Unlocking the Queue with Grid-Enhancing Technologies

CASE STUDY OF THE SOUTHWEST POWER POOL
FINAL REPORT – PUBLIC VERSION

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Brattle

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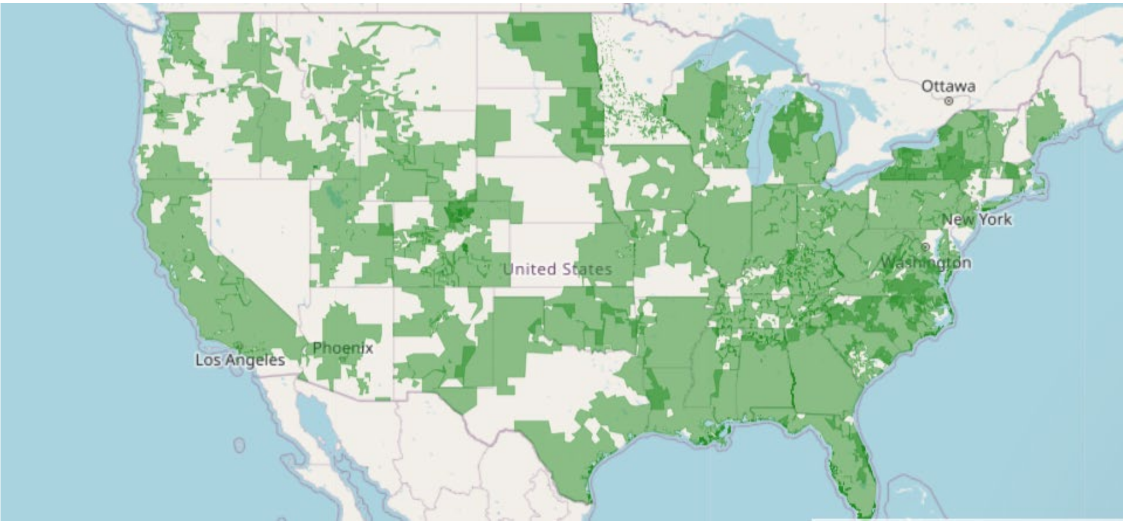
Issue at Hand - 1/2

Increasing renewable resources (often associated with carbon reduction) is a common goal.

- Many private entities including utilities, corporations, and academic institutes.
- Across jurisdictions from federal, state, to local (e.g., cities) levels.
- Increasing renewable projects provide jobs and other local benefits, and help boost the economy out from the current COVID-associated downturn.

Service Territories of Utilities With Announced Carbon Reduction Goals



Source: from Smart Electric Power Alliance Utility Carbon Reduction Tracker (Feb 2021)

Issue at Hand - 2/2

What are the roadblocks to integrating more renewables?

- Utilities and system operators have good understandings of the variability of renewable resources.
  - Wind became SPP's leading resource in 2020.
- Transmission availability is a major limiting factor.
  - Many renewable projects are locked up in the Generation Interconnection Queue.
  - There is a timing gap: renewables are developed (in months to years) much faster than transmission (in years to sometimes decades).
  - Utility-scale renewables are usually more cost efficient (on a $/MWh basis) compared to distributed resources.

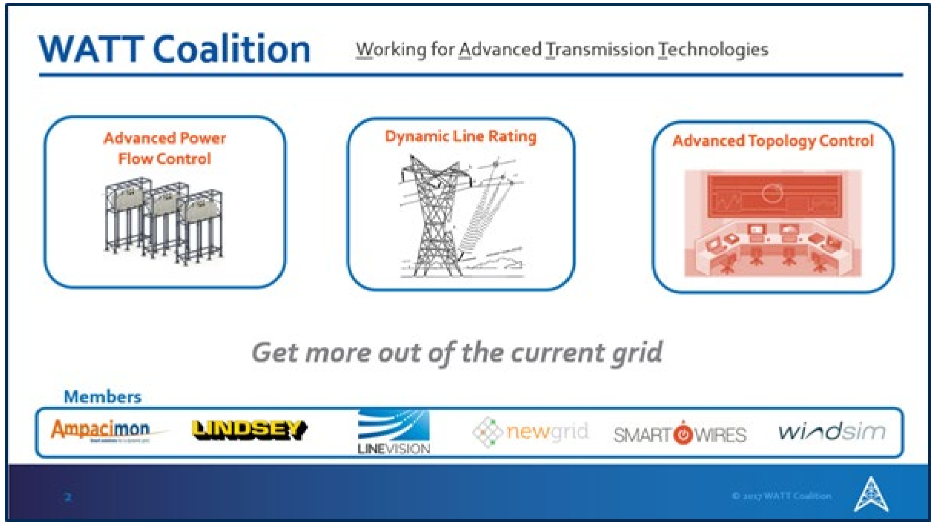
Can Grid-Enhancing Technologies (GETs) help integrate more renewables?

- GETs quickly and cost-effectively help maximize the capability of the existing transmission system

Study Overview - 1/2

Goal: Analyze how much additional renewables can be added to the grid using Grid-Enhancing Technologies (GETs):

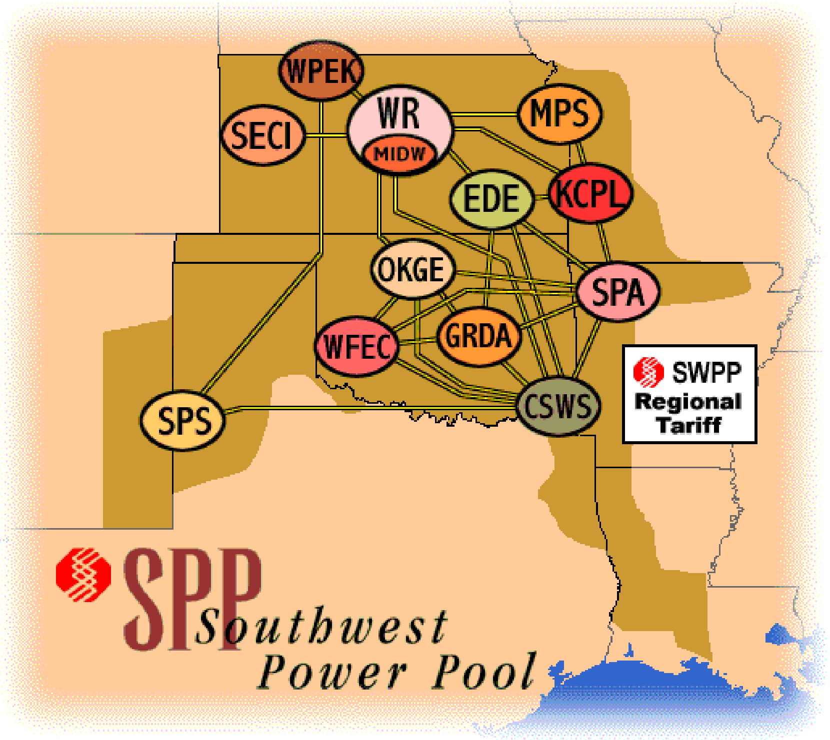
- GETs enhance transmission operations and planning.
- GETs complement building new transmission—they can bridge the timing gap until permanent expansion solutions can be put in place.
- While there are various types of GETs, this study focuses on the combined impact of the following three technologies:
  - **Advanced Power Flow Control**: Injects voltage in series with a facility to increase or decrease effective reactance, thereby pushing power off overloaded facilities or pulling power on to under-utilized facilities.
  - **Dynamic Line Ratings (DLR)**: Adjusts thermal ratings based on actual weather conditions including, at a minimum, ambient temperature and wind, in conjunction with real-time monitoring of resulting line behavior.
  - **Topology Optimization**: Automatically finds reconfiguration to re-route flow around congested or overloaded facilities while meeting reliability criteria.



Study Overview - 2/2

Goal: Analyze how much additional renewables can be added to the grid using Grid-Enhancing Technologies (GETs):

- Use the Southwest Power Pool (SPP) grid (focused on Kansas and Oklahoma, looking at 2025) as an illustrative case study.
  - SPP Generation Interconnection Queue* (GI Queue) shows ~9 GW of renewable resources with an Interconnection Agreement (IA) executed in Kansas and Oklahoma.
  - SPP Integrated Transmission Planning (ITP) Reports** show high congestion.
- Results metrics for the **combined** (not for individual) three GETs include:
  - Renewables added (capacity [GW] and energy [GWh]).
  - Economic benefits (production costs, investments, jobs, etc.)
  - Carbon emissions reduction.



SPP figure from http://opsportal.spp.org/Images/SPPMap.gif
* SPP GI Queue as of September 28, 2020
** 2019 Integrated Transmission Planning (available at: https://spp.org/Documents/60937/2019%20ITP%20Report_v1.0.pdf) and Q3 2020 Quarterly Project Tracking Report (available at: https://www.spp.org/documents/62710/q3%202020%20qpt%20report%20draft.pdf)

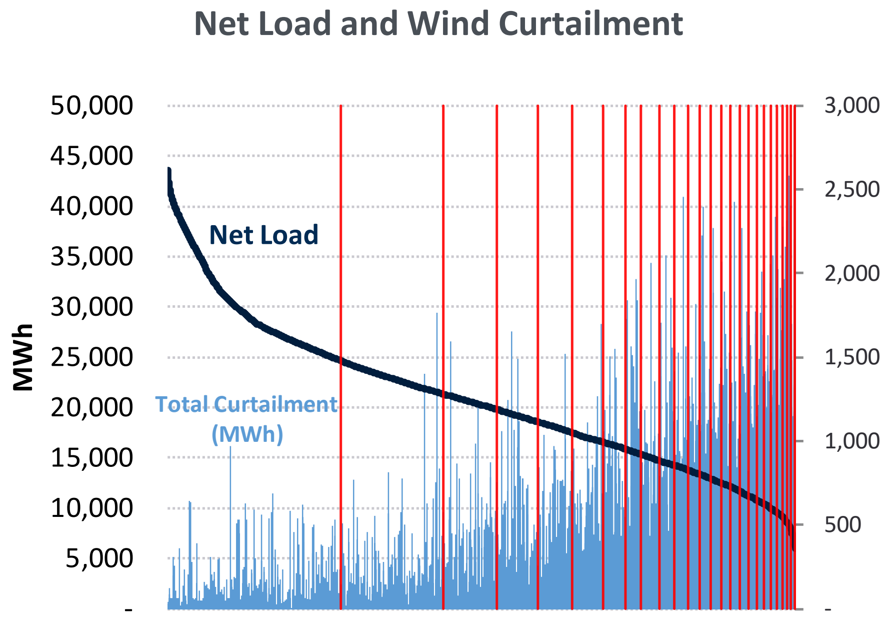
Study Approach - 1/2

Study purpose

- Quantify the benefits of **the three GETs combined** for integrating renewable resources (largely wind) using SPP as a test bed.

Analysis approach

- Select 24 representative historical power flow snapshots of SPP operations (2019 – 2020) that together reasonably represent a full year.
- Modify the snapshots to reflect new transmission upgrades, renewable projects from the GI queue, announced retirements, load change, etc.
- Find the maximum renewables amount (GW and GWh) that can be integrated under a business as usual scenario (Base Case) and then with GETs (With GETs Case), sequentially in the order of DLR, Topology Optimization, and Advanced Power Flow Control, by simulating the entire SPP system using the 24 power flow cases.
- Assess benefits of GETs including economic values (production costs, jobs, local benefits etc.) and carbon emissions reduction.



Areas between red line indicates the bins from which snapshots were selected, blue bars indicate curtailment of renewables. Each bin contains equal amounts of curtailment.

Study Approach - 2/2

Study purpose

- Quantify the benefits of **the three GETs combined** for integrating renewable resources (largely wind) using SPP as a test bed.

Finding the maximum amount of renewables that can be integrated

- Analysis is performed separately for the Base Case and With GETs Case for all 24 snapshots.
- Analysis is done using an iterative process:
  - Determine feasible reduction in thermal unit generation to accommodate additional renewable resources.
  - Dispatch wind and solar to their max output by running Security Constrained Optimal Power Flow (SCOPF).
  - Iteratively solve SCOPF (i.e., solve SCOPF, take out renewable projects with high curtailments, then resolve SCOPF, and repeat).
- Analysis assumes a 5% curtailment threshold for viability assessment (i.e., projects are viable if analysis indicates annual curtailments to be less than 5%).
  - Curtailment occurs largely for two reasons—transmission congestion (which the GETs will help solve) and minimum generation constraints of other generation resources.

Study Results - 1/5

GETs enable more than twice the amount of additional new renewables to be integrated.

- Potential Renewables Considered: 9,430 MW
  - Based on queue projects with IA executed.
- Integrated Renewables (without further transmission upgrades)
  - Base Case: 2,580 MW
  - With GETs Case: 5,250 MW
  - Delta (With GETs Case – Base Case): 2,670 MW

RENEWABLE POTENTIAL ASSUMED FOR KANSAS AND OKLAHOMA

State	Wind	Solar	Total
Kansas	3,410	120	3,530
Oklahoma	5,760	140	5,900
Total	9,170	260	9,430

[Rounded to the nearest 10 MW]

~1.5 times the amount of wind SPP integrated in 2019 (1.8 GW).

ADDITIONAL RENEWABLES INTEGRATED

State	Base Case			With GETs Case			Delta (GETs - Base)		
	Wind	Solar	Total	Wind	Solar	Total	Wind	Solar	Total
Kansas	1,710	0	1,710	1,910	0	1,910	200	0	200
Oklahoma	770	100	870	3,200	140	3,340	2,430	40	2,470
Total	2,480	100	2,580	5,110	140	5,250	2,630	40	2,670

X2

[Rounded to the nearest 10 MW]

Study Results - 2/5

GETs enable more than twice the amount of additional new renewables to be integrated.

- Additional renewables enabled by GETs: **2,670 MW / 8,776 GWh**.
  - 2,630 MW of **new wind** is assumed to produce over 8,640 GWh of energy per year.
  - 40 MW of **new solar** is assumed to produce about 60 GWh of energy per year.
  - GETs lower curtailment of **existing wind** by over 76,000 MWh per year.
- GETs installation cost is about $90 million.
  - Annual O&M costs is estimated to be around $10 million.
- GETs benefits (other than the value of additional renewables) include:

Additional Renewables enabled by GETs
2,670 MW / 8,776 GWh

ANNUAL PRODUCTION COST SAVINGS
$175 million

ANNUAL REDUCED CARBON EMISSIONS
3 million tons

LOCAL JOBS
650 long-term jobs and
11,300 short-term jobs

OTHER LOCAL BENEFITS
$15 million land lease and
$32 million tax revenues per year

Study Results - 3/5

GETs enable more than twice the amount of additional new renewables to be integrated.

- Estimated annual production cost savings: **$175 million**.
  - Pay-back for GETs investment (~$90 million) is about half a year.
  - $175 million conservatively assumes $20/MWh savings for 8,776 GWh of energy.
  - $20/MWh is at the lower end of the generation cost of a new natural gas-fueled combined cycle plant or coal plant and lower than average 2019 LMP (both day-ahead and real-time).
- Estimated job benefits associated with the increased renewables (2,670 MW):
  - Over 11,300 direct short-term jobs (largely construction of renewables).
  - Over 650 direct long-term jobs for operation and maintenance of the renewable resources.
- Estimated carbon emissions reduction: **Over 3 million tons per year.**
  - Conservatively assumes the renewables replace carbon emissions from natural gas-fueled combined cycle plants.
  - Less efficient resources with higher heat rates and emission rates are more likely to be replaced.
- Other estimated benefits include:
  - Local benefits estimated to be over $32 million annual tax revenues and $15 million land lease revenues (based on literature research).

Study Results - 4/5

Key benefits of GETs for Kansas and Oklahoma

- Enable more than **twice** the amount of additional new renewables to be integrated.
  - This is 1.5x the amount of wind SPP integrated in 2019.
- Estimated annual production cost savings: $175 million.
  - Payback for GETs investment is about 0.5 years.
- Estimated carbon emissions reduction: Over 3 million tons per year.
- Over 11,300 direct short-term and 650 direct long-term jobs.
- Over $32 million annual tax revenues and $15 million land lease revenues.

Potential Nation-Wide Benefits

Extrapolating these results to a nation-wide level* indicate GETs to provide **annual benefits** in the range of:

- Over **$5 billion** (~$5.3 billion) in production cost savings.
- **$90 million tons** of reduced carbon emission (more than enough to offset **ALL NEW** automobiles sold in the U.S. a year).
- About **$1.5 billion** in local benefits (local taxes and land lease revenues).
- More than 330,000 short-term (only for first year) and nearly 20,000 long-term jobs.
- Investment cost is $2.7 billion (only for first year). Ongoing costs would be around $300 million per year.

