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Economic and Life Cycle Analysis of Renewable Energy Systems

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Abstract

Renewable energy resources such as wind and solar are playing increasingly important role in present and future energy scenarios of both developed and developing countries. For example, the installed wind energy in the United States increased from 12 GW in 2006 to 47 GW in 2011 averaging 30% increase over the five year period. Over the same period, global wind energy capacity has increased from 74 GW to 238 GW. Engineering students and future engineers, who will be involved in making decisions on design and implementation of these renewable energy systems, require knowledge of economic and life cycle assessments of these systems in order to make an informed decision. Environmental impact and sustainability as well as tax credit and incentives play key roles in conducting an economic analysis of renewable energy systems. The present paper discussed aspects of economic and life cycle analysis of renewable energy systems that are different from those of conventional energy systems. Two case studies were used to demonstrate the major differences in the economic analyses of renewable and conventional energy systems. These case studies were used in two courses that the author taught at Lamar University.

Introduction

Design, construction, and implementation of engineering systems are ultimately decided by economic decisions. Engineering students must therefore understand the importance of economics and they must be able to conduct economic analyses such as life cycle cost, net present value, and payback period to assess economic feasibility of engineering systems. At Lamar University, an engineering economics course is a required course for all engineering disciplines. However, typical engineering economics courses cover topics fundamental to economics such as cash flow diagrams, discount rates, depreciation, and taxes. Thermal and energy systems in general require more capital investment as well as operating costs compared to other engineering systems. As a result, economic feasibility and life cycle cost analyses of thermal and energy systems are much more involved, and students who will be in thermal and energy stems of engineering must be capable of conducting these analyses.

Renewable energy resources such as wind and solar are playing an increasingly important role in the present and future energy scenarios of both developed and developing countries. For example, the installed wind energy in the United States increased from 12 GW in 2006 to 47 GW in 2011 averaging 30% increase over the five year period[1]. Over the same period, global wind energy capacity has increased from 74 GW to 238 GW[2]. Engineering students and future engineers who will be involved in making decisions on design and implementation of renewable energy systems require knowledge of economic and life cycle assessment of these systems in order to make an informed decision. However, conducting an engineering economic analysis of renewable energy systems involves consideration of federal and state tax credit, renewable energy certificates, costs related to environment, and carbon credits. Environmental impact and sustainability as well as tax credit and incentives play key roles in conducting an economic analysis of renewable energy systems.

This paper discussed major differences between an engineering economic analysis of a typical energy system and that of a renewable (green) energy system. Some terminologies and methodologies related to economics of renewable energy systems were discussed and two case studies were used to demonstrate the major differences between economic analyses of conventional and renewable energy systems.

Economic Analysis and Levelized Cost of Energy (LCOE)

The economics of energy systems includes initial cost of delivering components that function in the system (turbines, high-voltage transmission lines and so forth), ongoing costs associated with fuel, maintenance, wages, and other costs, and the price that can be obtained in the market for a kWh of electricity[3]. However, many different energy technologies exist for generating electricity: coal-fired steam power plants, gas turbine combine-cycle power plants, fuel cells, hydropower power plants, wind power, solar, and many others. When comparing these different technologies for an energy system, a method is needed that incorporates the role of both initial capital costs and ongoing operating costs. One of the tools commonly used and accepted by industry is known as Levelized Cost of Energy (LCOE)[3-5]. LCOE is a useful metric used to compare an owner's life-cycle cost by converting all costs into a single cost of electricity rate, usually expressed in cents or dollars per kilowatt-hour of electricity[4]. The levelized cost per unit of energy output provides a way to combine all cost factors into a cost-per-unit measure that is comparable between technologies[3]. It can be defined as[3]

$$levelized\ cost = \frac{total\ annual\ cost}{annual\ output}\ in\ units\ of\ kWh \qquad \text{Eq. (1)}$$

where total annual cost = annualized capital cost + operating cost + return on investment (ROI). The use of levelized cost of energy will be demonstrated in the second case study.

In calculating the levelized cost above, total annual costs contain only capital costs and operating costs that are known as direct costs. There may be external costs incurred such as health costs of lost agricultural productivity, cost due to pollution from the energy system and other[3]. These external costs are becoming increasingly important in engineering economic analyses of energy systems as more environmentally conscious public demands development of alternative and sustainable energy systems such as renewable energy systems. In addition, there are methods of intervention as called by Vanek and Albright[3] that must be taken into account in assessing economic feasibility of renewable energy systems. These interventions can take many forms including direct cost support, tax credits, and interest rate buy down by local, state and federal governing bodies. Detailed explanations of these interventions and examples can be found in Vanek and Albright[3]. Table 1 shows the most recent data on estimated levelized cost of new generation resources in 2017 from Annual Energy Outlook 2012 published by the Department of Energy (DOE)[6]. From Table 1, it is interesting to note that renewable energy power plants will have higher LCOE than fossil fuel and other conventional power plants in the near future.

