A review of the benefits of a residential solar power installation in western North Carolina

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Abstract

This paper examines the costs and benefits of a five kilowatt solar photovoltaic (PV) system in Cullowhee, North Carolina (NC) in the United States of America (USA). Cullowhee is located in a mountainous region and not suited to solar power due to potential terrain shading. The PV system studied is installed on a north facing slope with substantial shading, but has provided the owners with financial benefits which justify the system costs. A review of the historic power output of the system, details of the rebate programs available, and recommendations for future system installations are provided to assist potential future PV system owners with detailed information to consider prior to purchasing and installing a system of their own.

Introduction

The mountainous region of western NC in the USA is not well-known as a region suited to solar power due to potential shading of systems located in areas affected by north facing mountains and the corresponding power losses due to terrain shading. However, the availability of federal and state tax rebate programs have assisted residential owners with purchasing and installing grid connected, solar photovoltaic (PV) systems in areas not perfectly suited to these types of smaller output systems of 10 kilowatts output or less. These systems provide owners with income based upon the amount of power generated and delivered to the grid. While larger, megawatt sized PV systems may be justified financially for business owners with relatively larger tax burdens by the income realized from the generated, grid delivered power, smaller residential systems must be carefully designed and physically located to ensure a net positive financial scenario.

The unexpected reluctance of the local electrical power generating and transporting companies to deal with a mass of small, low quantity power generating systems is another consideration for potential PV owners especially in western North Carolina. Coordination and identification of the specific benefits of a proposed system need to be clear before the first panel is purchased.

This paper examines a five kilowatt PV solar power array that was installed at a home in 2011 with the intent to reduce the owner's environmental footprint. The home is located in Cullowhee, the extreme western region of NC within the Appalachian Mountains. There is a great deal of consideration for the environment among the residents in the region, and this was a primary reason given by the owners for installing the system. Many of the people in the region are genuinely concerned with the preservation of the beauty of the mountains and surrounding area. The PV system is grid connected and has provided an income stream for the past five years. The system was partially funded by tax credits through rebates provided by federal and state programs amounting to 65% of the initial approximate $20,000 costs of installation. Income paid by the power company has amounted to about $3800 since the system was connected, about six years ago.

Students in the Construction Management program at Western Carolina University (WCU) have been instructed in the theory and basic configuration of PV systems, and an online database for this system is available for classroom use to observe real time power generation levels. Photovoltaic systems have been covered in the Environmental System course, CM-390, and the Mechanical and Electrical System course, CM-375. A new course will be introduced in the fall semester, 2017 which will be available to all students in all majors, CM-190, Sustainability in Construction. This system will be used to provide new freshman students with a first experience in solar power in the Sustainability in Construction class.

Background

Maximum irradiance is a significant factor to consider for PV panels and arrays to optimally perform. There is evidence that shading can not only inhibit the performance of the array, but can cause power to be absorbed into shaded panels from non-shaded panels. The phenomenon termed *hot-spot* can occur when an imperfection in materials, flaws in fabrication, partial shading or some form of damage to the panel(s) has occurred (Pandian, 2016).

An important factor in the absorption of irradiance by PV panels is the state in which the solar faced glass surface is maintained. Regular cleaning intervals are recommended and are usually determined by both physical and geographic location of the array. Partial shading of PV panels by foliage may exacerbate poorer performance due to organic material adhering to the glass such as leaf debris, sap, or pollen. Airborne contaminants from metropolitan areas may form a layer of debris build up over time reducing the translucence of the glass panel overall affecting the level of irradiance able to be absorbed by the cells. The term *soft-shading* is used when air pollution has caused shading, and the term *hard shading* is used to refer to accumulation of solids such as dust (Maghami, 2016). In a situation of soft-shading, the voltage stays the same but the current is affected, whereas in hard-shading, it is dependent upon whether some cells are shaded or all cells are shaded. If only some cells are shaded, then some irradiance may reach the non-shaded cells and produce a lower output in voltage (Maghami, 2016).

The cost effectiveness of PV technology is a direct variable of the life expectancy of the modules. It is estimated by tests developed by the International Electro-technical Commission that PV modules should be reliable up to 30 years once installed, but exposure to outdoor conditions may cause an escalated rate of degradation not represented in laboratory tests (Sharma & Chandel, 2013).

