Feasibility of Wind Turbine Systems in Highway Maintenance Facilities

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Many federally run buildings and associations have started to increase their interest in the pursuit of different renewable energy options. In addition to reducing energy costs and the consumption of fossil fuels, federal energy policies are placing the additional pressure of meeting specific savings or reductions for buildings such as the highway maintenance facilities run by the Department of Transportation. To help meet their energy saving goals, an investigation into potential renewable energy technologies was completed for the Ohio Department of Transportation. This paper focuses on wind turbine systems and how they can be potentially successful options for these facilities. It discusses factors such as the wind resource availability and terrain conditions specifically for the state of Ohio. It also gives a description of highway maintenance facilities and their energy use characteristics and discusses the importance of performing a life cycle costing analysis, and gives an example that illustrates the impact that wind speed has on the potential success of wind turbine systems.

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

Introduction

The Department of Transportation’s (DOT) highway maintenance facilities are one type of buildings that are affected by the recent federal energy policies which encourage or require federal agencies to reduce energy demands and environmentally harmful emissions, and to actively seek out effective strategies and methods for utilizing renewable energy technologies (RETs) (Federal Energy Management Program (FEMP), 2010). The potential to benefit from RETs led the National Cooperative Highway Research Program (NCHRP) to recently complete a study and develop a nationwide guide of strategies for utilizing various RETs and other energy efficiency options at these facilities (NCHRP, 2013). A similar research project with parallel goals, but focusing on the specific state conditions and characteristics of Ohio, was completed by the authors of this paper for the Ohio Department of Transportation (ODOT). The applicability and feasibility strategies and findings for wind turbine systems at Ohio facilities are discussed in this paper. These strategies help to demonstrate the importance of evaluating technologies to ensure positive feasibility, and help to establish and build upon best practices for organizations considering the pursuit of renewable energy projects.

Technology Description

Wind turbines generate electricity from wind turning the turbine blades, which spin a shaft that connects to a generator. In grid connected wind turbines systems, the system feeds electrical energy directly into the electric utility grid. The major components of modern wind energy systems are show in Figure 1 (Rangi, Templin, Carpentier, & Argue, 1992). A typical wind turbine will have 2 or 3 blades, which convert the wind energy into mechanical energy which is passed onto a generator. Various automatic controls operate the system to help improve the performance. One major control is an anemometer that continuously measures wind speed. When the wind speed is high enough to overcome friction in the wind turbine drive train (about 4 m/s), the controls allow the rotor to rotate, producing power. Power output increases rapidly as the wind speed rises. The wind speed at which rated power is reached is called the rated wind speed of the turbine, and is usually a strong wind of about 15 m/s. Eventually, if the wind speed increases further, the control system shuts the wind turbine down to prevent damage to the machinery. This typically occurs when the wind speed reaches 25 m/s. The majority of wind turbines in the wind energy market use three blades on a horizontal axis. Different designs however can have advantages under certain circumstances. Horizontal turbines are best suited to areas that have wind in primarily one direction, while vertical axis designs can take advantage of more random wind patterns (Federal Energy Management Program (FEMP), 2009). Vertical turbines tend to be less efficient than the popular horizontal design, but in areas with inconsistent wind flow this can be outweighed by the flexibility of the designs. The various components and factors of wind turbines require them to be well evaluated to ensure they are a feasible option. The rest of this paper discusses some of the strategies and recommendations made for the Ohio DOT for their evaluation process.