Table 1 Estimated LCOE of different technologies in 2017[6]

		U.S. Average Levelized Costs (2010 $/megawatt hour) for Plants Entering Service in 2017				
Plant type	Capacity Factor (%)	Levelized Capital Cost	Fixed OEM	Variable O&M (including fuel)	Transmission Investment	Total System Levelized Cost
Conventional Coal	85	65.8	4	28.6	1.2	99.6
Advanced Coal	85	75.2	6.6	29.2	1.2	112.2
Advanced Coal with CCS	85	93.3	9.3	36.8	1.2	140.7
Natural Gas-Fired						
Conventional Combined Cycle	87	17.5	1.9	48	1.2	68.6
Advanced Combined Cycle	87	17.9	1.9	44.4	1.2	65.5
Advanced CC with CCS	87	34.9	4	52.7	1.2	92.8
Conventional Combustion Turbine	30	46	2.7	79.9	3.6	132
Advanced Combustion Turbine	30	31.7	2.6	67.5	3.6	132.0
Advanced Nuclear	90	88.8	11.3	11.6	1.1	112.7
Geothermal	92	76.6	11.9	9.6	1.5	99.6
Biomass	83	56.8	13.8	48.3	1.3	120.2
Wind	34	83.3	9.7	0	3.7	96.8
Wind-Offshore	27	300.6	22.4	0	7.7	330.6
Solar PV	25	144.6	7.7	0	4.2	156.9
Solar Thermal	20	204.7	40.1	0	6.2	251.0
Hydro	53	77.9	4	6	2.1	89.9

Economics of Renewable Energy Systems

When conducting an economic analysis of a renewable energy system, whether it is a residential, commercial or utility system, one of the key components is the renewable energy tax credit. In United States, the tax credit may be offered by federal government as well as an individual state. The main source for this tax credit can be found in a database called DSIRE[7] maintained by the US Department of Energy (DOE). DSIRE is a comprehensive source of information on state, federal, local, and utility incentives and policies that support renewable energy and energy efficiency. Established in 1995 and funded by the U.S. Department of Energy, DSIRE is an ongoing project of the North Carolina Solar Center and the Interstate Renewable Energy Council, Inc[7]. For example, 30% tax credit is allowed for solar and fuel cell installations for commercial, industrial, utility, and agricultural sectors. Federal government also allows renewable energy production tax credit (PTC), a per-kilowatt-hour tax credit for electricity generated by qualified energy resources and sold by the taxpayer to an unrelated person during the taxable year, for wind, geothermal, and other renewable energy technologies. DSIRE database provides information related to tax credit and other incentives for renewable energy systems for each state. In the state of Texas, rebates, loans, and incentives are offered to residential and commercial entities.

Case Studies

Two case studies discussed in the paper are regularly used in the author's classes on thermal and energy systems. The first case study involves a solar photovoltaic (PV) system for a residential home in Austin, Texas. The project scenario is to conduct an economic analysis of a 5 kW photovoltaic system for a residential home with 3000 square foot of space. First, the monthly savings in electricity cost from the PV system is calculated by the PVWatts calculator from National Renewable Energy Lab (NREL)[8]. The PVWatts calculator determines energy production and cost savings of grid-connected photovoltaic (PV) energy systems throughout the world by allowing homeowners, installers, manufacturers, and researchers to easily develop estimates of the performance of hypothetical PV installations[8].

The calculator uses the weather database to obtain an average solar insolation for a particular location and determines monthly AC power generation and the value of electricity based on local electricity rate. The cost of electricity is assumed to be $0.097/kWh in determining the energy value of the PV system. The main results of the calculator are as follows:

Average solar insolation: 5.35 $kWh/m^2/day$

Total AC power generated: 6812 kWh

Total energy value: $660.76

Figures 1 shows monthly values of average solar insolation and AC power generated while figure 2 shows monthly energy values of a 5 kW PV system for a residential home in Austin, Texas.

