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Using NREL System Advisor Model to Teach Renewable Sustainable Energy

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Abstract

This paper presents the use of the modeling and simulation software package National Renewable Energy Laboratory System Advisor Model (NREL SAM) to perform decision making regarding renewable energy technology infrastructure. The paper illustrates how the NREL SAM software can be used within the curriculum to address the learning outcome and objectives of the renewable energy related coursework. The paper then outlines the various performance models and the financial models used in NREL SAM. This is followed by several student performed NREL SAM case studies (solar photovoltaic, solar thermal, concentration solar /thermal energy storage) used to illustrate the software's capability of supporting decision making and renewable energy technology selection.

Keywords: *Modeling, Simulation, Renewable, Sustainable, Education*

1. Introduction

The National Renewable Energy Laboratory (NREL) System Advisor Model (SAM) Blair et al. (2014) is a valuable turnkey 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 people involved in the renewable energy industry: Project Managers, Energy Engineers, Policy Analysts, Technology Developers, Researchers and Urban Planners. The recent paper by Tran and Smith (20170 presents an evaluation of renewable energy technologies and their potential for technical integration and cost-effective use within the U.S. energy sector. Thus, renewable energy planning and decision making remains at the forefront of today's policy and decision making forums. The NREL SAM simulation tool is a viable software for renewable energy technology trade studies. This paper presents a series of case studies used to demonstrate the viability of using NREL SAM for decision making regarding renewable energy technologies. The theory of the physical and financial performance models used by NREL SAM are first reviewed. A series of case studies including Solar PV, Solar Thermal, Concentrated Solar/Thermal Energy Storage and Geothermal are then presented to illustrate the functionality of the NREL SAM software.

1.1. Performance Models

The current version of NREL SAM includes performance models for the following technologies: Photovoltaic systems (flat-plate and concentrating),Battery storage model for photovoltaic systems, Parabolic trough concentrating solar power, Power tower concentrating solar power (molten salt and direct steam), Linear Fresnel concentrating solar power, Dish-Stirling concentrating solar power, Conventional thermal, Solar water heating for residential or commercial buildings, Wind power, Geothermal power and geothermal co-production, Biomass power. The NREL SAM physical performance models are detailed by documentation provided by NREL, Freeman et al. (2014). The work of Freeman et al. (2014) outlines a validation analysis based on the performance of NREL SAM for 100 locations. The paper of Rudie et al. (2014) describes a flat plate photovoltaic (PV) performance modeling validation effort. The research of [6] compares results of NREL SAM to real performance data. The case studies documented herein were taken from actual student projects from the "Solar Thermal Engineering "ME 407/L course at California State Polytechnic University at Pomona.

1.2. Financial Models

The built-in capability of financial modeling for NREL SAM is detailed in Short et al. (1995)**.** 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. Projects can be either on the customer side of the utility meter, buying and selling electricity at retail rates, or on the utility side of the meter, selling electricity at a price negotiated through a power purchase agreement (PPA). System Advisor Model's performance models make hour-by-hour calculations of a power system's electric output, generating a set of 8,760 hourly values that represent the system's electricity production over a single year. System Advisor Model's financial model calculates financial metrics for various kinds of power projects based on a project's cash flows over an analysis period that the user specifies. Residential and commercial projects are financed through either a loan or cash payment, and recover investment costs through savings from reduced electricity purchases from the electricity service provider. For electricity pricing, SAM can model simple flat buy and sell rates, monthly net metering, or complex rate structures with tiered time-of-use pricing. For these projects, SAM reports the following metrics: Levelized cost of energy (LCOE), Electricity cost with and without renewable energy system, Electricity savings, After-tax net present value, Payback Period. The most commonly used of the above is the LCOE, which is also known as Levelized Energy Cost (LEC), is the net present value of the unit-cost of electricity over the lifetime of a generating asset. 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 NREL SAM 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 [11]