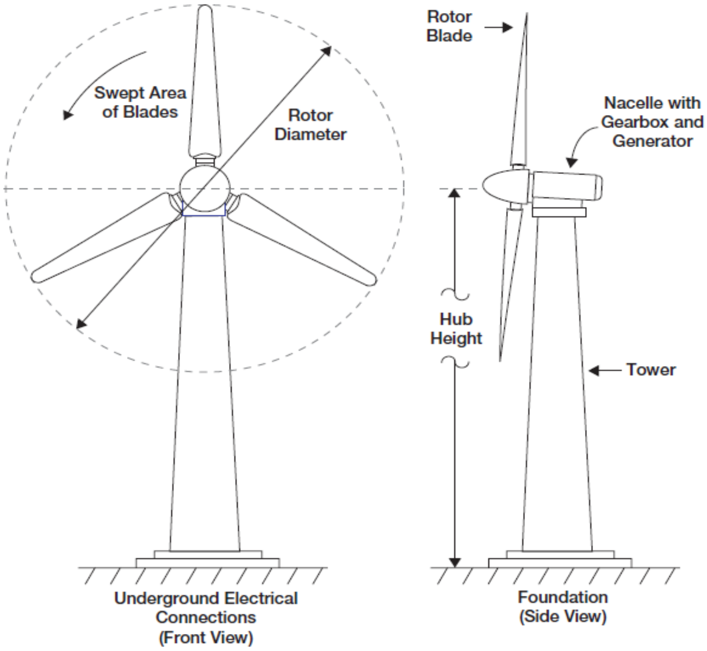


Figure 1: Components of a wind turbine (NCHRP, 2013).

Project Type

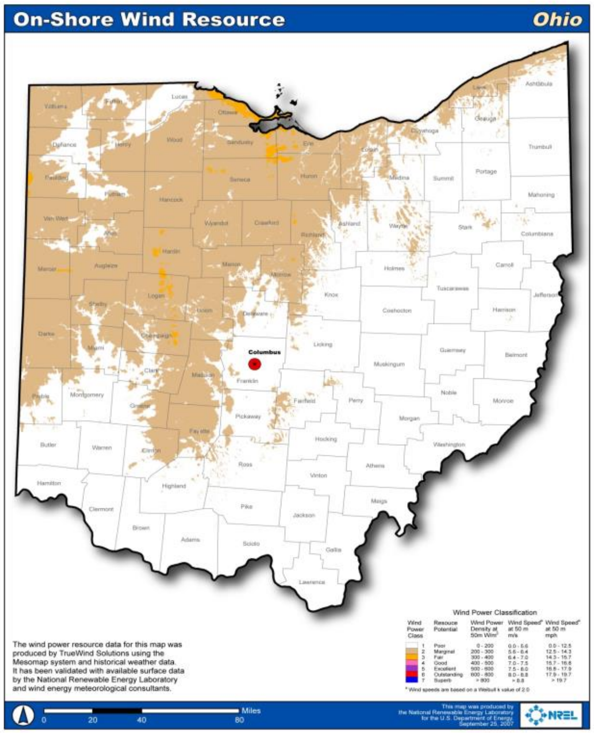
Highway maintenance facilities are buildings and sites run by the Department of Transportation. A typical maintenance facility is comprised of two major building sections. The first section is made of offices, restrooms, a break room and/or meeting room, and a stock room. This section of a facility operates 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. These areas have parking bays for multiple maintenance vehicles, on average around 15, and also typically have two or three maintenance bays for vehicles to be worked on. The garage areas also include a wash bay, storage spaces, and areas for stationary equipment. The garages 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.

Evaluation Criteria

When evaluating the potential of a renewable energy technology at a specific site or building type, an initial strategy that can e beneficial 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 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. Wind turbines do not generate any emissions in the electricity they produce. They do have other environmental concerns however, such as potential interference with bird migrations and social impacts such as sight and noise concerns. The next category of criteria was the Reliability, which involved considerations of the maturity of the technology. The typical useful life, typical warranties on the technology and its components, and the consistency or ability to meet requirements without interruption were all factors. Wind turbines are reliable systems and can be expected to last 20 years. 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. 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. Wind turbines are reliable but do require regular inspections and they have many mechanical parts that can require repair or replacements. 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. Wind systems have high capital costs, and depending on the size and performance of the system the payback periods can reach 15 to 25 years. In general, wind turbines were one of the more highly recommended technologies for these facilities, but feasibility was still depended on many factors.

