21, rue d'Artois, F-75008 PARIS
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# Unlocking the Queue with Grid-Enhancing Technologies: Case Study of the Southwest Power Pool

| B. TSUCHIDA | J. CASPARY, J. SCHNEIDER | T. BLOCH-RUBIN | J. MARMILLO | P. RUIZ |
|---|---|---|---|---|
| The Brattle Group | Grid Strategies | Smart Wires | LineVision | NewGrid |
| USA | USA | USA | USA | USA |

## SUMMARY

Transmission availability has proven to be a major limiting factor in large-scale renewable resource development. As more renewable resources interconnect to the grid without enough transmission capacity to accommodate them, transmission congestion often causes renewable curtailment. While transmission expansion can help alleviate congestion and curtailment issues, major transmission expansion can take years, or even decades, to complete. Renewable capacity, on the other hand, can be developed more quickly, which can leave renewable projects stuck in generator interconnection queues when there is insufficient transmission. If no solution is adopted, the number of renewable projects caught in these queues will increase as intensifying clean energy and carbon reduction goals encourage more renewable development.

Grid-Enhancing Technologies (GETs) allow for quick and cost-effective maximization of the existing transmission system capability by increasing the capacity, efficiency, and reliability of transmission facilities. This study focuses on the combined potential impact of utilizing three technologies on the Southwest Power Pool (SPP) grid: Dynamic Line Ratings (DLR), Advanced Power Flow Control, and Topology Optimization. Using 24 historical power flow snapshots of SPP operations that cover the entire SPP network, the analysis looks at how much additional renewables can be added in Kansas and Oklahoma by the potential transmission capacity improvements from the combined use of all three GETs. After modifying power flow snapshots to reflect projects in interconnection queues, planned generation retirements, and planned transmission expansion, this study estimates that combined GETs usage can double the annual renewable development in Kansas and Oklahoma in 2025 relative to a Base Case with no GETs deployment (2,580 Megawatts [MW] under the Base Case and 5,250 MW with the Change Case, an increase of 2,670 MW, which is more than a 100% increase from the Base Case). GETs installation and annual O&M costs to achieve this are estimated to total $90 million and $10 million, respectively. Therefore, the incremental cost of integrating these additional renewables is about $34/kW, which is about 2 to 3 percent of the assumed development cost of $1,500/kW for large-scale wind projects. The annual production cost savings from the 2,670 MW of large-scale renewables are estimated to total $175 million. Additionally, GETs deployment creates over 11,300 direct short-term renewable construction jobs and over 650 direct long-term jobs for operation and maintenance of the renewable resources. Local benefits are also estimated to include over $32 million in annual tax revenues and $15 million in land lease revenues. Lastly, GETs deployment generates carbon emissions reductions estimated to total over 3 million tons per year.

Jcaspary@gridstrategiesllc.com

Extrapolating the results of this study in SPP's territory to the national level demonstrates that GETs can enable annual production cost savings increase to over $5 billion. The corresponding GETs installation and annual O&M costs are $2.7 billion and $300 million, respectively. GETs deployment at the national level also creates over 330,000 short-term jobs and nearly 20,000 long-term jobs while local benefits include approximately $1.5 billion in local taxes and land lease revenues. Additionally, carbon emissions reductions are estimated to increase to nearly 90 million tons annually, which is more than enough to offset all new cars sold in the US on an annual basis.

## KEYWORDS

Grid-Enhancing Technologies (GETs), Advanced Power Flow Control, Dynamic Line Ratings (DLR), Topology Optimization, Southwest Power Pool (SPP), Renewable Integration, Transmission Capacity, Flexible Alternating Current Transmission Systems (FACTS)

## I. Introduction and Scope

This study assesses how much additional renewable capacity could be integrated onto the SPP grid in the year 2025 with the assistance of DLR, Topology Optimization, and Advanced Power Flow Control technologies (in this specific order), and quantifies the economic and carbon emissions reduction benefits associated with their deployment leading to higher levels of renewable integration. The analysis focuses on deployment specifically in Kansas and Oklahoma as an illustrative case study because they are areas within SPP that have been identified to have significant transmission constraints and planned large-scale renewable capacity. At the time of this analysis, the SPP interconnection queue showed more than 9 Gigawatts (GW) of large-scale renewable resources with executed Interconnection Agreements [1]. Despite the large amount of renewable capacity in the queue, the SPP Integrated Transmission Planning (ITP) reports show high congestion in the region, which would result in renewable generation curtailments once the projects are ultimately placed in service [2].