* EIA shows 2019 generation in Kansas and Oklahoma combined (136 TWh) was about 1/30 of the nationwide generation from utility-scale resources (4,100 TWh). EIA data, available at: https://www.eia.gov/electricity/state/kansas/, https://www.eia.gov/electricity/state/oklahoma/, and https://www.eia.gov/electricity/annual/html/epa_01_01.html

Study Results - 5/5

GETs utilized in this study include:

- **Hardware solutions**: DLR on 56 lines and Advanced Power Flow Control on 8 locations.

Hardware Solutions by Voltage Level	345	230	161	138	115	69	Total
DLR*	10	3	11	22	3	7	56
Advanced Power Flow Control	3	0	4	1	0	0	8

- **Software solutions**: 204 unique Topology Optimization reconfigurations, averaging 13 per snapshot.**

Software Solutions by Voltage Level	345	230	161	138	115	69	Total
Lines	20	10	31	75	4	30	170
Substations	4	0	1	1	0	0	6
Transformers (high voltage terminal)	10	1	4	13	0	0	28

- Estimated costs for implementing the above GETs: ~$90 million.
  - Initial investment costs is estimated to be around $90 million.***
  - Ongoing costs of around $10 million per year.***

* Every DLR installation requires 15 to 30 sensors.

** Average actions represent the average number of actions that remain per case, not actions per hour. Based on other studies the average number of actions per hour is expected to be smaller, typically less than the number of topology changes due to planned outages.

*** Costs can vary project by project, and also on how the GETs service is provided—for example, Topology Optimization can be provided as a software subscription service to reduce the initial cost. We also assume utilities can incorporate these technologies without large costs.

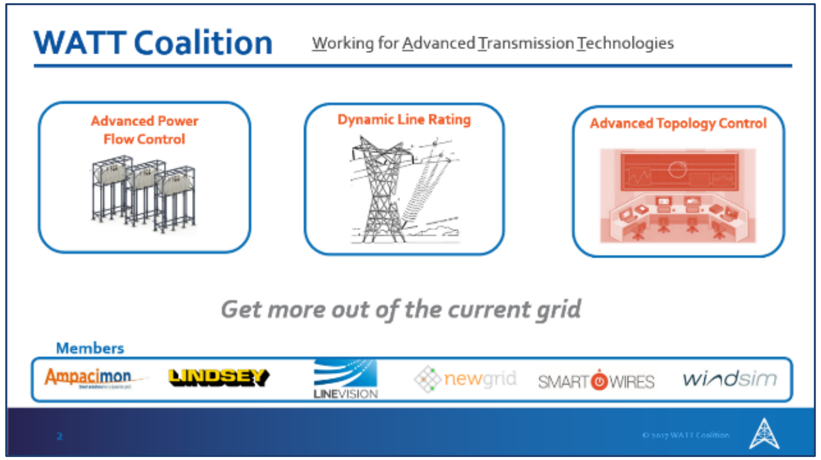
Table of Contents

Table of Contents

Study Scope and Purpose

Study purpose

- Analyze how much additional renewables can be added to the grid using three GETs:
  - Advanced Power Flow Control
  - Dynamic Line Ratings (DLR)
  - Topology Optimization



Study scope

- Use the Southwest Power Pool (SPP) grid with the focus on **Kansas and Oklahoma** looking at 2025 as an illustrative case study.
  - SPP Generation Interconnection Queue* shows ~9 GW of renewable resources with Interconnection Agreements executed.
  - SPP Integrated Transmission Planning (ITP) reports** shows high congestion.
- Results metrics for the **combined** (not for individual)*** GETs include:
  - Renewables added (capacity [GW] and energy [GWh]).
  - Economic benefits (production costs, jobs, local benefits, etc.)
  - Carbon emissions reduction.

* SPP GI Queue as of September 28, 2020.

** 2019 Integrated Transmission Planning (available at: https://spp.org/Documents/60937/2019%20ITP%20Report_v1.0.pdf) and Q3 2020 Quarterly Project Tracking Report (available at: https://www.spp.org/documents/62710/q3%202020%20qpt%20report%20draft.pdf)

*** This is because the order of analysis matters—being the first GETs to be analyzed will likely show more benefits than being the last.

GETs – Introduction

Traditional thinking treated transmission as if it is fixed and cannot be operated dynamically.

- Transmission has a fixed capacity, much like roads or railways do (e.g., the number of cars or trains that can go through at any given time).
- Advancements in maps and GPS technology have allowed for safer, easier and more efficient driving on the same roads and railways.
- Are there similar technologies that allow for such innovation in transmission **operations** (and planning)?

GETs enhance transmission operations and planning.

- GETs considered in this study: DLR, Topology Optimization, and Advanced Power Flow Control.
- These technologies have matured over the past several decades, are commercially proven and **actively operating** on grids around the world.
- They **focus on operational improvements** and have a much lower cost and faster implementation than traditional transmission technologies.
  - Similar to the comparison between building a road to reduce congestion (long-term investment) and having a good map/GPS system to avoid congested roads (operational improvements).

Dynamic Line Ratings - 1/2

Historical practice was largely based on Static Line Ratings (SLR).

- Maximum operating temperature for a given line is pre-determined.
  - Uses conservative assumptions, such as low wind, high temperature, high solar irradiance, etc., to accommodate most conditions.
  - It is similar to setting highway speed limit based on snowy road conditions.
  - Recently more transmission operators have adopted ambient adjusted rating (AAR).

DLR enhances AAR further and utilize real-time data.

- Commonalities between SLR, AAR, and DLR.
  - Minimum allowable electrical clearance is the same.
- Differences between SLR, AAR, and DLR.
  - SLR applies uniform weather conditions to all lines and is generally lower than AAR and DLR that applies line-specific conditions.
  - AAR requires line-specific data and ambient temperature, but has a ≥ 15% risk of exceeding electrical clearance limitations (as commonly implemented in the U.S.)*
  - DLR requires line-specific data in conjunction with real-time monitoring of ambient temperature, wind and conductor position, and can provide forecasts for operations planning.*

* Post-Technical Conference Comments of the WATT Coalition, November 2019, available at: https://watttransmission.files.wordpress.com/2019/11/post-technical-conference-of-the-watt-coalition.pdf, pp 2-5.

Dynamic Line Ratings - 2/2

DLR adjust limits based on ambient conditions.

- Thermal ratings use real-time measurements the line location (along line corridor).
  - Line temperature, line sagging, ambient conditions (temperature, humidity, solar irradiance, wind, precipitation etc.).
  - DOE/ONCOR study indicates DLR transfer capability to be 5 to 25% higher than SLR.
- Accumulation of real-time data can be used for future calibration.
  - DLR is variable and requires a forecast for operations planning.
- High wind leads to higher cooling and allows for increased flow.
  - High degree of overlap between wind production and DLR-induced allowable flow increase has been observed.
  - European studies indicate DLR contributes to approximately 15% reduction in wind curtailments in some areas.

Advanced Power Flow Control - 1/2

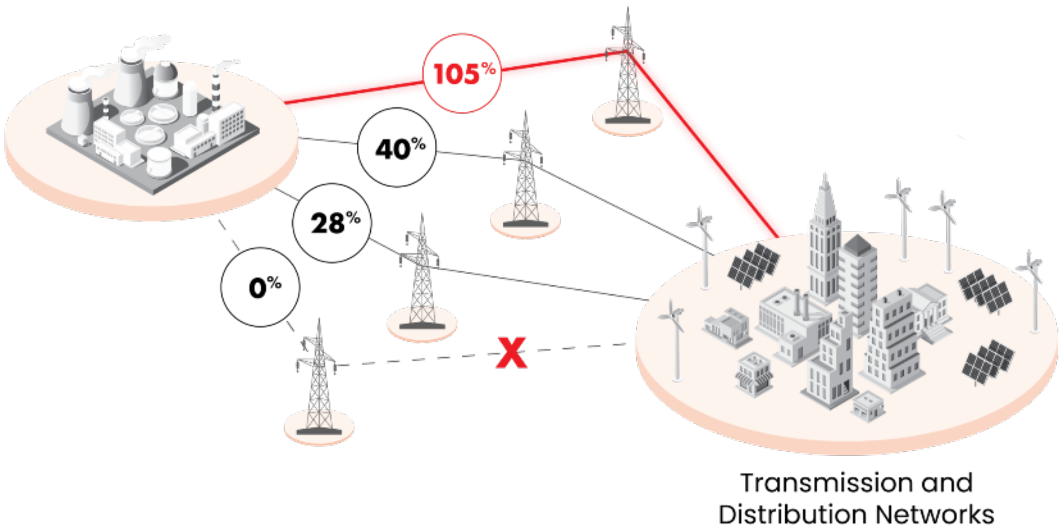
Phase Shifting Transformers (PSTs)[*] and Flexible Alternating Current Transmission Systems (FACTS) devices help the operator control flow through a given path.

- These devices are widely accepted in the industry.
  - The largest drawback is the cost—for example, a recently-installed PAR[*] between Michigan and Ontario has an annual carrying cost of over $10 million.
- FACTS devices are power-electronic-based static devices that allow for flexible and dynamic control of flow on transmission lines or the voltage of the system.
  - Some FACTS devices alter the reactance of a line to control the flow (i.e., increasing the reactance will push away flows while decreasing the reactance will pull in more flow to the line).
  - FACTs devices typically cost less than PARs, can be manufactured and installed in a shorter time, are scalable, and in many cases, are available in mobile form that can be easily deployed (or redeployed, as needed) while providing flexible layout options.

* Phase Shifting Transformers are also called Phase Angle Regulators (PARs).

Advanced Power Flow Control - 2/2

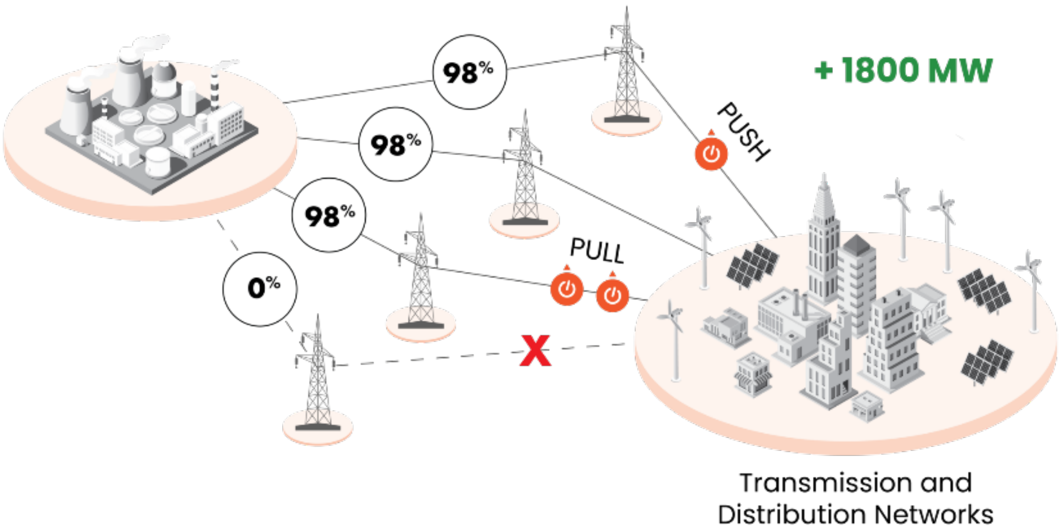
Before FACTS Device*



Traditional solutions include:

1. Redispatch generation
2. Reconductor constraining element
3. Install PSTs/Series Capacitor/Series Reactor
4. Construct a new parallel circuit

After FACTS Device



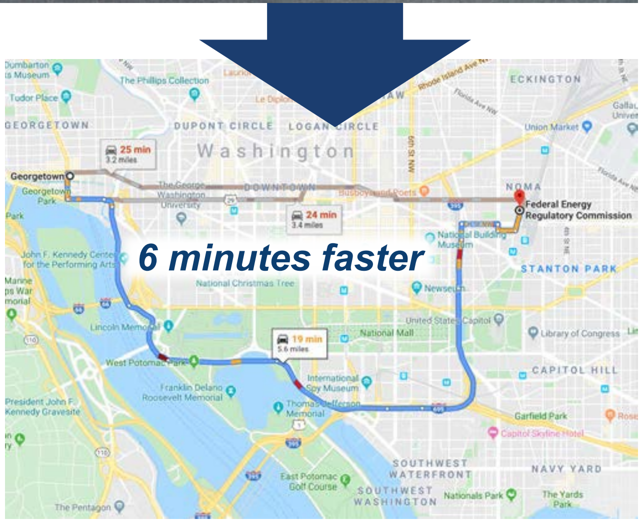
Power can be **PUSHED** and **PULLED** to alternate lines with spare capacity—leading to maximum utilization (typically obtained by a number of small applications on more than one circuit.)

* Illustrative example from Smart Wires, https://www.smartwires.com/smartvalve/

Topology Optimization - 1/2

Topology Optimization is analogous to Waze: “Arrive to destination reliably, with minimum delay even when there are events on the road” by re-routing.

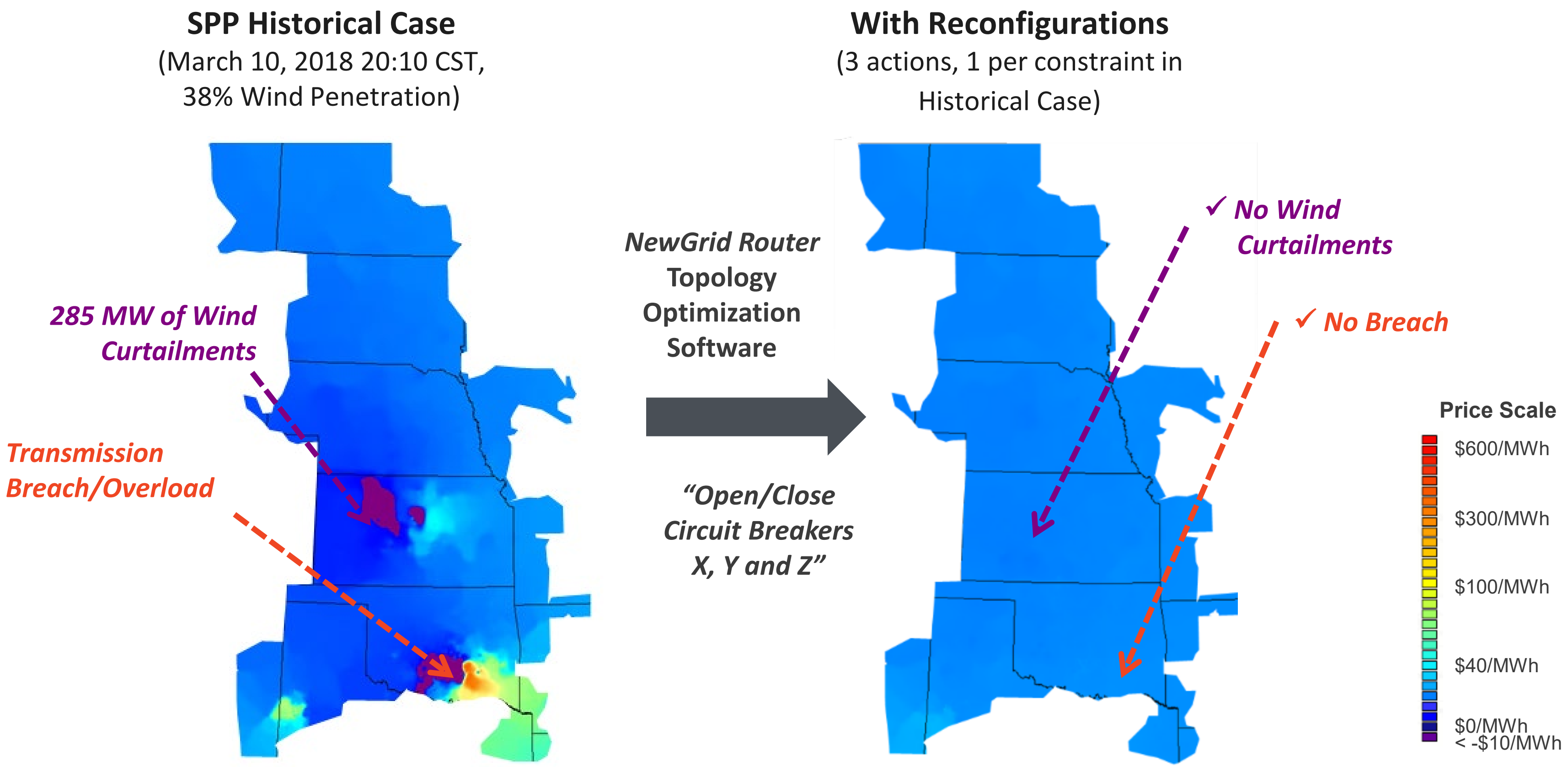
- Re-routing is achieved by grid reconfigurations: switching circuit breakers open or close.
  - Analogous to temporarily diverting traffic away from congested roads to make traffic smoother.
  - Similar effect as advanced flow control devices, using existing equipment.
- Reconfiguring the grid in operations is feasible today.
  - Circuit breakers are capable of high duty cycles and extremely reliable—some breakers are switched very frequently today, e.g., those connecting generating units with daily start and stop operations.
  - Switching infrastructure is already in place—most breakers are controlled remotely over SCADA by the TO.
  - Low cost: usually $10-$100 per switching cycle.



