An Effective Load Carrying Capability Study of Existing and Incremental Solar Generation Resources

on the

Public Service Company of Colorado System

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Executive Summary

This report presents the results of a recent Effective Load Carrying Capability ("ELCC") study conducted on existing and incremental solar generation resources on the Public Service Company of Colorado (the "Company") system. The most recent solar ELCC study was conducted in 2013. The results of that study estimated solar ELCC values of roughly 35% for fixed systems and roughly 50% for tracking systems (MW_{AC} basis).

The current study was designed to determine ELCC values for existing and incremental solar generation as a function of geographic location and tracking capability. At the end of 2015, the Company had ~370 MW of interconnected solar; 58% of the interconnected solar (215 MW) is interconnected at distribution voltages. The study examined incremental solar additions up to 1,500 MW at three separate solar resource zones for fixed and tracking installations. In addition, the study was designed to determine potential beneficial impacts of existing wind generation on the calculation of solar ELCC values.

Based on the results of this study, ELCC values for existing solar generators are consistent with the prior study results; i.e., roughly 35% for fixed systems and 50% for tracing systems. Study results also clearly show the degradation in solar ELCC that occurs at higher installation levels.

The study did find a beneficial impact of including existing wind generation in the base generation portfolio when conducting the existing solar ELCC study. The ELCC of solar was found to be about 9% higher when wind is included in the base portfolio.

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Introduction

Background

In order to reliably serve its customers' electrical demands, Public Service Company of Colorado ("Public Service" or the "Company") forecasts expected, peak annual loads for its system as well as the ability of its existing and planned generation resources to reliably serve those forecast loads. For resource planning purposes, different generation technologies can be relied on to provide different levels of their nameplate generation capacity rating toward serving customer load. In general, the Company affords 100% of a dispatchable, fossil-fuel fired generator's summer net dependable capacity for resource planning purposes, but less than 100% of nameplate capacity for non-dispatchable, intermittent generation technologies such as wind and solar. Underestimating the contribution of intermittent generation resources to help meet forecast system peaks can result in the acquisition of additional generation capacity and higher system costs. Overestimating the ability of intermittent generation resources to help serve forecast system peaks can result in lower levels of system reliability and increased risks of customer load curtailment.

A facility's capacity credit (or capacity value) is frequently confused with the facility's capacity factor. A facility's capacity credit is a probabilistic measure of the fraction of the facility's nameplate rating (measured in MW) [1] that can be relied on to serve customer loads. A facility's capacity factor is the ratio of the total amount of energy (measured in MWh) that the facility is expected to generate over a specific time period to the maximum amount of energy it could generate if it were operated during the time period at full nameplate capacity; capacity factors are typically provided on an annual basis.

Although several methodologies have been proposed through which an intermittent generation resource's capacity credit can be estimated,[2] for its resource planning purposes the Company utilizes an effective load carrying capability ("ELCC") metric. ELCC study results are dependent upon the selection of a specific reliability target. In this study, as in its previous studies, the Company utilized a loss of load expectation ("LOLE") reliability metric of 1 day in 10 years.

[1] Unless otherwise indicated, the terms "MW" and "MWh" in this study report refer specifically to MW_{AC} and MWh_{AC}.

[2] See, for example, "Determining the Capacity Value of Wind: An Updated Survey of Methods and Implementation", M. Milligan and K. Porter, NREL/CP-500-43433, June 2008 and "Photovoltaic Capacity Valuation Methods", T. Hoff, R. Perez, J.P. Ross, and M. Taylor, SEPA Report #02-08, May 2008.

Prior Solar ELCC Study

The Company has conducted two prior solar ELCC studies (completed in February 2009 and March 2013).[3] At the time of the 2009 and 2013 solar ELCC studies the Company had 25 MW_{DC} and 240 MW_{DC} of interconnected solar, respectively. Neither of the previous solar studies calculated ELCC values for significant incremental levels of solar generation. The results of the 2013 solar ELCC study are shown in Table 1 below.

