Modeling for KCEC Short-Term Transition Planning
Renewable Taos, 6 February 2015

Introduction

Kit Carson Electrical Cooperative (KCEC) asked Renewable Taos to join a group to do short-term transition planning for increasing the amount of renewable energy (RE) generated within KCEC's service area. This request was motivated by the recent decision by the KCEC Board of Directors to terminate KCEC's contract with Tri-State Generation and Transmission Association, Inc. (Tri-Sate). This contract limits KCEC's self-generation (and therefore RE) to 5% of KCEC's annual sales. Terminating the contract, and negotiating new ones will allow KCEC to generate much more RE.

For preliminary modeling, Renewable Taos is using a spreadsheet produced by EnergyShouldBe.org. This free model uses hourly values of demand, and of RE production from a variety of sources, to determine the amounts of RE produced, electricity that must be purchased to meet demand, excess RE that can be sold to other utilities, and the resulting consumer price of electricity. It also includes a simple model of battery storage. Results are displayed numerically and in 2D and 3D graphs. Members of Renewable Taos have met the creator of the model, Ken Reagalson of Boulder Colorado. He has supported our efforts to modify and use the model, and is willing to continue this support.

KCEC asked Renewable Taos to investigate the possibility of increasing the installed capacity of RE to 20% of KCEC's peak demand. This would be a total of 13 MW of PV, about two-and-a-half times the existing amount. However, our modeling results, and reports on existing PV systems with much higher percentages, led us to extend the investigation to models with higher amounts of RE.

Changes to the Model

The EnergtShouldBe.org spreadsheet *Modeling Electricity & Renewables v2.7.xlsx,* was modified in a number of ways to make it more suitable for the Kit Carson Electrical Cooperative (KCEC) situation:

- A composite year of KCEC hourly demand data was substituted for the Boulder data that comes with the file.

- PVWatts® hourly simulated outputs for the large scale tracking and fixed PV arrays in the KCEC area were substituted for two of the sets of wind data that come with the model. Changes were made so that these display, and can be scaled, on the USER_INPUT tab.

- Graphs were added and changed:
    - A new tab was added to display the KCEC demand minus renewable output in 3D.
    - The scales of the graphs on the USER_INPUT tab were changed.
    - Graphs were added to show the hourly output of Wind, PV, and the combination of the two for each Scenario.

- Changes were made to the way costs are entered and calculated. KCEC is more likely to sign purchase power agreements (PPAs) than to finance the up-front costs of renewable energy (RE) facilities, so:
    - The resulting values of $/kWh in Cell L40-L43 were linked to the user inputs for up-front costs of PV and Wind in B39 – C40. (Cells refer to USER_INPUT in the modified model, unless otherwise stated.) The user now enters up-front costs in B39 – C40, and confirms that these produce the desired PPA costs in L40 – L43.
    - A new cost calculation section was added in A53 – I79. This uses the PPA cost (L40 – L43) and other inputs to calculate the price per kWh to KCEC members. .

- A brief description of the two scenarios in each file was added to F1 – F3.

These changes and other minor ones are detailed in the new tab Changes, and are implemented in the current set of models:

ModelElec&RenewV2.7-JG-KCEC-11.xlsx
ModelElec&RenewV2.7-JG-KCEC-12.xlsx
ModelElec&RenewV2.7-JG-KCEC-13.xlsx
ModelElec&RenewV2.7-JG-KCEC-14.xlsx
ModelElec&RenewV2.7-JG-KCEC-15.xlsx
ModelElec&RenewV2.7-JG-KCEC-16.xlsx
ModelElec&RenewV2.7-JG-KCEC-18.xlsx

This set should be used as templates for further modeling, and any changes should be documented and explained.

Data

The year of hourly KCEC demand required by the model was created as follows: KCEC sent Renewable Taos a set of demand data beginning with 1 September 2012 and ending on 31 August 2013. There is a large drop in demand values beginning on 12 August due to missing data from two of the Tri-State – KCEC transfer points. The first half of August was copied over the second half, and the data was rearranged to begin on 1 January and end on 31 December. This "composite year" should be replaced with more recent and complete data, which Renewable Taos is trying to obtain.