$$LCOE = \sum_{n=0}^{N} \frac{C_n}{(1+d)^n} \Big/ \sum_{n=0}^{N} \frac{Q_n}{(1+d)^n} \qquad \text{(eq. 1)}$$

or alternatively,

$$LCOE = TLCC \Big/ \sum_{n=0}^{N} \frac{Q_n}{(1+d)^n} \qquad \text{(eq. 2)}$$

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. The NREL SAM software calculates financial metrics from project annual cash flows representing the value of energy savings for projects using retail electricity rates, and the value of revenue from electricity sales for projects selling electricity under a power purchase agreement. The following type of studies can be carried out using SAM: Parametric Analysis, Sensitivity Analysis, Stochastic per Short et al. (1995).

1.3. NREL SAM Weather Data Input

The solar resource and meteorological data in a SAM weather file may have been developed from ground measurements, data from a satellite, or a combination of the two. A computer model is usually involved in preparing the weather file, and may be used to fill gaps in the data, determine typical-year months, or calculate values. Common sources of weather files for SAM's solar performance models are listed at https://sam.nrel.gov/weather. Further details of the format of the weather file used by SAM and the various inputs included for given simulation can be found at https://sam.nrel.gov/weather.

2. Renewable Energy in the Curriculum

The Mechanical Engineering curriculum at Cal Poly Pomona includes various coursework related to renewable and sustainable energy. The following courses (and their various objectives) related to renewable energy are offered at the university via the Mechanical Engineering Department:

- ME 306 “Energy Management” Energy system modeling; forecasting techniques; analysis of energy requirements; energy audits; net energy analysis; conservation strategies; energy, environment and economics interface; role of energy management and case studies.
- ME 307 “Alternative Energy Systems” Analysis and synthesis of energy systems; fossil fuel systems; viable alternative energy sources, solar, geothermal, wind, biomass, hydro and ocean resources; conversion, storage, and distribution. Environmental impact and economics of alternative systems. Synthesis of energy system components.
- ME 407/L “Solar Thermal Engineering/Lab” Solar radiation distribution and measurement; methods of solar energy collection; thermal analysis of flat plate solar collectors; experimental testing and efficiency determination; solar energy storage; solar economics; transient and long-term system performance; computer modeling for solar space and water-heating applications.
- ME 499 “Intro. to Renewable Energy” Advanced topics in alternative, renewable, sustainable energy.
- ME 590 “Solar Energy Systems” Analysis of advanced, hybrid solar collectors. Advanced solar energy storage. Design of solar energy systems.
- ME 591 “Direct Energy Conversion” Conversion of primary chemical, nuclear, solar and heat energy directly to electrical energy without intermediate mechanical elements. Fuel cells, solar cells, MHD generators, and fusion plasma generators.

Note in the above listing, ME 3XX, ME 4XX, ME 5XX, denotes junior level, senior level, and graduate level, respectively. The coursework objectives are tied to the Accreditation Board for Engineering and Technology, Inc. (ABET) outcomes as shown in rubric of Table 1. The rubric of Table 1 shows how the use of the NREL SAM modeling software can address the outcomes and objectives of the renewable energy curriculum.

Tab. 1: Renewable Energy Curriculum in Mechanical Engineering at Cal Poly Pomona

ABET Outcome	Can NREL SAM be Used to Address this ABET Outcome ?	ME Course Addressing this ABET Outcome
(a) an ability to apply knowledge of mathematics, science, and engineering	√	ME 407, ME 590, ME 591
(b) an ability to design and conduct experiments, as well as to analyze and interpret data	√	ME 407, ME 499
(c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability	√	ME 306, ME 307, ME 407, ME 499
(d) an ability to function on multidisciplinary teams	√	ME 306, ME 307, ME 407, ME 499
(e) an ability to identify, formulate, and solve engineering problems	√	ME 306, ME 307, ME 407, ME 499
(f) an understanding of professional and ethical responsibility	√	ME 306, ME 307, ME 407, ME 499
(g) an ability to communicate effectively	√	ME 306, ME 307, ME 407, ME 499
(h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context	√	ME 306, ME 307, ME 407, ME 499, ME 590, ME 591
(i) a recognition of the need for, and an ability to engage in life-long learning	√	ME 306, ME 307, ME 407, ME 590, ME 591
(j) a knowledge of contemporary issues	√	ME 306, ME 307, ME 407, ME 499
(k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.	√	ME 306, ME 307, ME 407, ME 499