Table 1 2013 Solar ELCC Study Results[4]

Solar Zone	Fixed	Tracking
Northern Front Range	36%	48%
Southern Front Range	38%	47%
San Luis Valley	32%	55%
Western Slope		54%

Currently-Installed Levels of Wind and Solar

At the end of 2015, the Company had ~2,580 MW of interconnected wind[5] and ~370 MW of interconnected solar distributed across the state of Colorado as illustrated in Figure 1 below.[6] Additional detail as to the distribution of wind and solar generation is provided in Tables 2 and 3 below.

[3] "An Effective Load Carrying Capability Study for Estimating the Capacity Value of Solar Generation Resources on the PSCo System", Xcel Energy Services, Inc., February 2009; and, "Effective Load Carrying Capability (ELCC) Study for Solar Generation Resources", Xcel Energy Services, Inc., May 23, 2013.

[4] Values shown in Table 1 have been converted to a MW_{AC} denominated basis from the MW_{DC} denominated values provided in the 2013 Solar ELCC study report using an AC/DC conversion factor of 0.85.

[5] The total wind as calculated here does not include approximately 11 MW of research and development wind generators located at NREL's Wind Technology Center.

[6] The 120 MW_{AC} Comanche Solar facility shown in Figure 1 as "SFR Solar" is expected to be in-service by the summer of 2016.