The two sets of hourly PV output data required by the model were simulated by PVWatts®. Separate runs were done for the aggregates of existing tracking and fixed arrays in the KCEC service area. This simulated data should be replaced or complemented with actual hourly data from tracking and fixed arrays. Renewable Taos is also trying to obtain that data.

Costs of electricity from Tri-State and potential future suppliers, costs of renewable energy, and operating costs were estimated based on previous discussions with KCEC. These should also be updated with more current and accurate information.

Definitions

Many of the terms used to describe amounts of renewable energy can be ambiguous so it's necessary to start with some exact definitions.

Amounts of renewable energy can be defined as follows:

- Installed Capacity (MW): The "nameplate" output of a facility. The amount produced under rated conditions: 1,000 W/m^2 of solar radiation for PV, the maximum output for wind. For PV this can be the DC output of the panels, or the AC output of the system, including inverters, etc. For our purposes, installed capacity should always be defined as AC output.
- Penetration Rate (%): Installed Capacity divided by Peak Annual Demand. For KCEC, this is installed capacity divided by 65.9 MW. When RE is referred to as a percentage, this is what is usually meant because it was generally believed that is was the most important factor in determining how much RE a system could handle without producing problems.
- Installed Capacity as a percentage of Minimum Annual Demand. For KCEC, installed capacity divided by 23.1 MW. This may be a better measure of the amount of RE a system can handle. For PV, minimum daytime demand should be used, if known.
- Energy Produced (MWh): The amount of electricity an RE facility puts onto the system in a year.
- Energy Produced (%): The energy produced (MWh) divided by the amount of energy delivered by the system in a year. For KCEC, energy produced divided by 315,523 MWh.

The Cost of Electricity:

- Purchase Power Agreement (PPA) ($/kWh): The price at which a utility contracts to buy power from a third party that is not a utility. Examples include KCEC's contracts to buy PV electricity from the Amalia and Blue Sky arrays.
- Contract Price ($/kWh): The average cost that KCEC pays another utility for electricity. This includes the price per kWh, demand charges, penalties and taxes (if any). The cost to KCEC of the electricity that KCEC does not produce or have PPAs for.
- Excess Purchase Price ($/kWh): The cost that another utility will pay KCEC for electricity that KCEC puts onto the grid when RE production is greater than total consumption.
- Consumer Price ($/kWh): The average price paid by all of a utility's customers (or coop members). This includes all types of customers (residential, large commercial, etc.), and all demand charges, fuel adjustments, etc. It does not include taxes.

Inputs

The following costs of energy and other values are used in the currents set of models:

- *Up-front cost of PV* (Solar, B39 & C39): 1.286 M$/MW. This results in a PPA of 0.080 $/kWh, which is believed to be the PPA cost of recent large-scale PV projects in the KCEC area.

- *Up-front cost of Wind* (B40 & C40): 2.95 M$/MW. This results in a PPA of 0.587 $/kWh, which is the mid-range value of the Lazard LCOEs for wind.

- *Cost of Batteries* (B41 & C41): 0.50 M$/MWh. Based on a discussion with Ken Regalson, the creator of the spreadsheets. His cost of 0.10 M$/MWh is about 25% lower than ARPA/DOE goal for 2022, while the current price is about 0.75. 0.50 M$/MWh assumes batteries won't be used for a few years, and the price will drop in the meantime.

- *Interest rate & Term:* Left at 6% and 20 years. These are not important in the modified spreadsheets. They are applied to the up-front cost to determine the PPA costs, and only the PPA costs matter (except for batteries, below).

- *Sell Excess Overgeneration at* (Excess purchase price in the above definitions): Left at 0.03 $/kWh. This seems a reasonable amount for other utilities to pay for KCEC's excess RE. KCEC would be asking them to take it whenever it happens to occur. Most of the models produced so far limit excess RE to 1% or less of total RE production.

- *Annual Operating Expense:* 15 M$, from the KCEC 2010 Annual Report (the latest available on-line). 35 M$ total minus 20 M$ for power.