Road closure picture from https://www.islandecho.co.uk/plea-motorists-heed-road

Topology Optimization - 2/2

Topology Optimization software technology automatically finds reconfigurations to route flow around congested elements ("Waze for the transmission grid").

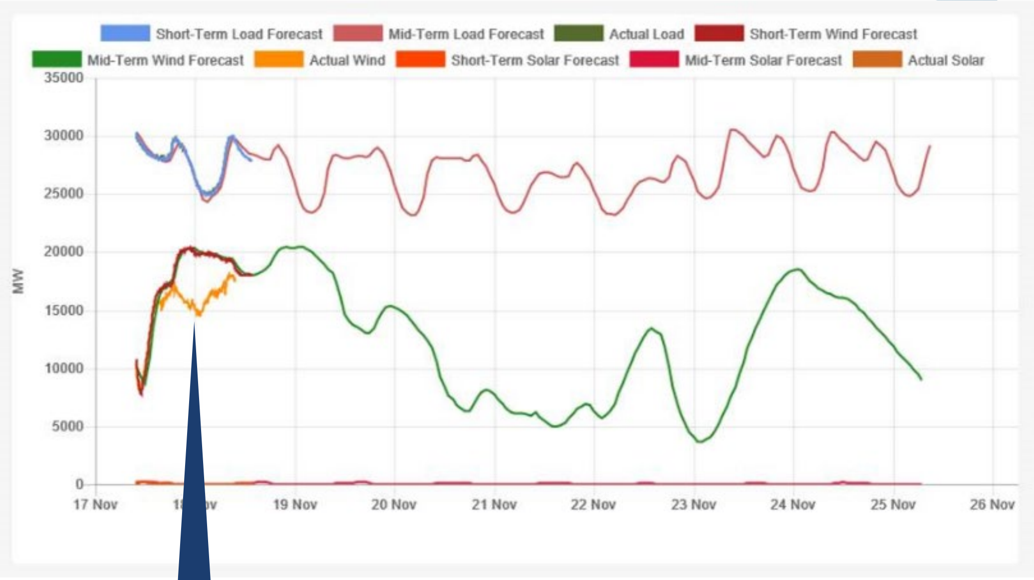


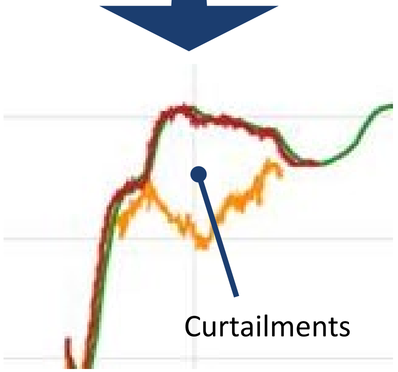
Why GETs?

GETs enhance transmission operations and planning.

- GETs **focus on operational improvements** and can be implemented quicker and at a lower cost than traditional transmission technologies.
  - Similar to the comparison between building a road to reduce congestion (long-term investment) and having a good map/GPS system to avoid congested roads (operational improvements).
- SPP operations data shows renewable curtailments likely caused by transmission congestion (indicated by transmission shadow prices).

SPP REAL-TIME MARKET DATA SNAPSHOT FROM NOVEMBER 18, 2020





Actual wind production (shown in yellow) is lower than forecasts. Wind (and load) forecasts for both the short- and mid-term trend are over each other, indicating that the reduced wind production is likely due to curtailments.

Table of Contents

Study Objective, Approach, and Steps

Overall study objective

- Quantify the combined benefits of three GETs for integrating renewables:
  - For a future year 2025.
  - For a select area within SPP.
  - Using 24 representative snapshots (power flow cases) to represent a full year.

Analysis approach and steps

Step 1: **Identify preferred area** for analysis.

Step 2: **Select 24 representative snapshots** from SPP operational power flow cases.

Step 3: **Modify the snapshots** to reflect new transmission upgrades, renewable plants from the generation interconnection queue, announced retirements, etc.

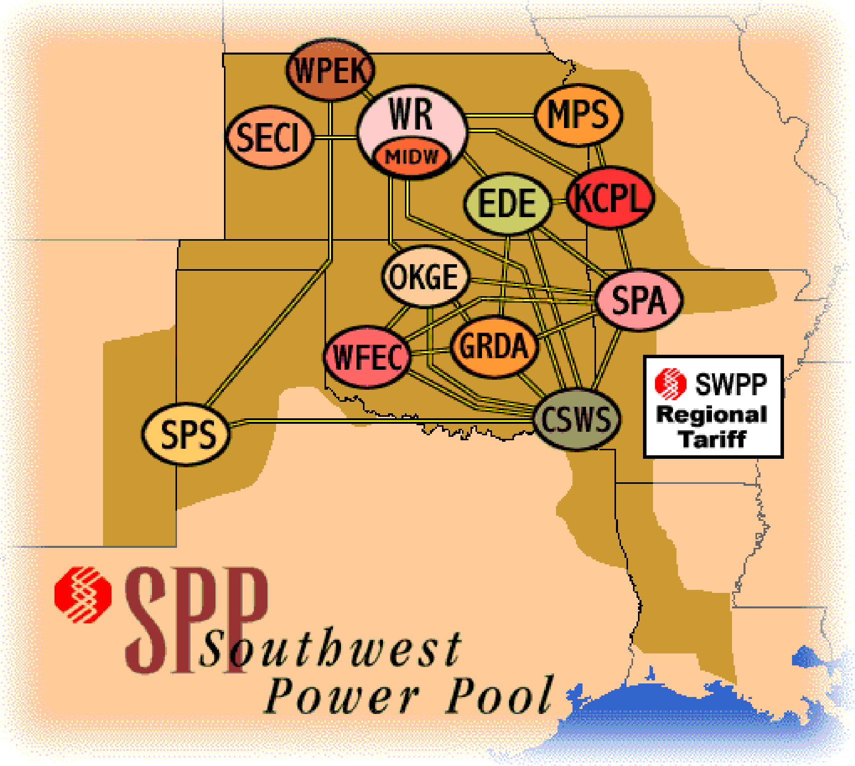
Step 4: **Find the maximum amount of renewables** that can be integrated under a business as usual scenario (Base Case) and then with GETs (With GETs Case) in the order of DLR, Topology Optimization, Advanced Power Flow Control. This will be done by solving the power flow cases (for the entire SPP footprint) prepared in Step 3, with and without GETs.

Step 5: **Assess benefits** including economic values (production cost savings, job creation, local benefits, etc.) and carbon emissions reduction.

Step 1: Identify Preferred Areas - 1/4

Step 1: Identify preferred area for analysis.

- GETs focuses on transmission operation.
  - These technology options are particularly helpful in increasing renewable penetration when transmission congestion is curtailing renewables (or preventing interconnection).
  - More renewables (largely wind in SPP) will likely to higher transmission congestion.
- Therefore, the preferred areas would be:
  - Areas with transmission constraints identified in SPP transmission studies.
    - Preferred areas to be identified by studying the SPP Integrated Transmission Planning (ITP) Assessment Report and quarterly updates.
  - Areas with significant generation resource changes (large amounts of new renewable projects and retirements of existing resources).
    - Preferred areas to be identified by studying the SPP GI Queue.



SPP figure from http://opsportal.spp.org/Images/SPPMap.gif

Step 1: Identify Preferred Areas - 2/4

Based on the observations from the ITP report and GI queue, **Kansas and Oklahoma** are selected as the focus areas.

- Selection criteria for new renewables projects are set to those where Interconnection agreement has been fully executed.*
  - GI queue status of IA Fully Executed/On Schedule or IA Fully Executed/Suspended.
- This approach will include over 9,400 MW of renewable projects:

RENEWABLE POTENTIAL ASSUMED FOR KANSAS AND OKLAHOMA

State	Wind	Solar	Total
Kansas	3,410	120	3,530
Oklahoma	5,760	140	5,900
Total	9,170	260	9,430

[Rounded to the nearest 10 MW]

WIND SITING PLANS FROM 2019 ITP

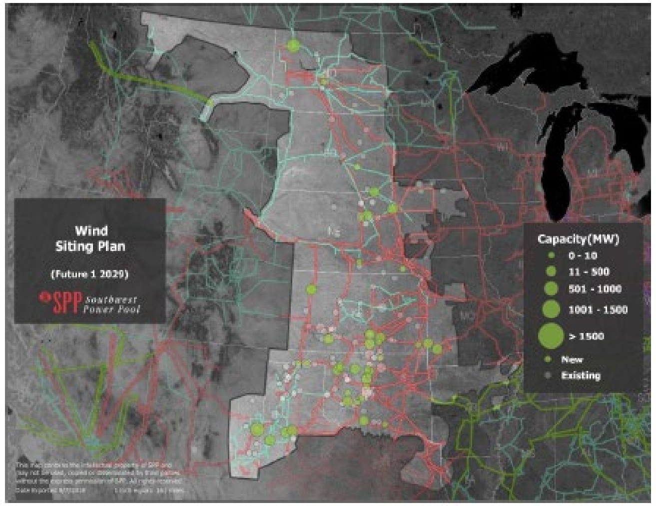


Figure 2.19: 2029 Future 1 Wind Siting Plan

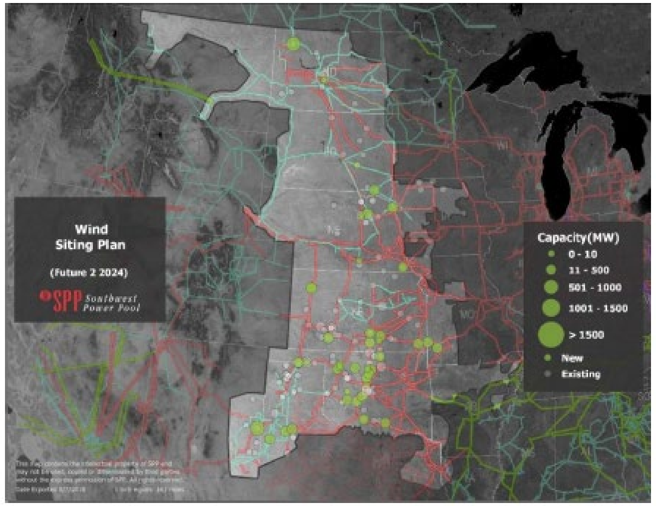


Figure 2.20: 2024 Future 2 Wind Siting Plan

* The 2010 SPP Wind Integration Study uses a similar approach.

Step 1: Identify Preferred Areas - 3/4

SPP identifies two target areas in its 2019 Integrated Transmission Planning (ITP) Assessment Report as areas that needed additional analysis and could benefit from closer attention.

4.1.1.1 Southeast Kansas/Southwest Missouri Target Area (Target Area 1)

Southeast Kansas/Southwest Missouri was identified as Target Area 1, requiring additional analysis for several reasons. The area has been the site of historic and projected congestion on the EHV system and has had unresolved transmission limits identified in multiple studies, most recently in the 2018 ITPNT. By defining this corridor as a target area in the 2019 ITP, SPP is able to address the TWG's direction to provide a path forward for the area to properly evaluate and resolve the issues present in day-to-day operations and in the planning horizon.

4.1.1.2 Central/Eastern Oklahoma Target Area (Target Area 2)

Central/Eastern Oklahoma was identified as Target Area 2 due to heavy congestion and parallel system correlation with Target Area 1. Additional analysis was unnecessary for Target Area 2 because system issues in this area were only related to congestion and underlying voltage stability concerns. The main point of congestion in Target Area 2 is related to the Cleveland 345/138 kV station west of Tulsa, Oklahoma. The renewable forecast in the 2019 ITP drives increased bulk transfers across central Oklahoma. EHV contingencies in the area shift congestion mostly to the lower-voltage system.

Step 1: Identify Preferred Areas - 4/4

SPP's GI Queue shows significant renewable additions and material retirements of existing generation resources for Kansas and Oklahoma.

KS/OK

Planned Capacity and Retirement 2020-2025

		Planned Capacity (MW)				**Planned Retirement** (MW)			
Control Area	Entity	Total	Solar	Wind	Battery	Total	Fuel Oil	Coal	Natural Gas
OKGE	**Oklahoma Gas & Electric Co**	**10,837**	**2,036**	**7,623**	**1,178**	**339**	**28**		**312**
Evergy	**Evergy**	**10,276**	**1,812**	**8,148**	**316**	**1,223**	**410**		**813**
KCPL	Kansas City Power & Light	2,911	550	2,361	-	727	297		431
WERE	Westar Energy	7,365	1,262	5,787	316	893	114		382
SPS	**Southwestern Public Service Co**	**13,122**	**6,985**	**5,088**	**1,049**	**920**			**920**
AEPW	American Electric Power West	**9,335**	**3,249**	**5,344**	**742**	**474**	**12**	-	**462**
BEPC	Basin Electric Power Coop	2,740	700	2,040	-				
LES	Lincoln Electric System	1,065	306	659	100	99			99
MIDW	Midwest	948	50	878	20				
NPPD	Nebraska Public Power District	6,806	2,025	4,707	74	354	178		176
OPPD	Omaha Public Power District	1,808	1,027	135	646	605	136	199	270
SUNC	Sunflower Electric Power Corp	4,163	1,110	3,003	50	431	84		346
WAPA	WAPA Upper Great Plains West	3,441	388	3,053	-				
WFEC	Western Farmers Electric Coop	2,265	1,404	677	184	130			130
AR	Other AR Utilities	126	126	-	-	5	5		
IA	Other IA Utilities	300	-	300	-	6	6		
KS	Other KS Utilities	7,465	5,041	1,729	695	166	66		100
LA	Other LA Utilities	440	330	-	110				
MN	Other MN Utilities	-	-	-	-	43	43		
MO	Other MO Utilities	5,176	3,031	1,642	503	427	74	165	188
MT	Other MT Utilities	510	75	385	50				
ND	Other ND Utilities	1,033	72	887	74	4	4		
NE	Other NE Utilities	3,497	2,026	1,171	300				
NM	Other NM Utilities	500	500	-	-				
OK	Other OK Utilities	3,396	2,001	1,143	252	540		540	
SD	Other SD Utilities	1,832	63	1,705	63	34	10		24
TX	Other TX Utilities	2,482	920	852	710				
Total		**94,920**	**36,092**	**51,712**	**7,116**	**6,197**	**1,097**	**904**	**4,197**

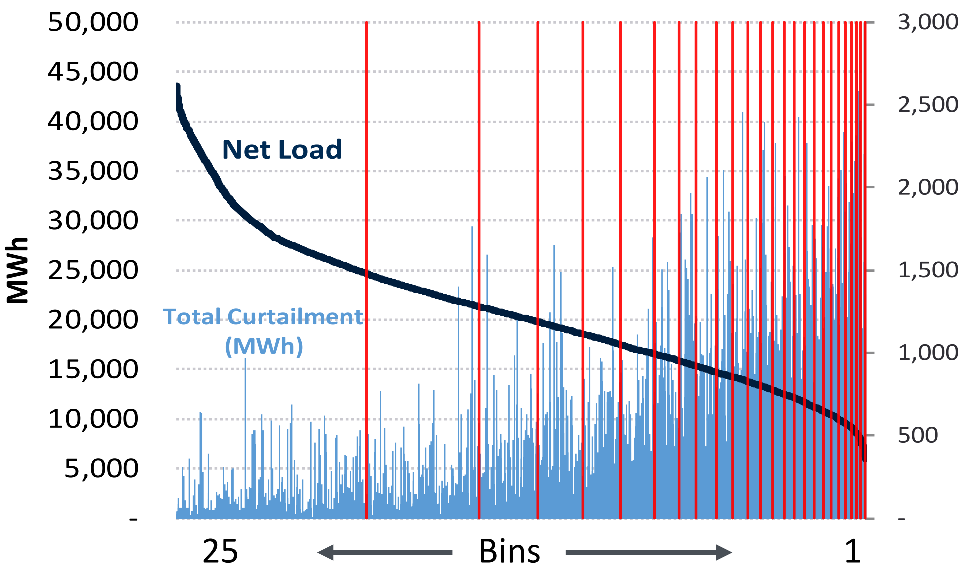
Planned Capacity Source: SPP GI Queue accessed September 28, 2020

Step 2: Identify 24 Snapshots - 1/5

Step 2: Select 24 representative snapshots from SPP operational power flow cases.