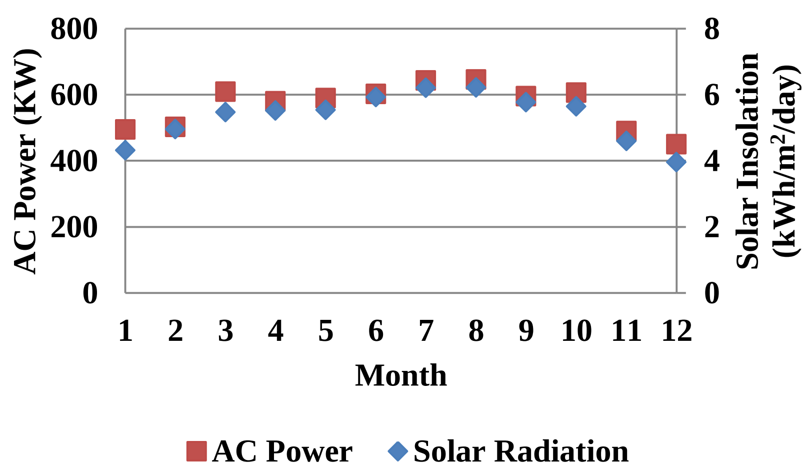

Figure 1 Solar Insolation and AC Power Generated from the PV System in Austin, Texas

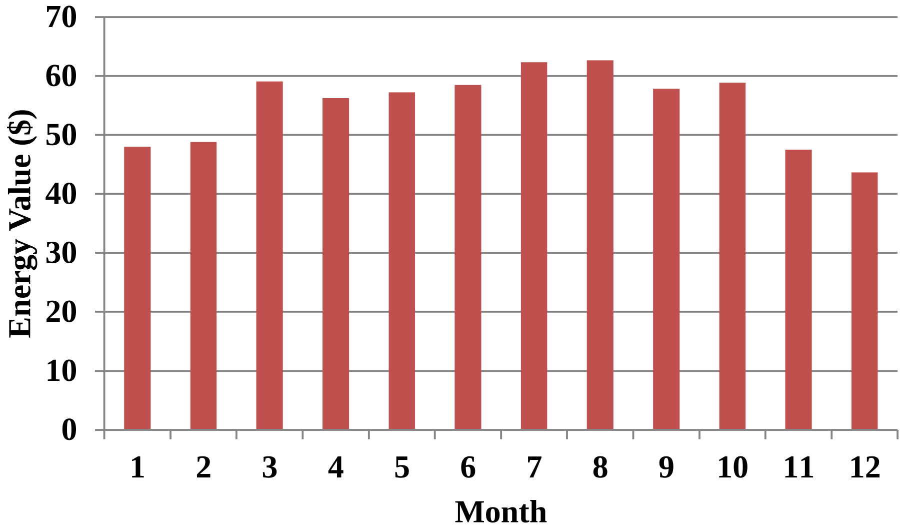

Figure 2 Total Energy Value (in $) of a 5 kW PV System in Austin, Texas

The next step is to conduct an economic analysis of the system using conventional engineering economics metrics without renewable energy credits, rebates, etc. Then, the comparison will be made with the results of an economic analysis taking into account all the applicable federal, state and local economic rebates, incentives, etc. The values of economic parameters used in both analyses are given in Table 2.

Table 2 Values of economic parameters used in the economic analysis

Item	Parameter
Cost of PV system (PV modules with installation) based on $5.71/Wp DC[9]	$29,132
Annual O&M cost:	$100
Lifetime: (years)	20
Interest rate: (%)	5

The comparison is made on two economic metrics: Net Present Value (NPV) and simple Payback Period. Here, NPV is defined as the sum of present values of all the costs and revenues associated with a particular project and a simple payback period is defined as the time period needed to recover the capital cost by taking the ratio of capital cost and total annual savings. It is worth noting that the analysis presented here is a very simplified analysis without any considerations on depreciations, taxes, loan discounts, etc. In addition, federal, state and local tax credit and the tariff rate may not be applicable or available in different locations. The analysis is also based on the peak output of the PV system and the actual output of the system will vary variable depending on the weather conditions and efficiency of the particular PV system. More detail discussions on the cost basis of different PV systems can be found in NREL Report No.

TP-6A20-533473[9]. The results of the comparison between the two economic analyses are given in Table 3.