3. Case Studies

This section of the paper outlines the various case studies used in the ME 407 “Solar Thermal Engineering” course to teach renewable energy project management. The case studies include i) solar photovoltaic retrofit of an existing engineering infrastructure, ii) solar thermal hot water heating of an existing engineering infrastructure, iii) concentrated solar power plant deisgn for application in the high desert region of Los Angeles, CA, and iv) a wind turbine power plant design for application to the Coachella Valley area of the Los Angeles desert area.

3.1. Solar Photovoltaic

The purpose of this case study is to provide a Solar PV 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.

Fig. 1: Building used for solar photovoltaic case study

The most common type of electricity generation for commercial buildings are solar power systems. To investigate life cycle cost analysis for solar power generation, the System Advisor Model (SAM) developed by the National Renewable Energy Laboratory was utilized. Actual annual energy consumption and current electricity rates were imported into SAM. Based on the initial Life Cycle Cost Analysis (LCCA), the payback period was calculated to be 5.8 years. After the payback period, the excess power will bring revenue for the facility. 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 SCE into SAM. A PV system usually consists of solar panels, an inventor, and an excess power system. To size the PV system, first the area, that the panels can be installed, need to be identified. Second, the type of solar panel and its orientation is selected. After that, the brand of module needs to be chosen. Then, an inverter is sized based on the peak power generation. The system design information taked from the NREL SAM software is shown in Figure 2.

PV System Technical Information			
Roof Area (m²)	6,636		
Area Used (m²)	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

Fig. 2: Photovoltaic case study NREL SAM PV selection inputs

The SAM "Photovoltaic, Detailed Commercial Model" was used for LCCA. Electricity rates was imported into SAM based on on-peak/off-peak hours. Currently there is no incentives offered for PV for commercial buildings by Southern California Edison (SCE), however, federal incentives were applied. The total direct cost of the project was estimated to be $ 1,257,818. As shown in Figure 3, the power generation was estimated to be more than the facility consumption. The excess power generation was added to the next bill and at the end of each year, total rolled over kWh was bought SCE.

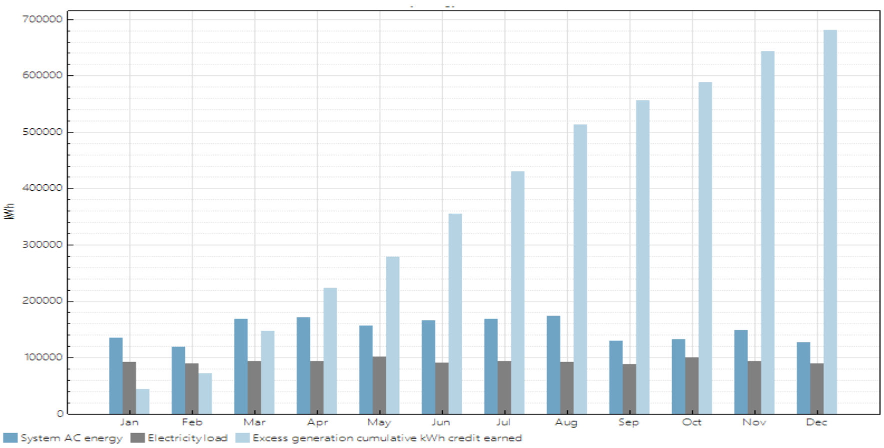

Fig. 3: Building consumption, demand, and cumulative excess kWh generation taken from NREL SAM

The analysis period was assumed to be 25 years. The life cycle cost analysis result is shown in the table below. 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 cost such as grid interconnection and sales tax was excluded from the results.

