MODELING AND SIMULATION OF SOLAR ENERGY LEVELIZED COST OF ENERGY FOR A PRE-EXISITNG BUILDING RETROFIT

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ABSTRACT

This paper presents the use of the renewable energy modeling and simulation software package National Renewable Energy Laboratory System Advisor Model (NREL SAM) to perform decision making regarding pre-existing building infrastructure. The Levelized Cost of Energy (LCOE) for each case study is summarized along with the financial analysis of each proposed renewable energy technology. Herein, the LCOE was found to be 4.41 ¢/kWh and 19.53 ¢/kWh for solar PV and solar thermal hot water heating retrofits, respectively. These values are in comparison to the average cost of electricity of 17.8 ¢/kWh for Los Angeles, CA.

Keywords: modeling, simulation, solar energy, LCOE, financial analysis

INTRODUCTION

Background

The National Renewable Energy Laboratory (NREL) System Advisor Model (SAM) (Blair et al., 2014,) [1] is a valuable turn-key tool which allows systems engineers as well as program managers to trade one technology against another with ease. System Advisor Model (SAM) is a performance and financial model designed to facilitate decision making for professionals involved in the renewable energy industry. The recent paper by [2] presents an evaluation of renewable energy technologies and their potential for technical integration and cost-effective use within the U.S. energy sector. At the forefront of renewable energy technologies are solar energy renewables, including solar photovoltaic (PV) and solar thermal. Many systems use a hybrid of solar PV and solar thermal technologies. The technology, construction and economics associated with large scale solar energy infrastructure projects is well documented in various case studies [3-5]. This current paper presents the use of NREL SAM via two case studies applied to the retrofitting of an existing university engineering laboratory building i) Solar Photovoltaic electricity power generation, and ii) Solar Thermal Hot Water Heating. Both technologies are cast in light of their relative financial merits to the large building energy operating costs.

NREL SAM Performance Models

The current version of NREL SAM [1] includes physical performance models for the following technologies: photovoltaic systems, battery storage, parabolic trough concentrating systems, power tower concentrating solar power (molten salt and direct steam), solar water heating, wind power, geothermal power etc. The paper of [6] describes a flat plate photovoltaic (PV) performance modeling validation effort. The work of [7] outlines a validation analysis based on the performance of NREL SAM for 100 locations. The research of [8] compares results of a performance modeling validation report using NREL

SAM. The work of [9] offers a compendium of case studies for NREL SAM compared to actual performance data. The report of [10] documents various thermal energy storage (TES) technologies (batteries, compressed air energy storage (CAES), pumped storage hydropower (pumped-hydro), thermal molten salt, high power flywheels, high power super capacities, hydrogen energy storage) for grid tied an off-grid situations available in NREL SAM. The paper of [11] shows a case study of using NREL SAM's geothermal model. The works of [12,13] compare the results of NREL SAM to other renewable energy modeling, financial forecasting software packages including RETScreen [14] which is a software tool offered by the Canadian government. The current paper focuses on the functionality of NREL SAM to serve as a decision making tool in the arenas of renewable energy technology selection and regulation. In particular, the NREL SAM tool is used herein as an aid to decision and policy making regarding retrofitting an existing infrastructure with solar energy renewables technologies.

NREL SAM Financial Models

The built-in capability of financial modeling for NREL SAM is detailed in [15]**.** The NREL SAM software makes performance predictions and cost of energy estimates for grid-connected power projects based on installation and operating costs and system design parameters that you specify as inputs to the model. The most commonly used financial metric in renewable energy proposals is the Levelized Cost of Energy (LCOE), The LCOE is often taken as a proxy for the average price that the generating asset must receive in a market to break even over its lifetime. In the NREL SAM software, the LCOE accounts for Installation costs, Financing costs, Taxes, Operation and maintenance costs, Salvage value, Incentives, Revenue requirements (for utility financing options only), Quantity of electricity the system generates over its life The LCOE is given mathematically in NREL SAM by the following [15]

$$LCOE = TLCC / \sum_{n=0}^{N} \frac{Q_n}{(1+d)^n} \tag{1}$$

where the total lifecycle cost $TLCC$, is the present value of project costs over its life N discounted at rate d, $C_n$is the project equivalent annual cost and Q_n is the quantity of electricity produced in a year.

