possess nodal markets and congestion rights structures. Their ancillary services are the same, with spinning reserves, regulation up and down, as well as supplemental reserves. Though ERCOT has more experience in operating these markets, due to the recent Integrated Marketplace implementation in SPP, they now possess similar market structures.

Frequency control, a common concern with wind integration, is handled differently in ERCOT and SPP. Though the details of frequency control are outside the scope of this research, the basic concept is demonstrated in Figure 11. We can see that if electricity demand is not correctly balanced with electricity generation, the frequency of the system will drop. Frequency control is required in ERCOT for wind generation that executes a Standard Generation Interconnection Agreement after January 1, 2010. There are no requirements in SPP for frequency response.

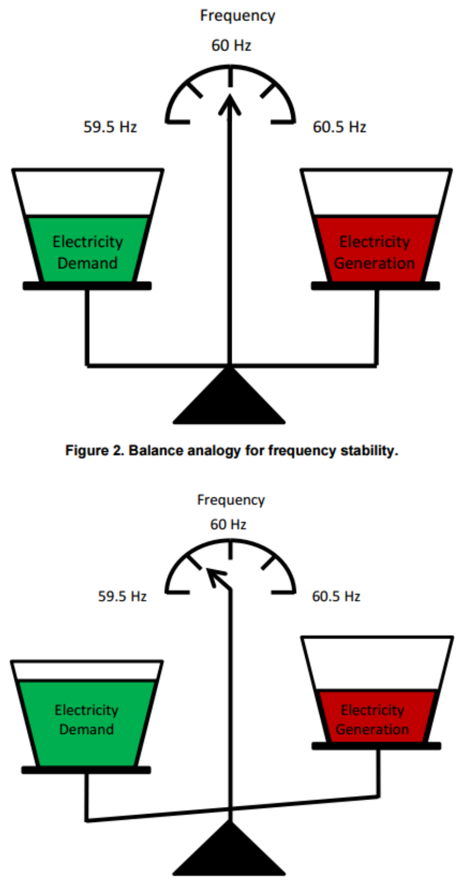

Figure 11. Frequency control visualization, showing the crucial balance needed on the electricity system. (Miller, Shao, Pajic, & D'Aquila, 2014).

Forecasting is one of the most crucial pieces of managing wind integration into a regional grid. If accurate wind forecasts can be provided, regional operators can "turn down" conventional generation when wind resources are expected to generate additional electricity. More accurate forecasts can also decrease the amount of curtailment, or lost wind generation, that occurs in a region. ERCOT has been utilizing wind forecasts since 2008, providing a separate ramping capability forecast update every 15 minutes. SPP has been utilizing wind forecasts since 2011, but does not have a separate ramping forecast. The 0-6 hour forecast in SPP predicts probabilistic ramping events.

FUTURE OF WIND INTEGRATION IN ERCOT AND THE SPP

Curtailment

Curtailment can occur when either the purchaser, owner, or transmission operator requires the wind generator to reduce or cease generation. As noted by Bird, Cochran, & Wang, "Curtailment is the reduction in the output of a generator from what it could otherwise produce given available resources, typically on an involuntary basis" (2014). Many times, the transmission operator has to curtail wind generation due to system constraints, such as transmission capacity limitations, local congestion, or excessive generation during low demand periods.

ELECTRIC RELIABILITY COUNCIL OF TEXAS (ERCOT)

In 2007, ERCOT experienced 1.2% of wind generation curtailment, but reached record levels of more than 17% by 2009, as demonstrated in Figure 12 (Wiser & Bolinger, 2015). The explosion of the wind generation market was part of the cause, as it can take as little as 6 months to put up a wind generation facility. In comparison, it can take more than 5 years to gain approval for routing and construction of new high-voltage transmission lines (Ackerman, 2012). More wind power generation was being put online than there was load in the area to utilize the electricity. To exacerbate the situation, excess electricity in the area was unable to be utilized at eastern population centers, due to limited transmission capacity. The curtailment experienced in 2009 by ERCOT is the largest amount of wind generation curtailment of any RTO/ISO experienced in the U.S. to date, as is demonstrated in Table 5. The closest that any other RTO has experienced would be the 2014 curtailment of 5.5 % in MISO.