- *Cost of baseload & peaking power:* For KCEC, this is the contract price. Set at 0.080 $/kWh. This is probably close to what KCEC is now paying Tri-State. Keeping it at that amount assumes that a) KCEC can get a better deal by shopping around, but b) a contract that allows 20 to 50% self-generation will probably come at a premium. Purchasing from a utility that is not adjacent to KCEC will involve transmission costs that may also raise the price.

- *Startup Cost:* Set to zero. Assumes that all additional costs for integrating RE will be part of the PPAs. An annual price of getting out of the Tri-State contract could be entered here when known.

- *Transmission:* Set to zero. Transmission costs assumed to be included in PPAs and contracts.

All of these costs are subject to change after discussions with KCEC and/or research into PPAs for RE of relevant scales and locations.

Results:

Some results are determined by the above costs without the need for modeling (and are confirmed by the models):

- Because the contract price is the same as the PPA price for PV, the addition of PV to the model does not change the consumer price. This is true until excess PV is generated and sold at the much lower excess purchase price.

- Because the PPA price for wind is lower than the contract price, the addition of wind to the model will lower the consumer price. This is true until enough excess RE is sold to cancel out the savings from wind.

- Because the excess purchase price is lower than all costs to buy electricity, having excess to sell will always raise the consumer price.

Better definitions of contract prices and PPAs may change the first two relationships. However, it seems unlikely that the excess purchase price will be higher than the others, so the third relationship is unlikely to change.

Modeling Results

Results of the models run so far are summarized in the four tables at the end of this report.

<u>No Renewable Energy</u>

Model *KCEC10 No RE* models the KCEC distribution grid as if it had no renewable energy. The resulting consumer price is 0.1275 $/kWh, which is believed to be close to the current average price.

<u>The Present Situation</u>

Model *KCEC11 Existing* models KCEC with its existing large scale PV arrays. Their approximate installed capacities are 4.25 MW of tracking arrays (mostly single axis), and 0.5 MW of fixed arrays. This is equal to a combined penetration rate of 7% of peak and 21% of minimum demand. The modeled energy produced is 9,377 MWh or 3% of the total. No excess RE is generated. The consumer price is 0.1275 $/kWh, unchanged from the *No RE* model, as expected.

This model can be improved by more accurate figures of the actual installed AC capacity, actual hourly production data from at least one tracking and one fixed array, and good estimates of the installed capacity of "behind the meter" PV on residences and businesses.

<u>20% PV</u>

KCEC asked Renewable Taos to investigate the possibility of having RE equal to 20% of installed capacity, and this is done in model *KCEC12 20% PV*. This is modeled by expanding the tracking and fixed PV arrays to 11.5 and 1.5 MW. The combined 13 MW is 20% of peak, and 56% of minimum demand. The modeled energy produced is 24,614 MWh, or 8%. No excess RE is generated, and the consumer price remains unchanged.

<u>50% PV</u>

The request to investigate 20% PV was based on two factors: A study by Los Alamos National Laboratory (LANL) indicating that more than 20% RE would destabilize KCEC's grid, and a perception that the KCEC Board will not accept more than 20%. Renewable Taos has not yet been given a copy of the LANL study, but has found EPRI and NREL reports stating that much higher penetration rates have been achieved without problems on a variety of distribution grids.

20% PV would be achieved - or nearly achieved, by projects already approved or being considered by the KCEC Board. These could easily be installed and operating within a year, so it would be a serious mistake to sign contracts limiting KCEC to 20% until 2020. The mission of Renewable Taos is to educate people about the possibility of having Taos become 100% renewable, and a source of renewable energy to other parts of the country.

Therefore, we have taken the initiative to investigate significantly higher RE penetration rates, starting with 50% PV in model *KCEC13 50% PV*. This is achieved by 33 MW of installed PV capacity (29 tracking & 4 fixed), which is 50% of peak, and 143% of minimum. The modeled energy produced is 64,945 or 21%. 0.1 MWh of excess electricity is produced (0.00003% of the PV production). This excess is not enough to change the consumer price, which remains 0.1275 $/kWh.