Traditional thinking treats transmission as if it has a fixed capacity and cannot be operated dynamically. However, much like how advancements in maps and GPS technologies have allowed for safer, easier, and more efficient travel on roads, GETs have allowed for more flexibility in how the grid can be operated. GETs have matured over the past several decades and are commercially proven to be cost-effective and fast-acting solutions on grids around the world. The three GETs considered for this analysis are explained in more detail below.

### DLR

Transmission line ratings are traditionally based on Static Line Ratings (SLR) where the maximum operating temperature for a given line is pre-determined. SLR uses conservative assumptions, such as low wind, high temperature, and high solar irradiance, to accommodate most conditions. In a way, it is similar to setting the highway speed limit based on snowy road conditions. Recently, more transmission operators have adopted ambient adjusted rating (AAR).

DLR goes beyond AAR and increases line capacity by adjusting 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. Other measurements that can be taken into consideration when calculating DLR include line temperature and line sagging. The DOE/ONCOR study indicates DLR transfer capability to be 5% to 25% higher than SLR [3]. DLR is particularly useful in integrating wind energy, as there is a high degree of overlap between wind production and DLR-induced allowable flow increases. European studies indicate DLR contributes to an approximately 15% reduction in wind curtailments in some areas. DLR can also be useful in the accumulation of real-time data, which can be used for future calibration, as DLR is variable and requires a forecast for operations planning.

### Topology Optimization

Topology Optimization automatically finds reconfigurations to re-route flow around congested or overloaded facilities while meeting reliability criteria. Power flow re-routing is achieved by switching circuit breakers open or close, which has a similar effect to power flow control technologies (discussed next) while using existing equipment. In a sense, Topology Optimization is analogous to temporarily diverting traffic away from congested roads to make traffic smoother and is often referred to as the "Waze" for the transmission grid.

Reconfiguring the grid in operations is feasible today. Circuit breakers are capable of high duty cycles and are extremely reliable. Some breakers are switched very frequently today – for example, those connecting generating units have daily start and stop operations. Additionally, switching infrastructure is already in place—most breakers are controlled remotely over Supervisory Control and Data

Acquisition (SCADA) by the transmission operator. Topology Optimization is relatively low cost and usually costs approximately $10-$100 per switching cycle.

**Advanced Power Flow Control**

Power flow control technologies can come in the form of Phase Shifting Transformers (PSTs), also referred to as Phase Angle Regulators (PARs). These technologies have been widely accepted in the industry. The largest drawback for these technologies is the deployment cost—for example, a recently-installed PAR between Michigan and Ontario has an annual carrying cost of over $10 million. Flexible Alternating Current Transmission Systems (FACTS) are power-electronic-based static devices that allow for flexible and dynamic control of flow on transmission lines or the voltage of the system. Advanced Power Flow Control analyzed in this study is a FACTS device that alters 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 frame, 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. Today's Advanced Power Flow Control technology deployments are typically cost competitive with legacy power flow control, and a fraction of the cost of new line construction or rebuilds.

The rest of the study is structured as follows. Section II contains the analysis approach, section III contains the study results, and section IV concludes.

## II. Analysis, Approach, and Assumptions

The analysis approach for this report is composed of the following five steps:

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

GETs focus on transmission operations and planning and are particularly helpful in increasing renewable penetration when transmission congestion curtails renewables (or prevents their interconnection). More renewables (largely wind in SPP) will also likely lead to higher levels of transmission congestion if there is no significant transmission expansion. Therefore, the preferred areas identified in this study are (1) areas with transmission constraints identified in SPP transmission studies, and (2) areas with significant generation resource changes (large amounts of new renewable projects and retirements of existing resources). Based on the observations from SPP's 2019 Integrated Transmission Planning (ITP) report and Generator Interconnection (GI) queue, Kansas and Oklahoma are selected as focus areas. The ITP report identifies two target areas:

- **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 can 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.

- **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.

