Economic Feasibility Study of Photovoltaic System on UNH Campus

Jongsung Lee

BS Civil Engineering

Faculty Mentor: Dr. Byungik Chang

ABSTRACT

All renewable energy sources are land intensive. A solar photovoltaic (PV) system requires a lot of spaces, and roofs of buildings are perfect places for installation of campus-wide PV system since most universities cannot afford to waste their land for PV modules. There are 25 buildings on the University of New Haven (UNH) campus with 30,000 m^2 of roof areas that are structurally suitable for solar photovoltaic. UNH is located in West Haven, Connecticut, where an average of 206 days, which is equivalent to approximately 2,585 hours of sun shine is annually present. The average annual insolation at this location is about 4.0 to 4.5 kWh/m^2/day. This geographical information suggests that solar resource at this location is sufficient to supply all PV markets. This study focused on the economic feasibility of solar photovoltaic systems on the University of New Haven campus. The result of this study will be used to analyze and further develop the feasibility study of PV systems for universities in the New England (NE) region, which share similar characteristics of climate and economic factors. The electricity price in Connecticut is one of the highest in the nation. Based on the average retail electricity price to the residential sector in 2014, the state's rate of 20.19 cents / kWh was 4th highest in the U.S., and the electricity demand in the NE region has been continuously increasing. This suggests that the prosperity of PV systems in the region and development of precise models for economic analysis are urgent.

INTRODUCTION

As the use and the demand for energy continue to grow, fossil and nuclear fuel research is becoming increasingly limited. Figure 1 shows that more than 80% of total energy consumption is made from natural resources [1]. Needs for the development of alternative energy have been emerging while the study on the potential of solar power (photovoltaic) system has been very promising as shown in Figure 2. The demand for the use of solar energy will constantly increase, and solar energy can be operated for an indefinite period of time without wearing out, unlike other natural resources such as oil, coal, and natural gas. Therefore, the sun is the most dependable source of energy for the future, and solar energy can reduce the carbon footprint and the cost of electricity significantly.

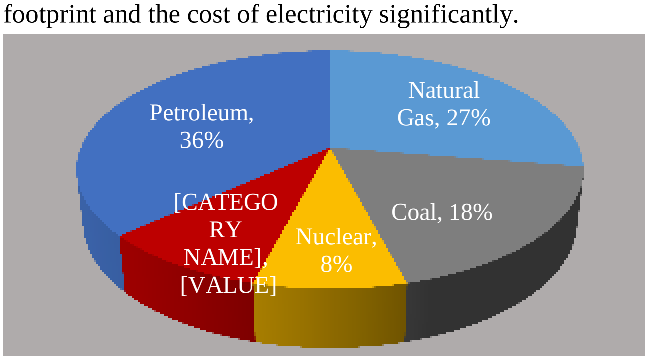

Figure 1. U.S. primary energy consumption by resource in 2012

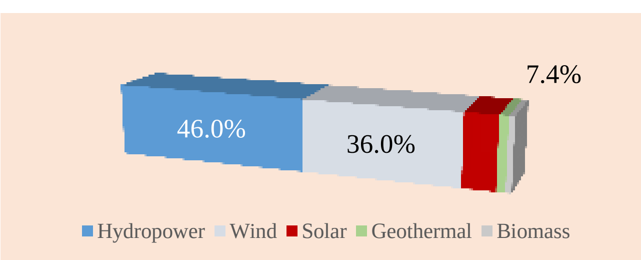

Figure 2. U.S. Renewable energy distribution

The primary objective of this research is to examine the feasibility of installing PV systems in Connecticut universities based on the data collected from UNH buildings. In order to accomplish this objective, the PV system currently installed at Celentano Hall is used as a research model. Based on the weather data provided by SAM software, favorable roof pitches and cardinal directions of the UNH buildings were determined, and solar energy production was calculated accordingly. The payback periods were determined based on the solar energy generation of each UNH building and other economic criteria. Through the evaluations and economic analysis, suitable UNH buildings for PV systems would be determined, and other universities in Connecticut would benefit from this economic model.