A study was conducted on a 26+ year old PV power plant in Phoenix, Arizona to determine performance, durability and reliability. The plant consisted of eight sub-arrays rated at 200kWdc, standard test conditions (STC). Power output measured in 2011 at STC decreased from the original 200 KWdc to 76 kWdc representing a power loss of 62% over the 26+ years of operation. It was also determined that some installation practices contributed to the power loss. In summary, both non-cell interconnect ribbon breakages and encapsulation browning were primarily at fault for the power loss I-V (current-voltage) (Belmont, 2013).

Figure 1. Winter exposure. (Google Earth, 2017)

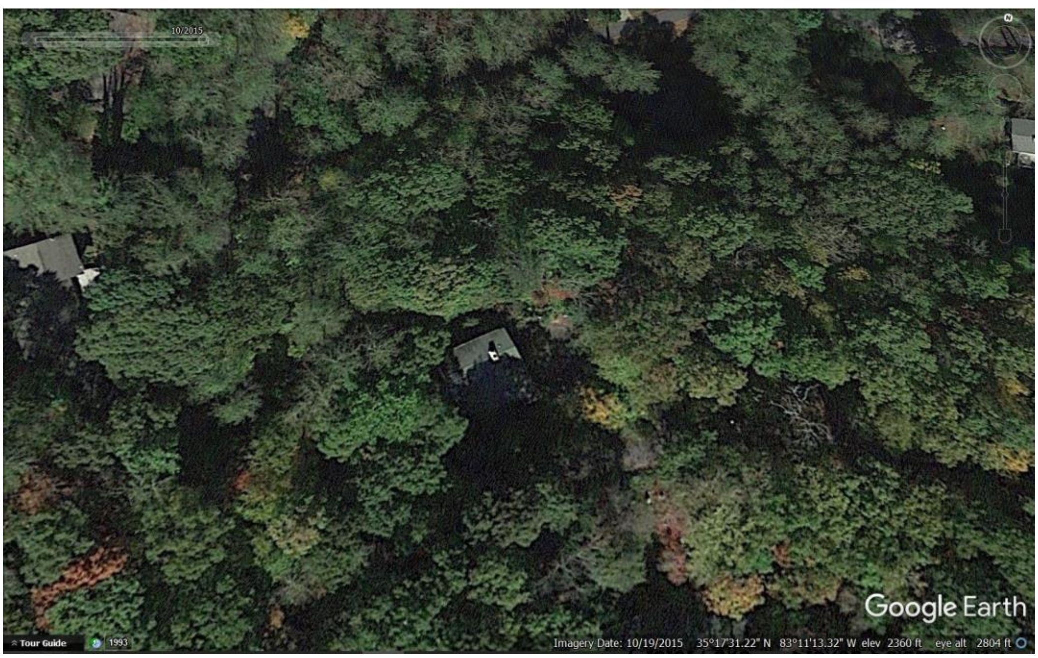

Figure 2. Summer exposure. (Google Earth, 2017)

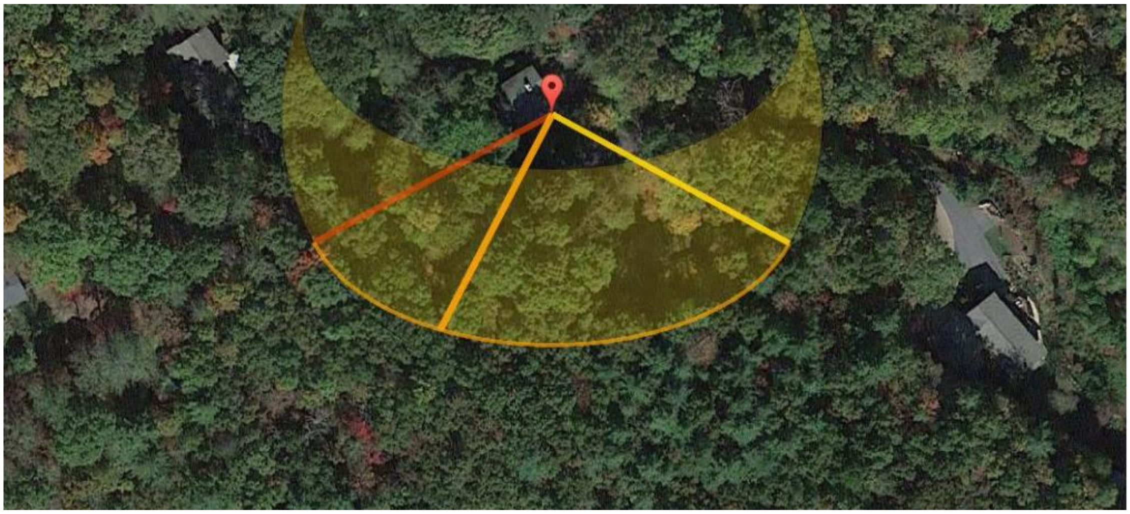

Figure 3. Sun path December 21, 2016. Lat. 35.2919 (SunCalc 2017)
(Redline shows panel exposure to sunlight, yellow lines show highest sun exposure and end of panel sunlight exposure.)

