**Co-locating Wind and Solar Resources in a Constrained Transmission Environment**


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ABSTRACT

This paper evaluates the opportunity to load co-located wind and solar generation capacity onto a constrained transmission system while engendering only minimal losses. It quantifies the economic and energy opportunities and costs associated with pursuing this strategy in two Texas locations – one in west Texas and the other in south Texas. The study builds upon previous work published by the American Solar Energy Society (ASES) which illuminated the potential benefits of negative correlation of wind and solar generation in some locations by quantifying the economic and energy losses which would arise from deployment of solar generation in areas with existing wind generation and constrained transmission capacity. Clean Energy Associates (CEA) obtained and incorporated wind and solar resource data and the Electric Reliability Council of Texas (ERCOT)) load and price data into a model which evaluates varying levels of solar thermal, solar photovoltaic (PV) and wind capacity against an assumed transmission capacity limit at each of the two locations.


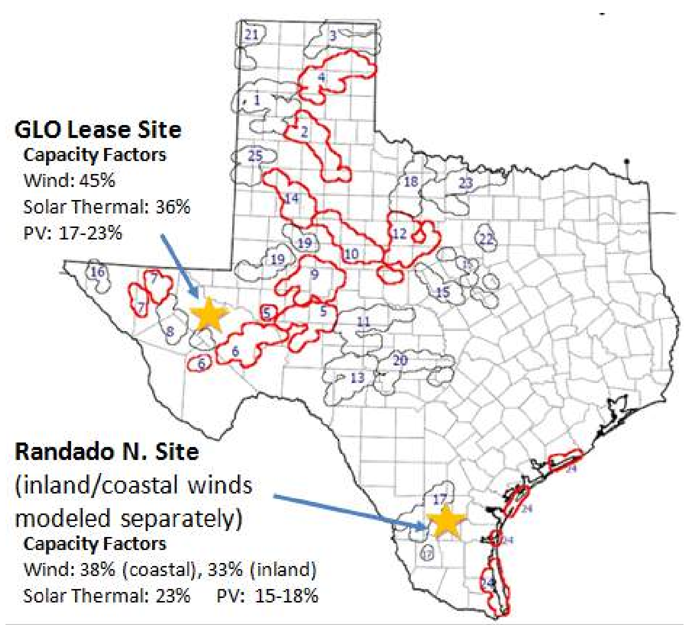


Figure 1: GLO Lease and Randado N Site Locations

## 1. MODEL DEVELOPMENT

A model, developed by CEA, evaluates varying levels of solar PV, solar thermal, and wind capacity against an assumed transmission capacity limit, and quantifies the total combined wind and solar generation as well as the amount of generation in excess of the assumed transmission limit, measured in both MWh and economic value. The capacity and transmission limits can be adjusted to estimate energy and economic losses resulting from additional solar generation capacity under specific scenarios. The capacity and transmission limits can be adjusted to evaluate specific scenarios.

The model incorporates data from the following sources:

- **Solar Data Sources**: National Renewable Energy, Laboratory's (NREL), National Solar Radiation Database (NSRDB), Texas Solar Radiation Database (TSRDB)
- **Wind Data Sources**: ERCOT Competitive Renewable Energy Zone (CREZ) and UPLAN data, Alternative Energy Center, West Texas A&M University, AWS TrueWind, Austin Energy - King Mountain
- **Load/Energy Price Data Sources**: ERCOT Marginal Cleaning Price of Energy (MCPE), ERCOT System Wide Load

## 2. CORRELATIONS

As shown below in Figure 2, at the GLO Lease site wind production is negatively correlated with all four solar applications and slightly negatively correlated with the marginal clearing price of energy (MCPE).

| Correlation | W | ST | PVT | PVF | PVFSW |
|---|---|---|---|---|---|
| Wind | 1.00 | | | | |
| ST | -0.24 | 1.00 | | | |
| PVT | -0.23 | 0.59 | 1.00 | | |
| PVF | -0.23 | 0.68 | 0.80 | 1.00 | |
| PVFSW | -0.27 | 0.71 | 0.79 | 0.96 | 1.00 |
| MCPE | -0.07 | 0.18 | 0.15 | 0.12 | 0.15 |

Note: Wind modeled at the McCamey B bus to the same solar generation at the GLO Lease Site was slightly less strongly negatively correlated to solar output (-0.20 for ST, PVT and PVFSW, and -0.18 for PVF), and slightly more strongly negatively correlated to MCPE (0.08).

