

Applications of Grid Connected Photovoltaic Systems to Highway Maintenance Facilities

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The interest in renewable energy has been increasing in recent years as attempts are being made to reduce energy costs as well the consumption of fossil fuels. Many federally run buildings and associations, such as highway maintenance facilities run by the Department of Transportation, also have the added pressure of meeting the mandates of federal energy policies which dictate specific savings or reductions. To help meet their energy saving goals, the authors conducted an investigation into the potential of grid connected photovoltaic systems at the Ohio Department of Transportation (ODOT)'s maintenance facilities. This paper discusses the applicability of photovoltaics specifically for the state of Ohio based on factors such as the available solar resource and proper orientations. It also discusses the characteristics of highway maintenance facilities and the importance of performing a life cycle costing analysis and gives an example which highlights the importance of financial incentives to photovoltaic projects.

Key Words: Renewable Energy, Photovoltaics, Life Cycle Cost Analysis, Highway Maintenance Facilities

Introduction

Recent federal energy policies are encouraging or requiring federal and state agencies to implement strategies toward reducing energy demands and environmentally harmful emissions. These policies motivate federal and state agencies and organizations to actively seek out effective strategies and methods for utilizing renewable energy technologies (RETs) (Federal Energy Management Program (FEMP), 2010). The Department of Transportation's (DOT) highway maintenance facilities are one type of buildings that has been identified as having the potential to benefit from RETs. The authors of this paper completed a research project that evaluated the feasibility and application of grid connected photovoltaics (PV) at Ohio highway maintenance facilities. The research observations and strategies discussed in this paper help to demonstrate the importance of evaluating technologies to ensure positive feasibility. They also help to establish and build upon best practices for organizations considering the pursuit of renewable energy projects, by demonstrating an effective analysis and decision making tool.

Technology Description

Photovoltaic (PV) systems use photovoltaic modules to convert sunlight into electricity. The modules collect solar radiation through absorptivity. The main component of a PV system is a PV module or array made of individual PV cells which absorb solar radiation. Another main component is the inverter which is required to convert the direct current (DC) power produced by the PV module into alternating current (AC) power. AC power is used by many buildings' appliances and equipment. Utility grids also use AC power and therefore grid-connected systems always require the use of an inverter. A system will also require a structure used to mount or install the PV modules. The structure should orient the PV modules in such a way that the modules will catch the maximum amount of sunlight possible. Batteries are commonly used with PV systems but are not necessary when the system is grid-connected and will not produce electricity in exec of what is needed by the facility. The major benefit of grid connected PV systems is that the utility company is able to provide power during periods when there is no available sunlight and the PV system output is not sufficient to meet the facility's loads. PV systems will not always be designed to generate electricity to power all of the loads in the building, but will at least reduce the amount of electricity that the building owner must purchase from the grid by powering some of the loads. If a system does generate excess power, than in many areas a potential exist in which the utility company allows electricity that is in excess of the facility's requirements to be exported to the grid, and pays for this electricity via a net metering arrangement (Leng, Dignard-Bailey, Bragagnolo, Tamizhmani, & Usher, 1996), (RETScreen International, 2004).

Highway Maintenance Facilities and their Energy Use Profile

Highway maintenance facilities are buildings and sites run by the Department of Transportation. A typical maintenance facility is comprised of two major building sections. The first section is made of offices, restrooms, a break room and/or meeting room, and a stock room. This section of a facility operates with similar characteristics to any commercial building and has basic heating, cooling, and lighting needs for employee comfort and productivity. The second major section is the garage and maintenance areas. The maintenance area has an indoor space for mechanics to work on vehicles and contains all the equipment and tools needed by a mechanic to perform the various required maintenance activities. These activities vary widely from simple maintenance and fluid changes for fleet cars and light trucks, to major overhauls of large equipment such as bucket loaders, graders, and snow plows. The maintenance area may include welding and bodywork areas depending on the type of work performed at the facility. The maintenance area is heated in the winter and typically not mechanically cooled in the summer. The maintenance area should be well lit to enable the mechanics to safely carry out their required activities. The garages and maintenance areas typically have high ceiling and large amounts of open space and so have high heating and ventilation demands in the winter months and also require large amounts of lighting fixtures so that mechanics are able to work in all areas.