METERIALS AND METHODS

UNH PV system background

Celentano Hall is the first green residence hall at the University of New Haven with LEED gold certification status. The building is located at the center of the main campus and supplied with sufficient solar energy for the PV system year round. The PV system consists of 228 modules of Hanwha HSL72 on Panelclaw Polar Bear racking and three Solectria inverters. Three inverters were used to maximize the efficiency. As shown in Figure 3, the fixed panel array system of 228 photovoltaic modules are facing south with an inclination of 12 degrees. Figure 4 shows the maximum amount of solar insolation as a function of module angle and latitude. According to Figure 4, this specific angle allows the modules to absorb the most amount of solar radiation at the location. The lifetime of the current PV systems in the market is estimated to be 25 years. The installation of fixed mount array with DC system size of 67.27 kW was finished in December 2015, and the PV system started generating electricity in January 2015 [2].

Therefore, nine-month performance data were used for this research.

Figure 3. Celentano hall fixed modules with 12° inclination

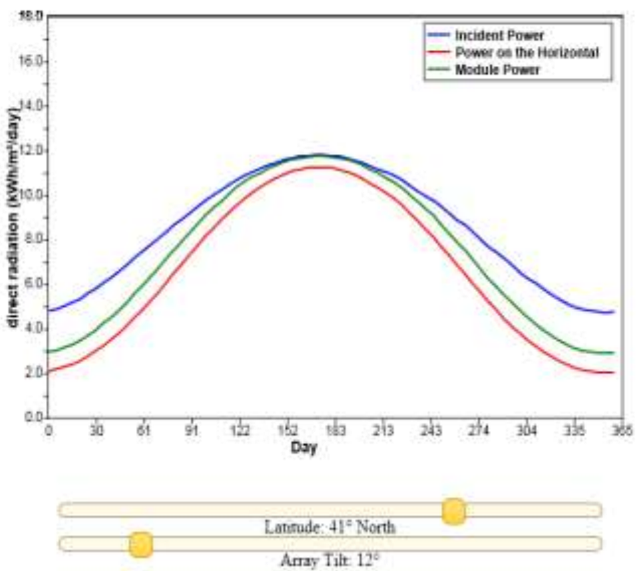

Figure 4. Solar insolation [3]

Celentano Hall PV system performance

The actual solar energy generation data of the PV system at Celentano Hall is monitored by Bella Energy Company. Figure 5 shows monthly energy production from the start of its operation. The peak energy generation of 11,000 kWh occurred in August, and the lowest of 1,698 kWh in January.

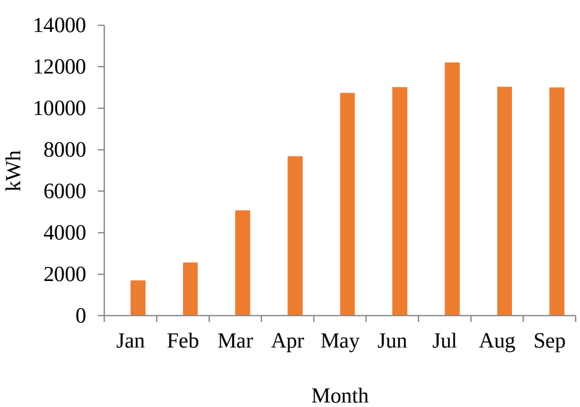

Figure 5. Celentano Hall PV system monthly energy generation [4]

UNH campus

West Haven, Connecticut, is located in the Northeastern region of the U.S. and has a humid continental climate with hot summer days. The campus is located in the northern hemisphere with latitude of 41.29° N and longitude of 72.96° W [5]. Throughout the year, the daily temperature varies between 24 °F and 84 °F and rarely reaches below 10 °F or above 88 °F. The warm season usually starts on June 1 and ends on September 19, with an average daily high temperature of 82 °F. An average of 206 days, which is equivalent to approximately 2,585 hours of sunshine, is annually present.

The economic analysis for UNH buildings is designed based on the data comparison between the Celentano Hall PV system and each UNH building. Dimensions, roof types, and average historical electricity usages of each building were taken into consideration for the PV economic analysis. Even though the economic driving factors are different based on the characteristics of the buildings, the data collected from Celentano Hall as a model for the analysis would provide accurate estimates for each building because the buildings are located at the same latitude. The yearly energy production and payback period are calculated accordingly.