3.2.Solar Thermal Hot Water

This next case study was selected from the area of solar thermal hot water heating. The same facility of the previouse case study was used, which is shown in Figure 1. For this analysis, domestic hot water usage of the building was estimated based on number of fixtures in the building. For this report, ten Sunearth Thermoray flat plate solar collectors were assumed. Finally, performance model and LCCA were calculated using NREL SAM. The result of SAM was based on an electric auxiliary heater, however, building 17 uses natural gas as the only source energy for domestic hot water. Therefore, SAM was unable to model a commercial auxiliary gas-fired system. For this report, only LCOE financial model was performed and the results compared with national average data. The solar thermal analysis performed within SAM is based on the algorithm described in Burch and Christensen (2007) "Towards Development of an Algorithm for Mains Water Temperature". The solar energy gained based on the correlation to local air temperature used in the Building America Benchmark is used in the framework of the analysis. Due to its exceptional durability, Thermoray Series Liquid Flat Plate Collectors were selected for this analysis. The performance data for model TRB-40 was manually inputted into SAM based on the certification from Solar Rating & Certification Corporation (SRCC). Per American Socitey of Heating Refrigeration and Air Conditioning Engineers (ASHRAE) 2011 Handbook-HVAC Applications, hot water demand per fixture for a school building was calculated. After that the peak demand for hot water draw was calculated using ASHRAE recommended 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. The solar hot water design from NREL SAM is shown in Figure 4.

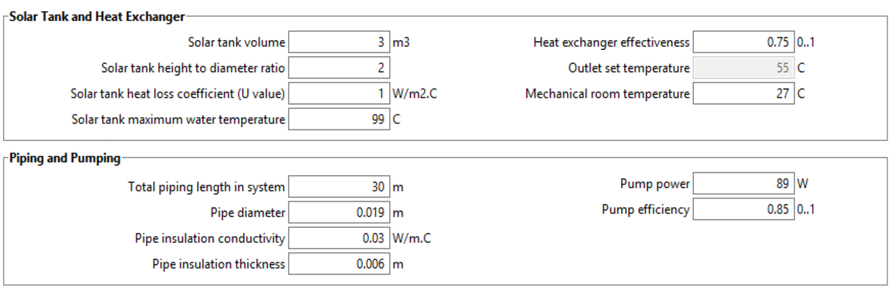

Fig. 4: Solar thermal hot water system selectino and design per NREL SAM

The economic model of NREL SAM for the solar hot water case study is shown in Figure 5. The LCOE is computed in Figure 5. The initial cost of $80,000 includes 10 solar collectors, installation costs, an 800 gallon storage tank, plumbing, and maintenance fees. The Levelized Cost of Energy (LCOE) was estimated to be $195/MWh.