- The 24 snapshots should represent varying conditions over a full year.
  - This is an alternative approach to performing production simulation type analyses.
  - This approach may reflect historical operational conditions better than production simulations.
- Create 25 bins (numbered 1 through 25) using historical data (one full year).
  - Sort all hours in the year by decreasing net load.
  - Create 25 bins (separated by red lines in the chart to contain about 1/25th of the total (annual) curtailment observed.
  - Curtailment is higher in hours where net load (shown as the thick black line in the chart to the right) is lower.
  - Analysis will be for 24 bins, excluding the first bin (bin 25) with minimal average curtailment.
- Select appropriate snapshots to represent each bin.

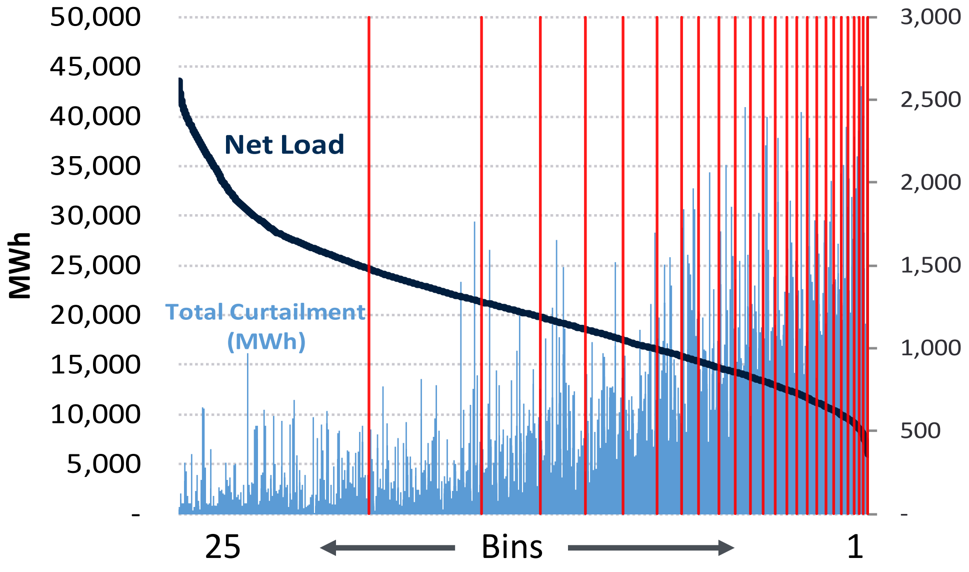
NET LOAD AND WIND CURTAILMENT



Step 2: Identify 24 Snapshots - 2/5

25 bins (numbered 1 through 25) created using historical data (one full year).

- Each bin (separated by red lines in the chart to the below) contains approximately 1/25th of the total (annual) curtailment observed.



Areas between red line indicates the bins from which snapshots were selected, blue bars indicate curtailment of renewables. Each bin contains equal amounts of curtailment.

To be analyzed (bins 1–24)

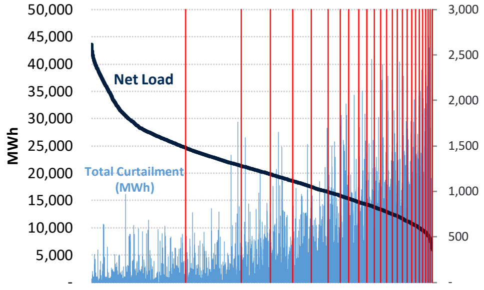
BIN INFORMATION

Bin	Wind Production Potential [MWh]	Wind Curtailment [MWh]	Average Curtailment [%]	Average Curtailment [MWh]	No of Hours
1	930,179	56,420	6%	973	58
2	801,517	57,229	7%	1,122	51
3	995,079	55,534	6%	868	64
4	1,190,204	56,178	5%	711	79
5	1,272,130	56,782	4%	668	85
6	1,418,124	56,184	4%	579	97
7	1,454,767	56,198	4%	573	98
8	1,690,406	57,186	3%	485	118
9	1,734,496	55,497	3%	455	122
10	1,916,544	56,104	3%	422	133
11	1,743,862	56,538	3%	449	126
12	2,054,919	55,794	3%	374	149
13	2,111,623	56,131	3%	364	154
14	2,154,600	56,823	3%	351	162
15	2,569,128	56,044	2%	289	194
16	2,698,718	56,007	2%	269	208
17	3,225,928	56,365	2%	217	260
18	2,680,982	56,487	2%	262	216
19	3,792,959	56,089	1%	179	313
20	4,647,197	56,480	1%	130	434
21	4,940,542	56,082	1%	117	480
22	5,436,156	56,237	1%	98	575
23	6,560,518	56,340	1%	75	750
24	10,239,766	56,239	1%	39	1436
25	13,951,550	56,266	0%	23	2421

Step 2: Identify 24 Snapshots - 3/5

Select a representative hour from each bin to obtain 24 snapshots that span the conditions where wind curtailment occurs.

- Maintain daily and seasonal spread.
  - No same day.
  - More than 4 per season (4 Winter, 6 Spring, 6 Summer, 8 Fall).



BIN Information

To be analyzed

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24	10,239,766	56,239	1%	39	1436
25	13,951,550	56,266	0%	23	2421

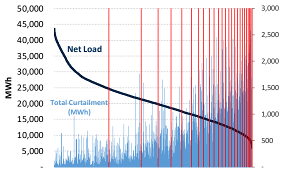
Bin	Date	Time*
1	April 12, 2020	Early Morning
2	September 28, 2020	Early Morning
3	June 1, 2020	Early Morning
4	September 21, 2020	Early Morning
5	June 13, 2020	Early Morning
6	September 9, 2020	Early Morning
7	March 8, 2020	Mid Day
8	January 9, 2020	Early Morning
9	November 11, 2019	Late Afternoon
10	January 8, 2020	Late Afternoon
11	April 18, 2020	Early Morning
12	September 10, 2020	Early Morning
13	December 7, 2019	Late Afternoon
14	April 16, 2020	Late Afternoon
15	March 4, 2020	Late Night
16	December 19, 2019	Late Afternoon
17	May 10, 2020	Late Night
18	November 15, 2019	Late Afternoon
19	December 11, 2019	Late Afternoon
20	November 16, 2019	Mid Day
21	August 13, 2020	Early Morning
22	September 6, 2020	Mid Day
23	August 20, 2020	Late Night
24	June 26, 2020	Late Night

* SPP provides limited snapshots (Early Morning: 0500, Mid Day: 1100, Late Afternoon: 1700 Late Night: 2300)

Step 2: Identify 24 Snapshots - 4/5

Select a representative hour from each bin to obtain 24 snapshots that span the conditions where wind curtailment occurs.

- Average wind production potential in sample: 14.3 GW.
  - Sample wind production potential ranges from 7.9 GW to 18.3 GW.



Bin	Date	Time*
1	April 12, 2020	Early Morning
2	September 28, 2020	Early Morning
3	June 1, 2020	Early Morning
4	September 21, 2020	Early Morning
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10	January 8, 2020	Late Afternoon
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12	September 10, 2020	Early Morning
13	December 7, 2019	Late Afternoon
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19	December 11, 2019	Late Afternoon
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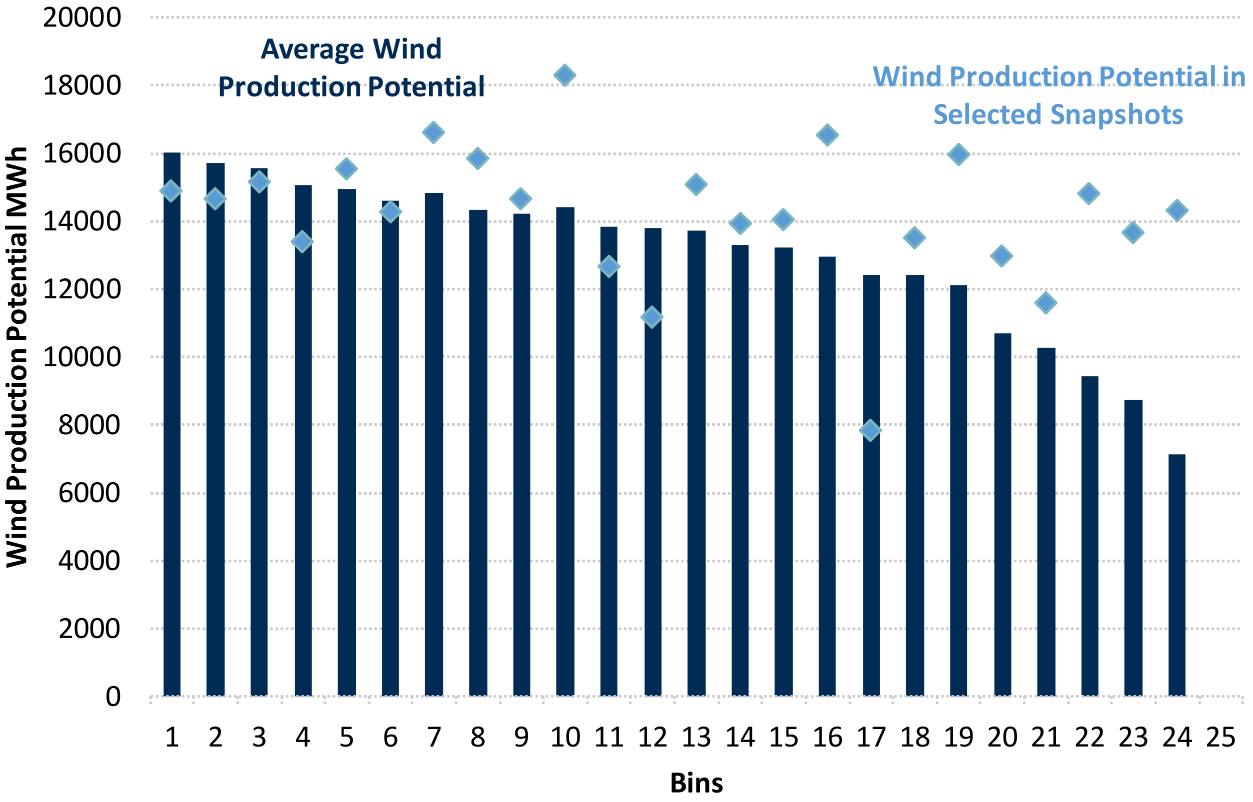
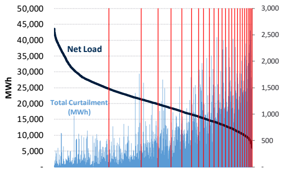
21	August 13, 2020	Early Morning
22	September 6, 2020	Mid Day
23	August 20, 2020	Late Night
24	June 26, 2020	Late Night



Step 2: Identify 24 Snapshots - 5/5

Select a representative hour from each bin to obtain 24 snapshots that span the conditions where wind curtailment occurs.

- Average capacity factor: 63.2% (annual SPP CF 41.5%).
- Average curtailment in sample: 2.8%.



Bin	Date	Time*
1	April 12, 2020	Early Morning
2	September 28, 2020	Early Morning
3	June 1, 2020	Early Morning
4	September 21, 2020	Early Morning
5	June 13, 2020	Early Morning
6	September 9, 2020	Early Morning
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8	January 9, 2020	Early Morning
9	November 11, 2019	Late Afternoon
10	January 8, 2020	Late Afternoon
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12	September 10, 2020	Early Morning
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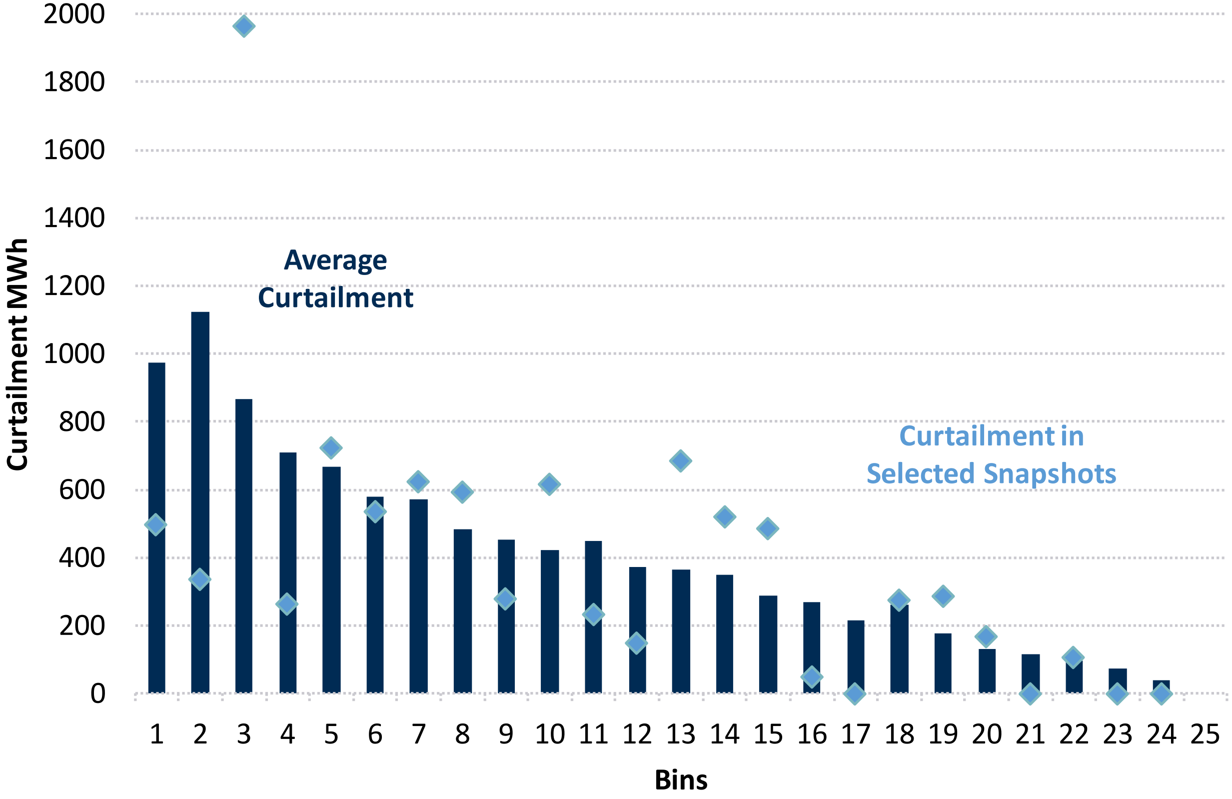
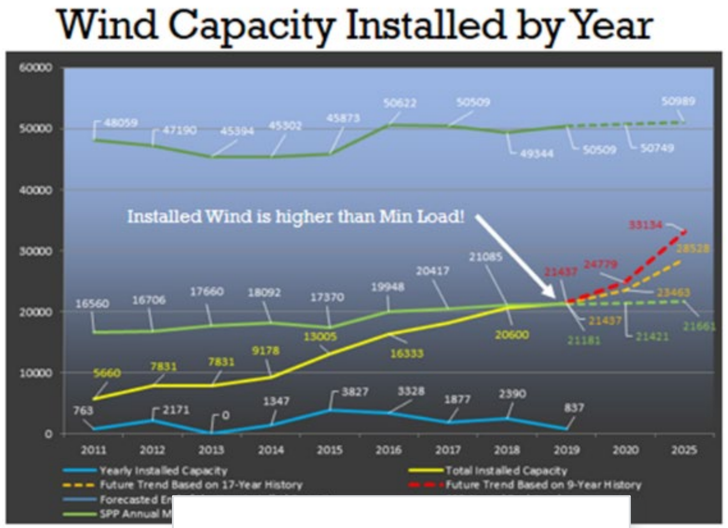
14	April 16, 2020	Late Afternoon
15	March 4, 2020	Late Night
16	December 19, 2019	Late Afternoon
17	May 10, 2020	Late Night
18	November 15, 2019	Late Afternoon
19	December 11, 2019	Late Afternoon
20	November 16, 2019	Mid Day
21	August 13, 2020	Early Morning
22	September 6, 2020	Mid Day
23	August 20, 2020	Late Night
24	June 26, 2020	Late Night

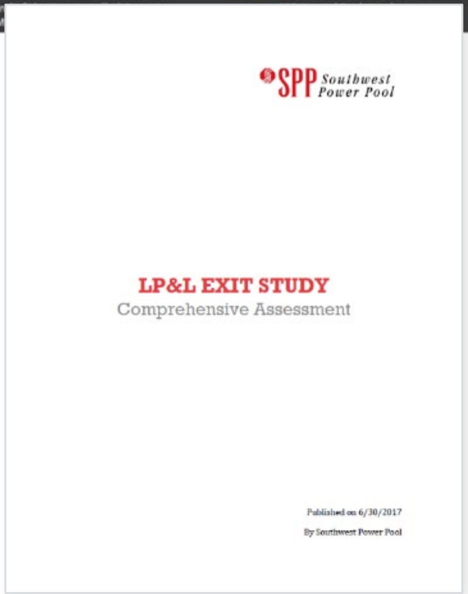


Step 3: Modify the 24 Snapshots - 1/2

Step 3: Modify the snapshots from SPP to reflect new transmission upgrades, wind and solar units from the generation interconnection queue, announced retirements, load changes, etc., to model 2025.