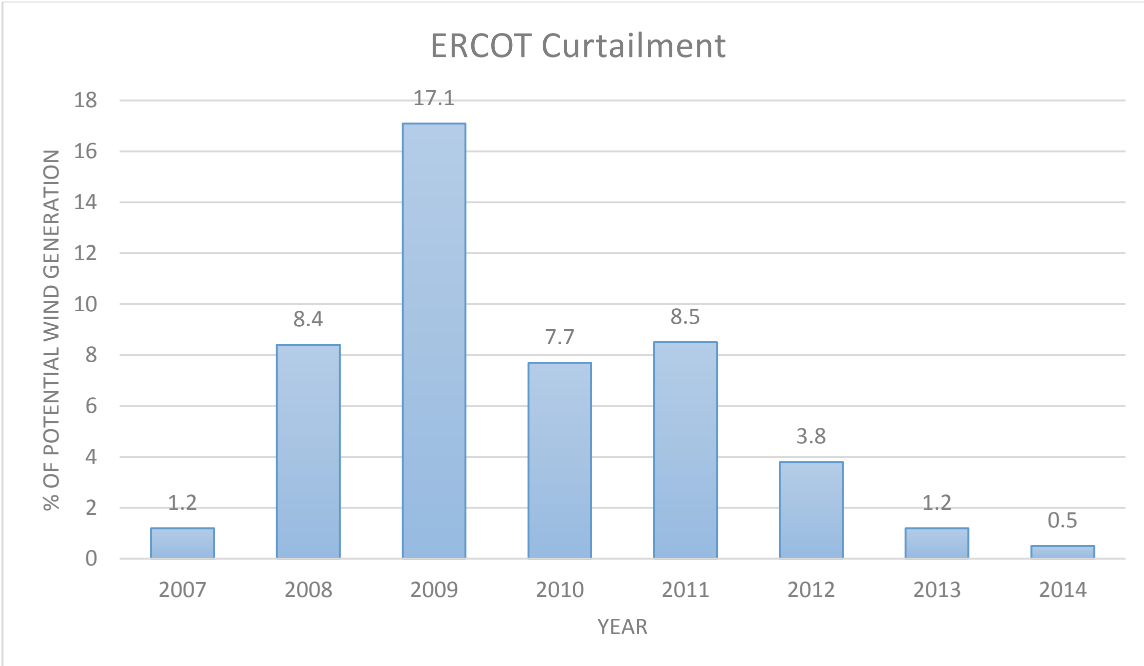

Figure 12. Percentage of potential wind generation that has been curtailed in the ERCOT market since 2009. This percentage represents the wind generation that could have been utilized, but was "turned off" due to multiple operational issues (LBNL Wind Technologies Report, 2014).

SOUTHWEST POWER POOL (SPP)

As we can see, SPP did not report curtailment percentages until 2014. The percentage shown below in Table 5 for 2014 only incorporates the time frame from March through December of that year. This is due to the implementation of the Integrated Marketplace in the SPP, which implemented new automatic curtailment methods. Prior to the Integrated Marketplace, the SPP utilized manual curtailment measures, which made it difficult to track percentages. As a result, data is only available for a shorter time frame than other RTOs shown below.

The SPP did look at curtailment percentages in detail in their 2015 Integrated Transmission Plan, analyzing the available months of 2014 data. They assessed the curtailment of all renewable units, noting any unit that experienced more than 3% curtailment (SPP Engineering, 2015). Only three wind farms from the entire service territory experienced greater than 3% curtailment, showing curtailment of 5.64%, 5.64%, and 6.91% (SPP Engineering, 2015). Each of these were examined in greater detail to alleviate this high level of curtailment. As a service territory, though, SPP fell well below their 3% margin for curtailment of wind generation.