Project Factors

Some of the main factors that can limit wind turbine successes are location factors such as the wind speed, the wind turbine power capacity, the type of wind turbine (i.e. vertical axis or horizontal axis, site terrain and nearby obstructions. Wind turbines can run into problems and restriction due to their location for several reasons. There must be adequate space for a turbine to be built at least 30 feet above and 300 feet away from any obstructions in order to avoid turbulent airflows (Federal Energy Management Program (FEMP), 2009). There may be set back from roadways and neighboring properties in tight locations as well as the potential of complaints of sight or noise concerns from neighbors with close proximity. There may also be various environmental or governmental regulations that limit potential such as the migratory path of birds. Turbines also need to be checked for proximity to airports and potential interference with radar and other systems at military installations. Generally, it is assumed that wind energy can be economically viable if wind speeds are higher than 4 m/s, measured on an altitude of 10 meters, or about 9 to 10 mph at 30 feet (RETScreen International, 2004). Coastal regions and plains are particularly suitable for wind turbines as they experience the highest wind speeds due to limited interference and obstructions (National Renewable Energy Laboratory (NREL), 2010b). Another major factor that affect the feasibility of wind turbines of sites are the wind resource availability. Wind resource has much larger variation than solar resource and meteorological studies are crucial to ensuring that the resource availability of an area is well known. Figure 2 shows the Ohio 50m wind resource availability and also shows the standard system used to classify wind resource levels. It lists the amount of available power in the wind for corresponding ranges of average annual wind speed. The figure shows that, on a state level, the largest amount of opportunities for developing wind energy in the Ohio are found in the northern and north-western part of the state. Since wind varies considerably a proper wind resource assessment at the site should be performed during the feasibility study. Terrain can also cause variations on efficiency and wind availability. Terrain is considered in analysis through Wind Shear Value. Table 1 shows different types of terrain and their associated wind shear values. Similarly obstacles such as buildings and trees can affect performance by creating turbulence. The concept of micro-sitting is the idea that there should be adequate space to place the turbine away from obstructions to prevent turbulent airflow, and is shown in Figure 3 (RETScreen International, 2004). The evaluation of these various factors can be crucial to the future performance of a system, and one way to effectively analyze the impact of factors is through the use of a Life Cycle Cost Analysis.



The wind power resource data for this map was produced by TrueWind Solutions using the Mesomap system and historical weather data. It has been validated with available surface data by the National Renewable Energy Laboratory and wind energy meteorological consultants.

Wind Power Class	Resource Potential	Wind Power Density at 50m W/m²	Wind Speed* at 50 m m/s	Wind Speed* at 50 m mph
1	Poor	0 - 200	0.0 - 5.6	0.0 - 12.5
2	Marginal	200 - 300	5.6 - 6.4	12.5 - 14.3
3	Fair	300 - 400	6.4 - 7.0	14.3 - 15.7
4	Good	400 - 500	7.0 - 7.5	15.7 - 16.8
5	Excellent	500 - 600	7.5 - 8.0	16.8 - 17.9
6	Outstanding	600 - 800	8.0 - 8.8	17.9 - 19.7
7	Superb	> 800	> 8.8	> 19.7

* Wind speeds are based on a Weibull k value of 2.0

This map was produced by the National Renewable Energy Laboratory for the U.S. Department of Energy. September 25, 2007

Figure 2: NREL's Ohio 50 m wind resource availability (National Renewable Energy Laboratory (NREL), 2013b)

Table 1

Different types of terrain and their associated wind shear values (The Cadmus Group, 2012).

Land Cover Type	DSAT Terrain Roughness Category	Wind Shear Value (α)
Ice, open pavement, snow, level beach, water	Ice or pavement	0.08
Grass	Cut grass	0.15
Agricultural	Cropland/agricultural	0.21
Scattered	Scattered trees and hills	0.29
Sparse	Sparse forest	0.34
Suburban	Scattered buildings and suburban	0.34
Dense Forest (50-100ft)	Dense forest	0.44
Urban	Urban	0.44