The garage and vehicle maintenance areas of a facility will make up the majority of a facility's energy demands. The cooling needs are less high as garage doors can be left open in summer months to cool the area. The offices portions of facilities do make up a share of the energy usage, but are generally overshadowed by the demands of the garage areas. Figure 1 shows a breakdown of the main energy consuming process in vehicle service buildings as reported by the 2003 Commercial Building Energy Consumption Survey (CBECS) (U.S. Department of Energy, 2012). The main drivers of energy use are heating and then lighting, followed by process loads, which are categorized as "Miscellaneous" in Figure 1. Process loads are generally the equipment used in the servicing or repair of vehicles, including compressed air systems, welding, and any number of power tools used. The next highest category is ventilation processes, and together these four highest categories represent 90 percent of energy consumption in vehicle service buildings.

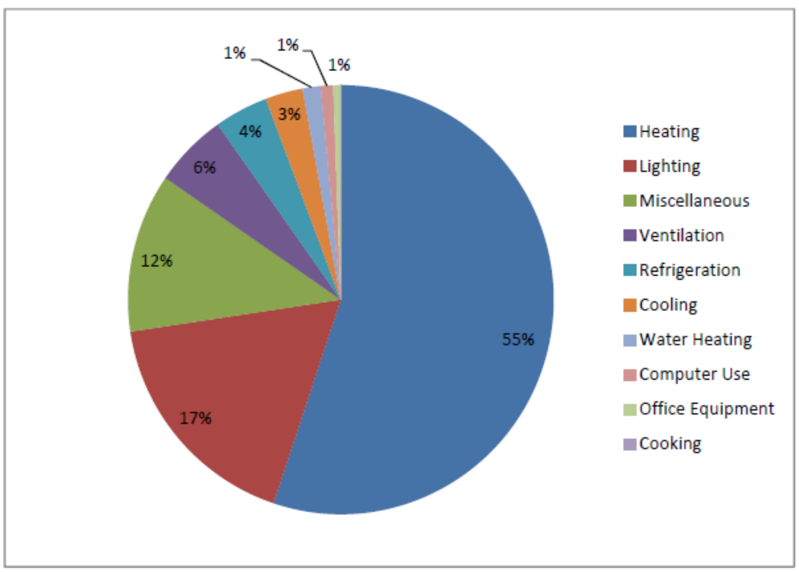

Figure 1: Energy consumption by end use of vehicle service buildings (U.S. Department of Energy, 2012).

Energy use data was collected from numerous ODOT facilities in the form of electricity and natural gas usage records and utility costs. Data was evaluated to determine facilities' monthly energy use profiles to identify seasonal variations, compare to published regional energy data, and determine any impact of facility characteristics such as age and size. Energy usage was also compared to heating degree days and cooling degree days which are representations of outside air-temperature data and are widely used in the energy industry for calculations relating to the effect of outside air temperature on building energy consumption (BizEE Software, 2013). The degree days' charts were superimposed over the monthly energy use charts to identify any correlation between degree days and electricity and natural gas consumption. Figure 2 shows an example of heating degree days and natural gas consumption and Figure3 shows an example of the heating degree days and electricity. The relationship displayed in Figures 2 and 3 was consistent throughout the facilities studied. The natural gas consumption tends to follow the heating degree days trend steadily throughout the year. This was expected since natural gas is primarily used for space heating and hot water. When electricity consumption was plotted together with heating degree days as shown in Figure 3, it was noticed that electricity usage also increases with the increase in heating degree days in winter. A careful evaluation of the energy use profile of maintenance facilities has explained this trend; electricity is used more in the winter to run the exhaust fans used in building ventilation. These exhaust fans are not used in the summer since overhead doors are open in the summer to naturally ventilate the maintenance facilities.