Case Study for Solar Photovoltaic Electricity Generation

The purpose of this case study is to provide a Solar Photovoltaic (PV) electricity generation system life cycle cost analysis on the Engineering Building of California Polytechnic University of Pomona. The proposed Solar PV location is the roof of Building 17 shown in Figure 1.

Figure 1 – California State Polytechnic University, Pomona Engineering Building

a. Building Energy Usage

The total annual electric usage of the Building-17 in 2015 was 1,113,874 kWh with the peak demand at 192 KW. The annual electricity cost was $177,242 based on the Southern California "Time of Use, General Service, Non-Demand Metered" schedule. The excess electricity sell rate is 0.0289 $/kWh based on the data imported from Southern California Edison (SCE) into SAM.

b. Photovoltaic System Selection

A PV system usually consists of solar panels, an invertor, and an excess power system. To size the PV system, first the area, that the panels can be installed, need to be identified. Secondly, the type of solar panel and its orientation is selected. For this analysis the PV system shown in Table 1 was selected from the built in NREL SAM PV library.

Table 1 – Modules, Invertors, and Array Information based on the Vendor Data

PV System Technical Information			
Roof Area (m^2)	6,636		
Area Used (m^2)	5,170		
Mudules		**Inverters**	
Brand	LG NeON™	Brand	SMA America
Module Product Number	LG385N2W-G4	Product Number	STP 60-US-10 (400 VAC) 400V
Module Nameplate efficiency	19.10%	Max. input voltage	1,000 V
Cells	6 x 12	Unit capacity	59.859 AC kW
Cell type	Mono-c-Si	Input voltage	570 - 800 VDC DC V
Degradation for first year	2%	Quantity	1500%
Degradation rate after first year	0.6%/year	Total capacity	897.9 AC kW
Life of Module	30 years	DC to AC Capacity Ratio	1.17
Tilt deg	40	AC losses (%)	1
MPP voltage (Vmpp)	39.6	**Array**	
MPP current (Impp)	9.5	Strings	160
Open circuit voltage (Voc)	48.3	Modules per string	17
Short circuit current (Isc)	10.04	String voltage (DC V)	68170.00%
Module efficiency (%)	19.1	Tilt (deg from horizontal)	40
Operating temperature (°C)	-40 ~ +90	Azimuth (deg E of N)	180
Maximum system voltage (V)	1000	DC losses (%)	440%
Maximum series fuse rating (A)	20	Tracking System	Fixed
Power tolerance (%)	0 ~ +3	Shading	No

c. Life Cycle Cost Analysis

Electricity rates was imported into SAM based on on-peak/off-peak hours. The total direct cost of the project was estimated to be $ 1,257,818. An analysis period of 25 years was assumed. The payback for this project was 5.8 years and it would add 700,000 KWh to the grid over its life span. The initial cost of the project was based on the direct capital cost only. Indirect costs such as grid interconnection and sales tax was excluded from the results presented herein. The LCOE was found to be 0.0441 $/kWh as summarized in Table 2.

Table 2 – LCCA results from SAM based on the hourly data

LCCA Results	
Annual energy (year 1)	1,795,061 kWh
Capacity factor (year 1)	19.50%
Energy yield (year 1)	1,713 kWh/kW
Performance ratio (year 1)	0.81
Battery efficiency	0.00%
Levelized COE (nominal)	5.43 ¢/kWh
Levelized COE (real)	4.41 ¢/kWh
Electricity bill without system (year 1)	$177,242
Electricity bill with system (year 1)	($2,918)
Net savings with system (year 1)	$180,160
Net present value	$472,916
Payback period	5.8 years
Discounted payback period	8.0 years
Net capital cost	$1,257,818
Equity	$1,257,818

Case Study for Solar Thermal Hot Water Heating

This case study considers a commercial solar water heating for a pre-existing university building. The performance model and life cycle cost analysis of a solar domestic water heating system were analyzed for Building 17, located at California Polytechnic University of Pomona, 3801 W Temple Ave, Pomona, CA 91768 as shown in Figure 1. The solar thermal analysis performed within SAM is based on the algorithm described in [16]. For this report, 10 Sunearth Thermoray [17] flat plate solar collectors were assumed. The solar energy gained based on the correlation to local air temperature used in the Building America Benchmark [18] is used in the framework of the analysis.