According to the model, the excess production occurs during one of the 8,760 hours of the year - 1:00 pm on 20 June. This is a somewhat coincidental occurrence of a drop in demand with a very high PV output in the particular data sets used. Most actual years could have no excess, but even if the excess production were 100 times higher in any actual year, it would still be an insignificant amount of the PV energy production, and could be considered an acceptable amount of curtailment. Thus, within the accuracy of the data and model, 50% PV is close to the limit of PV production with only insignificant excess.

None of the PV models reduce the peak annual demand at all. This is because the peak occurs at night – 8:15 pm on 3 January. This is not considered a coincidence caused by the particular demand and PV data because during the peak period of late December and early January, all peak demands occur after sunset. Therefore, no amount of PV will lower the peak demand. For this reason, Renewable Taos decided to add wind energy to the modeled RE.

<u>PV & Wind</u>

The EnergyShouldBe.org model comes with several sets of recorded hourly wind-electric outputs from wind farms in Colorado. Since there is no wind-electric data from KCECs service area, and since it is possible that KCEC would sign PPAs with wind farms in Colorado or eastern New Mexico, this data was used to give an indication of the effects of adding wind to the mix.

Model *KCEC14 PV, Wind* includes 16.5 MW of PV and 16.5 of wind. The installed RE capacity is 33 MW, 50% of peak, and 143% of minimum demand. The modeled energy produced is 75,226 MWh or 24% of the total. No excess RE is produced, and the consumer price is lowered slightly to 0.1246 $/kWh. Thus, compared with 50% PV, the distribution of the same amount of RE equally between PV and wind results in more energy produced, no excess production, and a lower consumer price. It also reduces the annual peak demand for non-RE from 65.9 to 64.2 MW.

Model *KCEC15 PV Wind+* increases the installed capacity of wind to 21 MW. The combined RE is then 37.5 MW, 57% of peak, and 162% of minimum demand. The modeled energy produced is 87,240 MW or 28% of the total. Excess production occurs during 13 hours, and is 11.9 MWh, or 0.004% of the RE produced. The consumer cost is further reduced to 0.1238 $/kWh. Thus, within data and modeling accuracy, this defines a combination of PV and wind with only insignificant excess production. Peak demand minus RE is reduced to 61.6 MW.

Model *KCEC16 PV+Wind++* pushes excess production to 1% of the RE produced, with 30.5 MW of PV and 29.5 of Wind. This 60 MW of installed RE capacity is 91% of peak and 260% of minimum demand. The modelled energy produced is 137,211 MW or 43% of the total. Excess production occurs during 518 hours (6% of the year), and is 3,330 MWh or 1.0% of RE production. Despite the increase in excess production, the larger amount of wind lowers the consumer cost to 0.1228 $/kWh. Peak demand minus RE is reduced to 60.2 MW.