Table 5. Estimated Wind Curtailment by Region as a Percentage of Potential Wind Generation (Wiser & Bolinger, 2015).

	2007	2008	2009	2010	2011	2012	2013	2014
ERCOT	1.20%	8.40%	17.10%	7.70%	8.50%	3.80%	1.20%	0.50%
MISO			1.90%	3.90%	3.20%	2.60%	4.70%	5.50%
BPA				0.10%	1.40%	0.70%	0.10%	
NYISO						0.30%	1.40%	0.70%
PJM						2.00%	1.90%	0.70%
ISO-NE								3.30%
SPP								0.70%
TOTAL SAMPLED	**1.20%**	**8.40%**	**11.10%**	**5.30%**	**5.40%**	**2.70%**	**2.50%**	**2.30%**

As was discussed by Bird, Cochran, and Wang, "Market solutions that base dispatch levels on economics offer the advantages of creating transparency and automation in curtailment procedures, which apply equally to all generators" (Bird, Cochran, Wang, 2014). Regional markets have the opportunity to utilize their structure to decrease curtailment, though constant evaluation of curtailment levels and continually improved protocols will be necessary.

Transmission Investment

The combination of significant installed wind capacity with insufficient transmission capacity can cause low cost generation to be lost, as this electricity cannot reach a load center where it could be utilized. It can also result in the additional need for curtailment. Transmission investment strategies differ among regions, though ERCOT has been noted for their success with the CREZ initiative.

ELECTRIC RELIABILITY COUNCIL OF TEXAS (ERCOT)

As discussed in the previous section, ERCOT has had significant issues with curtailment of wind energy due to constrained transmission capacity. In 2005, the Texas legislature put into motion the planning process that would identify the Competitive Renewable Energy Zones (CREZ) in Texas as prime targets for transmission investment and wind generation installation. Five regions were chosen for CREZ that would be comprised of 2,300 miles of new 345 kV transmission lines. Also included were plans for 28 new 345 kV substations. The estimate for this investment was around $5 billion. These 5 regions are shown below in Figure 13.