For an economic analysis, an estimated energy production of the PV system was determined using PVWatt calculator [3]. Estimated solar energy generation can be calculated using an equation,

$$E = A * r * H * PR \quad (1)$$

where,

E = Energy generation (kWh)
A = Total solar panel area (m^2)
R = Solar panel yield (%)
H = Annual average solar radiation on tilted panels
PR = Performance ratio (Default = 0.77)

The measurement for the entire roof area cannot be used in the array size calculation due to several technical factors. Typical PV module arrays require set-back spaces of 4 ~ 6 ft. from the edges for safety issues and enough spaces between solar panels for accessibility. The shades created by objects such as AC units and water tanks also affect solar power generations. Estimated total solar panel area for each building was measured according to these restrictions. Hanwha Solar panel yields 14.2 % module efficiency [6], and according to Figure 6, the annual average solar radiation on a tilted panel at this location is 1,742.93 kWh/m^2 [7]. The performance ratio for Celentano Hall PV system is 0.77 as shown in Table 1.

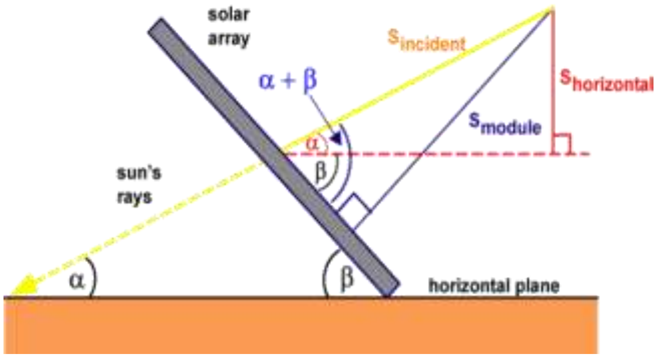

Figure 6. Solar radiation calculation on tilted module [7]

Table 1. Performance ratio for Celentano Hall PV system

Component Derate Factors	PVWATTS Default Ratio	Range
PV module nameplate DC rating	0.95	0.80 - 1.05
Inverter and Transformer	0.92	0.88 - 0.98
Mismatch	0.98	0.97 - 0.995
Diodes and connections	0.995	0.99 - 0.997
DC wiring	0.98	0.97 - 0.99
AC wiring	0.99	0.98 - 0.993
Soiling	0.95	0.30 - 0.995
System Availability	0.98	0.00 - 0.995
Shading	1	0.00 - 1.00
Sun-tracking	1	0.95 - 1.00
Age	1	0.70 - 1.00
Overall DC-to-AC Performance Ratio	0.77	

Feasibility Study

In July 2011, the state of Connecticut enacted legislation amending the state's renewables portfolio standard and created new classes of renewable energy credits for PV systems with a project size larger than 100 kW and up to 1 MW in nameplate capacity [4]. The amount of ZRECs award depends on the electricity generation amount, and therefore, the amount decreases every year due to the degradation factor (0.50 %) of the PV module. ZRECs were awarded to the Celentano Hall PV system; however this is not guaranteed for other buildings. A PV system with solar power generation greater than 100 kWh is qualified for reverse auction and the buildings with power generation less than 100 kWh will earn the opportunities by a lottery system. Currently 25 UNH buildings are qualified for ZREC requirement and could take substantial financial support for 15 years when awarded. Under the federal Modified Accelerated Cost-Recovery System (MACRS), commercial PV installation projects can recover investments through depreciation deductions. Connecticut enacted legislation in June 2007 (H.B. 7432) that established a sales and use tax exemption for solar energy equipment. The sales tax incentive covers 30% of both the equipment and labor services relating to the installation of the systems. UNH is categorized as a non-profit organization and therefore cannot take a full tax advantage. However, this credit is applicable if UNH chose to hire a solar panel company to own the PV system and buy solar electricity from them.

RESULTS

An economic analysis model is then generated based on both the technical and economic factors, and analyzed feasibility of each building. The annual estimated amount of solar generation is 81,847 kWh, and the total cash flow is approximately $493,319 for the life time of the Celentano Hall PV system with the payback period of 11 years. Application of this model to 24 other buildings on the campus with various roof sizes and electricity usages returns optimistic results that more than 80% of UNH buildings are economically feasible and generate positive cash flow within the life time of the system. Table 2 shows the results of economic analysis of PV system on UNH buildings. Most of those 25 buildings will qualify for ZREC and other government incentives and will start generating positive cash flow within 11 years. The average annual electricity saving from this campus-wide PV system is estimated to be a quarter million dollars and 5.2 million dollars over its life time as shown in Table 2.