- Generation
  - Add/retire announced thermal generation.
  - Add new wind and solar units from interconnection queue. Assume added units' max potential output based on capacity factor from nearby units of the same type (this will be done by snapshot).
  - Adjust wind/solar dispatch to reverse curtailment by observing historical data on LMPs to identify units that may have been be curtailed (e.g., LMP less than -$20/MWh).
  - For assumed curtailments, estimate what the non-curtailed dispatch might have been using nearby wind/solar units.
- Load
  - Adjust load to 2025 level.
  - Remove portion of Lubbock load that is scheduled to transfer to ERCOT.*
  - Keep imports/exports with neighboring areas constant.





* LP&L Exit Study, available at https://www.spp.org/documents/52338/2017-lpl%20exit%20study%20-%2020170630_final.pdf

Step 3: Modify the 24 Snapshots - 2/2

Step 3: Modify the snapshots from SPP to reflect new transmission upgrades, wind and solar units from the generation interconnection queue, announced retirements, load changes, etc., to model 2025.

- Transmission
  - Adjust transmission constraint limits by comparing binding constraints against historical data (and adjust as necessary.)
  - Add new transmission projects. Transmission projects that are planned to be in service by 2025 are selected from SPP's Integrated Transmission Planning (ITP) reports (See appendix for the list of projects.)
  - Identify outages in snapshots that correspond to capital projects, and put them back in service.
  - Setup single-element contingencies in SPP and neighboring areas (Mid-American, Associated Electric, Entergy etc.).

Step 4: Find Max Renewables - 1/3

Step 4: Find the maximum amount of renewables that can be integrated under a business as usual scenario (Base Case) and then with GETs.

- Dispatch wind and solar to their max output by running Security Constrained Optimal Power Flow (SCOPF).
  - Adjust output of non-renewable units. For fossil-fuel thermal units:
    - If capacity is < 100 MW, allow the unit to shut down.
    - If capacity is >= 100 MW, assume the unit's min-gen is 30% of max-capacity.
    - For night time snapshots, allow natural gas-fueled combined cycle units and simple cycle units to shut down as needed.
    - Leave nuclear units and units outside of SPP operating as is (i.e., no redispatch).
  - Set priority order for different generator units by unit type.
    - Prioritize wind and solar over other units, and prioritize existing wind/solar over new wind/solar.

Step 4: Find Max Renewables - 2/3

Step 4: Find the maximum amount of renewables that can be integrated under a business as usual scenario (Base Case) and then with GETs (With GETs Case). This will be performed by solving the power flow cases for the entire SPP footprint.

- Without GETs implemented (Business as Usual).
  - Assess curtailment without GETs.
  - Solve SCOPF (i.e., run contingency analysis to get violations, add interfaces to represent violations and re-run OPF, repeat these steps until no new violations are identified.) In doing so, enforce 69 kV and higher constraints within SPP, and 100 kV and higher constraints for external regions.
  - Save power flow case as Base Case.
  - Tally curtailment by comparing dispatch with limits for all wind and solar units. For new renewable projects (9,430 MW-worth from GI Queue), assume 5% curtailment thresholds for viability assessment (i.e., projects are considered viable if analysis indicates annual curtailments to be less than 5%). This will be an iterative process (i.e., run SCOPF, take out renewable projects with high curtailments, then resolve SCOPF, and repeat).

Step 4: Find Max Renewables - 3/3

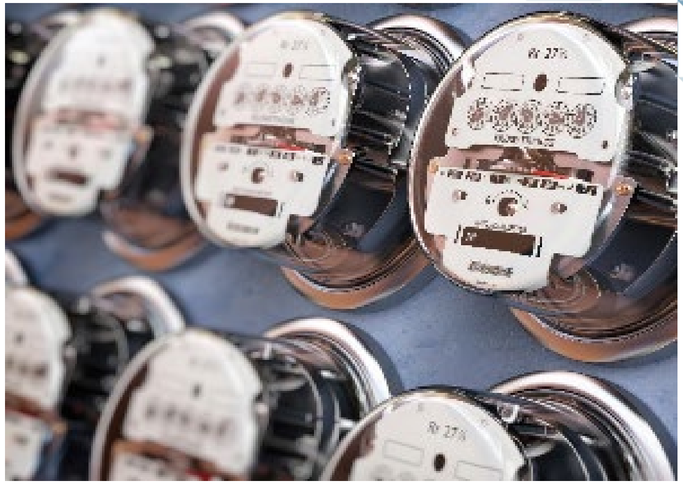
Step 4: Find the maximum amount of renewables that can be integrated under a business as usual scenario and then with GETs (in the order of DLR, Topology Optimization, and Advanced Power Flow Control). This will be performed by solving the power flow cases for the entire SPP footprint.

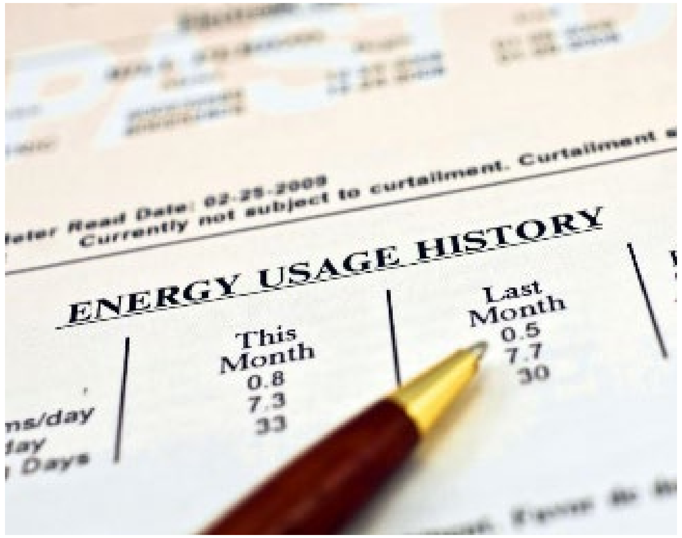
- With GETs implemented (repeat the analysis from the previous slide).
  - Perform DLR analysis on Base Case and save power flow case as DLR Case.
  - Perform Topology Optimization analysis on DLR Case, save power flow case as TC Case.
  - Perform Flow Control analysis on TC Case, save power flow case as FC Case.
  - Revisit FC Case to identify additional DLR and/or Topology Optimization opportunities.
  - Tally curtailment by comparing dispatch with limits for all wind and solar units. Apply the same 5% threshold to assess project viability.
- Results will be for the **combined benefits**, rather than individual GETs.
  - The order of GETs implemented in the analysis will likely change the benefits reaped by the individual technologies (i.e., being the first technology to be added would likely show larger benefits than being last).

Step 5: Assess Benefits - 1/3

Step 5: Assess benefits including economic values (production cost savings, job creation, local benefits, etc.) and carbon emissions reduction.

- Calculate production costs benefits and carbon emission benefits utilizing SPP market data where applicable.
- Review public studies on the economic impacts to estimate "per unit" benefits, and apply to the findings.
- GETs Vendors provide economic impacts associated with their respective technology installments.
  - Cost data for both initial investment, and ongoing operational costs once installed, provided by GETs vendors.



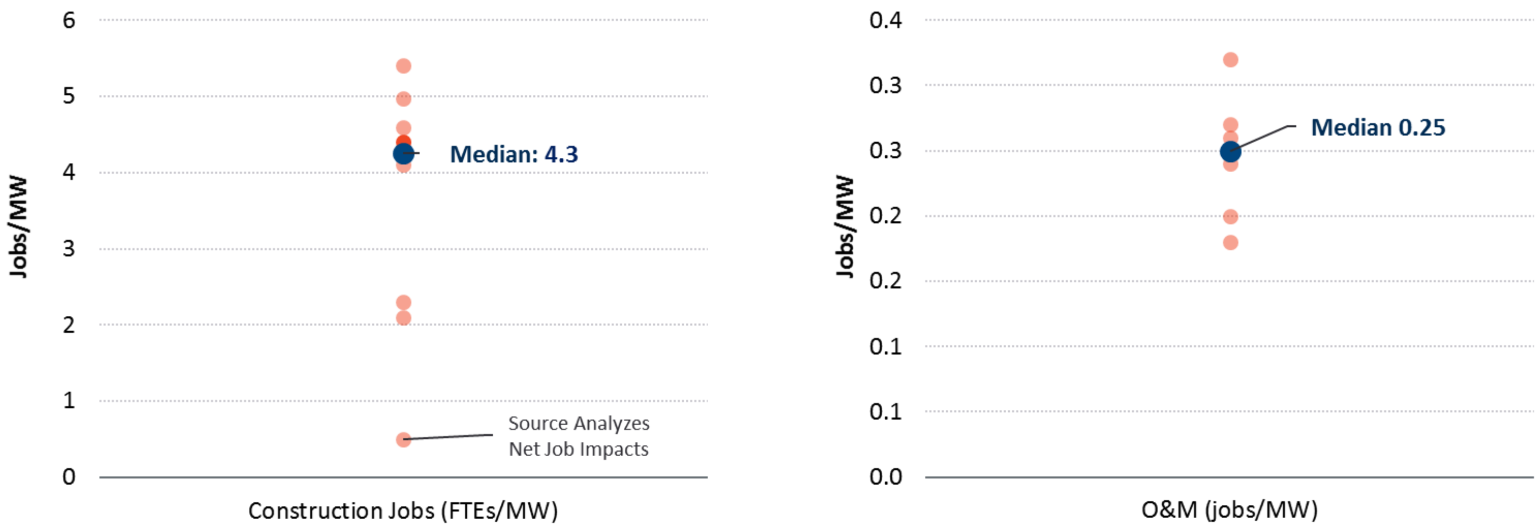


Step 5: Assess Benefits - 2/3

Adding more renewables produces jobs.

- Review of various public reports (14)* to assess job impacts through wind investments.
  - Direct, indirect, and induced jobs are included.
  - Data generally reflects short term jobs (e.g., construction jobs) rather than long term O&M jobs.
  - Impacts are at the state level (or smaller geographical areas).

COMPARISON OF JOB IMPACTS ACROSS STUDIES



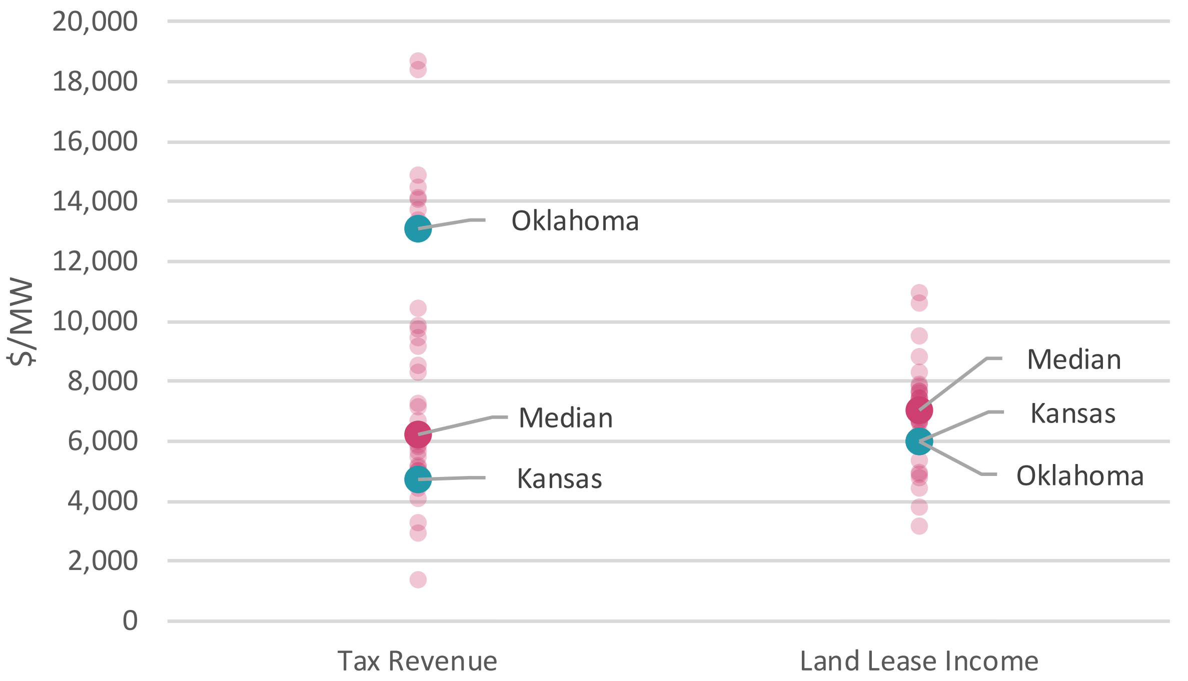
* See Appendix-B for list of reports reviewed.

Step 5: Assess Benefits - 3/3

Adding more renewables produces additional local benefits.

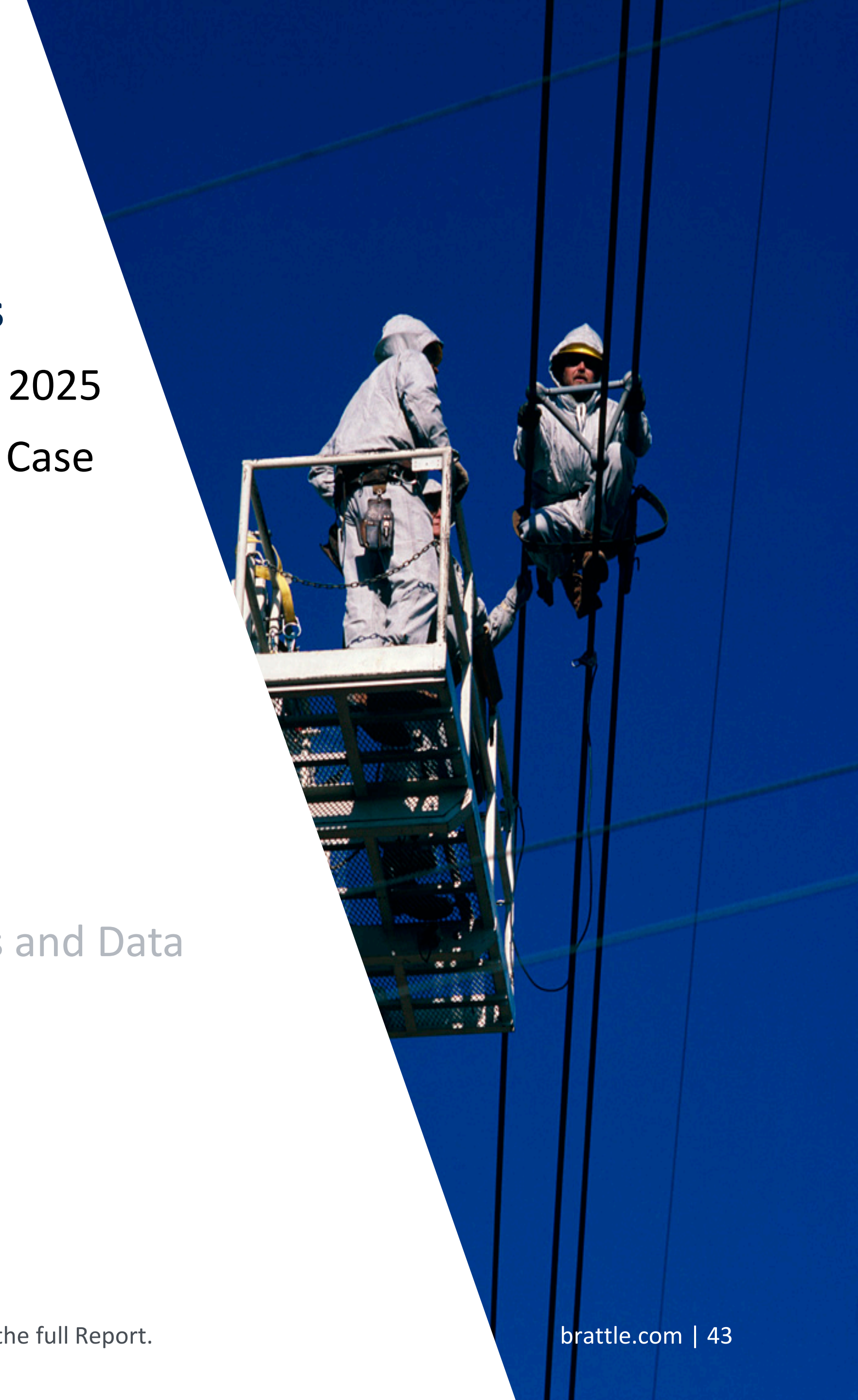
- Review of various public reports (7)* to assess land lease and tax revenues from wind development.

