Micro-Wind Turbine Feasibility Study for Dismas House of Massachusetts

An Interactive Qualifying Project Report
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Abstract

The project provided Dismas House, a non-profit organization in Worcester, a feasibility study to determine the financial and social benefit of wind power. There was insufficient information to warrant a wind power project. Interviews, site based research, and financial analysis informed this conclusion. The project reviewed funding opportunities, analyzed wind, and compared turbine models. Recommendations are to survey wind for a year with an onsite anemometer, and to retain a professional to secure funding.

Acknowledgements

First our team would like to thank the Dismas House for sponsoring our project. We would like to especially thank Dave McMahon, Bill Wahrer, and Dismas residents for their cooperation during our project. Also we would like to extend our thanks to Stevens Farm and Holy Name High School for their participation. Lastly, we would like to thank our Worcester Polytechnic Institute professors and advisors, Professor Ingrid Shockey, Professor Angel Rivera, and Professor Robert Traver.

Executive Summary

Organization Background

Dismas House of Massachusetts is a non-profit organization that seeks "to reconcile former prisoners to society, and society to former prisoners, through the development of a supportive community"(Dismas House). The organization consists of three facilities in Central Massachusetts: Dismas House, Dismas Family Farm and The Father Brooks House. For the project, our team focused specifically on the Dismas Family Farm.

As part of an initiative to become more self-reliant, the organization seeks to reduce their energy costs through energy efficiency to allocate more financial resources to their programs. Currently, each location has implemented solar panels that have the ability to generate energy credit. Dismas House is now considering wind energy to increase energy generation.

Project Goal and Objectives

The main goal of our project was to determine the feasibility of installing an affordable micro-wind turbine on Dismas House property. There are three objectives to complete this goal. Objective one will examine the proposed sites to determine the optimum site location with respect to wind speeds, environmental effects, and social impacts. Our second objective will explore funding opportunities to aid in feasibility and implementation of a micro-wind turbine. Lastly, the third objective will identify characteristics and compare performance of micro-wind turbine designs. Three micro-wind models will be considered based on feasibility and economic options.

Methodology

The project determined the feasibility of installing an affordable micro-wind turbine on Dismas House property. There were three objectives:

1. Examine the proposed sites to determine the optimum site location with respect to wind speeds, environmental impact, and social influence.
2. Review funding opportunities to aid in feasibility and implementation of a micro-wind turbine.
3. Identify favorable characteristics of micro-wind turbines and evaluate models based on feasibility and economic options.

Objective 1: Site Assessment

To meet objective one, we compiled photographic documentation, researched zoning bylaws, and conducted structured interviews to complete a baseline assessment. Photographs were taken at the farm to document potential turbine placement and obstacles. Research of the zoning laws for Oakham, MA provided our team with site restrictions for turbine placement and installation. Average and maximum wind speeds from local weather stations were examined to estimate wind speeds on the farm. Interviews were administered with Dismas Family Farm residents to document any concerns related to installation of a micro-wind turbine. These tasks provided our team with a baseline to determine feasibility.

Objective 2: Financial Savings and Funding Opportunities

To complete objective two, our team conducted archival research and research on external funding opportunities. The Dismas House energy archives provided the team with knowledge about energy expenses, specifically electricity. Extensive research of current funding opportunities provided Dismas House with financial options to aid in the installation of a micro-wind turbine. Private and state grants were examined, which provided the Dismas organization with various funding opportunities. These financial options will supply the Dismas organization with additional funding once they select a micro-wind turbine for implementation.

Objective 3: Comparison of Models

To complete objective three, 39 micro-wind turbine models from allsmallwindturbines.com were reviewed. The provided data was compiled. Turbines were ranked based on the following characteristics: rotor diameter, rated power output, swept area, area affected by shadow flicker, and cut-in wind speed. Smaller values were desired in each category, with the exception of rated power output. The summation of scores across these five categories allowed collective ranking of the reviewed models. After ranking, three potential models were selected.

Findings

For this section our team will explain our project's findings.

Site Baseline

In the site baseline assessment, locations where a micro-wind turbine cannot be implemented were identified. This was accomplished through mapping of the farm. It was determined that the land 1,200 feet north of the main house was unusable for turbine implementation because it is not owned by Dismas House. The roof of the barn was identified as a potential location due to the higher elevation relative to the surrounding area.