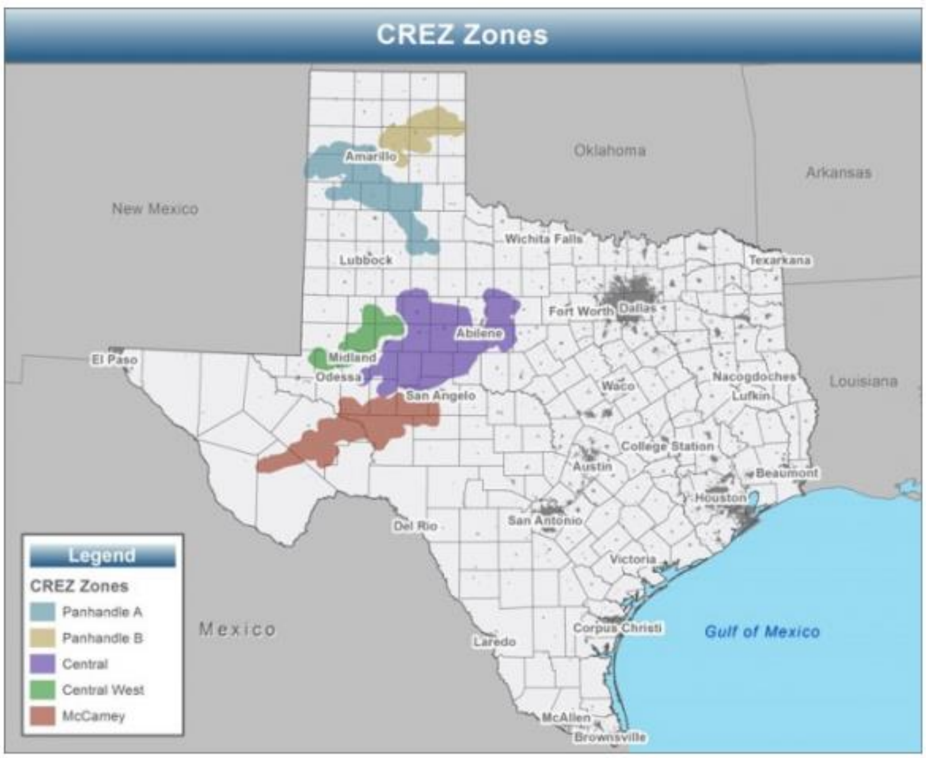

Figure 13. CREZ Zones established by the PUCT and ERCOT (Gimon, O'Boyle, & Aggarwal, 2015).

Eight different transmission providers were awarded portions of the projects. For many of these transmission providers, this represented one of the largest projects they had undertaken. One of these providers, American Electric Power (AEP), released a public statement identifying their portion of the

CREZ project as the “largest construction venture in AEP’s history” (American Electric Power, 2013). In 2013, as all elements of the project were close to completion, ERCOT reiterated the goals of the project:

> “The Electric Reliability Council of Texas (ERCOT), the system operator overseeing the project says that the CREZ enhancements were made with an eye toward reactive power that stabilizes voltage conditions on the grid, and the transmission projects are poised to alleviate curtailment and unlock congestion” (Del Franco, 2013).

The final system has the capability to transmit approximately 18.5 GW, with a final cost of $6.9 billion (Del Franco, 2015).

Did the transmission investment of the CREZ program solve all integration issues facing wind generation? Curtailment continues to occur in ERCOT, as we discussed earlier in Figure 12, though at much lower levels than previously encountered. The CREZ program can be identified as a large part of the reduction in curtailment, and along with that, a reduction in negative hourly West Hub prices, as we can see in Figure 14. Negative spot prices occur when excessive generation cannot be utilized by load centers and the electrical grid needs generators to decrease generation or go offline. This is an economic market result that is often accompanied by automatic curtailment. Though Figure 14 may look like the problem is becoming much less common, this may not last. Matt Mooren, an energy and utility advisor at PA Consulting Group, says that Texas is “at the point of wind generation where they are maxing out” capacity on the CREZ lines. “Negative pricing in the last six to nine months in the western zone is much more prevalent than it was in the prior six to nine months, and it’s because of wind penetration and wind quality levels” (Malik, Weber, 2016).