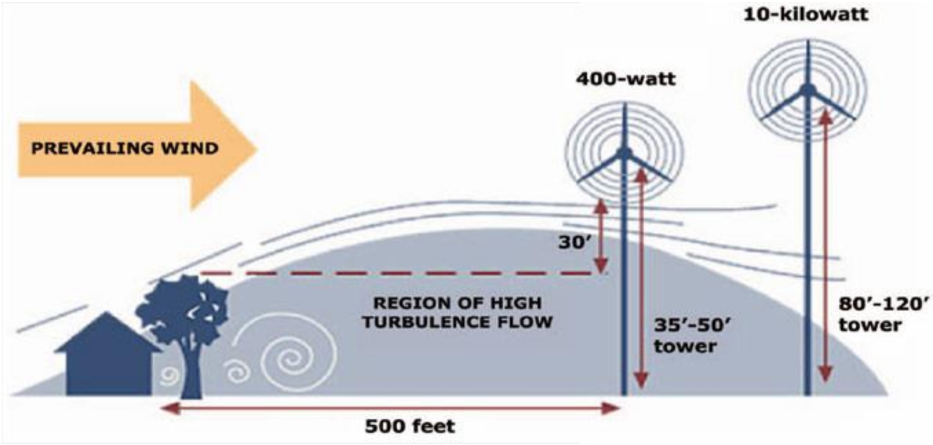
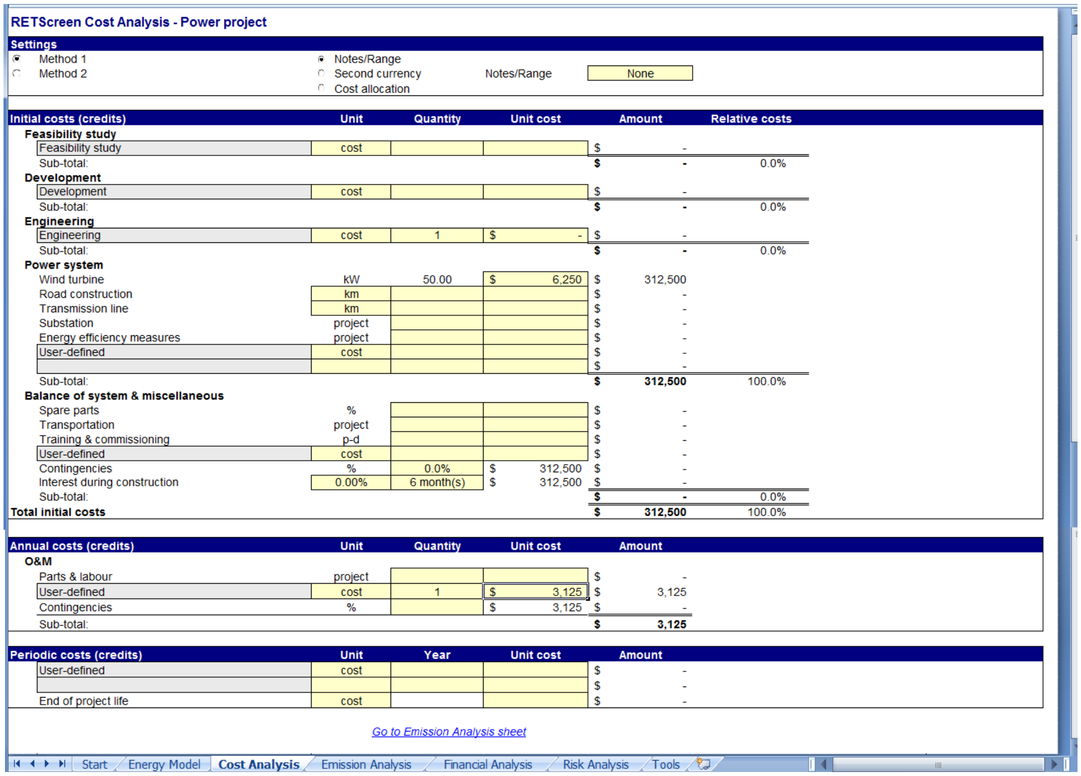