Figure 1 Wind and Solar Geographic Zones

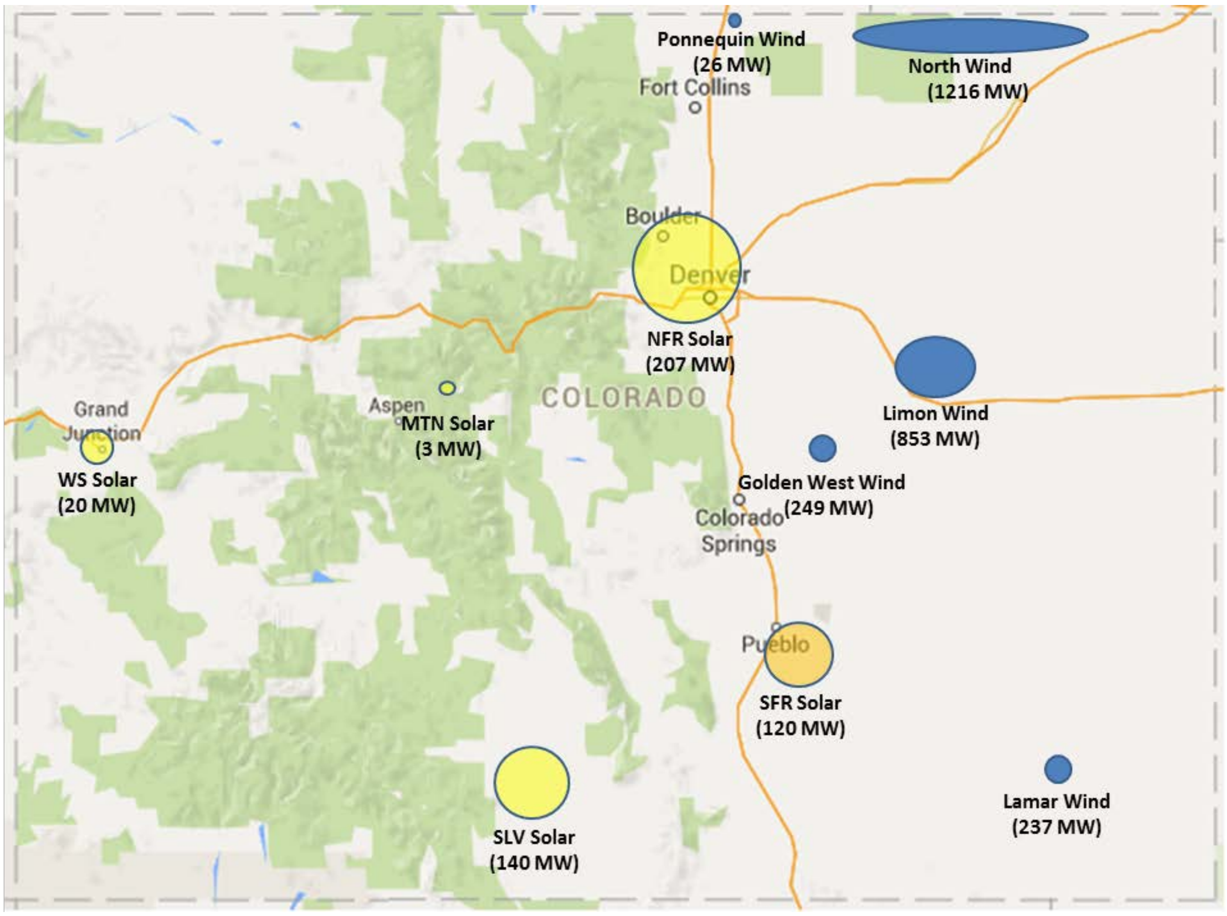


Table 2 Wind Generation Portfolio by Geographic Location

Wind Resource Zone	MW
North	1,216
Ponnequin[7]	26
Limon	853
Golden West	249
Lamar	237
Total	2,581

[7] The 26 MW Company-owned Ponnequin wind farm was retired on 12/31/2015. Generation meter data from this facility was included in the North wind generation profiles used in this study.

All of the wind resources shown in Table 2 are interconnected at transmission voltage and, except for the Ponnequin facility, are acquired through purchase power agreements.

Table 3 Solar Generation Portfolio by Geographic Location and Tracking Capability[8]

	MW		
Solar Resource Zone	**Fixed**	**Tracking**	**Total**
Mountain (MTN)	3		3
Northern Front Range (NFR)	200	6	207
San Luis Valley (SLV)	3	138	140
Western Slope (WS)	19	2	20
	225	145	370
Southern Front Range (SFR)[7]		120	120
	225	265	490

Of the ~370 MW of installed solar at the end of 2015, ~155 MW are acquired through purchased power agreements including contracts from five, large-scale tracking units in the San Luis Valley and from smaller solar garden-type facilities located across Colorado. The remaining ~215 MW have been installed behind our customers' meters; of this generation ~85% has been installed within the Company's Denver metro area load center (Northern Front Range) in fixed orientations.

Study Methodology

The Company's methodology in this ELCC study follows the "Preferred Methodology" described in a 2011 Institute of Electrical and Electronics Engineers ("IEEE") publication[9] and the Effective Load Carrying Capability methodology described in a 2012 National Renewable Energy Laboratory ("NREL") publication.[10] Following the methodology in those publications, the steps the Company utilized to estimate the ELCC of the target solar generators were:

[8] Behind-the-meter solar generation resources are typically acquired and denominated in MW_{DC} terms. In this study, those generation resources have been denominated in MW_{AC} terms using a conversion factor of 0.85. Differences between individual values and totals in Table 3 are the result of minor rounding errors.

[9] "Capacity Value of Wind Power"; Keane, Milligan, Dent, Hasche, D'Annunzio, Dragoon, Holttinen, Samaan, Söder, and O'Malley. IEEE Transactions on Power Systems, Vol. 26, No. 2, May 2011.

[10] "Comparison of Capacity Value Methods for Photovoltaics in the Western United States"; Madaeni, Sioshansi, and Denholm. Technical Report, NREL/TP-6A20-54704, July 2012.

1. For the generation portfolio that the Company expects to be in-service starting in 2018,[11] the LOLE of the base system without the target generators was calculated for the annual period under study.
2. If the LOLE of the base system was not equal to the reliability target of 1 day in 10 years,[12] equal amounts of load were either added to or subtracted from each hour of the annual study period until the reliability target for the base system was achieved.
3. The target generators were added to the system and the LOLE was recalculated.
4. Keeping the target generators in the system, a constant load was added to each hour.[13] The level of the constant load was adjusted and the resulting LOLE recalculated until the portfolio LOLE once again achieved the target reliability.
5. The amount of load added in Step #4 was the ELCC of the target generators.

Study Goals

The Company's goals in this study were to estimate the ELCC of:

1. Solar at existing levels of wind and solar,
2. Incremental levels of solar (as a function of geographic location and tracking capability) above existing levels of wind and solar.