For Kansas and Oklahoma in particular, SPP's GI Queue shows significant renewable additions and material retirements of existing generation resources as shown in table 1 below:

**Table 1: Planned Capacity and Retirement 2020-2025**

KS/OK

| | | 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** |

Selection criteria for new renewables projects are set to those where Interconnection Agreements have been fully executed. This approach includes over 9,400 MW of renewable projects, as shown in table 2 below:

**Table 2: 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 |

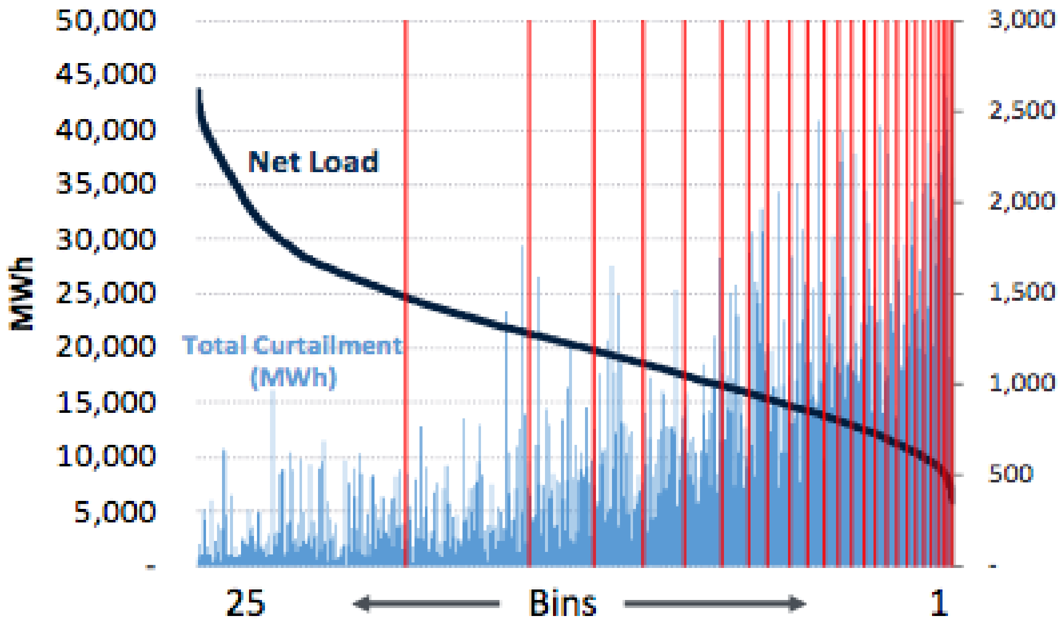
Note: Rounded to the nearest 10 MW

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

The study analyzed 24 snapshots representing varying conditions over a full year for the entire SPP territory. This is an alternative approach to performing production simulation type analyses and will likely reflect historical operational conditions better than production simulations. This section discusses how the 24 snapshots were selected.

All hours from a calendar year (summer 2019 through summer 2020) were sorted by decreasing net load (i.e., SPP load minus SPP wind) and divided into 25 bins (numbered 1 through 25), with each bin containing about 1/25th of the total annual curtailment observed. These bins are shown in figure 1 below, where the areas between the red lines mark each of the 25 bins. The count of hours is higher in bins where the net load (shown as the thick black line in the chart) is higher (i.e., towards the left side of the figure). The curtailment rate (curtailment per hour, shown in %) increases towards the right-hand side of the chart (as the distance between the red lines, or count of hours represented in each bin, decrease).

**Figure 1: Net Load and Wind Curtailment**




A more granular look into the bin information can be found in table 3 below. When analyzing the bins below, the first bin (bin 25) is excluded, as it represents the minimal average curtailment rates (fourth column in table):

**Table 3: Bin Information**

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 |

Historical power flow cases that best represent bins 1 through 24 in the figure above (i.e., snapshots) are then selected. The 24 snapshots span the conditions where wind curtailment occurs as shown in table 4 below. To maintain a daily and seasonal spread, we avoid choosing hours from the same day:

**Table 4: Bin Information – Representative Hour Selections**

| 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** |

Wind production potential and curtailment for each bin can be found in figures 2 and 3 below. The wind production potential in the sample ranges from 7.9 to 18.3 GWs, with the average value totaling 14.3 GW.