Figure 3: Obstacle Clearance Parameters (Source: http://www.smallwindtips.com/tag/tower-height/)

Life Cycle Costing Analysis

A life cycle cost analysis (LCCA) is a crucial part of any RET selection since financial considerations such as cost effectiveness and payback periods are often some of the main concerns of those deciding whether or not to pursue a RET project. An LCCA is a methodology for evaluating different project alternatives and will account 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. Cost considerations of a sample RETScreen are shown in Figure 4, which include development, design and construction costs as well as annual costs such as maintenance, energy consumption and operation costs, and future replacement costs. Additional financial parameters include incentives, rebates, inflation rate, fuel escalation rate, debt ratio, debt interest rate, rate of electricity exported to grid, equipment depreciation for tax purposes, and greenhouse gas reduction income.



RETScreen Cost Analysis - Power project

Settings

● Method 1
○ Method 2

● Notes/Range
○ Second currency
○ Cost allocation

Notes/Range: None

Initial costs (credits)	Unit	Quantity	Unit cost	Amount	Relative costs
Feasibility study					
Feasibility study	cost			$ -	
Sub-total:				**$ -**	0.0%
Development					
Development	cost			$ -	
Sub-total:				**$ -**	0.0%
Engineering					
Engineering	cost	1	$ -	$ -	
Sub-total:				**$ -**	0.0%
Power system					
Wind turbine	kW	50.00	$ 6,250	$ 312,500	
Road construction	km			$ -	
Transmission line	km			$ -	
Substation	project			$ -	
Energy efficiency measures	project			$ -	
User-defined	cost			$ -	
				$ -	
Sub-total:				**$ 312,500**	100.0%
Balance of system & miscellaneous					
Spare parts	%			$ -	
Transportation	project			$ -	
Training & commissioning	p-d			$ -	
User-defined	cost			$ -	
Contingencies	%	0.0%	$ 312,500	$ -	
Interest during construction	0.00%	6 month(s)	$ 312,500	$ -	
Sub-total:				**$ -**	0.0%
Total initial costs				**$ 312,500**	100.0%

Annual costs (credits)	Unit	Quantity	Unit cost	Amount
O&M				
Parts & labour	project			$ -
User-defined	cost	1	$ 3,125	$ 3,125
Contingencies	%		$ 3,125	$ -
Sub-total:				**$ 3,125**

Periodic costs (credits)	Unit	Year	Unit cost	Amount
User-defined	cost			$ -
				$ -
End of project life	cost			$ -

Go to Emission Analysis sheet

Figure 4: A sample RETScreen analysis page

To demonstrate how various project factors can affect the cost effectiveness of wind energy systems, two LCCA scenarios are compared and discussed in the remainder of the paper. There are many factors that influence a projects performance, but a single factor should be considered individually to see the full extent of its impact. Since the available wind speed of a location plays a significant role in the performance and cost effectiveness of a wind energy system, wind speed will serve as the example variable. The first LCCA is for a proposed installation at the Seneca county garage where the wind resources are fair (i.e. wind speed at 50 m = 6.8 m/sec), and the second is for a proposed installation at the Pike county garage where the wind resources are poor (i.e. wind speed at 50 m = 4.0 m/sec). The LCCA was performed for a 50kW ReDriven wind energy system which would be expected to provide most of the electricity needed for the facility (RETScreen International, 2004). The design parameters used for each scenario are shown in Table 2.

Table 2

LCCA design parameters

	Seneca County		Pike County	
Wind turbine nominal kW	50	kW	50	kW
Cost $/KW	6,000	$/kW	6,000	$/kW
Annual maintenance $/kW	40	$/kW	40	$/kW
Inverter replacement cost in years 10, 20	15,000	$	15,000	$
Electricity cost ($/kWh)	0.13	$/kWh	0.13	$/kWh
Wind speed at 50 m	6.8	m/sec	4	m/sec
Wind shear value	0.12		0.12	
Electricity escalation rate	5	%	5	%
Inflation rate	2	%	2	%
Discount rate	2	%	2	%
Project Life	30	years	30	years
Incentives	0		0	
REC ($/kWh)	0	$/kWh	0	$/kWh