Figure 4 . Sun path June 21, 2016, Lat. 35.2919 (SunCalc, 2017)
(Redline shows panel exposure to sunlight, yellow lines show highest sun exposure and end of panel sunlight exposure.)

A common-sense approach to determining the angle at which the solar array is positioned would be to mount the array to maximize a 90° angle of incidence. Since the declination of the sun is consistently changing, the array angle should permit optimal irradiance throughout the year. A mid latitude (between 30°and 60°) study was done on the roof of the Institute of Meteorology and Climatology (IMuK) in Hannover, Germany over the course of a year. Southward solar collectors were mounted at tilt angles ranging from 0° to 70° in 10° increments. It was found that there was a 6% difference in minimum and maximum values during the summer months and a 10% difference in minimum and maximum values during the winter months. It was concluded that there was little difference in performance of the solar cells at the varied tilt degrees (Beringer, Schilke, Lohse, & Seckmeyer, 2011).

Research Method

This study examined the historical power output of a PV system installed on the roof of a home located in the mountainous area of NC. The system consists of 24 modules, which were installed with an expectation of twenty years of operation. The relationships between the power output and the length of day and the sun's altitude were analyzed. The system is sited on a north facing slope with significant shading exacerbated by large hardwoods also located on the site, see Figures 1 thru 5.

Figure 5. Residential solar power system, 5kw.

	Column 1	Column 2	Column 3	Column 4	Column 5
Row 5	1,126	1,172	1,243	1,237	
Row 4	1,055	1,109	1,146	1,203	1,231
Row 3	901	941	1,109	1,166	1,189
Row 2	849	904	935	978	1,018
Row 1	775	807	827	887	918

Figure 6. Panel output showing panel location in the array.

Results

The output of the individual panels over the life of the system in kilowatt- hours is shown in Figure 6. The effect of shading issues may be immediately identified. When observing the panels facing north, the lower left panels receive the least amount of solar incidence. Figure 6 also shows the total output generated by each solar module for six years from 2011 to 2016. The higher elevated location relative to the ground of the solar module, the more power they generated. There is an approximately 42% difference in the outputs between Row 1 and Row 5. The modules installed at more easterly position also produced more electricity. The difference in outputs by row location can be explained by mountain shading in conjunction with the Sun's location above the horizon and the length of day which changes each day during the year. The greatest output of the system is achieved in the month of May each year.

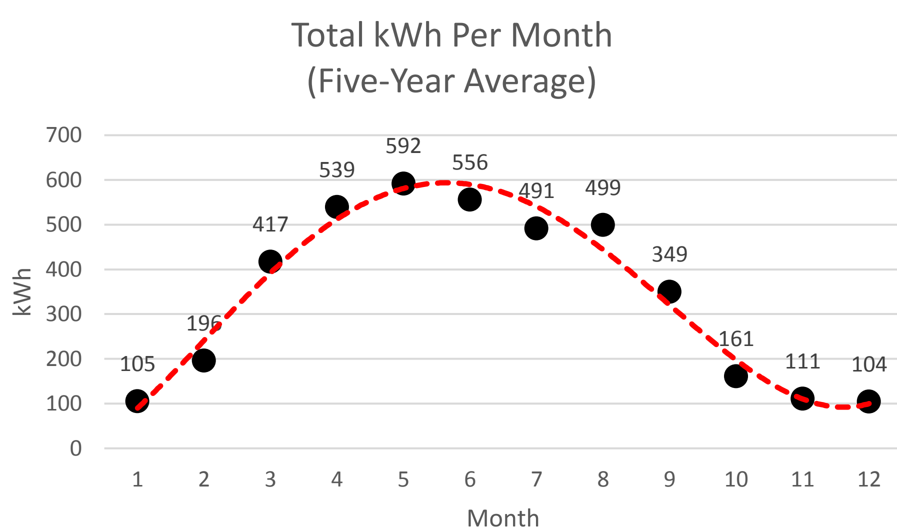

Figure 7. System output in Kw-Hrs. versus month of the year.
(Polynomial 4th order fit curve using Excel Trendlines, (typical))

Monthly outputs correlate with the length of day (hours from sunrise to sunset) and the sun's peak altitude as shown Figure 7 through Figure 9. However, the rankings of the monthly outputs do not exactly match those of the length of day or the sun's peak altitude. For example, the output of May ranked first, and the output of June ranked second, whereas the length of day of June ranked first, and the length of day of May ranked third. The number of rain days and sky conditions might be a cause of this mismatch. On average, there were more rainy days in June than in May in Cullowhee, NC, U.S.A. during the last six years, see Table 1.