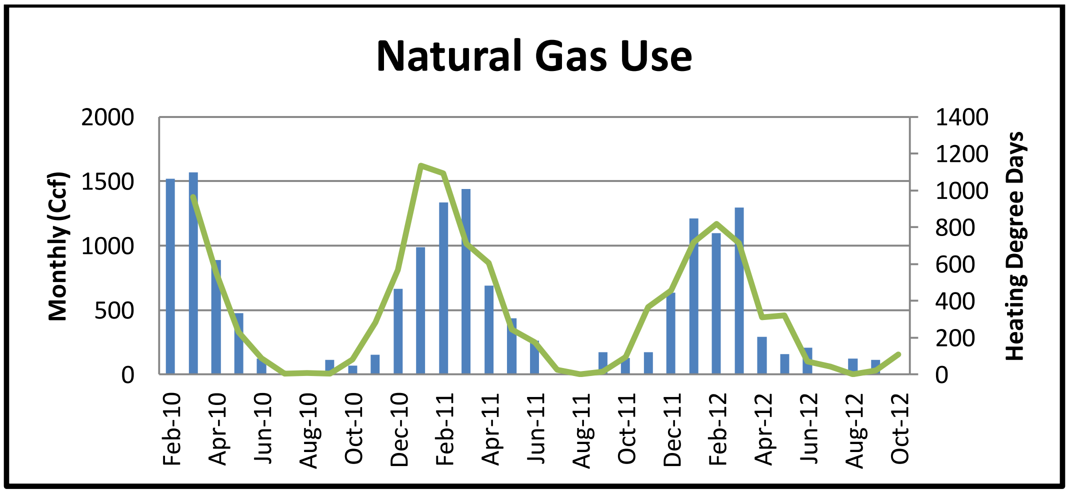

Figure 2: An example of a facilities monthly natural gas usage and heating degree days.

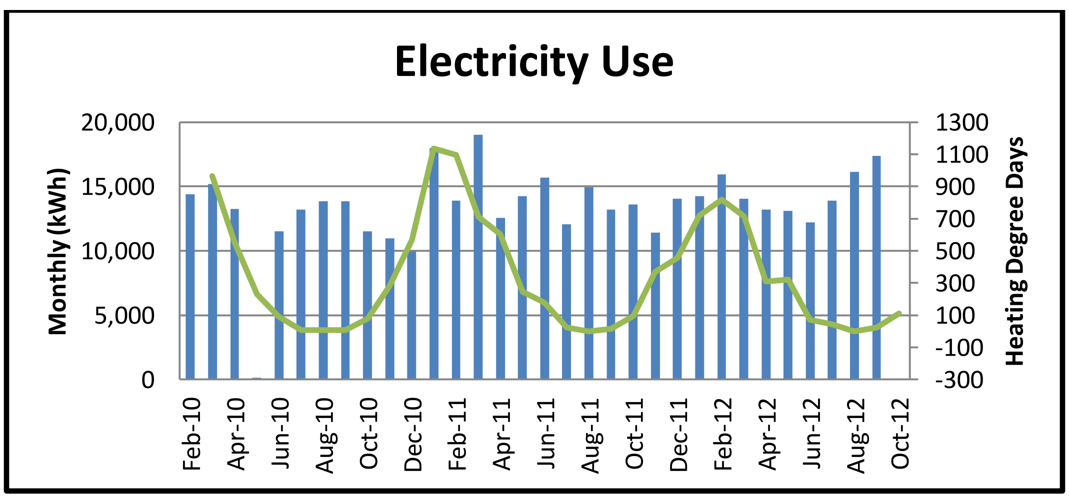

Figure 3: An example of a facilities monthly electricity usage and heating degree days.