ELCC values for the existing solar fleet are used on the Company's loads and resources tables to determine the need for incremental resources in order to meet planning reserve reliability targets. ELCC values for incremental solar resources are used to evaluate the economic value (e.g., avoided generation capacity costs) of proposed solar projects.

Numerous studies have illustrated the law of diminishing returns for the generation capacity credit attributable to higher penetrations of non-dispatchable generation.[14] That is, all else equal the value of avoided generation capacity attributable to incremental solar is less than the value of

[11] The generation portfolio starting in 2018 reflects the final changes to the Company's coal-fired fleet resulting from the 2007 Colorado Energy Plan and the Clean Air, Clean Jobs Act of 2010; specifically, the retirements of Arapahoe Units 3 and 4, Cherokee Units 1-3, and Valmont Unit 5 and the operation of Cherokee Unit 4 on natural gas. In addition, it also reflects the addition of the gas-fired, combined cycle Cherokee Units 5, 6, 7 and the gas-fired generation acquired as a result of the Company's 2013 All-Source Solicitation.

[12] 1 day in 10 years = 0.1 day per year = 2.4 hours per year.

[13] The resulting LOLE in Step #3 was lower than the LOLE of the base system because an additional generator had been added, thus additional load must be added to increase LOLE.

[14] See, for example, "Changes in the Economic Value of Variable Generation at High Penetration Levels: A Pilot Case Study of California"; Mills and Wiser. LBNL-5445E, June 2012 and "Representation of Solar Capacity Value in the ReEDS Capacity Expansion Model"; Sigrin, Sullivan, Ibanez, and Margolis. Technical Report, NREL/TP-6 A20-61182, March 2014.

the avoided generation capacity of the existing solar. Thus it is important to evaluate how quickly solar ELCC values decrease at increasing levels of incremental generation.

At the start of the study, the Company also believed it important to evaluate the inter-relationship between wind and solar generation on the study results. The Company is a late-afternoon, summer peaking system and it is the level of wind or solar generation during these periods that most impacts the ELCC results. Typically wind generation from the Company's fleet is increasing from noon through this late-afternoon period while, of course, solar generation is decreasing as the sun drops lower in the sky.[15] Given that wind generation tends to increase during the later portion of the afternoon peak period, it was expected that solar ELCC values would be higher for a generation portfolio that included wind in the base system.

The Company selected incremental tranches of solar generation at levels of 100, 250, 500, 1000, and 1500 MW for this study.

Data Sources

To conduct the ELCC study, interval wind and solar generation meter data with hourly frequency were obtained. Table 4 below shows, for the seven year period of 2008-2014, the number of wind farms with generation data available for a complete calendar year for each of the three geographic zones in which the Company has wind generation.

Table 4 Number of Wind Farms with Generation Data Available

Wind Resource Zone	2008	2009	2010	2011	2012	2013	2014
North	6	6	8	8	9	9	9
Limon					1	3	3
Lamar	2	2	2	2	2	2	2

The Company's most recently-acquired wind generator is the 249 MW Golden West facility located near the existing Limon geographical zone; however, this facility only entered service in October 2015. Given the lack of operational experience with this facility at the time the study was conducted, the Company elected not to assume an hourly generation profile for this facility and include it as an existing generator, but instead to study an existing wind portfolio of 2,332 MW which excluded it.

[15] In addition, the Front Range of Colorado is subject to summer afternoon monsoon conditions which typically results in increasing levels of cloud cover as the afternoon progresses.

As Table 4 shows no generation meter data exists prior to 2012 at the Limon location; however the Limon location currently accounts for between 33% and 40% of the installed wind generation,[16] which is a major portion of the wind portfolio. Based on the lack of Limon wind generation data prior to 2012, the Company estimated existing solar ELCCs in this study using generation meter data from the period 2012-2014.[17]

Sources of solar generation meter data include interval production meters from the five, large San Luis Valley tracking facilities and from interval production meters that have been set for net-metered customers on a demand-rate tariff who have both interval load and solar generation meters installed. The Company had no sources of interval generation meter data over the 2012-2014 period for the Mountain or the Southern Front Range solar resource zones. As such, this study does not calculate solar ELCC values for those locations.