Table 2. PV system economic analysis on UNH campus

	Building	Area (m2)	No. of Solar Modules	Cash Flow after 25 yrs ($)
1	Arbeiter Maenner Chor	248	26	94,737
2	Bartels Hall	475	50	100,319
3	Beckerman Rec. Center	3755	392	627,855
4	Bergami Hall	1196	125	194,407
5	Bethel Hall	929	97	141,080
6	Bixler Hall	1048	109	173,982
7	Bookstore Security	702	73	117,164
8	Botwinik Hall	744	78	238,934
9	Buckman Hall	1570	164	258,541
10	Celentano Hall	2186	226	352,070
11	Charger Gymnasium	1651	172	273,015
12	Charger Plaza	795	83	134,967
13	Dental Center	805	84	137,081
14	Dodds Hall	2133	223	349,040
15	Dun, Shef, Winch Halls	3601	376	603,140
16	Echlin Hall	897	94	144,780
17	Forest Hills Apt	2916	304	496,371
18	Gate House	194	20	48,666
19	Henry C. Lee	389	41	61,762

	Institute			
20	Kaplan Hall	668	70	110,858
21	Maxcy Hall	730	76	141,446
22	Peterson Library	1380	144	223,324
23	Ruden Street Apt	606	63	102,421
24	S. Campus Hall	279	29	50,605
25	Subway Building	275	29	47,500
	Total	30172	3147	5,224,064

CONCLUSION

Energy cost makes up a significant portion of overall university operation expenses. UNH is currently spending approximately $3 million annually for electricity, and this expense will continuously increase. Installations of PV systems throughout UNH campus will contribute significant monetary savings to the university, which would allow extra supports in improving facilities, funding additional programs and, reducing burdens on students' tuition bills. Successful outcomes from Celentano Hall encouraged installation of a PV system at Westside Hall, taking advantage of similar measures, and this will raise the level of awareness to the greater UNH community for sustainable efforts. A higher level of awareness will promote additional interests and investments in renewable energy research and sustainability projects, as well as greater responsibilities for wise use of our depleting natural resources. The conclusion of this research proved the feasibility of PV system installation at the University of New Haven. In the near future, feasibility of PV systems at other universities in Connecticut can be evaluated using the economic analysis model created from this research.

FUTURE STUDY

Data for the PV system performance at the Celentano Hall will be continuously collected. A more accurate and precise economic analysis model can be constructed with more data collected. Further research on the developing solar module technologies and future data collection will be useful to promote application of such a system at the universities throughout the NE.

For the purpose of this research, the electricity rate was assumed as the same for all UNH buildings. In the future study, different electricity rates based on the different characteristics of the buildings can be used for the economic analysis.

This research can be applied to the universities in different states in the United States. With the information about the local weather and the local government incentives, the cash flow can be calculated, and the feasibility of the PV system can be evaluated.

REFERENCES

1. Renewable Energy Data Book 2013. National Renewable Energy Laboratory (NREL). Web. 5 June 2015. <http://www.nrel.gov/>.
2. Annino, Louis C., Jr. "PV Systems on the UNH Buildings." Personal Interview. 28 Jan. 2015.
3. PVEducation. PVEducation. Web. 7 July 2015. <http://pveducation.org/>.
4. Chris Lotspeich, "PV System on Celentano Hall." Personal Interview. 22 July. 2015
5. Latitude & Longitude, Find Your Latitude & Longitude Coordinates. 27 July. 2015.
6. "Hanwha Solar Specification." HSL 72l. Poly UL. Hanwha SolarOne, 2013. Print.
7. William Marion, Stephen Wilcox, "Architecture and solar radiation." National Renewable Energy Laboratory (U.S.) National Renewable Energy Laboratory, 1995

ACKNOWLEDGEMENTS

I would like to acknowledge everyone who has assisted me throughout this program. I would first like to thank Mr. and Mrs. Carrubba and SURF committee for giving me this wonderful opportunity. I would also like to thank Chris Lotspeich and Louis C. Annino for sharing their extensive knowledge and experiences on the PV system. And many special thanks to my mentor, Dr. Byungik Chang, for his continuous support and encouragement.

BIOGRAPHY

I am currently a junior at the University of New Haven majoring in Civil Engineering. I am a member of American Society of Civil Engineers (ASCE) student chapter. I am also working as a research assistant for Dr. Chang, and currently exploring a numerical modeling of highway support structures. I plan on pursuing my career as a structural engineer and construction manager upon graduation in May 2017.