Wind Studies

Average wind speed data was collected from six weather stations in surrounding towns. The wind speed data from these locations provided a basic understanding of the wind speeds in the area of the farm. It was found that the wind speeds recorded at the Worcester Regional Airport were much higher than at other locations. This difference might be caused by more accurate equipment at Worcester Regional Airport than other stations. Another possible reason for the difference in wind speeds may be anemometer location. The airport is an open area on top of a hill that has fewer obstacles to wind flow. The other locations may be in areas with trees or buildings that obstruct the wind near the anemometer.

Social and Environmental Impact

Interviews were conducted to understand the potential social and environmental effects from installation of a wind turbine. During interviews with Dismas Family Farm residents, Stevens Farm, and Holy Name High School topics concerning avian life, noise, green energy, and shadow flicker were discussed. Discussion about avian life, shadow flicker, and noise revealed minimum concerns for wind turbine implementation. For both Stevens Farm and Holy Name High School, avian life was not affected. Shadow flicker and noise were also not an issue for those surrounding the turbines. All interviewees agreed green energy provides a strong option to reduce energy costs. Due to the information discovered during these interviews, our team concluded these potential issues will be minor factors when considering a micro-wind turbine.

Financial Savings

The Dismas House has made a conscious effort to reduce their budget allocated towards energy. Once a list of grants was received along with energy usage data from the past five years, our team analyzed energy costs. We reviewed the total energy usage and cost through analysis of the Dismas WeGoWise account. Our team compared total energy usage with total energy cost to determine the amount of finances allocated towards each individual utility. Fuel oil no longer contributes to the total expenses because fuel oil was replaced by the pellet stove. Therefore, electricity costs compose the majority of Dismas House energy expenses. The installation of solar panels has reduced electrical costs. Advancement in wind energy will reduce energy costs, ultimately supplying the Dismas organization with more funds to allocate towards their residents.

Associated Grant Makers

Our team reviewed 169 potential grant opportunities from Associated Grant Makers. The raw data provided information including title, state, and contact information. To separate grants into a spectrum, ranging from those best suited to Dismas House needs and those not, a score rubric was used. Categories were determined based on the provided raw materials and the sponsor need. These categories were determined to be the grant focus, geographic influence, limitations, and application style. Grants that could not be readily accessed through research were not reviewed due to the scope and timeline of the project. Through review of the grants, the top 20 grants were identified and suggested to Dismas House directors.

Massachusetts CEC Grant

In particular, our team reviewed the Massachusetts Clean Energy Center (CEC) Micro-Wind rebate program. The program outlines the expectations for selected turbine models, installer requirements, power output criteria, and installation requirements. Key expectations require the installation to be conducted by a licensed professional electrician, and that the turbine meets specifications. The rebate program also requires that a feasibility study be conducted. The Massachusetts CEC clearly outlines the program expectations and provides all documents for potential applicants. The significance of this grant is the ease of application and the focus of the grant. As this grant has open applications and is specifically focused on the implementation of micro-wind turbines and applicants in Massachusetts, it fits the majority of criteria.

Model Comparison

The models reviewed were limited to those with a rotor diameter of 6 meters or less. This limit was selected to account for the assumed placement of the turbine on top of the barn structure. Following the compilation of data, all 39 models were ranked according to the summation of rated power output, rotor diameter, swept area, area affected by shadow flicker, and cut-in wind speed rankings. To provide a variety of model designs for Dismas House, the top HAWT, VAWT Darrieus, and VAWT Savonius models were considered.

Recommendations

Through our feasibility study, it was determined that there is not enough information to support the immediate implementation of a micro-wind turbine. Specifically, there is no wind speed data directly from the farm’s location. To gather this data, Dismas House should place an anemometer on top of the barn structure. The implementation of an anemometer will allow for

Dismas House to collect wind speed data particular to the farm location. This will aid in the pursuit of future feasibility studies and grants.

The roof of the barn at the Dismas Family Farm is believed to be the ideal location for wind turbine implementation due to the increased elevation and close proximity to the electrical grid. We recommend that Dismas House hires a professional structural engineer to evaluate and ensure that the barn's structure will be able to support the weight and vibrations caused by a turbine. This is crucial to prevent collapse of the barn.

We also recommend that Dismas House hires a professional to conduct another feasibility study following the collection of wind speed data. This will provide the professional detailed information for further analysis and research into implementation. This hired professional will aid in the pursuit of grants, such as those through the Massachusetts CEC.

Authorship

This project report represents the joint work of Anthony Capuano, Rachel Cody, and Andrew Kenyon.