**Figure 2: Wind Production Potential in Selected Snapshots**

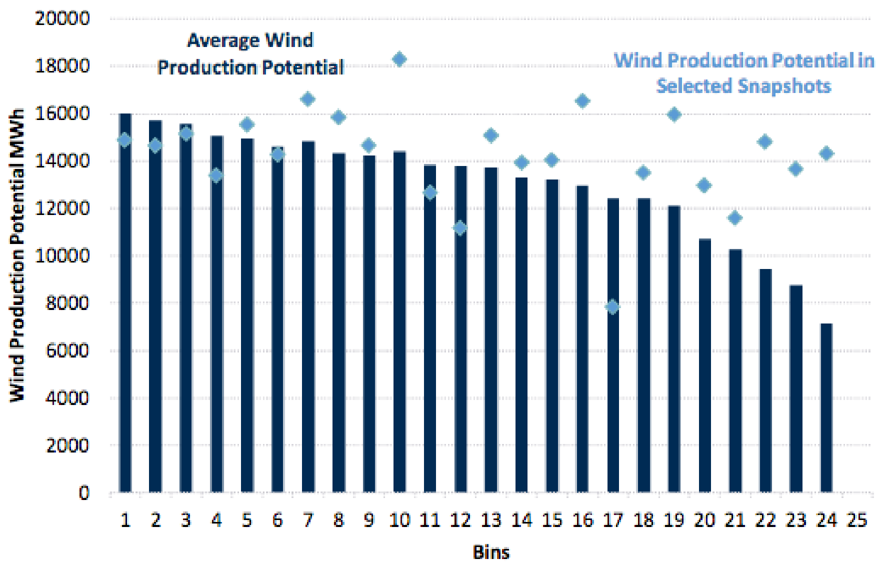
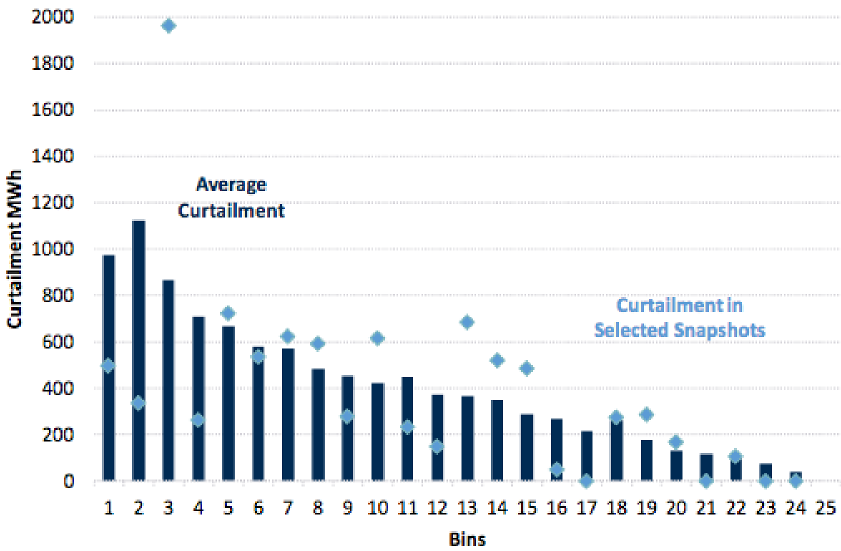


**Figure 3: Curtailment in Selected Snapshots**




**Step 3: Modify the snapshots**

Each of the 24 snapshots is then modified to model 2025 by reflecting new transmission upgrades, wind/solar units and announced retirements from the SPP GI queue, and load changes. To account for transmission changes, we adjust transmission constraint limits by comparing binding constraints against historical data (and adjust as necessary). Additionally, we added over 70 transmission projects from SPP's ITP reports that are planned to be in service by 2025, as summarized in table 5 with details in tables 6-9:

**Table 5: Summary of 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 |

**Table 6: 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 |

**Table 7: 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 |

**Table 8: 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 |

**Table 9: 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 |

We also identify outages in the snapshots that correspond to capital projects and put them back in service. We additionally setup single-element contingencies in SPP and neighboring areas (Mid-American, Associated Electric, Entergy etc.).

The analysis also reflects changes in generation. To do this we add new wind and solar units from the SPP GI queue and assume added units' max potential output based on capacity factor from nearby units of the same type (this is done by snapshot). We also adjust wind/solar dispatch to reverse curtailment by observing historical data on Locational Marginal Prices (LMPs) to identify units that may have been curtailed (e.g., LMP less than -$20/MWh). For assumed curtailments, we estimate what the non-curtailed dispatch might have been using nearby wind/solar units. We also track any new thermal generation additions or retirements in the GI queue.

For the purposes of the study, load is adjusted to reflect 2025 levels. SPP estimates 240 MW of load growth between 2020 and 2025. The analysis also removes the portion of Lubbock load (470 MW) that is scheduled to transfer to ERCOT in 2021 [4]. Finally, the study assumes imports and exports with neighboring areas to remain constant at historical levels.