**Figure 2: Correlation of Wind (McCamey A), Solar (GLO Lease Site), and MCPE**

At the Randado N site (Figure 3), coastal winds are weakly negatively correlated with all four solar applications. Wind production is slightly positively correlated with the MCPE, and all solar applications are more positively correlated with the MCPE.

| Correlation | W | ST | PVT | PVF | PVF SW |
|---|---|---|---|---|---|
| Wind | 1.00 | | | | |
| ST | -0.01 | 1.00 | | | |
| PVT | -0.04 | 0.54 | 1.00 | | |
| PVF | -0.09 | 0.69 | 0.78 | 1.00 | |
| PVF SW | -0.06 | 0.73 | 0.78 | 0.98 | 1.00 |
| MCPE | 0.05 | 0.20 | 0.15 | 0.11 | 0.15 |

**Figure 3: Correlation of Wind, Solar and the MCPE for Coastal Wind Regime at Randado N. Site**

## 3. BASE CASE ANALYSIS

The analysis evaluates the performance of a solar thermal power plant and three solar PV configurations: single-axis tracking, fixed tilt and orientation (due south), and fixed tilt and orientation (southwest) at each location. The base case scenario assumes the following parameters:

- Wind Capacity: 100 MW
- Transmission Limit: 100 MW
- Solar Capacity: 30 MW (AC for solar thermal, DC for solar PV)

When fully utilized, wind generation capacity alone reaches but does not exceed the transmission capacity limit in each study location. The additional solar capacity in the same location results in a combined wind and solar capacity which sometimes exceeds the assumed transmission capacity limit, and these losses are attributed to the solar generator. Figure 4 summarizes the base case energy and economic value losses at each site.

| | GLO Lease Site | | Randado N. Site - Coastal | | Randado N. Site - Inland | |
|---|---|---|---|---|---|---|
| | % Solar MWh Lost | % Solar Value Lost | % Solar MWh Lost | % Solar Value Lost | % Solar MWh Lost | % Solar Value Lost |
| Wind+ST | 7.5% | 5.7% | 11.2% | 14.7% | 3.9% | 4.1% |
| Wind+PVT | 4.2% | 3.2% | 4.9% | 6.6% | 1.7% | 1.4% |
| Wind+PVF | 3.8% | 2.8% | 3.7% | 4.4% | 1.7% | 1.4% |
| Wind+PVFSW | 3.5% | 2.2% | 3.9% | 5.2% | 1.7% | 1.3% |

**Figure 4. Energy and Economic Losses, Base Case**

As shown in graphs 5 and 6 below, energy and value losses are greatest at the Randado N. Site when solar technologies are paired with coastal winds. (One exception is that solar energy losses are slightly greater for a fixed, south-oriented PV array at the GLO Lease Site; though in this case economic value losses are greater at the Randado N. Site.) The high rates of losses when solar is paired with coastal wind results from the higher correlation of solar and coastal wind resources, and from the relatively high correlation of lost production due to transmission constraints with the price of energy.

The GLO Lease Site and Randado N. Site paired with inland winds generally result in lower economic losses than energy losses. This suggests that co-located wind/solar production tends to exceed transmission constraints during periods when prices are relatively low. Solar energy and economic losses tend to be lowest at the Randado N. Site when solar is paired with inland wind, but this is partially due to the lower overall productivity of both wind and solar generation at this site relative to the GLO Lease Site.