a. Solar Collector Selection

The performance data for SUNEARTH solar collector model TRB-40 [19] were manually input into the NREL SAM user interface based upon the certification information taken from [19].

b. Hot Water Consumption

The ASHRAE 2011 Handbook-HVAC Applications [20] stipulate the hot water demands per fixture for university buildings. The peak demand for hot water draw was calculated using the recommended ASHRAE [20] demand factor. In addition, domestic hot water consumption was calculated by assuming 15 hours of operation. Furthermore, a domestic hot water storage with the capacity of 800 gallons was selected.

c. Solar Water Heating LCOE Model

The initial cost and the operating cost for the solar heating retrofit from the NREL SAM financial analysis simulation software are shown in Figure 2.

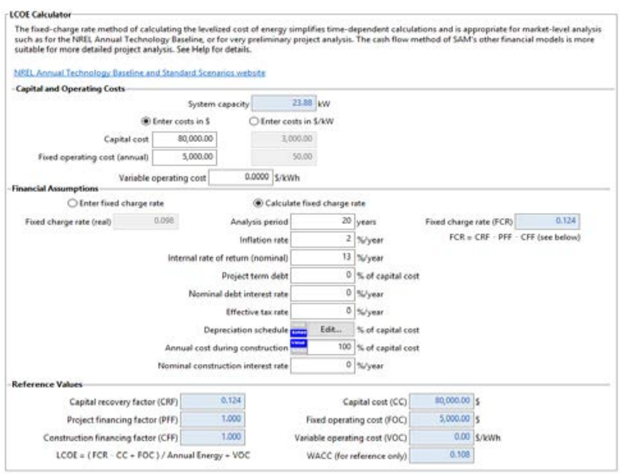

Figure 2 – Financial parameters section from the SAM model

d. Financial Analysis

The initial cost of $80,000 includes 10 solar collectors, installation costs, an 800 gallon storage tank, plumbing, and maintenance fees. The analysis period was assumed to be 20 years. The financial analysis shows that the solar hot water system can save the facility 76,316 kWh of energy. The LCOE was calculated to be 195 $/MWh which was about the lowest LCOE of a solar thermal system in the United States. Nevertheless, 195 $/MWh is still higher than all other sources of energy based on the Energy Information Administration data of [21].

Policy Implications of the Model

This section of the paper addresses how the modeling results influence policy and what the consequences of these policy implication are. California has ambitious goals for zero net energy buildings. Per state goals, 50% of all commercial buildings would be retrofitted to zero-net energy by 2030. The California State University is also committed to sustainability by implementing policies to promote sustainable buildings. California aims to promote energy efficiency by incentivizing retrofit projects and providing low-interest rate loans. There are wide variety of incentive programs for commercial public buildings such as university buildings. Southern California Edison (SCE) offers up to 50% of the cost of qualifying energy efficiency programs. The cost of HVAC optimization and LED lighting retrofits for the current project are estimated to be $140,000 [22]. Thus, in addition to $36,000 annual savings in electricity costs offset with the solar PV system, the facility would receive $70,000 worth of incentives. The Energy Conservation Assistance Act (ECAA) offers $3M, 1% interest rate loans for public university buildings. The (ECAA) program can be used to finance the HVAC optimization and the LED retrofits proposed herein. The payback period of 5.7 years and availability of multiple loans and incentives programs makes this net-zero retrofit project attractive and in compliance with California's policy goals to promote zero-net energy buildings.

Summary

This paper has demonstrated the capabilities and functionality of the NREL SAM renewable energy modeling and simulation tool as a guide to policy and decision makers. In particular, this paper has presented the use of NREL SAM (System Advisor Model) software as a tool to predict the physical performance and financial cost benefits or solar photovoltaic (PV) and solar thermal hot water heating retrofits of a pre-existing engineering laboratory building. The LCOE was 4.41 ¢/kWh and 19.53 ¢/kWh for solar PV and solar thermal hot water heating retrofits, respectively. Note that the national average cost of electricity is 12 ¢/kWh, while in Los Angeles (the location of the retrofit), the average cost of electricity is 17.8 ¢/kWh. Thus, both solar technologies addressed herein are viable candidates for the retrofit of the pre-existing building considered.

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