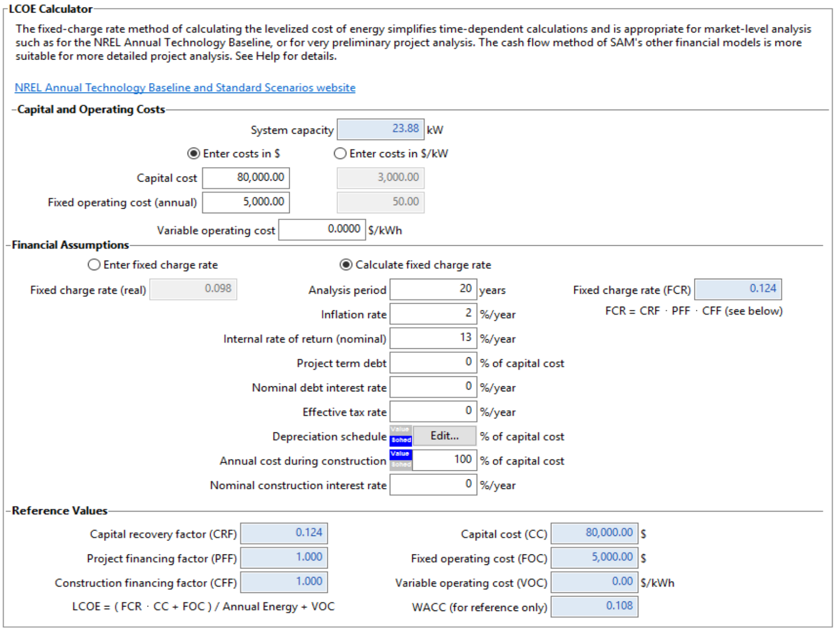

Fig. 5: Solar thermal hot water heating ecomonic analysis output from NREL SAM

The LCOE was calculated to be 195 $/MWh which was about the lowest LCOE of a solar thermal system in the United States.

3.3. Concentrated Solar Power

This next case study was select from the area of Concentrated Solar Power (CSP). The study is for a site located in the surrounding desert of Lancaster, California. The power plant of Figure 6 spans a total of 2,042 acres, 1,459 of which is made up of parabolic solar collectors.

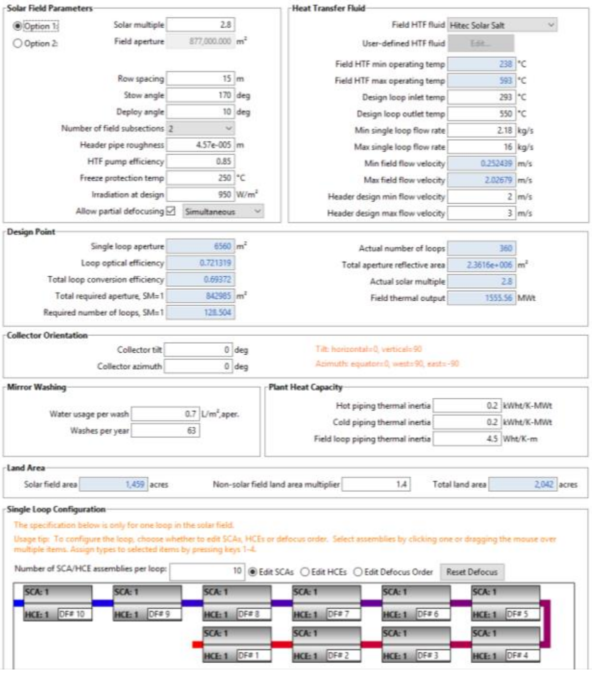

Fig. 6: Concentrating solar power design input from NREL SAM

Each power block is made up of two Siemens SST-300 ns. Steam Turbines for CSP Plant steam turbines capable of 50 MW each. The design of proposed power plant site within NREL SAM is shown in Figure 6. The financial model used for this system was a utility single owner utility. The storage, heat transfer fluid (HTF) system, and solar field were calculated at a rate of \$65/kWh, \$60/m², and \$150/ m² respectively land cost.

3.4. Wind Power Generation

The final case study was the design of wind turbine located in Coachella Valley, CA. The design of the wind turbine inputs is given in Figure 8.