Evaluation Criteria

When evaluating the potential of a renewable energy technology at a specific site or building type, an initial strategy to utilize is to consider how the technology rates compared to others in various groupings of criteria. In this project, the researchers used five different categories of criteria that represented the various major concerns surrounding the implementation of renewable energy projects. Each category considered several factors that would influence the scores a RET received. The scores an RET received can be used by personnel to evaluate the feasibility of a project based on the researchers recommendations and by which criteria they value the most for a project. The first category identified was that of Environmental Attributes. The Greenhouse Gas (GHG) emissions reduction potential of the RET was the primary consideration for this criteria. This evaluation included both emissions created during the manufacturing process of the RET components and emissions eliminated during the expected life of the RET. For PV panels, emissions only occur during manufacturing, and the lifetime emissions of GHG resulting from generating electricity using PV modules are 5 to 10 times less than if the same quantity of electricity is produced with fossil fuels. The next category of criteria was the Reliability, which involved considerations of the maturity of the technology. The typical useful life (25 to 40 Years for PV), typical warranties on the technology and its components, and the consistency or ability to meet requirements without interruption were all factors. While PV systems rarely break, they may fail to provide power or have inconsistent power generation in periods of overcast weather. For grid connected system this is not a large concern since electricity will be provided by the utility. Practicality was the third category. The major considerations included ease of construction and/or installation, special code or zoning requirements, availability of the renewable resource in Ohio and at the project site, and whether or not the technology matched ODOT maintenance facilities' energy demand patterns. PV is a simple technology that can be easily installed in ODOT maintenance facilities. PV modules can easily be mounted on the roof of a structure. Roof mounted PV systems are very practical in ODOT maintenance facilities since they typically have large roof areas. They can also be mounted on the ground or on the building walls. When mounting PV modules on the roof of an existing building it is important to ensure that the roof is able support the additional weights of the modules and support structures and that the roof's life is at least as long as the expected life of the PV modules. Roof mounted PV modules are more practical in new construction projects since roof life is typically longer than in existing projects. On existing projects, roof mounted PV systems may not be practical if the roof slope is oriented east or west. The fourth category considered was Maintenance. This category involved the levels of maintenance and upkeep that would be associated with adding a specific RET to a building or project. PV systems contain few components and have very basic operating and maintenance procedures. The PV system, unlike wind turbines, bio mass systems or generators, is simple, very reliable, and can be maintained by people who have no background in power systems. This is particularly important for ODOT maintenance facilities which may not have adequate staff with proper expertise to operate complex power systems. Cost Effectiveness of a project made up the final category. This was the consideration of the economic feasibility. The economic feasibility was evaluated based on not only initial cost but also the total life cycle cost, annual savings potential, and payback periods. PV systems costs are dropping but can still have paybacks over 20 years when financial incentives are not used, especially if standard electricity costs are low.

Project Factors

The energy performance of a photovoltaic system is influenced by a number of factors such as the amount of solar radiation hitting the solar collectors, the collector type and materials, the slope and orientation of the collector, shading obstructions, and the solar tracking mode. When evaluating a PV project, a thorough analysis of available solar radiation is required because the amount of solar radiation varies by location and climate. The National Renewable Energy Lab has developed a variety of resources and tools to provide initial and detailed information on site-specific solar radiation (National Renewable Energy Laboratory (NREL), 2013a). Figure 4 shows the annual solar radiation in Ohio at a tilt angle equal to the latitude, and it can be seen that there is a modest solar resource available everywhere in Ohio. Another factor is the orientation of PV modules. Optimal performance is achieved from orienting panels facing south and mounting them at a tilt angle equal to the latitude of the location, with respect to the horizontal. In general tilt angles of +/- 10 degrees from latitude, and orientations of +/- 30 degrees from true south do not greatly change the performance (RETScreen International, 2004). Ensuring the panels will receive the maximum potential amount of sunlight and solar radiation is the most crucial factor in the success. The evaluation of various factors can be crucial to the future performance of a PV system, and one way to effectively analyze the impact different factors and characteristics may have on a project is by using a Life Cycle Cost Analysis.

Figure 4: Annual solar radiation at a tilt angle equal to the latitude for Ohio (National Renewable Energy Laboratory (NREL), 2013a).