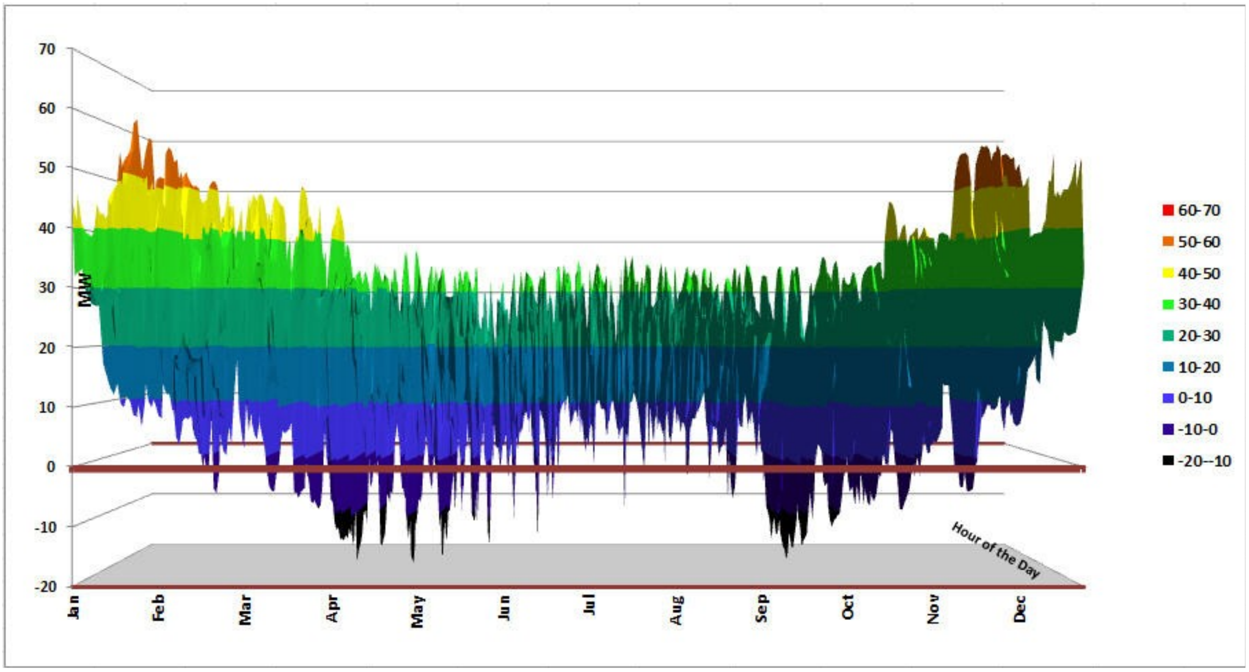

Figure 1. A 3D graph of KCEC's hourly demand for non-RE electricity.
From Model *KCEC16 PV+WIND++*. Each slice going into the page represents one day.
Purple and black below zero on the vertical axis represent excess RE.

KCEC16 PV+Wind++ indicates two potential RE issues. First, adding large amounts of wind energy does not reduce the peak demand for non-RE electricity very much. 29.5 MW of wind (45% of peak demand) only reduces the peak by 9%, from 65.9 to 60.2. This still leaves KCEC with a very high winter peak of purchased electricity, as shown in Figure 1. Second, as the figure also shows, the excess production occurs mainly in the spring and fall. This creates a potential problem. Given the facts that KCEC is strongly winter peaking, while most utilities are summer peaking, Renewable Taos has assumed that rather than have KCEC supply all its own energy from renewable sources, it would make more sense for KCEC to buy electricity in the winter from summer peakers, and then sell them excess solar electricity in the summer. But since KCEC's excess is likely to occur in the spring and fall, when demand from other utilities is lower, this creates a miss-match. Possible solutions are discussed below.

Model *KCEC18 PV,W,St* is more speculative. It includes very high amounts of both PV and wind, and also 300 MWh of batteries. The installed capacity of PV and wind are 50 MW each, and the combined RE is 152% of peak and 433% of minimum demand. The modeled produced energy is 224,722 MWh, or 69% of the total. A lot of excess RE is generated throughout the year, but much of it charges the batteries, and is used later the same day. The amount of excess to be sold is 6,873 MWh, or 2% of RE generated. The peak is reduced to 59.5 MW. Despite the large amount of wind, the batteries raise the consumer price to 0.1611 $/kWh, an almost certainly unacceptable cost. Most of the excess RE is still produced in the spring and fall, and, compared to *KCEC16,* the peak is only reduced from 60.2 to 59.5 MW.

<u>Consumer Cost Calculations</u>

As mentioned in the section on Changes to the Model, a new cost calculation section was added that uses PPA costs to calculate consumer price. There are differences between the prices calculated by the new section and those in the original spreadsheet's calculations. These differences get larger with larger amounts of PV, going from -0.5% for existing PV to -4.4% for *KCEC16*. (Prices in the new section are lower.) The differences are not explained at this point, but may be due to complex uses of Excel's loan payment function, PMT, in the original. The new section is considered more accurate (and is used throughout this report) because it calculates costs directly from the PPA costs. The only exception is the cost of batteries in the new section, which uses the PMT function to determine the annual cost of batteries paid for up-front. The cost of batteries is problematic in any case, and is only used in the final, speculative model.