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

The base case is created by dispatching wind and solar to their max output by running Security Constrained Optimal Power Flow (SCOPF). The output of non-renewable units is then adjusted in the following ways:

- 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 nighttime 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).

A priority order is then established for wind and solar (existing wind/solar is prioritized over new wind/solar).

The analysis assesses curtailment without GETs. First, we perform contingency analysis and add appropriate interfaces needed to represent the contingency analysis results. We enforce transfer limits for all lines 69 kV and higher within SPP, and 100 kV and higher for external regions. We then add the new renewable projects (over 9 GW) to the power flow cases and solve SCOPF to identify feasible projects. For new renewable projects (9,430 MW-worth from GI Queue), we assume a 5% curtailment threshold for viability assessment (i.e., projects are considered viable if the analysis indicates annual curtailments to be less than 5%). This is performed through an iterative process (i.e., we first add all 9+ GW of large-scale renewable projects, run SCOPF, identify projects with high curtailments, take out those renewable projects with high curtailments, add back the rest of the projects, then resolve SCOPF, identify projects with high curtailment levels from this subset of projects, take them out, and repeat this process until all projects remaining are deemed feasible with annual curtailments below the threshold level).

The maximum amount of renewables that can be integrated in the Base Case and the With GETs Case are found by solving the power flow cases (for the entire SPP footprint) with and without GETs. When assessing the With GETs Case, the analysis identifies opportunities presented first by DLR, then by Topology Optimization, and lastly by Advanced Power Flow Control. The With GETs Case analysis assumes the same 5% threshold to assess project viability. It is important to note that the results are for the combined benefits of GETs usage, rather than for 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 including economic values (production cost savings, job creation, local benefits, etc.) and carbon emissions reduction.**

The analysis outlined in Step 4 will determine the projects that are feasible and provide the total capacity (MW) of such projects. To assess the benefits of deploying GETs on the SPP grid we first calculate the annual generation (MWh) from these feasible projects. In doing so, we rely on historical generation level by renewable type (i.e., solar and wind). For this study we conservatively assumed a 37.5% capacity factor for wind (based on average capacity factor of all existing wind within SPP) and 18.0% for solar. This is conservative because newer plants do show higher capacity factors. We then convert the generation values into production cost benefits and carbon emission benefits utilizing SPP market data where applicable. We further reviewed public studies on the economic impacts to estimate "per unit" benefits and apply those to the findings. In addition, we relied on cost data provided by GETs vendors for both initial investment and the ongoing operational costs once installed.

To estimate the number of renewable jobs generated from the increased amount of renewable energy capacity facilitated by GETs, we reviewed 14 public reports shown in table 10 below to assess job impacts through wind investments. 11 of the 14 reports had useful information, and include information regarding direct, indirect, and induced jobs. The data generally reflects short-term jobs (e.g., construction jobs) rather than long-term O&M jobs, and the impacts are largely at the state level (or smaller geographical areas).

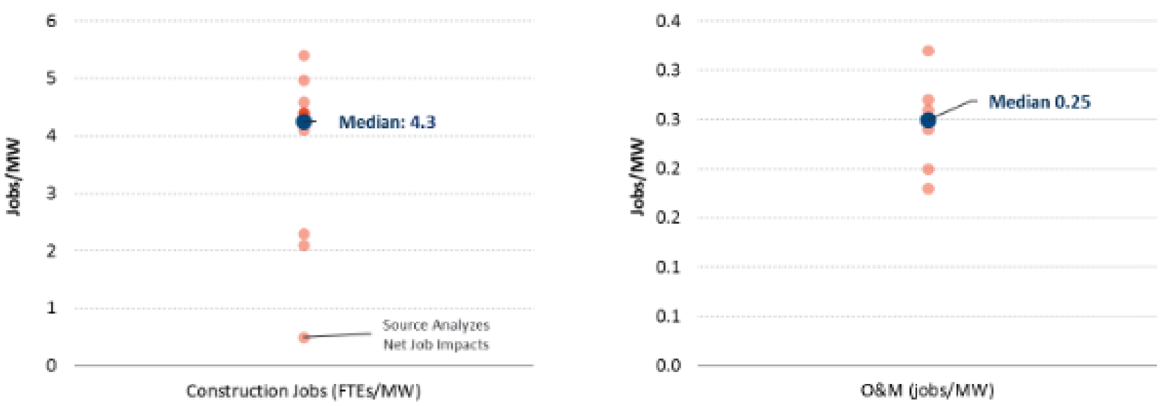
**Table 10: 11 Studies on the Economic Benefits of Wind Development**

| 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.