Life Cycle Costing Analysis

A life cycle cost analysis (LCCA) is a methodology for evaluating different project alternatives and accounts for all the costs that exist throughout the life of product or project. In this research LCCA were performed with the software RETScreen, which is a powerful model that is capable of considering all life cycle costs associated with design alternatives, accounting for various financial parameters, and performing several financial analyses (RETScreen International, 2004). RETScreen also allows for numerous project factors and characteristics to be input, which ensures the generated model well represents a specific site and project.

To demonstrate how various project factors can affect the cost effectiveness of PV systems, two LCCA scenarios were performed and are described in the remainder of the paper. The availability of the solar resources along with proper orientation is typically the biggest factor in the feasibility of a PV project, but since the solar resources is mostly consistent throughout Ohio, the two scenarios investigate the impact that financial incentives have on the cost effectiveness of a project. The first LCCA is for a proposed installation at the Seneca county garage, which has proper building orientation for a PV system, without the consideration of financial incentives, and the second LCCA scenario is for an identical system but including a consideration of financial incentives. The scenario is for a system designed for ideal orientation conditions with a roof facing directly south (an azimuth of 0°) and a tilt angle equal to the site location latitude, in this case approximately 35°. A Sunpower “mono-Si - SPR-210-BLK” that has a nominal efficiency of 16.9% was used in both LCCAs and the RETScreen calculated area of PV modules was 1270 square feet. The rest of the project parameters are shown in Table 1. The only differences in the two scenarios are that the second LCCA assumes a financial incentive of 30 percent of the project cost, and that the project will certify the PV system with the proper agencies and be able to sell SREC at $100/MWh. The financial incentive is factored into the analysis by entering the characteristics of the incentive into the appropriate prompts in RETScreen. The RETScreen program will calculate the impact to the yearly cost data. In this case, a 30 percent incentive is achieved through teaming up with a third party through a power purchasing agreement and applying for the Business Energy Investment Tax Credit which is available nationwide and is worth 30 percent of the upfront expenditures for a PV system (NCHRP, 2013). The 30 percent credit reduces the upfront cost and potential value of a project loan.

Table 1
LCCA design parameters

	Without Incentives		With Incentives	
PV nominal kW	20	kW	20	kW
Cost $/kW	3,000	$/kW	3,000	$/kW
Annual maintenance $/kW	20	$/kW	20	$/kW
Inverter replacement cost in years 10,20	10,000	$	10,000	$
Electricity cost ($/kwh)	0.13		0.13	
Azimuth	0	°	0	°
Tilt	35	°	35	°
Electricity escalation rate	5	%	5	%
Inflation rate	2	%	2	%
Discount rate	2	%	2	%
Project Life	30	years	30	years
Incentives	0		30	%
SREC ($/kwh)	0	$/kWh	0.1	$/kWh
Calculated area for PV modules	1270	sf	1270	sf

RETScreen calculates the energy generated annually and the capacity factor which is the ratio of the average power produced by the power system over a year to its rated power capacity (RETScreen International, 2004). Based on the energy performance of the PV system, RETScreen then calculates various financial indicators to assess the life cycle cost feasibility of the project. These results are compared for the two scenarios in Table 2. As can be seen from the financial results, both LCCA scenarios have positive indicators of a potentially successful project. The second scenario however shows that the addition of financial incentives can greatly improve the payback times and annual savings. The addition of the incentives dropped the payback time from around 16 years to around 6.5 years and increased the expected annual life cycle savings from about $2400 to about $8600 per year. The cumulative annual cash flow graphs from the LCCA are shown in Figure 7. With all other project characteristics and parameters kept consistent, the value of financial incentives to the success of a project is easy to see. The first LCCA scenario is a project with positive results, but the second is one with a much higher appeal to organizations and decision makers since cost effectiveness is typically the primary concern.