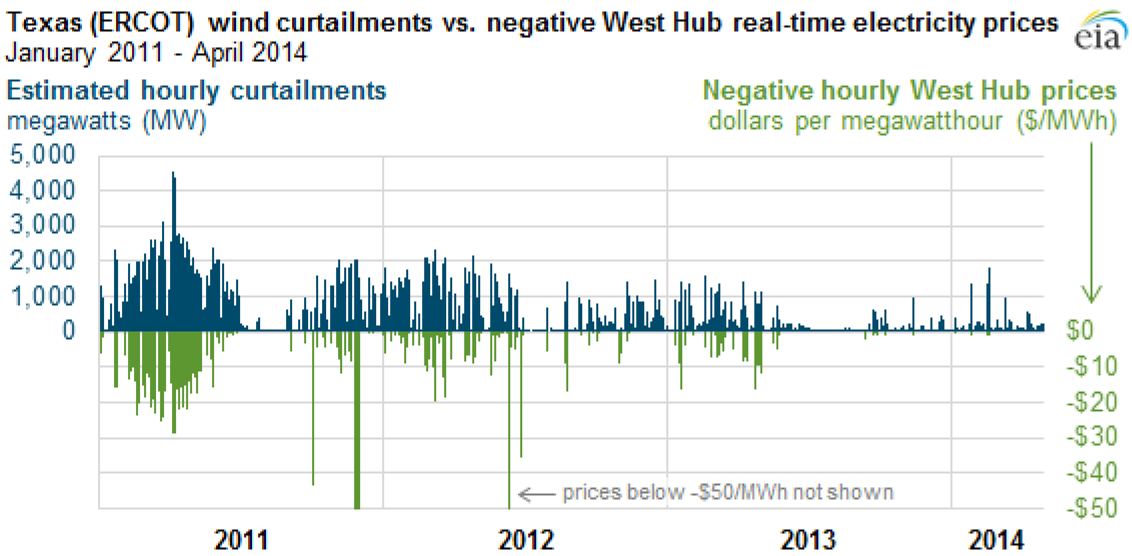

Figure 14. Curtailment and negative spot prices for ERCOT have decreased as a result of the Competitive Renewable Energy Zone Investment (Energy Information Administration, 2014).

SOUTHWEST POWER POOL (SPP)

As was previously discussed, LMPs not only reflect marginal costs of energy, but also reflect the congestion status for different areas of the grid. Historically, the SPP has encountered minor congestion issues due to transmission constraints. With the addition of the IS, the pricing patterns continue to change, posing new challenges and trends. The largest issue for the SPP is finding ways to utilize inexpensive coal resources and wind resources from the northern (recent IS expansion) and western regions of the SPP territory. Much of the challenge comes in the limited transmission capabilities between the northern and western regions and the eastern region, which possesses the majority of the load centers. This transmission limitation results in congestion factoring into a large LMP price differential between these areas of the SPP territory. "The challenge of moving inexpensive power from coal and wind resources out of the north and west of the SPP market footprint to the eastern load centers resulted in an average $20/MWh spread between the lowest and highest LMP points" (SPP Marketing Monitoring Unit, 2015).

Interconnection Requests

Interconnection Agreements are the permits that allow a generating unit to connect into the electrical system. In 2003, FERC issued Order 2003 that established standards for large generator interconnection, which are generators with a nameplate capacity greater than 20 MW (Porter, Fink, Mudd, & Decesaro, 2009). Many RTOs and ISOs have continued to refine and improve their interconnection processes, timelines, and queues, in spite of growing interest in additional generation. As stated by the Southwest Power Pool, the Interconnection Queue, "…provides a means for generation planners and developers to submit new generation interconnection projects into the Queue for validation, study, analysis and, ultimately, execution of a Generation Interconnection Agreement" (Southwest Power Pool, 2015e).

When utilizing the SPP Interconnection Queue data, multiple alterations were made to the data. When generators were designated as CT, we assumed that this "Combustion Turbine" signified natural gas as the fuel source. When steam turbines were identified, we assumed coal would be utilized as a fuel source. For the SPP Queue, we used the "In-Service Date" as opposed to the "Commercial Operation Date" as the determinant for its integration into the grid in the future. For ERCOT interconnection queue data, we utilized the "Projected Date", scrubbing out all completed projects.

Approximately 11,002 MW of the total 26,324 MW in the ERCOT Interconnection Queue is potential wind capacity, representing 42% of the Interconnection Queue (ERCOT, 2016). The level of wind generation in the SPP has the potential to increase dramatically, as wind generation makes up a very 15,775 MW of the 21,240 MW of generation in the interconnection queue (Southwest Power Pool, 2016b). This is 74% of all MW of generation that are proposed for interconnection in the Southwest Power Pool, as is shown in Figure 15. Additional research should be done into how each RTO allocates the cost for interconnection and any associated transmission upgrades and investment, as that is outside the scope of this study.