Other Considerations

These models indicate that RE penetrations of much higher than 20% of peak demand are possible with reduced consumer costs. Studies of existing PV installations by EPRI and NREL have shown that much higher penetrations do not result in grid instability. They do require some regulation by transformers with tap changers, capacitors or smart inverters. These will add some cost to RE facilities that may not be included in the PPA costs used here. The other cost that isn't modeled is the cost of getting out of the contract with Tri-State.

While the cost of regulation is expected to be small, the cost of getting out of the contract could be prohibitive. Tri-State has asked for $135,000,000 ($135 million). If paid over the 25 years remaining on the contract, this would amount to $15.71 per month for each of KCEC's 28,642 members. This is almost certainly prohibitive. Even a third of this amount would probably cause a lot of resistance, and would be difficult to make up for by less expensive RE. So, Tri-State may remain the only significant obstacle to very high amounts of RE.

Conclusions

This study indicates that very large amounts of renewable energy can be added to KCEC's grid without economic or technical problems. The economic limit may be defined by the difference between the costs of renewable energy to KCEC and the price KCEC can get for excess energy from other utilities. Using a combination of local PV and purchased wind power, it should be possible to have an installed capacity of 91% of peak demand, supplying about 43% of annual energy, before this limit becomes significant. This level of renewable energy is unlikely to be achieved in less than ten years, and in the meantime technologies and prices can be expected to change significantly.

Even with today's technologies, it may be possible to affect the economic limit by the use of other sources of wind energy, geothermal-electric and/or concentrating solar power with thermal energy storage (CSP TES). CSP TES cannot be modeled with the EnergyShouldBe spreadsheet, so Renewable Taos intends to acquire and use more sophisticated models.

Renewable Taos has created the models needed to investigate the results of increasing amounts of renewable energy on the KCEC grid. These models need to be improved with better demand and PV data, and better information and estimates of costs. Unless it turns out that PPAs for renewable energy are higher than costs of current and future purchased energy – which seems unlikely, then the main conclusions of this preliminary study should stand or be strengthened. In that case Renewable Taos will strongly recommend that Kit Carson Electric Cooperative enact a firm commitment to 20% renewable energy by2020 with no restrictions on larger amounts, and an equally firm commitment not to enter into contracts limiting KCEC to less than 100%.

The End

Summary of EnergyShouldBe runs for KCEC Short-Term Transition Planning

KCEC Annual Demand (MW): Peak: 65.9, Average: 36.0, Minimum: 23.1. Energy Supplied: 315,523 MWh.

Run	Description
KCEC10 No RE	Kit Carson Electrical Cooperative (KCEC) Hourly Demand with No Renewable Energy
KCEC11 Existing	KCEC Demand with existing large scale PV – 4.25 MW of Tracking Arrays, 0.5 MW of Fixed Arrays. Not including behind the meter.
KCEC12 20% PV	KCEC Demand with PV equal to 20% of Peak Demand = 13.0 MW. Supplies 8% of Annual Energy.
KCEC13 50% PV	KCEC Demand with PV equal to 50% of Peak Demand= 33.0 MW. Supplies 21% of Energy. Maximum PV with no selling.
KCEC14 PV, Wind	KCEC Demand with 25% PV & 25% Wind = 16.5 + 16.5 MW. Supplies 24% of Energy. No Selling.
KCEC15 PV Wind+	KCEC Demand with 25% PV & 32% Wind = 16.5 + 21 MW. Supplies 28% of Energy. Maximum with no selling.
KCEC16 PV+Wind++	KCEC Demand with 46% PV & 45% Wind = 32.5 + 29.5 MW. Supplies 42% of Energy. "Maximum" with 1% selling.
KCEC18 PV,W,St	KCEC Demand with 75% PV & 75% Wind = 50 + 50 MW. 300 MW of Batteries. Supplies 69% of Energy. Sells 2.2% of RE. Hi price.