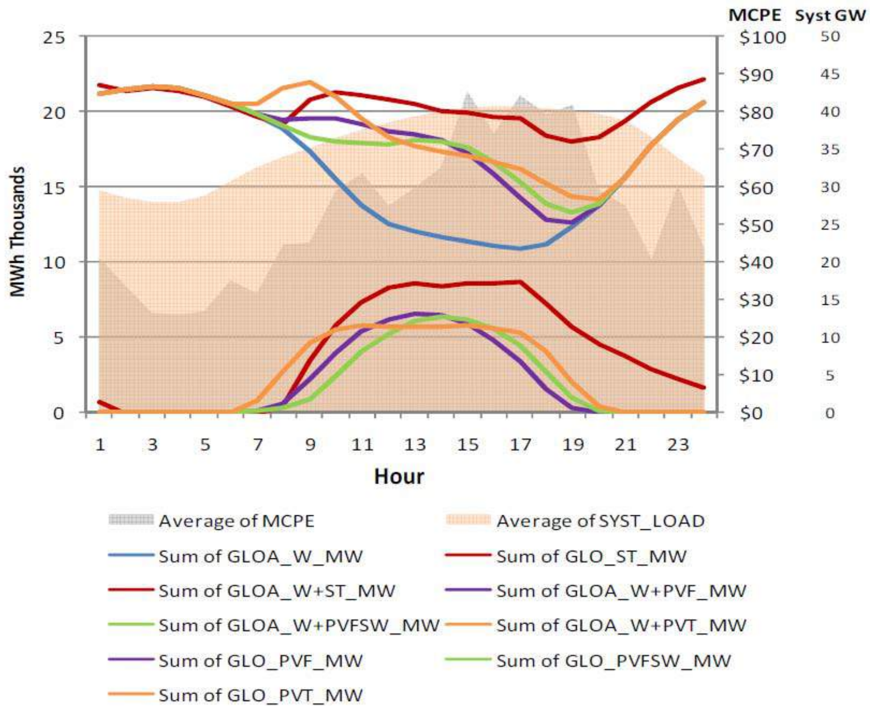


**Figure 5: Base Case Average Annual Wind, Solar and Combined Production by Hour at the GLO Lease Site**

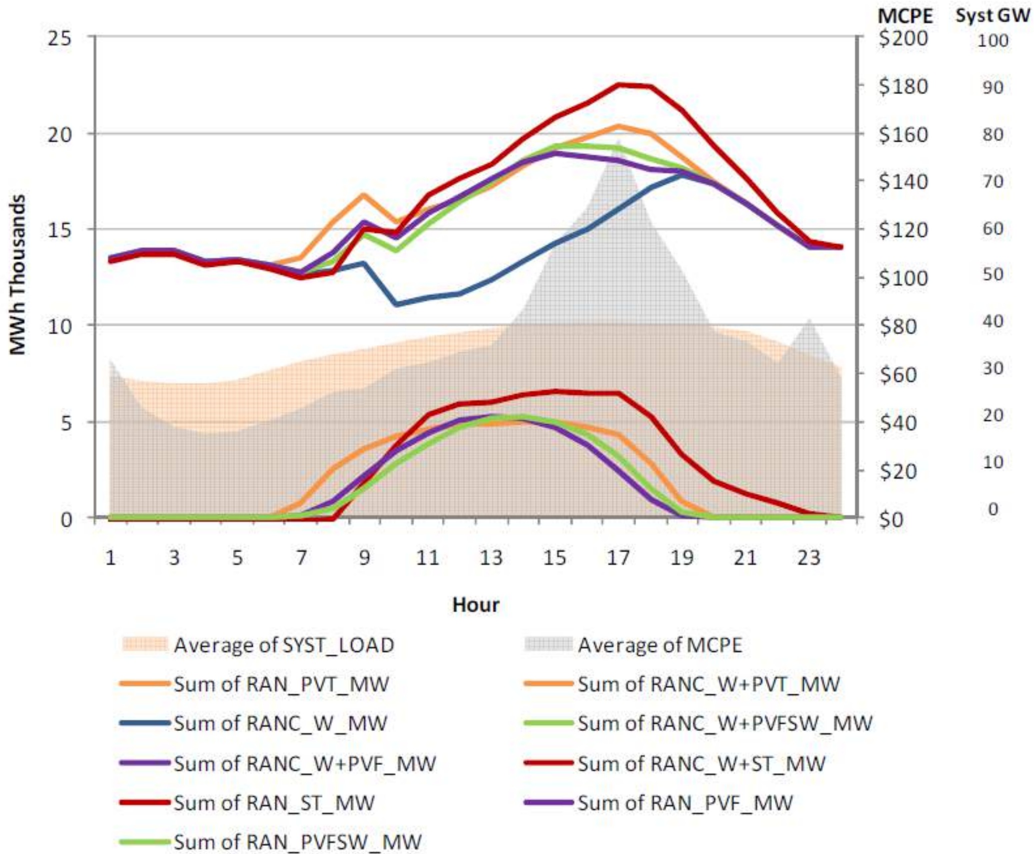


**Figure 6: Base Case Average Annual Wind, Solar and Combined Production by Hour at the Randado N. Site**

## 4. SENSITIVITY ANALYSIS

Sensitivity analyses revealed that solar energy and economic losses remained relatively low when solar was paired with inland winds (i.e., at the GLO Lease site or the Randado N. site when paired with inland winds) even when solar or wind capacity was increased, or when the assumed transmission limit was decreased. For example,

- At the GLO Lease Site (shown in Figure 7 below) solar thermal capacity could be increased from 30 to approximately 45 MW before economic losses exceeded 10%; solar PV capacity could be increased from 30 MW to approximately 70-90 MW before economic losses exceeded 10%.