Load Data Sources

Hourly system obligation load for 2012-2014 was used for the study. As these data are recorded from meters located at transmission substations, the effects of behind-the-meter solar generation and other solar generation interconnected at distribution voltages are embedded in the data. That is, the obligation load data are net of behind-the-meter and solar-garden-type solar generation; absent the impact of these generators, the obligation load data would be higher.

As the Company conducts its long-term planning operations consistent with Federal Energy Regulatory Commission ("FERC") orders regarding behind-the-meter generation,[18] it treats these generators consistent with other sources of generation. That is, it plans for its customers' entire load and carries distribution-interconnected solar generation (e.g., behind-the-meter generation and solar gardens-type generation) on its loads and resources table (reduced for their ELCC values) along with all other generation resources. Thus an estimate of ELCC for this category of solar generation is needed.

In order to estimate the ELCC value of existing distribution-interconnected generation, an additional set of ELCC calculations were conducted for the Northern Front Range-Fixed category at an incremental tranche of 50 MW. As stated previously, ~85% of the Company's behind-the-meter generation is located within the Northern Front Range geographic area and installed in a fixed orientation and is thus a reasonable proxy for the entire portfolio. If the

[16] The percentage is dependent upon whether the 249 MW Golden West facility is considered to be in the Limon region or not.

[17] For each year of the study, hourly wind generation data at Limon were grossed up to the existing level of Limon wind (i.e. 853 MW) in the Company's portfolio as shown in Table 6.

[18] See, e.g., FERC Order on Rehearing in Dockets No. ER08-394-004 and ER08-394-005 (February 19,2009) at ¶15.

ELCC results for an incremental 50 MW and an incremental 100 MW for fixed panels at this location were similar, then there is little to no degradation in ELCC going from 50 MW to 100 MW. As such, then too there should be little to no degradation going from the existing levels of distribution-interconnected generation to an incremental 50 MW. If so, then the average ELCC value estimated at a 50 MW incremental tranche should also apply to the existing levels of distribution-interconnected generation.

Study Results

Existing Solar

Table 5 shows the ELCC results by year for the 135 MW of San Luis Valley tracking solar modeled both with and without existing wind in the base system model.

Table 5 ELCC Results for Existing Solar Generation

	SLV Tracking ELCC	
Study Year	**0 MW Wind**	**2,332 MW Wind**
2012	49.6%	53.3%
2013	48.1%	54.8%
2014	52.6%	56.3%
average	50.1%	54.8%

As expected, the solar ELCC estimates for the existing SLV Tracking generators were higher for the cases in which existing wind generation was included. Comparing the average values in Table 5, the results were ~9% higher.

Based on the study results shown in Table 6 below, the Company ascribes an ELCC value of 55% to its existing portfolio of utility-scale, San Luis Valley tracking solar facilities. Based on the incremental analyses presented in the next section, the Company ascribes an ELCC value of 37% to its existing distribution-interconnected generation portfolio. [19]

[19] These ELCC results are applied to MW_{AC} nameplate solar capacity values.

Table 6 Existing Solar ELCC Study Results

Study Year	SLV Tracking ELCC
2012	53.3%
2013	54.8%
2014	56.3%
average	54.8%

Incremental Solar

ELCC estimates for incremental levels of solar were conducted with 2,332 MW of wind and 135 MW of San Luis Valley tracking solar in the base system model; as previously discussed the effects of distribution-interconnected solar generation are embedded in the obligation load data. Results for incremental solar generators by location and tracking are shown in Table 7 below.