Figure 4 below aggregates the data found in the 11 studies above:

**Figure 4: Comparison of Job Impacts Across Studies**



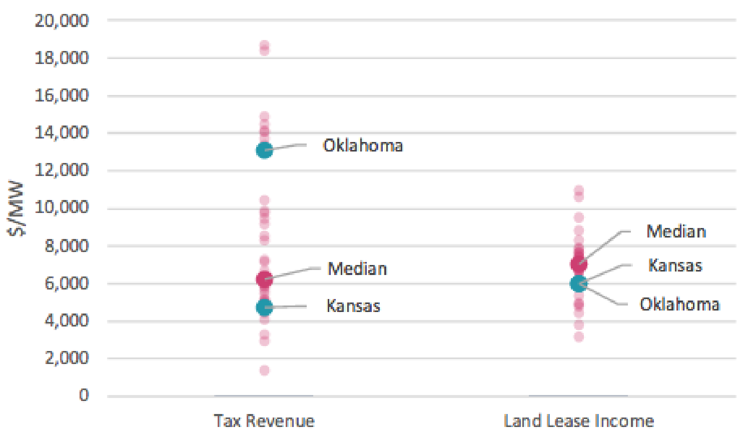

We also estimate the local benefits generated by increasing renewable production. A review of the 7 public reports in table 11 allows us to compare the land lease and tax revenues from wind development, found in figure 5 below.

**Table 11: 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.

**Figure 5: Comparison of Lease and Tax Revenues Across Studies and States**




## III. Study Results

### Renewables Under Base Case

Under the Base Case, approximately 2,580 MWs of renewable capacity can be integrated to the SPP grid in 2025. A few contributing factors include the retirement of existing thermal resources and the load growth from 2020-2025. Additionally, the Lubbock load departure works against the integration of renewables since it requires more renewable exports from the south plains of SPP. Table 12 below shows renewable integration in the Base Case in more detail:

**Table 12: 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% |

Note: Rounded to the nearest 10 MW

**Renewables Under With GETs Case**

The GETs utilized in the With GETS Case include DLR on 56 lines (15 to 30 sensors per DLR installation), 204 unique Topology Optimization reconfigurations, which average 13 per snapshot, and Advanced Power Flow Control at 8 locations. For Topology Optimization, average actions represent the average number of actions that remain per snapshot, 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. Tables 13 and 14 below outline hardware and software solutions by voltage level:

**Table 13: Hardware Solutions by Voltage Level**

| 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 |

**Table 14: Software Solutions by Voltage Level**

| 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 |

The estimated initial investment costs are around $90 million, while ongoing costs are estimated to total around $10 million per year. It is important to note that costs can vary project by project, and also based 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 into their existing control systems without large costs.

In the study areas of focus, the installation of GETs allows for over 5,200 MW of new renewables to be integrated onto the grid as shown in table 15 below. This is more than twice the amount of renewables integrated in the Base Case:

**Table 15: 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% |

Note: Rounded to the nearest 10 MW

A side-by-side comparison of additional renewables integrated in the Base Case and the With GETs case can be found in table 16 below:

**Table 16: Additional Renewables Integrated Base Case vs. With GETs Case**

| 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 |

Note: Rounded to the nearest 10 MW

The difference of 2,670 MW is approximately 1.5 times the amount of wind integrated in SPP in 2019 (1.8 GW). The $90 million in GETs investment enabling 2.670 MW of additional renewables calculates to approximately $34/kW for new renewables, or about 2% (less than 2.5%) of a typical new wind project investment cost estimated to be $1,500/kW.

This 2,670 MW conservatively translates to 8,776 Gigawatt-hours (GWh), of additional renewables integrated as a result of GETs deployment. It is made up of 2,630 MW/8,640 GWh of wind energy per year, and 40 MW/60 GWh of solar energy per year, assuming the aforementioned capacity factors of 37.5% for wind and 18.0% for solar, respectively.