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 wind energy 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 3. As can be seen from the financial results, the LCCA for the Seneca county location are significantly more practical simply based on the one design parameter of wind speed. The Seneca county project's financial results all have positive indicators of a potentially successful project could expect an annual life cycle savings of around $13000 and a return on the investment after around 16 years while the Pike county project has no positive indicator that it would be financially feasible. The cumulative annual cash flow graphs from the LCCA are shown in Figure 5. Neither of these scenarios took into consideration financial incentives which would improve the feasibility, and all other project characteristics were kept consistent except for the wind speed at the site location.

Table 3

LCCA financial results

	Seneca County		Pike County	
Capacity factor	25.2	%	7.1	%
Annual electricity generated	110	MWh	31	MWh
Total initial cost of wind system	300000	$	300000	$
Simple payback	24.3	years	146.7	years
Equity payback	16	years	> project	years
IRR equity	6.4	%	-4	%
Net Present Value	291,327	$	-208,791	$
Annual Life Cycle savings $/yr	13008	$/year	-9323	$/year
Benefit/ Cost ratio	1.97		0.3	
GHG reduction cost ($/tCO2)	-1084	$/tCO2	548	$/tCO2
Net Annual GHG reduction	62	tCO2/year	17	tCO2/year
Net GHG reduction (30 years)	1860	tCO2	510	tCO2

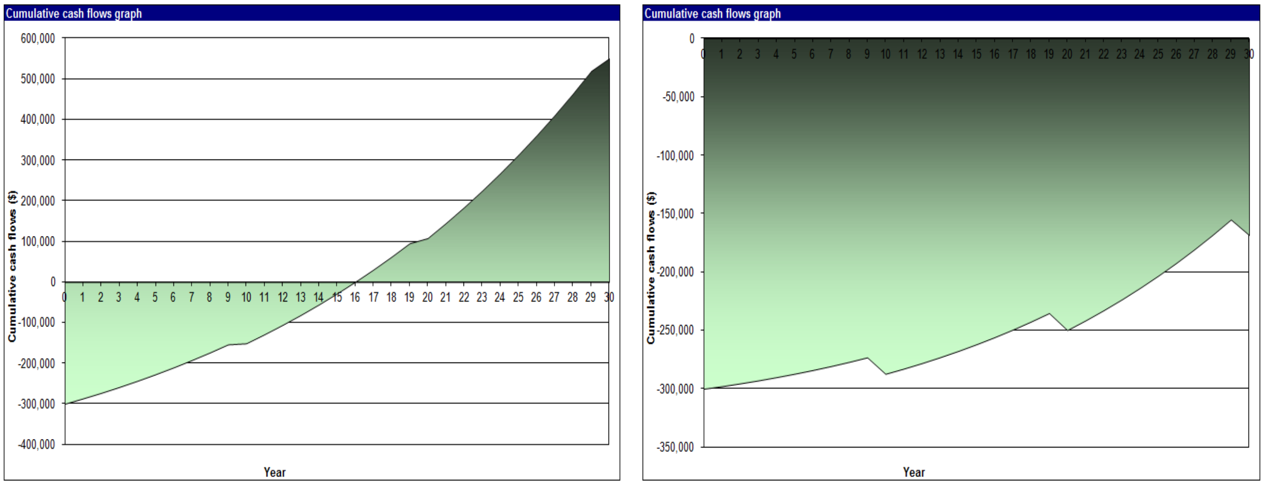


Figure 5: Seneca county (left) and Pike county (right) LCCA cumulative annual cash flows.

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 wind turbine systems at these facilities and show the importance of site specific considerations, such as the available wind speed, and the use of detailed project assessments such as life cycle cost analysis. The strategies used and the identification of factors to consider can help to demonstrate an analysis process and the importance of a detailed evaluation. This can add to the development of best practices in the pursuit of renewable energy projects, which when utilized effectively can help spread the view of wind turbines 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 wind turbines at highway maintenance 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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