Table 7 Average ELCC to Apply to Incremental Solar

Incremental Solar (MW)	Northern Front Range		San Luis Valley		Western Slope	
	Fixed	Tracking	Fixed	Tracking	Fixed	Tracking
50	37.0%					
100	37.0%	41.5%	43.5%	52.5%	41.5%	53.0%
250	35.8%	40.2%	42.2%	50.4%	41.0%	52.0%
500	33.9%	37.8%	39.1%	47.1%	39.0%	49.5%
1000	30.3%	33.2%				
1500	27.7%	29.1%				

ELCC estimates at incremental solar levels of 1,000 and 1,500 MW were calculated for fixed and tracking solar located in the Northern Front Range only. These incremental ELCC values were calculated only for the Northern Front Range as it encompasses the Company's Denver-area load center (and thus the main potential for incremental behind-the-meter solar generation) and the existing backbone transmission system serving the Denver load center.[20] The Northern Front Range also includes the broad plain region to the east and northeast of the Denver load center with relatively undeveloped land and may serve as locations for future utility-scale solar development.

[20] The Southern Front Range solar zone also includes the Company's backbone transmission system, however as explained earlier, the Company currently has no generation meter data through which to estimate ELCC values for this region.

The ELCC values in Table 7 are presented as the average ELCC values that should be attributed to the total level of incremental generation. For example, for an incremental level of 250 MW of Northern Front Range fixed solar the entire 250 MW would provide 90 MW of generation capacity credit (250 MW * 35.8%); for an incremental level of 500 MW of Northern Front Range fixed solar the entire 500 MW would provide 170 MW of generation capacity credit (500 MW * 33.9%).

As the ELCC for an incremental 50 MW and an incremental 100 MW of Northern Front Range fixed solar are equal, there is no reduction in ELCC between these levels of incremental solar. This implies that the average ELCC that can be attributed to the embedded distribution-interconnected solar is equivalent to the values shown at the 50 MW and 100 MW level. Based on this result the Company attributes its existing behind-the-meter and solar-gardens-type solar with an ELCC of 37%.[21]

Figures 2 – 4 below show the average and incremental solar ELCC values for the three solar zones studied. Also shown on these figures are the solar ELCC results from the 2013 solar ELCC study; these values are plotted on the x-axis at 0 MW in the Figures. Note that the ELCCs calculated in this study for the San Luis Valley fixed systems (~40-45%) are significantly higher than the value calculated in the 2013 study (32%). This low 32% value had been identified in the 2013 study as a potential anomaly.

[21] If an assumption were made that the ELCC values at the 100 MW incremental level shown in Table 7 for all the locations and tracking capabilities are also applicable as an estimate of the existing ELCC values for distribution-interconnected solar generation at those locations, then the resulting location and tracking capability-weighted ELCC would be 37.9% instead of the 37% calculated from the Northern Front Range fixed generation only.