Further investigation is needed to explain why there is a large difference in the outputs between February and March, and September and October. The authors suspect cloudy weather as a cause of lower system outputs, but data to confirm these suspicions is not readily available.

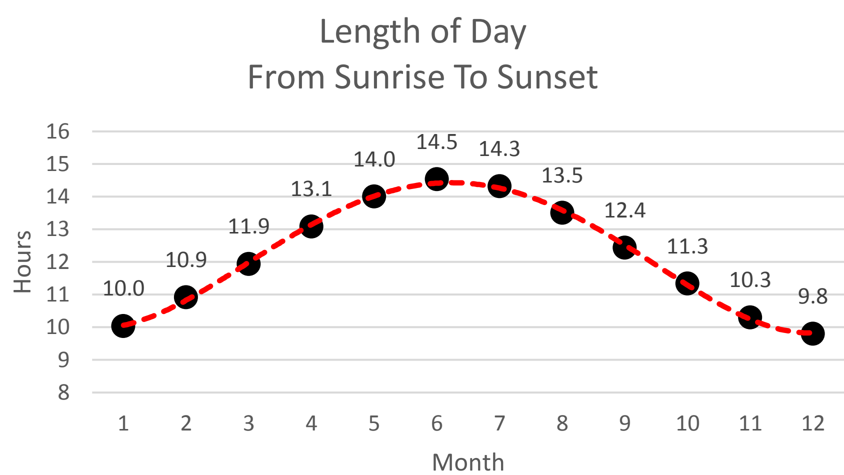

Figure 8. Length of daylight in hours versus month of the year.

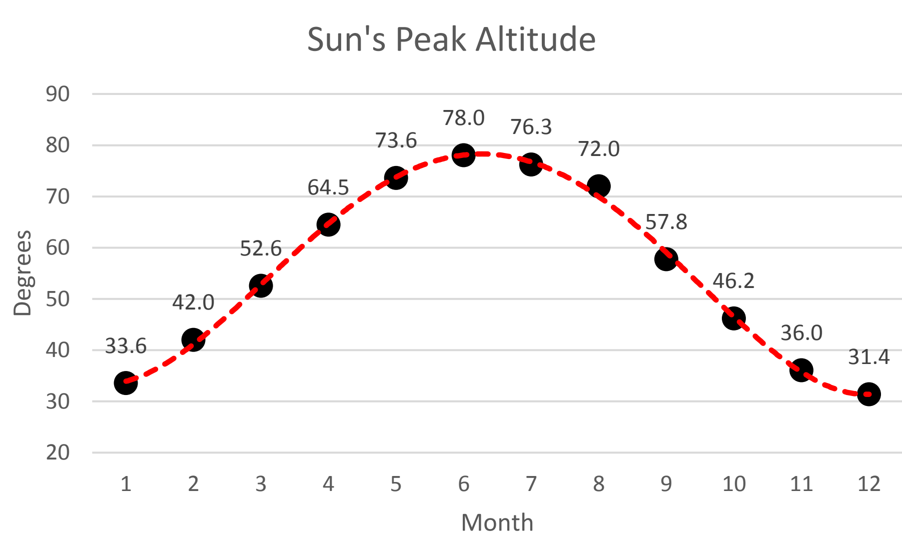

Figure 9. Sun's peak altitude in degrees versus month of the year.