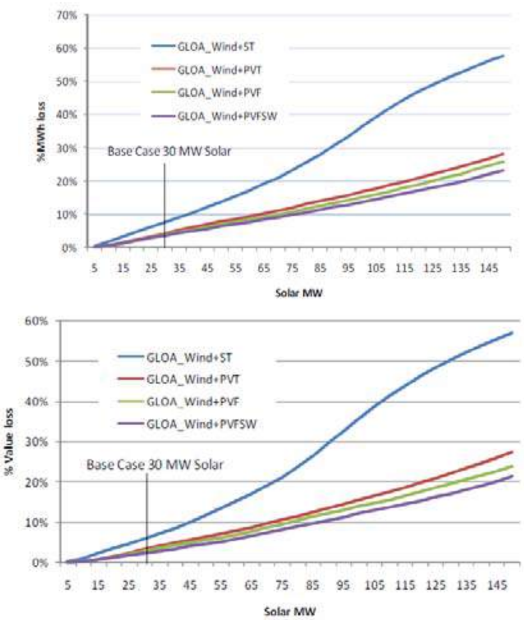


**Figure 7: Sensitivity Analysis for Solar Production at GLO Lease Site, by MWh and Economics Value**

- At the Randado N. Site (shown in Figure 8 below) where solar was paired with inland winds, economic losses exceeded 10% only when the transmission limit was reduced from 100 MW to about 75 MW for the solar PV configurations; or to about 85 MW for the solar thermal plant.

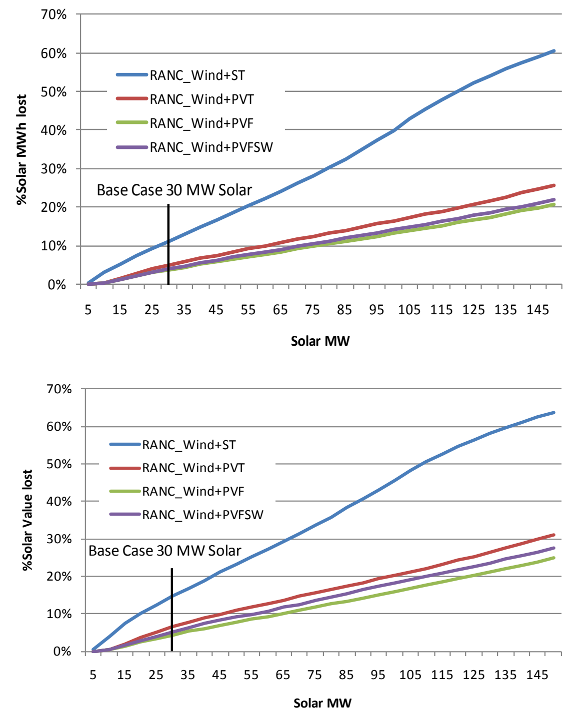


**Figure 8: Sensitivity Analysis for Solar Production at Randado N. Site, by MWh and Economics Value**

In contrast, when solar was paired with coastal winds (i.e., at the Randado N. site when paired with coastal winds) the relatively high correlation of wind and solar production meant there was less flexibility in maintaining losses at low levels. At this site wind capacity would need to be *reduced* from 100 MW to about 95 MW before solar thermal losses economic would amount to less than 10% of solar value.

Sensitivity analyses were also performed for transmission capacity and wind production. The transmission analysis found that expected losses from adding 30 MW of solar generation can be almost eliminated by adding just 10 MW of transmission capacity for PV plants, and 20 MW for solar thermal plants. The wind analysis produced graphs with a more pronounced S-shape than other sensitivity analysis due to daily variation in wind profiles

## 5. CONCLUSIONS

In sum, the base case model and sensitivity analysis demonstrated that solar generation can be reasonably accommodated within transmission systems already constrained by existing wind generation while experiencing only minimal energy and economic losses, especially when the solar and wind generation is negatively correlated, such as when solar generation is paired with inland wind generation in south or west Texas. The GLO Lease Site has the greatest wind and solar production capability as well as the most efficient fit between wind and solar applications.

Solar paired with the coastal wind regime at the Randado N. Site generates significant overall energy but carries a higher risk of curtailment. Despite the considerable production advantage that GLO Lease Site has over the Randado N.Site, the Randado N. Site has higher potential economic values due to higher average MCPE levels in south Texas. The modeled solar thermal application provides more energy given the same capacity than any of the PV applications. Incorporated storage continues producing energy late into the evening, and creates more consistent hybrid production levels at all sites, but leads to more curtailments when combined with Randado coastal winds.