COMPARISON OF LEASE AND TAX REVENUES ACROSS STUDIES AND STATES



* See Appendix-B for list of reports reviewed.

Table of Contents



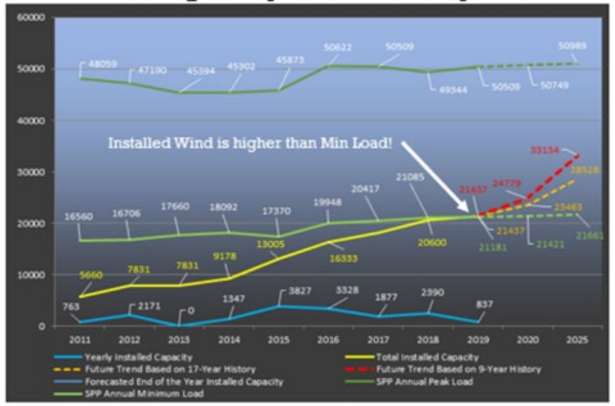
System Assumptions for 2025

Study focus area: Kansas and Oklahoma.

- Load Change
  - SPP estimates 240 MW load growth between 2020 and 2025.
  - Approximately 470 MW (summer peak) of Lubbock load estimated to transfer to ERCOT in 2021.
    - Load connected to the Xcel Energy system by four 230 kV nodes (LP-Milwakee, LP-Southeast, LP-Holly, and LP-Wadswrth) is scheduled to transfer. Roughly 180 MW will remain in SPP.
- Over 9,400 MW of potential renewable projects.
  - Projects in the SPP GI queue projects with IA executed.
- Over 70 new transmission projects added.
  - Based on status from ITP Assessment reports.

Detail data are included in the Appendix.

Wind Capacity Installed by Year



POTENTIAL RENEWABLE PROJECTS

State	Wind	Solar	Total
Kansas	3,410	120	3,530
Oklahoma	5,760	140	5,900
Total	9,170	260	9,430

[Rounded to the nearest 10 MW]

TRANSMISSION PROJECTS

Voltage Level	Project Counts
230 KV and Above	16
169 kV and 138 kV	27
115 kV	16
69 kV	14
Total	73

Renewables Under Base Case

Study focus area: Kansas and Oklahoma.

- Base Case (business as usual) allows for over 2,500 MW of new renewables to be integrated.
  - Retirements of existing thermal resources contribute.
  - While limited, load growth also contributes.
  - Lubbock load departure works against integrating more renewables.

ADDITIONAL RENEWABLES INTEGRATED – BASE CASE

State	Potential (MW)			Base Case (MW)			Realization (%)		
	Wind	Solar	Total	Wind	Solar	Total	Wind	Solar	Total
Kansas	3,410	120	3,530	1,710	0	1,710	50%	0%	48%
Oklahoma	5,760	140	5,900	770	100	870	13%	71%	15%
Total	9,170	260	9,430	2,480	100	2,580	27%	38%	27%

[Rounded to the nearest 10 MW]

Renewables Under With GETs Case - 1/3

GETs utilized in this study include:

- **Hardware solutions**: DLR on 56 lines and Advanced Power Flow Control on 8 locations.

Hardware Solutions by Voltage Level	345	230	161	138	115	69	Total
DLR*	10	3	11	22	3	7	56
Advanced Power Flow Control	3	0	4	1	0	0	8

- **Software solutions**: 204 unique Topology Optimization reconfigurations, averaging 13 per snapshot.**

Software Solutions by Voltage Level	345	230	161	138	115	69	Total
Lines	20	10	31	75	4	30	170
Substations	4	0	1	1	0	0	6
Transformers (high voltage terminal)	10	1	4	13	0	0	28

- Estimated costs for implementing the above GETs: ~$90 million.
  - Initial investment costs is estimated to be around $90 million.***
  - Ongoing costs of around $10 million per year.***

* Every DLR installation requires 15 to 30 sensors.

** Average actions represent the average number of actions that remain per case, not actions per hour. Based on other studies the average number of actions per hour is expected to be smaller, typically less than the number of topology changes due to planned outages.

*** Costs can vary project by project, and also on how the GETs service is provided—for example, Topology Optimization can be provided as a software subscription service to reduce the initial cost. We also assume utilities can incorporate these technologies without large costs.

Renewables Under With GETs Case - 2/3

Study focus area: Kansas and Oklahoma.

- GETs allow for **over 5,200 MW** of new renewables to be integrated.
  - This is **more than twice the amount** of renewables integrated in the Base Case.

ADDITIONAL RENEWABLES INTEGRATED – WITH GETS CASE

State	Potential (MW)			With GETs Case (MW)			Realization (%)		
	Wind	Solar	Total	Wind	Solar	Total	Wind	Solar	Total
Kansas	3,410	120	3,530	1,910	0	1,910	56%	0%	54%
Oklahoma	5,760	140	5,900	3,200	140	3,340	56%	100%	57%
Total	9,170	260	9,430	5,110	140	5,250	56%	54%	56%

[Rounded to the nearest 10 MW]

- Curtailment levels of existing renewables (wind) are also reduced.
  - Existing wind curtailment reduced by over 76,000 MWh.
  - No change for solar.

Renewables Under With GETs Case - 3/3

GETs enable more than twice the amount of additional new renewables to be integrated.

- Potential Renewables Considered: 9,430 MW
  - Based on queue projects with IA executed.
- Integrated Renewables (without further transmission upgrades)
  - Base Case: 2,580 MW
  - With GETs Case: 5,250 MW
  - Delta (With GETs Case – Base Case): 2,670 MW

RENEWABLE POTENTIAL ASSUMED FOR KANSAS AND OKLAHOMA

State	Wind	Solar	Total
Kansas	3,410	120	3,530
Oklahoma	5,760	140	5,900
Total	9,170	260	9,430

[Rounded to the nearest 10 MW]

~1.5 times the amount of wind SPP integrated in 2019 (1.8 GW).

ADDITIONAL RENEWABLES INTEGRATED

State	Base Case			With GETs Case			Delta (GETs - Base)		
	Wind	Solar	Total	Wind	Solar	Total	Wind	Solar	Total
Kansas	1,710	0	1,710	1,910	0	1,910	200	0	200
Oklahoma	770	100	870	3,200	140	3,340	2,430	40	2,470
Total	2,480	100	2,580	5,110	140	5,250	2,630	40	2,670

X2

[Rounded to the nearest 10 MW]

Benefits of Increased Renewables - 1/7

GETs enable more than twice the amount of additional renewables to be integrated.

- 2,670 MW = 5,250 MW (With GETs Case) – 2,580 MW (Base Case)
- 2,670 MW = 2,630 MW (Wind) + 40 MW (Solar)
- GETs investment cost is around $90 million.

SUMMARY OF BENEFITS OF INCREMENTAL 2,670 MW OF RENEWABLES - 1/2

Annual Renewables Benefits			Notes
Additional Generation	New Wind	8,640 GWh	Wind assumes 37.5% capacity factor, solar assumes 18.0% capacity facto, see slide 51.
	New Solar	60 GWh	
	Total	8,700 GWh	
Reduction in Curtailment from Existing Wind		76 GWh	
Total Increase in Renewable Generation		8,776 GWh	
Annual Production Costs Savings		$175 million	Assumes $20/MWh is avoided, see slide 52.
Annual Carbon Reduction		3 million tons	Assumes Combined Cycle Plant (350g per kWh), see slides 53 & 54.

Benefits of Increased Renewables - 2/7

GETs enable more than twice the amount of additional renewables to be integrated.

- 2,670 MW = 5,250 MW (With GETs Case) – 2,580 MW (Base Case)
- 2,670 MW = 2,630 MW (Wind) + 40 MW (Solar)
- GETs investment cost is around $90 million.

SUMMARY OF BENEFITS OF INCREMENTAL 2,670 MW OF RENEWABLES - 2/2

Renewables Benefits			Notes
Direct Jobs from Renewables	Short-term (Construction etc)	Over 11,300 person-year	See slide 55.
	Long-term (O&M etc)	Over 650 person-year	
Estimated Local Tax Revenues (Annual)		$32 million	
Estimated Land Lease Revenues (Annual)		$15 million	

- There are additional job benefits associated with the installation and operations of GETs.
  - 50 to 60 long-term jobs.
  - 20 to 30 short-term jobs (for installation).

Benefits of Increased Renewables - 3/7

GETs enable additional new renewables by: 2,670 MW / 8,776 GWh.

- 2,630 MW of Wind is assumed to produce over 8,640 GWh of energy per year.
  - Assumes 37.5% capacity factor for wind.
  - 2019 SPP State of the Market Report* shows wind producing roughly 74,000 GWh of power and SPP having 22,482 MW of wind at the end of 2019.
  - These figures conservatively suggest the realized average capacity factor of wind is 37.5% (after accounting for outages and curtailments).
  - In reality newer wind plants show higher capacity factors. SPP State of the Market Report shows real time capacity factors for wind in 2019 to be 39.4%.
- 40 MW of Solar is assumed to produce about 60 GWh of energy per year.
  - Assuming 18% capacity factor for solar.
- Curtailment of existing wind is reduced by more than 76 GWh a year.
  - Total increase in renewables generation enabled by GETs is 8,776 GWh.

* 2019 SPP State of the Market Report, available at: https://www.spp.org/documents/62150/2019%20annual%20state%20of%20the%20market%20report.pdf

Benefits of Increased Renewables - 4/7

GETs enable additional 8,776 GWh of generation from renewables.

- Estimated annual production cost savings: **Over $175 million**.
  - Conservatively assumes $20/MWh savings for 8,776 GWh of energy.
  - Generation cost of a new natural gas-fueled combined cycle plants would be in the $20/MWh to $25/MWh range (assuming $2.5-3.0/MMBtu fuel cost and 7,000 Btu/kWh heat rate plus VOM).
  - Generation cost of coal plants would be in the $20/MWh to $25/MWh range (assuming $2/MMBtu fuel cost and 10,000 Btu/kWh heat rate plus VOM).
  - LMPs can be used as an indicator for the marginal cost of power. The SPP State of the Market Report shows 2019 day-ahead prices averaged around $22/MWh and real-time prices averaged around $21/MWh. 2018 average was $25/MWh for both.
  - This value does **NOT** include any Production Tax Credit-driven savings.
  - Pay-back for GETs investment ($90 million) is about half a year.

Benefits of Increased Renewables - 5/7

GETs enable additional 8,776 GWh of generation from renewables.

- Estimated carbon emissions reduction: **Over 3 million tons per year**.
  - Conservatively assumes the additional new renewables replace carbon emissions from natural gas-fueled combined cycle plants (with emission estimated to be 350g per kWh, or 0.8 pound per kWh).
  - Less efficient resources with higher heat rates and emission rates are more likely to be replaced. The average coal plant produces approximately twice the amount of carbon emissions, compared to a combined cycle plant. An average natural gas-fueled simple cycle gas turbine (a.k.a. peakers) produces approximately 20% to 30% more carbon emissions, compared to a combined cycle plant.
  - Additional benefits include **reduced water usage**. By enabling twice the amount of renewables to be integrated, reduction in water usage for power production is doubled.

Benefits of Increased Renewables - 6/7

GETs, through enabling more renewables, is estimated to reduce carbon emission by over 3 million tons per year.

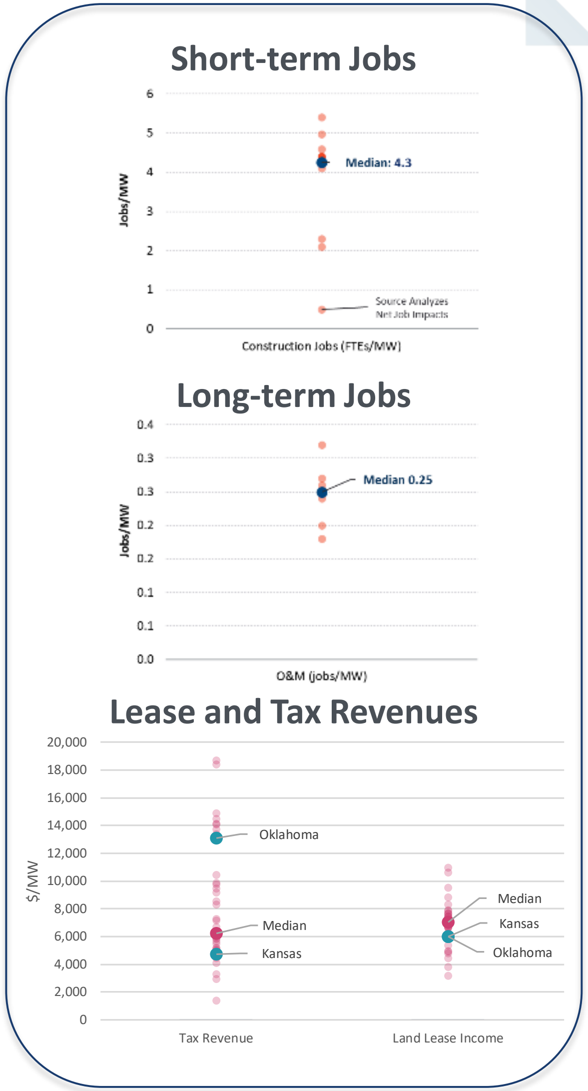
- Cumulative greenhouse gas (GHG) in the atmosphere is what causes warming, not the rate at which they are emitted in any given year (and they persist in the atmosphere for decades or longer).
  - Therefore, early reductions in GHG emissions are in many ways more important than eventual depth of reductions, because of the cumulative and persistent nature of GHGs in the atmosphere.
  - A recent whitepaper published by Brattle* illustrates how earlier adoption can lead to lower cumulative GHG emission (through 2050).
- Utilizing GETs could set an example for early adoption of existing technology to curb GHG emission.

* Clean Energy and Sustainability Accelerator, available at: https://brattlefiles.blob.core.windows.net/files/20809_clean_energy_and_sustainability_accelerator.pdf

Benefits of Increased Renewables - 7/7

The additional 2,670 MW (2,430 in Oklahoma and 200 MW in Kansas) of renewables enabled by GETs will provide jobs and other local benefits.

- Over 11,300 direct short-term jobs (largely construction of renewables).
  - Assumes 4.3 jobs (person-year) / MW for wind and 1.3 jobs (person-year) / MW for solar.
- Over 650 direct long-term jobs for operation and maintenance of the renewable resources.
  - Assumes 0.25 jobs (person-year) / MW for wind and 0.005 jobs (person-year) / MW for solar.
- Other estimated local benefits include over $32 million annual tax revenues and $15 million land lease revenues.
  - Tax revenues assumes $13,000/MW for the 2,430 MW in Oklahoma and $4,700/MW for the 200 MW in Kansas.
  - Land lease revenues assumes $5,900/MW for both Kansas and Oklahoma.