Table 2
LCCA financial results

	Without Incentives		With Incentives	
Capacity factor	14.20	%	14.20	%
Annual electricity generated	24.8	MWh	24.8	MWh
Total initial cost of PV system	60000	$	60000	$
Simple payback	21.2	years	7.9	years
Equity payback	16	years	6.5	years
IRR equity	6.3	%	17	%
Net Present Value	54,402	$	193,711	$
Annual Life Cycle savings $/yr	2,429	$/year	8,605	$/year
Benefit/ Cost ratio	1.91		4.21	
GHG reduction cost ($/tCO2)	-174	$/tCO2	-619	$/tCO2

Net Annual GHG reduction	14	tCO2/year	14	tCO2/year
Net GHG reduction (30 years)	420	tCO2	420	tCO2

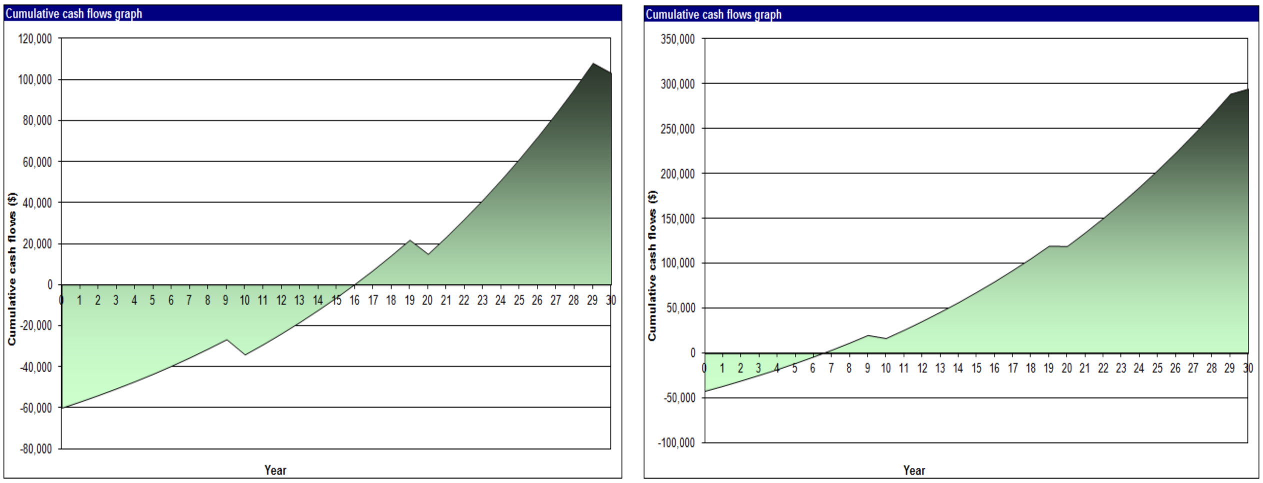

Figure 7: Seneca county LCCA without financial incentives (left) and with financial incentives (right).

Conclusions

Federal facilities such as highway maintenance facilities are prime candidates for the pursuit of renewable energy projects due to their energy consumption trends and the push of federal policies to reduce energy consumption. This paper attempts to illustrate the potential for success of grid connected Photovoltaic systems at these facilities and show the importance of site specific considerations, the pursuit of financial incentives, and the use of detailed project assessments such as life cycle cost analysis. The strategies and analysis tool used can help to demonstrate an analysis process and the importance of a detailed evaluation. This, along with the identification of major factors to consider, can add to the development of best practices in the pursuit of renewable energy projects, which when utilized effectively can help improve view of PV systems and other renewable energy technologies as feasible options for the building industry. To summarize the major observations from the research work, for the successful application of photovoltaic systems at highway maintenance facilities, it is important to:

- Determine the project needs and conditions by considering the energy use characteristics and building's characteristics.
- Consider the project's site features to determine the practicality of the technology
- Use LCCAs to indicate the feasibility of a project and which factors might influence the success
- Look at the financial requirements to determine the feasibility
- Utilize available tools such as RETScreen to perform detailed analysis and calculations.
- Evaluate similar past projects that have been successful for guidance.

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