Table 3 Comparison of the economic analysis with and without renewable energy credits

Parameters	**Conventional Analysis**	**Renewable Analysis**
Capital cost: ($)	29132	20392 (29132 minus 8740)
Interest rate: (%)	5	5
Life time: (years)	20	20
Savings/year: ($) from Fig. 1	661	1533 (661 plus 872)
Annual O&M: ($)	100	100
Salvage value	0	0
Federal credit, 30%: ($)	0	8740
State credit: ($)	0	0
Austin tariff, $0.128/kWh: ($)	0	872
NPV: ($)	***-22140***	***-2534***
Payback period: (years)	***52***	***14.2***

From Table 3, it can be seen clearly the importance of renewable energy tax credits, tariff rates, and other financial incentives on the results of an economic analysis of any renewable energy systems. In the present case study, inclusion of renewable energy credits and incentives results in a much higher net present value and a much shorter payback period. For comparison, a complete analysis of the same PV system in Austin, Texas was done using System Adviser Model (SAM) software from National Renewable Energy Laboratory (NREL). Results of SAM were compared with the results of the simple analysis in Table 4. All the major results such as annual energy production, NPV, and payback period showed reasonable agreement.

Table 4 Comparison of results between simple and SAM analyses

Result	**Simple Analysis**	**SAM**
Annual energy production (kWh)	6812	7719
NPV	-2534	1378
Payback period (years)	14.2	11.5
Overall generation cost ($/W)		5.92
LCOE (nominal)		$0.1183/kWh

Table 4 shows that SAM can provide additional financial information such as overall generation cost in $/W as well as contribution of individual components such as land, engineering, and PV module to the overall generation cost. Another important financial parameter provided by SAM is levelized cost of energy (LCOE) in $/kWh. LCOE is the parameter that is commonly used to compare cost of electricity generated from different sources and different energy systems as discussed above in the section, Economic Analysis and Levelized Cost of Energy (LCOE).

The second case study is taken from an example of Vanek and Albright[3]. It compares two different generation technologies, a coal-fired steam power plant, and a wind farm, to implement a utility-scale power plant of 500 MW rated electricity. The detail technical information on the two technologies and the results in the form of LCOE are provided in Table 5.

Table 5 LCOE Comparison of a coal-fired power plant and a wind farm

Parameters	**Coal-fired**	**Wind**
Rated power: (MW)	500	500
Capacity factor:	0.7	0.35
Initial costs: (million $)	300	1150 ($2300/kW)
Lifetime: (years)	20	20
Discount rate: (%)	8	8
Balance of cost: (million $)	18	17.5 ($35/kW)
Overall efficiency: (%)	26	
Annual fuel cost: (million $)	60	0
CO_2 production: (kg/kWh)	0.77	0
CO_2 capture and sequestration cost:	0.012[8]	0
Emission control cost: ($/kWh)	0.032[8]	0
Levelized cost of electricity w/o environment: ($/kWh)	***0.0353***	***0.0975***
Levelized cost of electricity w/environment: ($/kWh)	***0.0793***	***0.0975***

It is to ben noted that balance of cost for a coal-fired power plant is a catch-all that includes wages and benefits, operation and maintenance costs, overhead, and other miscellaneous items. The levelized cost of energy for wind technology was calculated using the Cost of Renewable Energy Spreadsheet Tool (CREST)[10] from NREL. CREST is an economic cash flow model designed to enable Public Utility Commissions (PUCs) and the renewable energy community assess projects, design cost-based incentives (e.g., feed-in tariffs), and evaluate the impact of tax incentives or other support structures. CREST is a suite of three analytic tools, for solar (photovoltaic and solar thermal), wind, and geothermal technologies, respectively[10]. The equation used to calculate LCOE for the wind farm is given below[10].

$$COE = \frac{FCR.ICC}{AEP_{net}} + AOE \qquad \text{Eq. (2)}$$

where COE = cost of energy ($/kWh), FCR = fixed charge rate or interest rate (%), ICC =initial capital cost including cost of turbines and balance of cost ($), AEP_{net} = net annual energy production (kWh/year) and AOE = annual operating cost ($/kWh).

Coal-fired power plants have the most impact on environment through emissions of pollutants such as NO_x, CO, SO_2 and Hg. Since coal-fired power plants are mainly responsible for emissions of CO_2, a major greenhouse gas (GHG), carbon capture and sequestration (CCS) of

CO_2 adds significant cost to the LCOE of a coal-fired power plant as can be seen in Table 5. With the inclusion of all external costs such as emission reduction and carbon capture, LCOE of coal-fired power plant increases by 120% from 0.0353$/kWh to 0.0793$/kWh. On the other hand, there is no external cost associated with the wind farm as a wind farm generally contributes negligible CO_2 emissions to environment through the construction of wind turbines[5].