Monthly Number of Days Precipitation >= 0.01 for CULLOWHEE, NC													
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Annual**
2011	10	5	14	11	7	16	12	6	11	7	11	9	119
2012	M	M	M	8	14	12	14	M	9	10	7	14	M
2013	15	17	11	12	12	15	24	19	8	6	10	15	164
2014	10	11	15	11	10	17	14	13	13	11	9	11	145
2015	M	9	16	17	11	14	11	14	12	12	13	17	M
2016	7	10	10	7	13	12	18	17	8	3	5	M	M
Mean	11	10	13	11	11	14	16	14	10	8	9	13	143
Max	15 2013	17 2013	16 2015	17 2015	14 2012	17 2014	24 2013	19 2013	13 2014	12 2015	13 2015	17 2015	164 2013
Min	7 2016	5 2011	10 2016	7 2016	7 2011	12 2016	11 2015	6 2011	8 2016	3 2016	5 2016	9 2011	119 2011

Table 1. Days of precipitation per month (Indicative of cloudy weather)

Total panel output decreased 4.36% on average for six years. In 2016, the solar panels generated 78.21% of the total kWh in 2011, see Figure 10. The manufacturer's specifications list an annual output loss at 5%, so the system is operating within design limits.

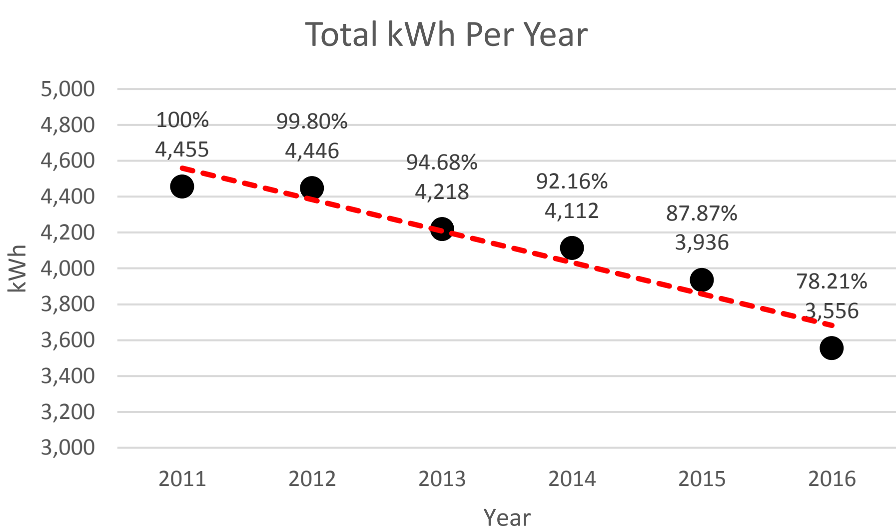

Figure 10: System output per year. (Indicative of system aging)
(Linear fit curve)

Conclusions

Three system limitations were observed with regard to siting parameters. First, shading due to mountain shadowing and trees has affected the system output. Second, the height of the array above the ground is a factor affecting panel output. Lastly the panel output has been reduced due to expected manufacturer's specifications.

System output might be improved by trimming the shrubbery immediately surrounding the system on the south facing side of the house and the solar panels. Additional possible benefits may be realized by trimming the hardwood trees overhanging the panels. Current system output might be increased by 25% which could provide almost an additional $100 per year of income at ten cents per kilowatt-hour. (The current contract provides 15.5 cents per kilowatt but is under re-negotiation and is expected to be reduced.)

The face of the panels were also noted to be yellowed and dirty. Cleaning the faces should be an easy task to accomplish and might improve panel output. An estimate of additional income is difficult to determine but could be significant.

Bibliography

Belmont, J. M. (2013). 26+ Year Old Photovoltaic Power Plant: Degradation and Reliability Evaluation of Crystalline Silicon Modules - North Array.

Beringer, S., Schilke, H., Lohse, I., & Seckmeyer, G. (2011). Case study showing that the tilt angle of photovoltaic plants is nearly irrelevant. *Solar Energy*, *85*(3), 470–476. http://doi.org/10.1016/j.solener.2010.12.014

Maghami, M. (2016). Power loss due to soiling on solar panel: A review. *Renewable and Sustainable Energy Reviews*, *59*.

Pandian, A. (2016). Fire Hazards and Overheating Caused by Shading Faults on Photo Voltaic Solar Panel. *Fire Technology*, *52*(2).

Sharma, V., & Chandel, S. S. (2013). Performance and degradation analysis for long term reliability of solar photovoltaic systems: A review. *Renewable and Sustainable Energy Reviews*, *27*, 753–767. http://doi.org/10.1016/j.rser.2013.07.046

SunCalc. (n.d.). Retrieved January 26, 2017, Figures 7 & 8 download on December 10, 2016 from http://suncalc.net/#/35.2919,-83.1871,19/2016.06.21/17:09

US Department of Commerce, N. N. W. S. (n.d.). National Weather Service. Precipitation data downloaded on December 10, 2016 from http://www.weather.gov/