Figure 2 Average and Incremental Northern Front Range Solar ELCC Values

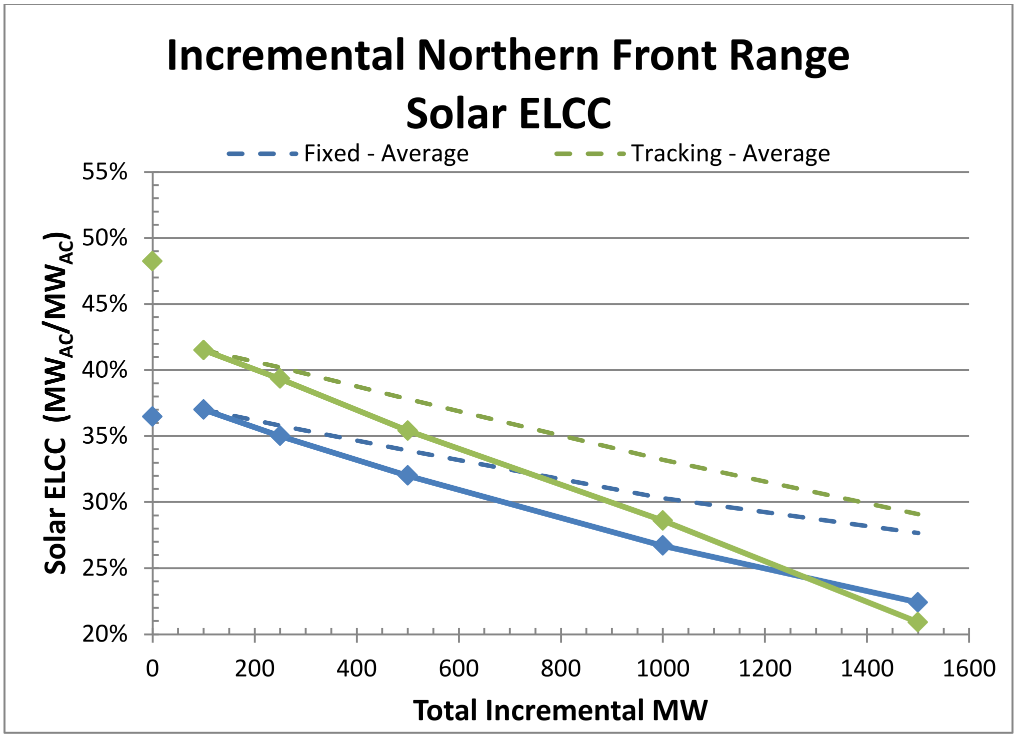


Figure 3 Average and Incremental San Luis Valley Solar ELCC Values

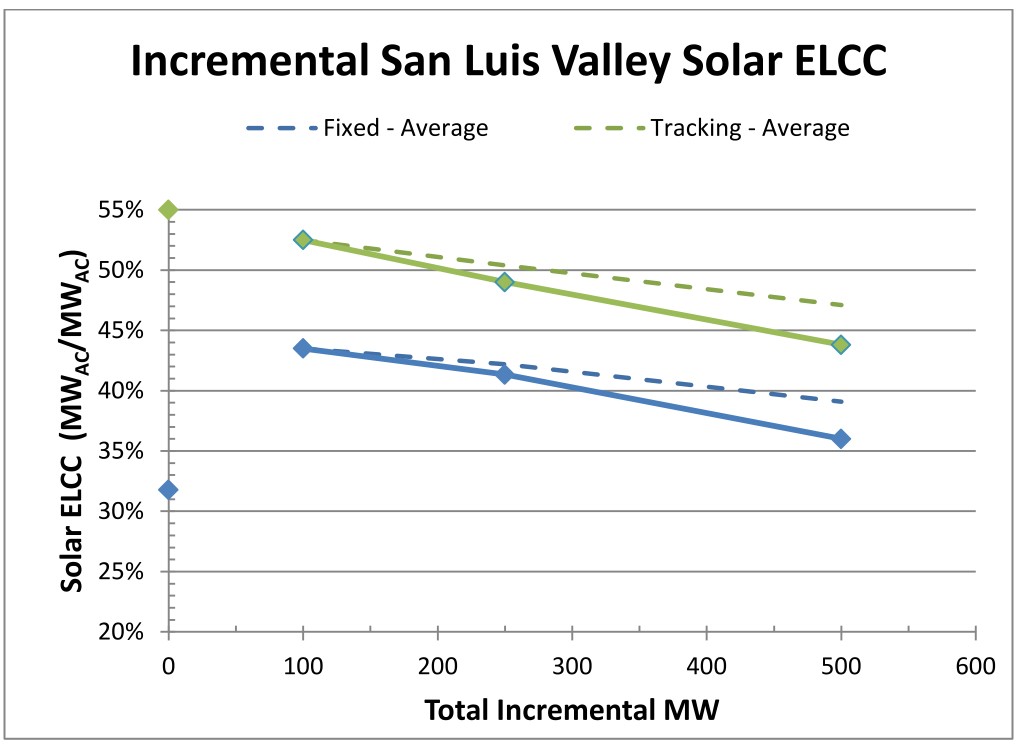
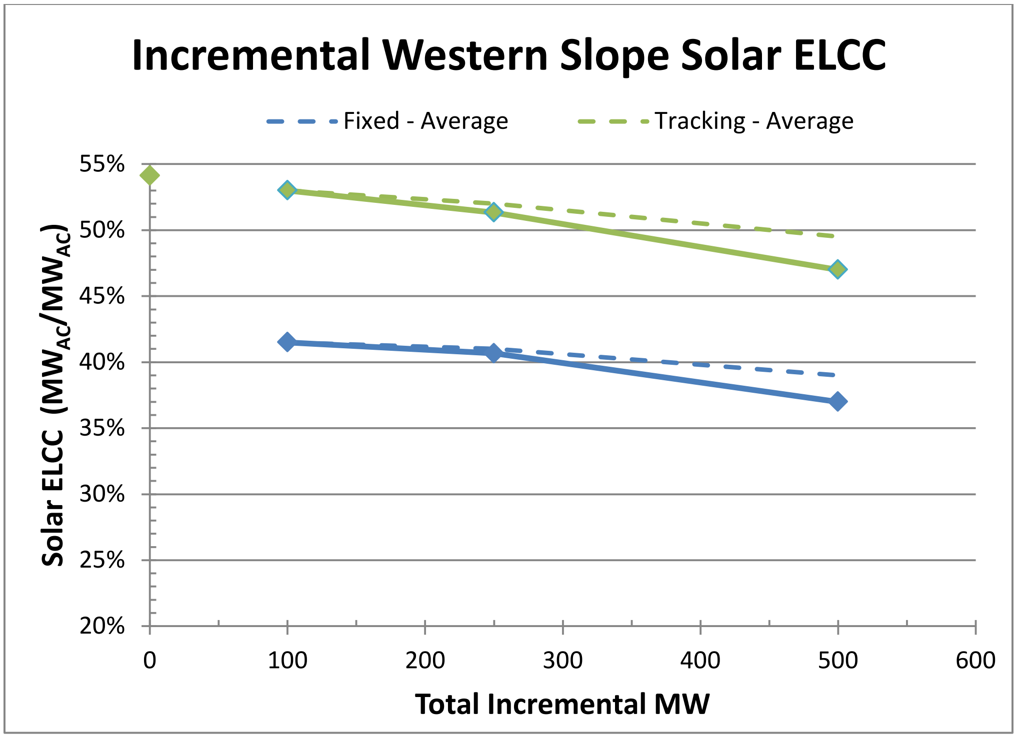