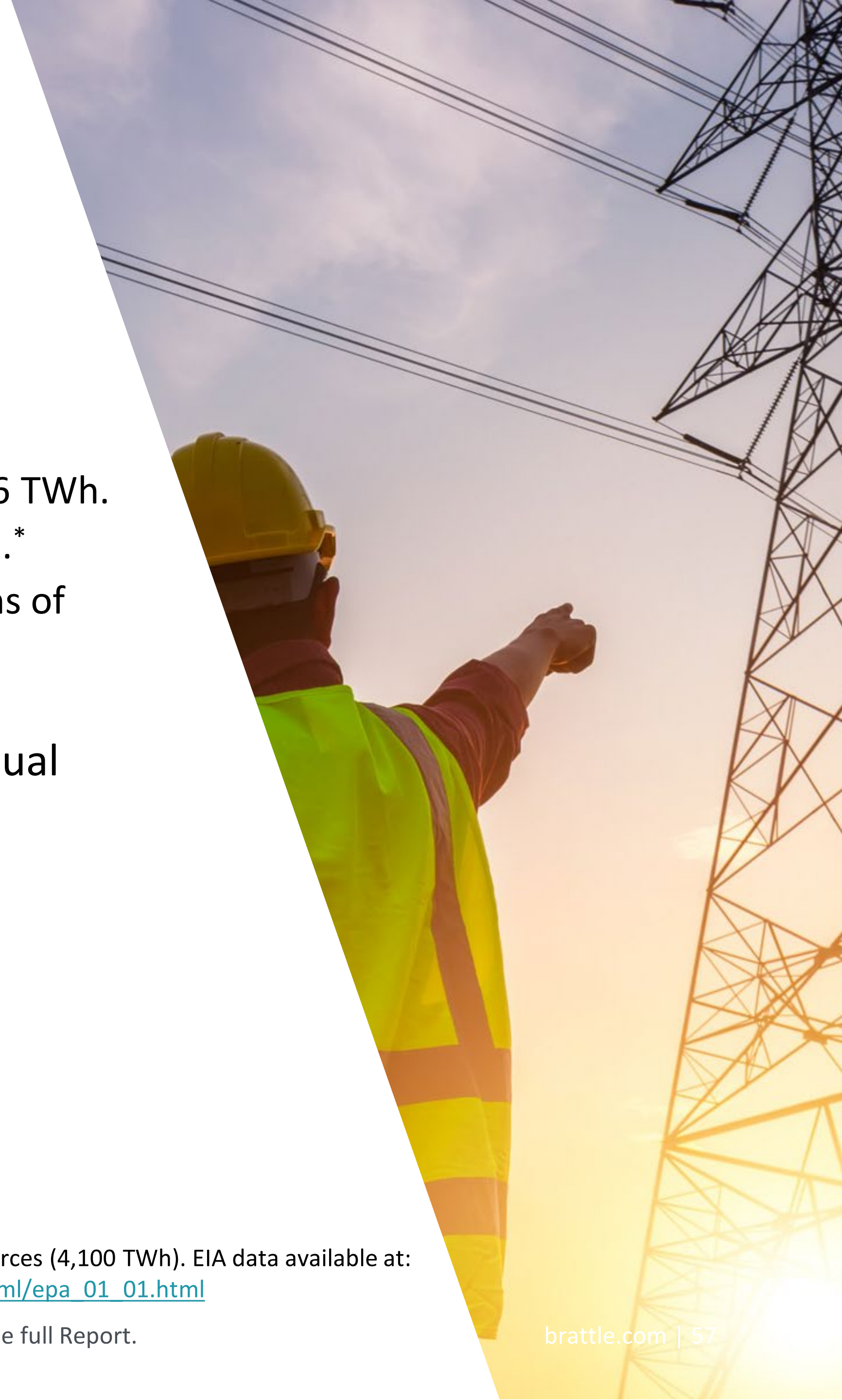


Summary of Benefits - 1/2

Key benefits of GETs for Kansas and Oklahoma

- Enable more than **twice** the amount of additional new renewables to be integrated.
  - This is 1.5x the amount of wind SPP integrated in 2019.
- Estimated annual production cost savings: **$175 million**.
  - This suggests the payback for GETs investment is about 0.5 years.
- Estimated carbon emissions reduction: **Over 3 million tons per year**.
- Other benefits include:
  - Over 11,300 direct short-term jobs (largely construction of renewables).
  - Over 650 direct long-term jobs for operation and maintenance of the renewable resources.
  - Over $32 million annual tax revenues.
  - Over $15 million land lease revenues.

Summary of Benefits - 2/2

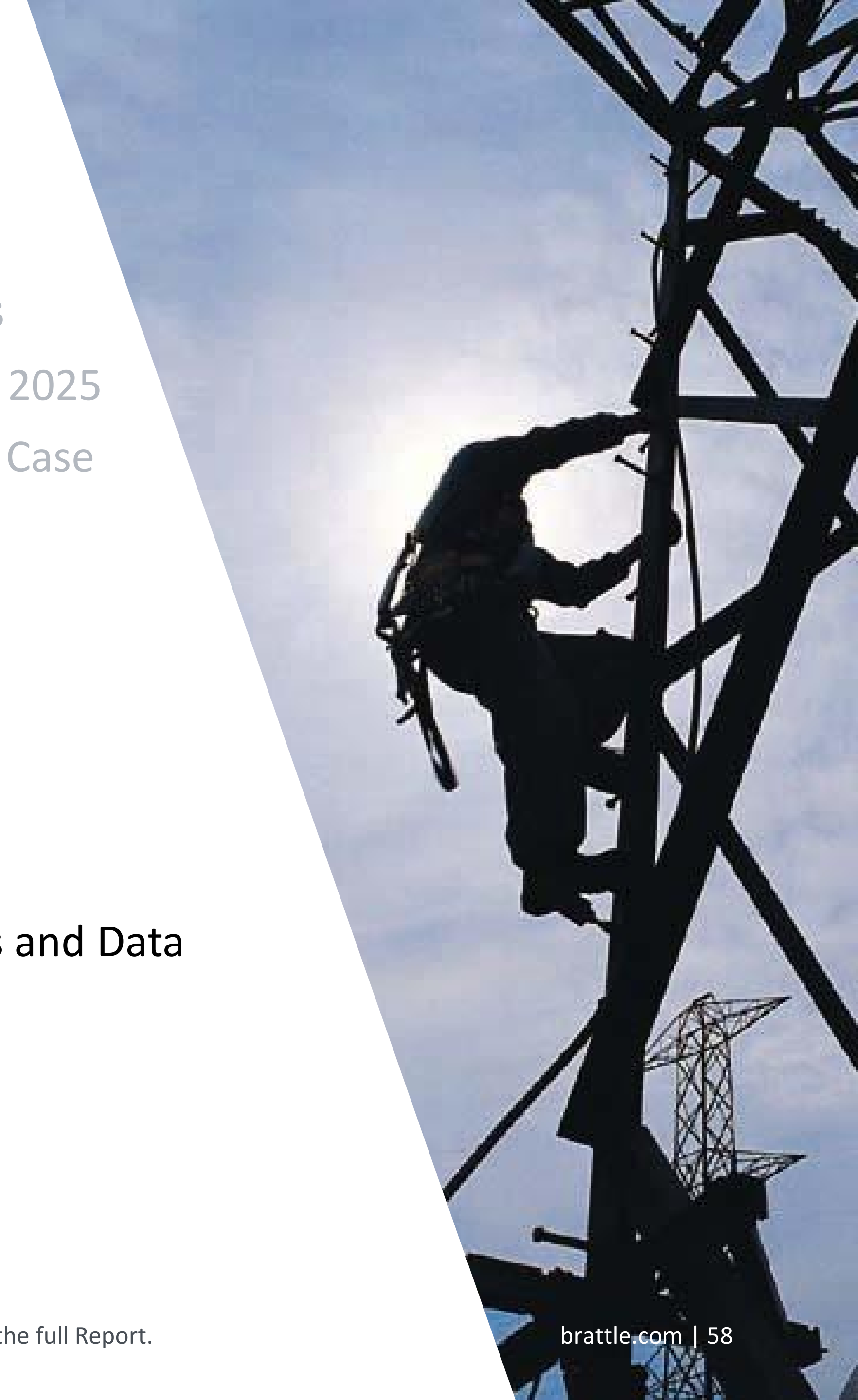


Potential nation-wide benefits of GETs

- Scaling Kansas and Oklahoma to nationwide:
  - 2019 generation in Kansas and Oklahoma combined was about 136 TWh.[*]
  - 8,700 GWh from the GETs enabled new renewable generation equates to 6.4% of 136 TWh.
  - The nationwide generation from utility-scale resources in 2019 was about 4,100 TWh.[*]
  - 6.4% of 4,100 TWh would equate to 260 TWh worth of clean power, or 90 million tons of carbon reduction assuming wind replaces natural gas burning CCs – the most clean conventional fossil-fuel based power generation technology.
- Extrapolating these results to a nation-wide level indicate GETs to provide annual benefits in the range of:
  - Over **$5 billion** (~$5.3 billion) in production cost savings.
  - **$90 million tons** of reduced carbon emission.
    - More than enough to offset **all new automobiles** sold in the U.S. in a year.
  - About **$1.5 billion** in local benefits (local taxes and land lease revenues).
  - More than 330,000 short-term (only for first year) and nearly 20,000 long-term jobs.
  - Investment cost is $2.7 billion (only for first year).
  - Ongoing costs would be around $300 million per year.

* EIA shows 2019 generation in Kansas and Oklahoma combined (136 TWh) was about 1/30 of the nationwide generation from utility-scale resources (4,100 TWh). EIA data available at: https://www.eia.gov/electricity/state/kansas/, https://www.eia.gov/electricity/state/oklahoma/, and https://www.eia.gov/electricity/annual/html/epa_01_01.html

Table of Contents



Glossary

AAR	Ambient Adjusted Ratings
DLR	Dynamic Line Ratings
FACTS	Flexible Alternating Current Transmission Systems
GETs	Grid-Enhancing Technologies
GHG	Greenhouse Gas
GI Queue	Generation Interconnection Queue
IA	Interconnection Agreement
ITP	Integrated Transmission Planning
LMP	Locational Marginal Price
PARs	Phase Angle Regulators
PSTs	Phase Shifting Transformers
SCOPF	Security Constrained Optimal Power Flow
SLR	Static Line Ratings
SPP	Southwest Power Pool

Potential Renewables from SPP GI Queue

Potential renewable generation projects selected from SPP's GI Queue.

Generation Interconnection Number	IFS Queue Number	Nearest Town or County	State	CA	Commercial Operation Date	Capacity	Generation Type	Substation or Line	Status
GEN-2010-005	0	Harper County	KS	WERE	12/31/2020	299.2	Wind	Viola 345kV	IA FULLY EXECUTED/ON SCHEDULE
GEN-2011-019	0	Woodward County	OK	OKGE	12/31/2020	175	Wind	Woodward EHV 345kV	IA FULLY EXECUTED/ON SCHEDULE
GEN-2011-020	0	Ellis	OK	OKGE	12/31/2020	165.6	Wind	Woodward EHV 345kV	IA FULLY EXECUTED/ON SCHEDULE
GEN-2015-013	IFS-2015-001-18	Kiowa County	OK	WFEC	12/1/2022	120	Solar	Snyder 138kV	IA FULLY EXECUTED/ON SCHEDULE
GEN-2015-029	IFS-2015-001-12	Dewey & Blaine County	OK	OKGE	12/1/2020	161	Wind	Tatonga 345kV	IA FULLY EXECUTED/ON SCHEDULE
GEN-2015-048	IFS-2015-002-11	Major County	OK	OKGE	10/1/2020	200	Wind	Cleo Corner 138kV	IA FULLY EXECUTED/ON SCHEDULE
GEN-2015-055	IFS-2015-002-25	Beckham County	OK	WFEC	12/1/2022	40	Solar	Erick 138kV Substation	IA FULLY EXECUTED/ON SCHEDULE
GEN-2015-062	IFS-2015-002-15	Garfield County	OK	OKGE	12/31/2021	4.5	Wind	Breckinridge 138kV	IA FULLY EXECUTED/ON SCHEDULE
GEN-2015-092	IFS-2015-002-36	Grady	OK	AEPW	12/31/2020	250	Wind	Lawton East Side-Sunnyside (Terry Road) 345kV	IA FULLY EXECUTED/ON SCHEDULE
GEN-2015-093	IFS-2015-002-37	Caddo	OK	OKGE	12/31/2022	250	Wind	Gracemont 345kV	IA FULLY EXECUTED/ON SCHEDULE
GEN-2015-095	IFS-2016-001-20	Woods County	OK	OKGE	6/1/2020	176	Wind	Tap Mooreland - Knob Hill 138kV	IA FULLY EXECUTED/ON SCHEDULE
GEN-2016-003	IFS-2016-001-45	Ellis	OK	OKGE	8/31/2021	248.4	Wind	Badger-Woodward EHV Dbl Ckt 345kV	IA FULLY EXECUTED/ON SCHEDULE
GEN-2016-016	IFS-2016-001-07	Edwards	KS	MIDW	11/1/2021	78.2	Wind	North Kinsley 115 kV	IA FULLY EXECUTED/ON SUSPENSION
GEN-2016-030	IFS-2016-001-26	Johnston County	OK	OKGE	12/1/2021	100	Solar	Brown 138kV	IA FULLY EXECUTED/ON SCHEDULE
GEN-2016-032	IFS-2016-001-11	Kingfisher County	OK	OKGE	12/31/2023	200	Wind	Crescent Substation 138 kV	IA FULLY EXECUTED/ON SCHEDULE
GEN-2016-045	IFS-2016-001-34	Cimarron, Texas County	OK	OKGE	12/31/2021	499.1	Wind	Mathewson 345kV	IA FULLY EXECUTED/ON SCHEDULE
GEN-2016-057	IFS-2016-001-35	Cimarron, Texas County	OK	OKGE	12/31/2021	499.1	Wind	Mathewson 345kV	IA FULLY EXECUTED/ON SCHEDULE
GEN-2016-071	IFS-2016-001-19	Kay	OK	OKGE	11/30/2021	200.1	Wind	Middleton Tap 138kV Substation	IA FULLY EXECUTED/ON SUSPENSION
GEN-2016-073	IFS-2016-001-48	Kingman County	KS	WERE	10/30/2022	220	Wind	Thistle-Wichita Dbl Ckt (Buffalo Flats) 345kV	IA FULLY EXECUTED/ON SCHEDULE
GEN-2016-102	IFS-2016-002-01	Pontotoc	OK	OKGE	12/1/2023	150.9	Wind	Blue River 138kV	IA FULLY EXECUTED/ON SUSPENSION
GEN-2016-118	IFS-2016-002-05	Kingfisher	OK	WFEC	10/1/2021	288	Wind	Dover Switchyard 138 kV Line	IA FULLY EXECUTED/ON SCHEDULE
GEN-2016-126	IFS-2016-002-06	Murray	OK	OKGE	10/15/2021	172.5	Wind	Arbuckle 138kV substation	IA FULLY EXECUTED/ON SCHEDULE
GEN-2016-131	IFS-2016-002-37	Grady	OK	OKGE	10/31/2020	2.5	Wind	Minco 345kV	IA FULLY EXECUTED/ON SCHEDULE
GEN-2016-132	IFS-2016-002-61	Roger Mills	OK	AEPW	5/6/2020	6.1	Wind	Sweetwater 230kV	IA FULLY EXECUTED/ON SCHEDULE
GEN-2016-150	IFS-2016-002-15	Nemaha	KS	WERE	12/30/2022	302	Wind	Stranger Creek 345kV	IA FULLY EXECUTED/ON SCHEDULE
GEN-2016-157	IFS-2016-002-20	Allen County	KS	KCPL	12/31/2022	252	Wind	West Gardner 345kV	IA FULLY EXECUTED/ON SUSPENSION
GEN-2016-158	IFS-2016-002-17	Allen County	KS	KCPL	12/31/2022	252	Wind	West Gardner 345kV	IA FULLY EXECUTED/ON SUSPENSION
GEN-2016-174	IFS-2016-002-19	Nemaha	KS	WERE	11/6/2020	302	Wind	Stranger Creek 345kV	IA FULLY EXECUTED/ON SCHEDULE
GEN-2016-176	IFS-2016-002-67	Nemaha County	KS	WERE	11/30/2021	302	Wind	Stranger Creek 345kV	IA FULLY EXECUTED/ON SCHEDULE
GEN-2014-001	IFS-2014-001-08	Marion	KS	WERE	7/28/2020	200.6	Wind	Tap Wichita - Emporia Energy Center 345kV	IA FULLY EXECUTED/ON SCHEDULE
GEN-2015-034	IFS-2015-002-08	Kay County	OK	OKGE	10/31/2020	200	Wind	Rose Hill (Open Sky)-Sooner (Ranch Road) 345kV	IA FULLY EXECUTED/ON SCHEDULE
GEN-2015-052	IFS-2015-002-03	Sumner	KS	WERE	12/1/2019	300	Wind	Open Sky-Rose Hill 345kV	IA FULLY EXECUTED/ON SUSPENSION
GEN-2015-066	IFS-2015-002-38	Roosevelt County	OK	OKGE	12/31/2022	248.4	Wind	Sooner - Cleveland 345kV	IA FULLY EXECUTED/ON SCHEDULE
GEN-2016-046	IFS-2016-001-12	Ford County	KS	SUNC	11/15/2021	299	Wind	Clark County-Ironwood 345kV	IA FULLY EXECUTED/ON SCHEDULE
GEN-2016-051	IFS-2016-001-13	Custer	OK	AEPW	12/31/2020	9.8	Wind	Clinton Junction-Weatherford Southeast 138kV	IA FULLY EXECUTED/ON SCHEDULE
GEN-2016-063	IFS-2016-001-17	Johnston	OK	OKGE	9/1/2021	200	Wind	Hugo-Sunnyside 345 kV	IA FULLY EXECUTED/ON SCHEDULE
GEN-2016-091	IFS-2016-002-22	Caddo	OK	AEP	12/31/2021	303.6	Wind	Gracemont-Lawton East Side 345kV	IA FULLY EXECUTED/ON SCHEDULE
GEN-2015-036	IFS-2016-001-44	Johnston County	OK	OKGE	8/30/2020	303	Wind	Johnston County 345kV	IA FULLY EXECUTED/ON SCHEDULE
GEN-2015-082	IFS-2016-001-28	Beaver	OK	OKGE	12/1/2020	198	Wind	Beaver County - Woodward EHV Dbl Ckt (Badger) 345kV	IA FULLY EXECUTED/ON SCHEDULE
GEN-2016-020	IFS-2016-001-27	Woodward County	OK	WFEC	12/15/2020	148.4	Wind	Moreland 138kV Substation	IA FULLY EXECUTED/ON SCHEDULE
GEN-2016-068	IFS-2016-001-40	Garfield	OK	OKGE	10/21/2020	250	Wind	Woodring 345kV	IA FULLY EXECUTED/ON SCHEDULE
GEN-2016-149	IFS-2016-002-14	Washington	KS	WERE	12/31/2022	300	Wind	Stranger Creek 345kV	IA FULLY EXECUTED/ON SCHEDULE
GEN-2016-061	IFS-2016-001-15	Garfield/Noble	OK	OKGE	8/1/2020	248.16	Wind	Sooner-Woodring 345 kV line	IA FULLY EXECUTED/ON SCHEDULE
GEN-2017-009	0	Neoshoe County	KS	WERE	10/31/2020	302.5	Wind	Neosho - Caney River 345 kV	DISIS STAGE