Run	PV Installed Capacity			PV Output		Wind Installed Capacity			Wind Output	
	MW	% of Peak	% of Min	MWh	% of Total	MW	% of Peak	% of Min	MWh	% of Total
KCEC10 No RE	0	0%	0%	0	0%	0	0%	0%	0	0%
KCEC11 Existing	4.75	7%	21%	9,377	3%	0	0%	0%	0	0%
KCEC12 20% PV	13.0	20%	56%	25,614	8%	0	0%	0%	0	0%
KCEC13 50% PV	33.0	50%	143%	64,945	21%	0	0%	0%	0	0%
KCEC14 PV, Wind	16.5	25%	71%	31,134	10%	16.5	25%	71%	44,092	14%
KCEC15 PV Wind+	16.5	25%	71%	31,134	10%	21	32%	91%	56,117	18%
KCEC16 PV+Wind++	30.5	46%	132%	58,380	19%	29.5	45%	128%	78,831	25%
KCEC18 PV,W,St	50	76%	216%	91,160	29%	50	76%	216%	133,613	42%

Run	RE Installed Capacity			RE Output		Batteries		Cost ($/kWh)			
	MW	% of Peak	% of Min	MWh	% of Total	MWh	M$/y	PV	Wind	Purchased	Total
KCEC10 No RE	0	0%	0%	0	0%	0	0	-	-	0.080	0.1275
KCEC11 Existing	4.7	7%	21%	9,377	3%	0	0	0.080	-	0.080	0.1275
KCEC12 20% PV	13.0	20%	56%	25,614	8%	0	0	0.080	-	0.080	0.1275
KCEC13 50% PV	33.0	50%	143%	64,945	21%	0	0	0.080	-	0.080	0.1275
KCEC14 PV, Wind	33.0	50%	143%	75,226	24%	0	0	0.080	0.0587	0.080	0.1246
KCEC15 PV Wind+	37.5	57%	162%	87,240	28%	0	0	0.080	0.0587	0.080	0.1238
KCEC16 PV+Wind++	60.0	91%	260%	137,211	43%	0	0	0.080	0.0587	0.080	0.1228
KCEC18 PV,W,St	100	152%	433%	224,772	69%	300	13.1	0.080	0.0587	0.080	0.1611

Run	Annual Demand minus RE (MW)			Annual Energy (MWh)		Sold Energy		
	Peak	Mean	Min	Purchased	Renewable	MWh	% of RE	M$
KCEC10 No RE	65.9	36.0	23.1	315,523	0	0	0%	0
KCEC11 Existing	65.9	34.9	20.3	306,146	9,377	0	0%	0
KCEC12 20% PV	65.9	33.1	14.3	289,909	25,614	0	0%	0
KCEC13 50% PV	65.9	28.6	-0.1	250,578	64,945	0.1	0.00003%	0
KCEC14 PV, Wind	62.4	27.4	0.6	240,297	75,226	0	0%	0
KCEC15 PV Wind+	61.6	26.1	-3.3	228,283	87,240	11.87	0.004%	0.0004
KCEC16 PV+Wind++	60.2	20.4	-21.2	181,612	133,911	3,300	1.0%	0.099
KCEC18 PV,W,St	59.5	10.7	-52.3	97,624	217,899	6,873	2%	0.206

References

EPRI: Jeff Smith and Matt Rylander, *EPRI Distributed PV (DPV) Feeder Impact Studies*, Electric Power Research Institute, PV Grid Integration Workshop, Tucson, AZ April 19, 2012. http://www1.eere.energy.gov/solar/pdfs/hpsp_grid_workshop_2012_smith_epri.pdf

Lazard: *Lazard's Levelized Cost of Energy Analysis – Version 8.0.* http://www.lazard.com/PDF/Levelized%20Cost%20of%20Energy%20-%20Version%208.0.pdf

NREL: J. Bank, B. Mather, J. Keller, and M. Coddington, *High Penetration Photovoltaic Case Study Report,* National Renewable Energy Laboratory, January 2013. http://www.nrel.gov/docs/fy13osti/54742.pdf