Figure 4 Average and Incremental Western Slope Solar ELCC Values



Application of Study Results to Current Loads and Resources Table

Based on the results of this study, the Company currently carries its existing distribution-interconnected solar generation at ELCC values similar to the prior study results; as such there is relatively little impact on the Company's loads and resources table due to the updated solar ELCC results. Existing utility-scale solar projects in the San Luis Valley are assigned an ELCC value of 55% consistent with Table 6. The under-construction 120 MW_{AC} Comanche utility scale solar facility is assigned an ELCC of 47% consistent with the Southern Front Range tracking ELCC calculated in the 2013 ELCC study. The Company assigns an ELCC value of 37% from Table 7 to its existing portfolio of solar generation installed at distribution voltages.[22] As an estimate of generation capacity credit for future additions of distribution-interconnected solar, the Company uses an average of the Northern Front Range fixed and tracking ELCC values shown in Table 7 on its loads and resources table.

[22] This portfolio includes generation acquired through its Solar*Rewards and Solar*Rewards Community (i.e., solar gardens) programs in addition to estimates of non-program distributed solar generation.

Conclusions

Based on the results of this study, the Company carries the existing portfolio of utility-scale tracking solar facilities in the San Luis Valley at an ELCC rate of 55% and the existing portfolio of distribution-interconnected solar at an ELCC rate of 37%. These results are similar to values calculated in the prior solar ELCC study and have little impact on the Company's loads and resources table.

Consistent with the findings of other generation capacity credit studies for solar generation, ELCC values for incremental solar generation are less than ELCC values for existing solar generation. In this study, the Company presents in Figures 2, 3, and 4 ELCC values that can be utilized for various incremental solar additions for fixed and tracking solar generators located in the Northern Front Range, San Luis Valley, and Western Slope regions of Colorado.

The study did find a beneficial impact to the ELCC calculations from including existing wind generation in the base generation portfolio when conducting the existing solar ELCC study for the San Luis Valley tracking generators. With wind in the base portfolio, the average ELCC rate increased from 50.1% to 54.8% which is ~9% higher.