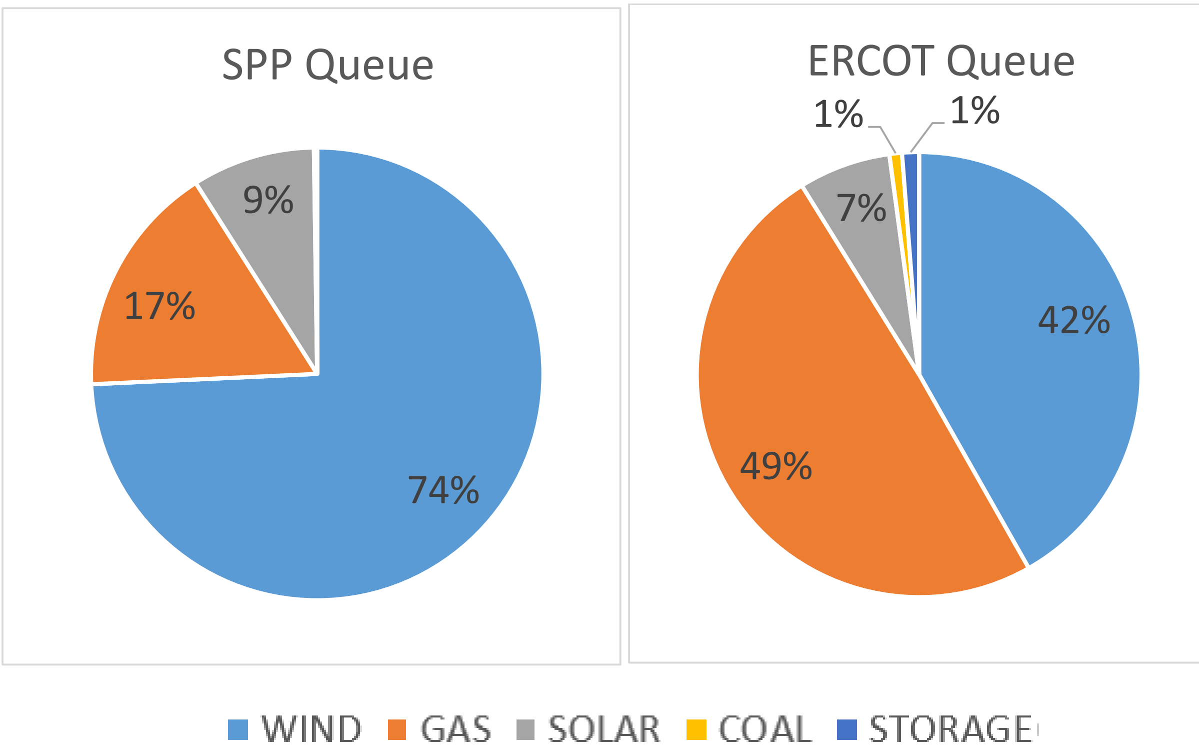

Figure 15. Interconnection Queue percentages by generation source between SPP and ERCOT. All projects within this data set have an In-Service Date later than April 4, 2016 (Southwest Power Pool, 2016b; ERCOT, 2016).

IMPLICATIONS FOR CORPORATE POWER PURCHASE AGREEMENTS

Wind generation has been, and will continue to be, a prominent resource for electricity generation. As we have shown the wind resource profiles between ERCOT and SPP are somewhat similar, with SPP having even stronger resources over a larger area. With the recent expansion of SPP, opportunities for increasing wind generation are apparent when looking at the wind resource available in this region. With this said, transmission mileage within SPP is only 1.5 times more than that of ERCOT, while covering almost 3 times more square miles. This could produce future transmission concerns, due to similar population gradients from west to east across these service territories. Both ERCOT and SPP have acquired similar installed capacity from Corporate PPA off-takers. With this said, there will be significant opportunity in SPP for additional corporate off-take as developers begin to utilize the expansion of the wholesale market.

Curtailment levels in ERCOT have been a concern for corporations looking for renewable energy, as this can alter their financial projections for generation of their asset. As additional wind generation is installed in ERCOT, if the amount of available capacity on transmission lines becomes saturated, this may affect the financial implications of existing off-take agreements. Diversity across regions is key to any corporate PPA initiative, as transmission constraints and curtailment can change over time. In the future, it will make sense for corporations to pursue PPAs in both markets, utilizing the strong wind resource potential, as well as the regional wholesale market structure.

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