List of Transmission Projects - 1/4

Transmission projects that are planned to be in service by 2025 are selected from SPP's 2019 Integrated Transmission Planning (ITP) Assessment Report.

PLANNED TRANSMISSION PROJECTS FROM 2019 ITP FOR 2020-2025 (230 KV AND HIGHER)

Project Name	Project Type	Owner	Project Status	In-Service Date
Multi - Gentleman - Cherry Co. - Holt Co. 345 kV	Regional Reliability	NPPD	Delay - Mitigation	6/1/2022
XFR - Thedford 345/115 kV	High Priority	NPPD	Delay - Mitigation	5/1/2021
XFR - Wolfforth 230/115 kV Ckt 1 Transformer	Regional Reliability	SPS	On Schedule < 4	4/15/2021
Sub - Amarillo South 230 kV Terminal Upgrades	Regional Reliability	SPS	On Schedule < 4	4/1/2020
XFR - Sundown 230/115 kV Transformer	Regional Reliability	SPS	Delay - Mitigation	12/15/2020
Multi - Tuco - Yoakum 345/230 kV Ckt 1	Regional Reliability	SPS	Delay - Mitigation	6/1/2020
Sub - Nichols - 230 kV	Regional Reliability	SPS	Delay - Mitigation	5/15/2020
Multi - Sheldon - Monolith 115 kV	Regional Reliability	NPPD	Delay - Mitigation	1/1/2021
XFR - Lawrence Hill 230/115kV	Regional Reliability	WR	Delay - Mitigation	6/1/2021
XFR - McDowell 230/115 kV Ckt 1	Regional Reliability	SPS	Delay - Mitigation	5/28/2021
Multi - China Draw - Road Runner 345 kV	Regional Reliability	SPS	Delay - Mitigation	11/15/2021
Line - Eddy County - Kiowa 345 kV New Line	Regional Reliability	SPS	On Schedule < 4	11/15/2020
Multi - S1361	Regional Reliability	OPPD	On Schedule < 4	6/1/2021
Multi - Cimarron - Northwest - Mathewson 345kV	Economic	OGE	On Schedule < 4	7/1/2020
Multi - Neset - New Town 230 kV	Regional Reliability	BEPC	Re-evaluation	12/31/2022
Sub - Neosho 345 kV	Sponsored Upgrade	WR	On Schedule < 4	7/1/2020

List of Transmission Projects - 2/4

Transmission projects that are planned to be in service by 2025 are selected from SPP's 2019 Integrated Transmission Planning (ITP) Assessment Report.

PLANNED TRANSMISSION PROJECTS FROM 2019 ITP FOR 2020-2025 (138 KV AND 169 KV)

Project Name	Project Type	Owner	Project Status	In-Service Date
Line - Cedar Grove - South Shreveport 138 kV	Transmission Service	AEP	On Schedule < 4	6/1/2020
Line - Keystone Dam - Wekiwa 138 kV Ckt 1 Rebuild	Regional Reliability	AEP	On Schedule < 4	6/1/2021
Line - Lincoln - Meeker 138 kV Ckt 1 New Line	Regional Reliability	OGE	Delay - Mitigation	7/31/2020
Multi - Driftwood 138/69 kV Substation and Transformer	Regional Reliability	WFEC	Delay - Mitigation	4/1/2022
Multi - DeGrasse - Knob Hill 138 kV New Line and DeGrasse 345/138 kV	Regional Reliability	WFEC	Delay - Mitigation	12/1/2024
Sub - Cleo Junction 138 kV Terminal Upgrades	Regional Reliability	WFEC	Delay - Mitigation	5/31/2023
Line - Crosstown - Blue Valley 161 kV New Line	Regional Reliability	KCPL	Re-evaluation	6/30/2023
Sub - Tupelo - Tupelo Tap 138 kV Terminal Upgrades	Economic	WFEC	Delay - Mitigation	12/31/2020
XFR - Creswell 138/69/13.2 kV Transformers	Regional Reliability	WR	On Schedule < 4	6/1/2021
Multi - Park Community - Sunshine 138 kV	Regional Reliability	WFEC	Delay - Mitigation	5/31/2021
Line - Cogar - OU SW 138 kV	Regional Reliability	WFEC	Delay - Mitigation	3/1/2024
Sub - Westmoore 138 kV	Regional Reliability	OGE	On Schedule < 4	12/31/2020
Sub - Santa Fe 138 kV	Regional Reliability	OGE	Re-evaluation	6/1/2021
Sub - Riverside Station 138 kV	Regional Reliability	AEP	Delay - Mitigation	11/1/2022
Sub - Southwestern Station 138 kV	Regional Reliability	AEP	Delay - Mitigation	11/1/2022
Sub - Moore 13.8 kV Breaker	Regional Reliability	NPPD	On Schedule < 4	6/1/2021
Sub - Craig 161 kV	Regional Reliability	KCPL	On Schedule < 4	12/31/2021
Sub - Leeds 161 kV	Regional Reliability	KCPL	On Schedule < 4	12/31/2020
Sub - Southtown 161 kV	Regional Reliability	KCPL	On Schedule < 4	12/31/2021
Sub - Mooreland 138/69 kV Breakers	Regional Reliability	WFEC	On Schedule < 4	5/1/2022
Line - Tulsa SE - S Hudson 138kV Ckt 1	Regional Reliability	AEP	Delay - Mitigation	11/1/2021
Line - Tulsa SE - 21st Street Tap 138kV Ckt 1	Regional Reliability	AEP	Delay - Mitigation	11/1/2021
Line - East Kingfisher - Kingfisher 138kV	Economic	WFEC	On Schedule < 4	1/1/2021
Line - Neosho - Riverton 161 kV	Transmission Service	EDE	NTC-C Project Estimate	10/1/2023
XFR - Pryor Junction 138/115	Regional Reliability	AEP	Delay - Mitigation	11/30/2021
Line - Anadarko - Gracemont 138kV	Economic	WFEC	On Schedule < 4	1/1/2021
Jayhawk Wind 161/69kV Transformer	Sponsored Upgrade	Apex		12/31/2021

List of Transmission Projects - 3/4

Transmission projects that are planned to be in service by 2025 are selected from SPP's 2019 Integrated Transmission Planning (ITP) Assessment Report.

PLANNED TRANSMISSION PROJECTS FROM 2019 ITP FOR 2020-2025 (115 KV)

Project Name	Project Type	Owner	Project Status	In-Service Date
Line - Northwest - Rolling Hills 115 kV Ckt 1	Regional Reliability	SPS	On Schedule < 4	5/15/2021
Line - Ainsworth - Ainsworth Wind 115 kV Ckt 1 Rebuild	Regional Reliability	NPPD	On Schedule < 4	6/1/2020
Sub - Carlsbad - Pecos 115 kV Terminal Upgrades	Regional Reliability	SPS	On Schedule < 4	6/1/2021
Carlisle - Murphy 115kV Terminal Upgrades	Regional Reliability	SPS	On Schedule < 4	6/1/2022
Sub - Carlsbad Interchange 115 kV	Regional Reliability	SPS	On Schedule < 4	6/1/2021
Sub - Hale Cty Interchange 115 kV	Regional Reliability	SPS	On Schedule < 4	6/1/2021
Sub - Denver City Interchange 115 kV North	Regional Reliability	SPS	On Schedule < 4	6/1/2021
Sub - Canaday 115 kV	Regional Reliability	NPPD	On Schedule < 4	6/1/2021
Sub - Hastings 115 kV	Regional Reliability	NPPD	On Schedule < 4	6/1/2021
Multi - Marshall County - Smittyville - Baileyville - South Seneca 115 kV	Regional Reliability	WR	Delay - Mitigation	6/1/2023
Sub - Firth 115kV	Regional Reliability	NPPD	Delay - Mitigation	6/1/2023
Sub - Amoco - Sundown 115 kV	Economic	SPS	On Schedule < 4	6/1/2020
Line - Hansford - Spearman 115kV	Economic	SPS	On Schedule < 4	1/1/2021
Multi-Hobbs Interchange-Millen 115kV	Regional Reliability	SPS	On Schedule < 4	6/1/2022
Sub - Denver City Interchange South 115 kV	Regional Reliability	SPS	On Schedule < 4	6/1/2021
Line - Aberdeen City - Aberdeen Industrial Park 115 kV	Sponsored Upgrade	NWE	On Schedule < 4	12/31/2021

List of Transmission Projects - 4/4

Transmission projects that are planned to be in service by 2025 are selected from SPP's 2019 Integrated Transmission Planning (ITP) Assessment Report.

PLANNED TRANSMISSION PROJECTS FROM 2019 ITP FOR 2020-2025 (69 KV AND LOWER)

Project Name	Project Type	Owner	Project Status	In-Service Date
Line - Elmore - Paoli 69 kV Rebuild	Regional Reliability	WFEC	Delay - Mitigation	3/1/2022
Line - Sara Road - Sunshine Canyon 69 kV Ckt 1 Rebuild	Regional Reliability	WFEC	Delay - Mitigation	12/31/2019
Device - S964 69 kV Cap Bank	Regional Reliability	OPPD	On Schedule < 4	6/1/2020
Line - Atoka - Atoka Pump - Pittsburg - Savanna - Army Ammo - McAlester City	Zonal Reliability	AEP	Delay - Mitigation	11/20/2020
Line - City of Winfield - Oak 69 kV Reconductor	Regional Reliability	KPP	On Schedule < 4	12/30/2020
Device - Dover SW 69 kV Cap Bank	Regional Reliability	WFEC	Delay - Mitigation	9/1/2023
Device - Cherokee SW 69 kV Cap Bank	Regional Reliability	WFEC	Delay - Mitigation	8/1/2023
Device - Clear Creek Tap 69 kV Cap Bank	Regional Reliability	WFEC	Delay - Mitigation	12/1/2020
Sub - Washita 69 kV	Regional Reliability	WFEC	On Schedule < 4	6/1/2021
Device- Gypsum 69 kV Capacitor Bank	Regional Reliability	WFEC	On Schedule < 4	6/1/2021
Sub - Cleo Corner - Cleo Junction 69kV	Regional Reliability	OGE	On Schedule < 4	6/1/2022
SUB - Marietta - Rocky Point 69 kV	Regional Reliability	WFEC	On Schedule < 4	12/1/2021
SUB - Forest Hill 69 kV Terminal Upgrades	Regional Reliability	OGE	On Schedule < 4	1/1/2021
DPNS-2019-March-1011 Shell Rock and Bauman Substation	Regional Reliability	CBPC	NTC - Commitment	6/1/2020

Review of Public Reports - 1/2

Adding more renewables produces jobs.

- Various (14) public reports were reviewed to estimating the jobs and other economic benefits of wind development (out of 11 had useful information).

11 STUDIES ON THE ECONOMIC BENEFITS OF WIND DEVELOPMENT

Study	Region
Aldieri et. al, Wind Power and Job Creation, 2019	U.S. and other countries
AWEA, Wind Powers America Annual Report, 2019	Nationwide
Brattle, Job and Economic Benefits of Transmission and Wind Generation Investments in the SPP Region, 2010	SPP
EIG, Statewide Economic Impact of Wind Energy Development in Oklahoma, 2014	Oklahoma
NREL, Economic Impacts from Wind Energy in Colorado Case Study, 2019	Rush Creek Wind Farm, Colorado
NREL, Economic Development Impact of 1,000 MW of Wind Energy in Texas, 2011	Texas
NREL, Economic Impacts from Indiana's First 1,000 MW of Wind Power, 2014	Indiana
NREL, Estimated Economic Impacts of Utility Scale Win Power in Iowa, 2013	Iowa
NREL, Jobs and Economic Development from New Transmission and Generation in Wyoming, 2011	Wyoming
UC Berkeley, Job Impacts of California's Existing and Proposed RPS, 2015	California
USDA, Ex-Post Analysis of Economic Impacts from Wind Power Development in U.S. Counties, 2012	Great Plains and Rocky Mountains

Note: Three additional studies reviewed (whose data was not directly applicable to the analysis) are: NREL, Analysis of the Renewable Energy Projects Supported by 1603 Treasury Grant Program, 2012; NYSERDA, New York Clean Energy Industry Report, 2019; and NREL, Counting Jobs and Economic Impacts From Distributed Wind in the United States, 2014.

Review of Public Reports - 2/2

Adding more renewables produces additional local benefits.

- Various (7) public reports were reviewed specifically to estimate the other economic benefits (tax and lease revenue) of wind development.

7 STUDIES ON THE ECONOMIC BENEFITS OF WIND DEVELOPMENT

Study	Region
EIG, Statewide Economic Impact of Wind Energy Development in Oklahoma, 2014	Oklahoma
NREL, Economic Impacts from Wind Energy in Colorado Case Study, 2019	Rush Creek Wind Farm, Colorado
NREL, Economic Development Impact of 1,000 MW of Wind Energy in Texas, 2011	Texas
NREL, Economic Impacts from Indiana’s First 1,000 MW of Wind Power, 2014	Indiana
NREL, Estimated Economic Impacts of Utility Scale Win Power in Iowa, 2013	Iowa
NREL, Jobs and Economic Development from New Transmission and Generation in Wyoming, 2011	Wyoming
Wind Powers America Annual Report, 2019	USA state-level data

Note: The WPA annual report contained data for each state. All other sources report values from a single project.

About Brattle

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