**Benefits of Increased Renewables**

The estimated annual production cost savings from GETs deployment are estimated to total over $175 million. This production cost savings value is calculated by conservatively assuming $20/MWh savings for the 8,776 MWhs of new renewables. This assumption is based on an estimated cost of generation from a new natural gas-fueled combined-cycle plant in the $20/MWh to $25/MWh range (assuming $2.5-3.0/ Million Metric British Thermal Units [MMBtu] fuel cost and 7,000 Btu/kWh heat rate plus Variable Operations and Maintenance [VOM]). Additionally, generation costs 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 [5]. The 2018 average was $25/MWh for both new natural gas-fueled combined-cycle plants and coal plants. It is important to note this value does not include any

Production Tax Credit-driven savings. With an estimated $175 million of production cost savings, the payback for GETs investment (estimated at $90 million) is about half a year.

Integrating an additional 2,670 MWs of renewables using GETs also yields environmental benefits. This analysis estimates carbon emissions reductions to total over 3 million tons per year. To calculate this value, we conservatively assume 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 pounds per kWh). In reality, the new renewables may replace less efficient resources with higher emissions. Additional benefits include reduced water usage. By enabling twice the amount of renewables to be integrated, the reduction in water usage for power production is doubled.

Renewables integration also creates jobs and other local benefits. The additional 2,670 MWs (2,430 MW in Oklahoma and 200 MW in Kansas) are estimated to create:

- Over 11,300 direct short-term jobs (largely construction of renewables), assuming 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, assuming 0.25 jobs (person-year)/MW for wind and 0.005 jobs (person-year)/MW for solar.
- $32 million in annual tax revenues and $15 million in land lease revenues. Tax revenues assume $13,000/MW for the 2,430 MW in Oklahoma and $4,700/MW for the 200 MW in Kansas. Land lease revenues assume $5,900/MW for both Kansas and Oklahoma.

The benefits in SPP above are summarized in tables 17 and 18 below:

**Table 17: 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 factor. |
| | 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. |
| Annual Carbon Reduction | | 3 million tons | Assumes Combined Cycle Plant (350g per kWh). |

**Table 18: Summary of Benefits of Incremental 2,670 MW of Renewables (2/2)**

| Renewables Benefits | | |
|---|---|---|
| **Direct Jobs from Renewables** | **Short-term (Construction etc)** | **Over 11,300 person-year** |
| | **Long-term (O&M etc)** | **Over 650 person-year** |
| **Estimated Local Tax Revenues (Annual)** | | **$32 million** |

| Estimated Land Lease Revenues (Annual) | $15 million |
|---|---|

**Potential Nation-Wide Benefits of GETS**

GETs deployment can also generate significant benefits on a national scale. To estimate GETs-enabled additional renewable integration at the national level, we begin by noting 2019 generation in Kansas and Oklahoma combined was about 136 Terrawatt-hours (TWh) [6]. 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; therefore, 6.4% of 4,100 TWh would equate to 260 TWh worth of clean power.

We estimate nation-wide GETs investment costs to be $2.7 billion (only for the first year) and estimate ongoing costs to be around $300 million per year. Extrapolating these results to a nation-wide level indicate that GETs can provide annual benefits in the range of:

- Over $5 billion (~$5.3 billion) in production cost savings.
- 90 million tons of reduced carbon emissions, assuming wind replaces natural gas burning combined cycle plants – the cleanest conventional fossil-fuel-based power generation technology. This reduction is more than enough to offset emissions from 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 the first year) and nearly 20,000 long-term jobs.

It should be noted that the benefits calculated here do not vary by market structure—these savings metrics are relevant to both utilities that are still vertically integrated and those that are under deregulated RTO/ISO wholesale markets.

## IV. Conclusion

GETs are capable of quickly and cost-effectively maximizing the capability of the existing transmission system and can provide benefits at both the local and national levels. We estimate that the combined deployment of DLR, Advanced Power Flow Control, and Topology Optimization can double the amount of annual renewable development (an increase of 2,670 MW) in Kansas and Oklahoma in 2025 relative to a base case with no GETs deployment. At installation and annual O&M costs of $90 million and $10 million, respectively, GETs deployment in SPP is estimated to generate $175 million in annual production cost savings, suggesting a pay-back period of half a year. Additional benefits include: 11,300 direct short- jobs and over 650 direct long-term jobs, $32 million in annual tax revenues and $15 million in land lease revenues, and carbon emissions reductions estimated to total over 3 million tons per year. We find these benefits to increase significantly as we extrapolate these findings to the national level.

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