NREL has compiled a database known as The Transparent Cost Database[11] that collects program cost and performance estimates for Energy Efficiency and Renewable Energy (EERE) technologies in a public forum where the data can be viewed and compared to other published estimates. The database includes literature on technology cost and performance estimates (both current and future projections) for vehicles, biofuels, and electricity generation. All data are downloadable for full transparency. The values of capacity factor, initial cost, and balance of cost for the wind farm are taken from that database[11]. Table 6 shows that LCOE presented in Table 5 are consistent with the values from the Transparent Cost Database validating the results of Table 5.

Table 6 Comparison of present LCOE results with Transparent Cost Database results

Source	**Coal-fired (w/o environmental cost)**	**Coal-fired (with environmental cost)**	**Wind farm**
	($/kWh)	**($/kWh)**	**($/kWh)**
Table 5	0.0353	0.0793	0.0975
Transparent Cost Database (range)	0.04	0.01-0.12	0.04-0.12

Use of Case Studies in Courses

The case studies described above are regularly used in two courses: MEEN 4313 Design of Thermal Systems, and MEEN 4333/MEEN 5316 Energy Engineering. More information on both classes can be found in earlier papers[12, 13] by the author. MEEN 4313 is a required course for senior undergraduate students and a Capstone design course for the thermal stem of mechanical engineering curriculum at Lamar University. The students are required to complete a design project that requires designing a component of a thermal system such as a heat exchanger, or an evaporator or a complete thermal system. A life cycle analysis of the component or the system is required as part of the design process. These case studies serve as examples for students in conducting an economic analysis of a real-world system.

MEEN 4333/MEEN 5316 is an elective course for senior undergraduate students and graduate students. In that class, analysis and design of many renewable energy systems are covered and case studies from this paper serve as major discussion points for students on technical and economic feasibilities of alternative energy systems, and impact of economic analysis on implementation and operation of renewable energy systems. Students use these case studies as base cases to conduct their own economic and life cycle analyses of different energy systems using simulation software packages such as SAM and RETScreen. The economic analysis forms a required component of their final design project for the course, and these case studies provide a starting point for students to complete economic aspects of their design project.

Conclusions

In summary, the paper discusses economic and life cycle analyses of renewable energy systems, highlighting major differences between economic analyses of a renewable energy system and a conventional energy system. Two case studies were presented as examples. The case studies clearly showed huge impact of economic incentives such as federal and state tax credit, tariff rates, cost of environment, and other financial incentives on the economic feasibility of renewable energy systems.

Bibliography

1. "AWEA U.S. Wind Industry Annual Market Report Year Ending 2011", AWEA, 2012.
2. "Energy Outlook 2030", British Petroleum (BP), 2012.
3. Vanek, F., and Albright, L. (2008). Energy Systems Engineering Evaluation & Implementation, McGraw-Hill.
4. Kutz, M. (2007). Environmentally Conscious Alternative Energy Production, John Wiley & Sons.
5. Kreith, F., and Kreider, J. (2011). Principles of Sustainable Energy, CRC Press.
6. "Annual Energy Outlook 2012", Department of Energy, 2013.
7. "DSIRE: Database of Energy Efficiency, Renewable Energy Solar Incentives, Rebates, Programs, Policy." DSIRE USA. http://www.dsireusa.org/. 01 Dec. 2012.
8. "NREL: Renewable Resource Data Center - PVWatts." NREL: Renewable Resource Data Center - PVWatts. http://www.nrel.gov/rredc/pvwatts/site_specific.html. 06 Dec. 2012.
9. Goodrich, A.; James, T.; Woodhouse, M. (2012). Residential, Commercial, and Utility-Scale Photovoltaic (PV) System Prices in the United States: Current Drivers and Cost-Reduction Opportunities. 64 pp.; NREL Report No. TP-6A20-53347.
10. "Featured Analysis." NREL: Energy Analysis Home Page. https://financere.nrel.gov/finance/content/crest-cost-energy-models. 10 Dec. 2012.
11. "Transparent Cost Database." Energy Information, Data, and Other Resources. http://en.openei.org/wiki/Transparent_Cost_Database. 10 Dec. 2013.
12. Aung, K., "Design of Thermal Systems: A lost course", Proceedings of 2007 ASEE Annual Conference and Exposition, Honolulu, Hawaii, June 2007.
13. Aung, K., "Energy Engineering: Development of a new senior elective course", Proceedings of 2004 ASEE Annual Conference and Exposition, Salt Lake City, Utah, June 2004.