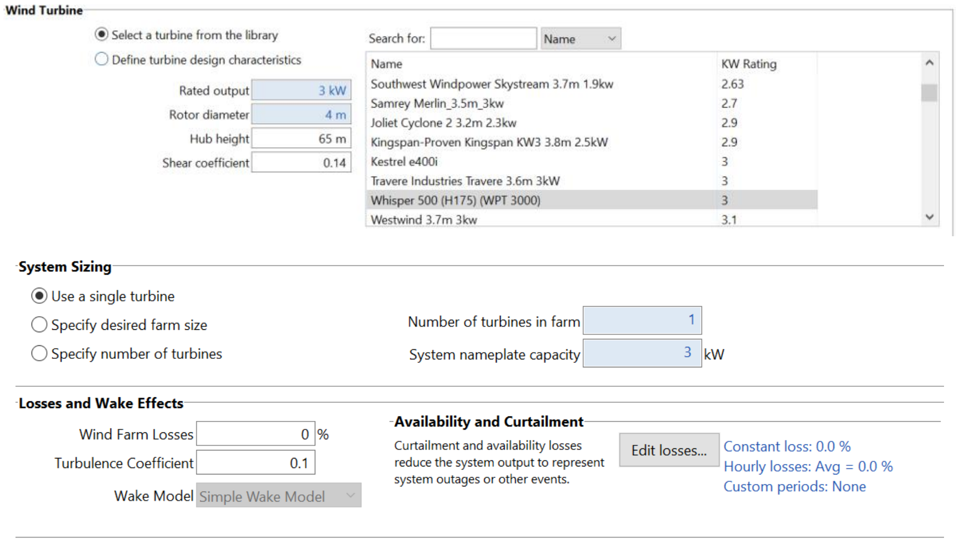

Fig. 8: Wind turbine design and selection from NREL SAM

The economic analysis of the wind turbine case study is given in Figure 9.

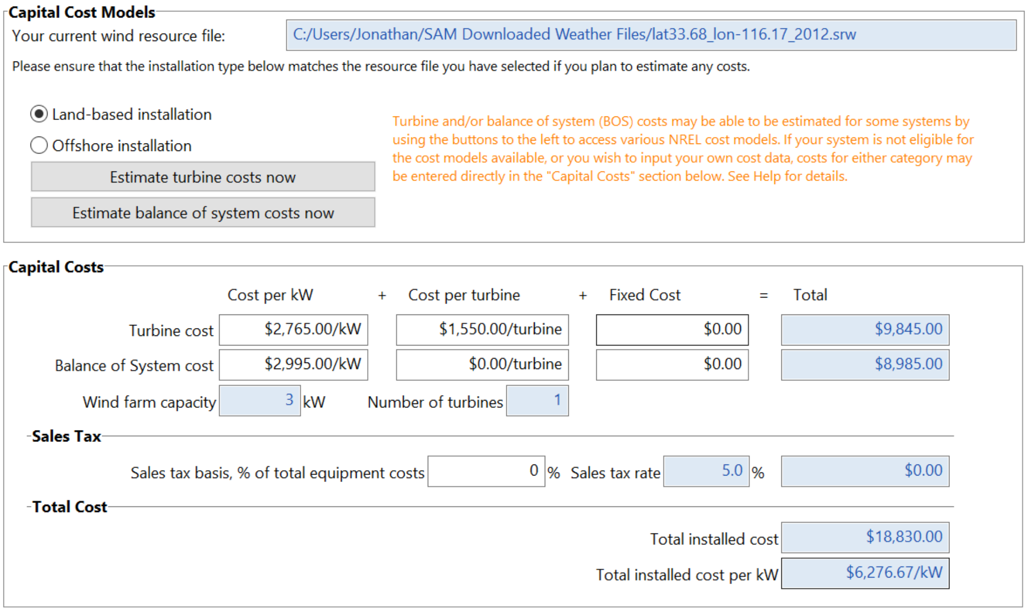

Fig. 9: Wind turbine financial analysis from NREL SAM

From the NREL SAM analysis module the payback period is found to be 18.02 years, the turbine can provide power to supplement the power provided by Southern California Edison to mitigate bills with a peak power generation of 2.2 kW, and the LCOE of 28.70 ¢/kWh is high compared to more conventional energy providers.

4. Conclusions

This paper has introduced the use of NREL SAM modeling software as a teaching mechanism for students learning about renewable energy technologies and economics. The relationship of the NREL SAM modeling tools within the framework of the outcomes and objectives of the Mechanical Engineering program at Cal Poly Pomona has been presented. This paper then presents several case studies completed with the NREL SAM software toolkit which have completed by undergraduate students enrolled in the Solar Thermal Engineering course at Cal Poly Pomona. Each case study has demonstrated the functionality of the NREL SAM modeling software. Addtionally, the economic viablitiy of each case study were analyzed with the NREL SAM modeling and simulation tools.

5. References

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