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Chapter 1: Introduction

Interest in renewable energy, for both commercial and domestic purposes, has increased as the supply of fossil fuels decreases worldwide. These effects are felt locally in organizations, including businesses, homes, and educational institutions. The Dismas House of Massachusetts, a non-profit, is one such organization. The Dismas House mission is "to reconcile former prisoners to society, and society to former prisoners, through the development of a supportive community"(Dismas House). As part of an initiative to become more self-reliant, the organization seeks to reduce their energy costs through energy efficiency and allocate more financial resources to their mission. A potential solution for Dismas House is the implementation of a micro-wind turbine.

The organization includes three locations in Central Massachusetts: Dismas House, Dismas Family Farm and The Father Brooks House. Dismas House has researched various methods to reduce energy costs among the properties, and has already implemented methods to reduce costs at each location. Currently, the locations use a pellet stove to heat their buildings. The organization has also reinsulated to become more energy-efficient and to reduce heat loss from buildings. All three locations have installed solar panels that have the ability to generate energy credit. Dismas House is now considering wind energy to provide a cost effective choice for supplying power.

Installation of a micro-wind turbine provides wind energy in place of fossil fuels. By installing a micro-wind turbine Dismas House shows social responsibility from an energy perspective. The micro-wind turbine will contribute to a further shift towards alternative energy throughout the organization. Not only can wind energy be efficient, but it can also be cost effective. Implementation of a wind turbine will add to the electricity generated and energy credit earned by Dismas House.

The main goal of our project was to determine the feasibility of installing an affordable micro-wind turbine on Dismas House property. There are three objectives to complete this goal. Objective one will examine the proposed sites to determine the optimum site location with respect to wind speeds, environmental effects, and social impacts. Our second objective will explore funding opportunities to aid in feasibility and implementation of a micro-wind turbine. Lastly, the third objective will identify characteristics and compare performance of micro-wind turbine designs. Three micro-wind models will be considered based on feasibility and economic options.

Chapter 2: Literature Review

This chapter will focus on the research our group has complied on topics in support of our goal for Dismas House of Massachusetts. The topics include assessments of wind studies, cost and site analysis, social and environmental impacts, and the availability for small-scale wind turbines in Worcester. Lastly, we review the lessons learned from two case studies. We begin with a description of the sponsoring agency and their mission.

2.1 Dismas House

Dismas House of Massachusetts was founded in 1974 by Reverend Jack Hickey to establish a stable housing environment for former offenders following their release from prison. The non-profit was established in Worcester fourteen years later, by concerned citizens working with Dismas House Director, Terry Hogan, and the College of the Holy Cross. Gradually, a house for Dismas graduates and families was opened in 2007, and in 2010 the organization constructed the 35-acre residential Dismas Family Farm in Oakham, Massachusetts to assist in recovery of former offenders (Dismas House).

The organization sustains sites throughout the region, partnering with organizations such as Worcester Initiative for Supported Reentry (WISR) and law enforcement agencies. Dismas House also partners with other supervised agencies to help former offenders develop skills that will ease their reintegration into society. Consequently, their mission is "to reconcile former prisoners to society, and society to former prisoners, through the development of a supportive community"(Dismas House). The Dismas House community offers a structured environment free of violence, alcohol, and drugs. The community provides counseling, activities, and structure through mandated dinners, curfews, and chores. The key to this approach is having the residents of the house become a family by working together to achieve their goals.

The Dismas Family Farm furthers this approach towards self-reliance by selling crops and finished wood products. During the winter months, the farm also produces candles and popcorn for retail sale. Residents on the farm maintain the farmhouse and are trained in activities that are used in everyday farm life, such as crop production and animal husbandry. Residents are required to work for the farm or maintain a full-time job elsewhere, but the site specifically allows for vocational and job related training in a substance free environment (Dismas House).

Over the last decade, the Dismas House has shifted from using fossil fuels to more energy efficient equivalents such as solar power and pellet stoves. The association is continuing to reduce their carbon emissions by focusing on implementing wind energy as another source of power. This will improve financial self-reliance and allow Dismas House to allocate more of their budget to the programs offered. Currently, the lead Co-Director, Dave McMahon, is behind the organization's initiative towards renewable energy use. McMahon also collaborates with a Board of Directors to further the renewable energy efforts. Under his leadership, Dismas House plans to install a micro-wind turbine to provide energy to the Dismas Family Farm.

2.2 Wind Turbines

We researched wind turbines and performance characteristics to understand the ability of wind power to increase the sustainability efforts of Dismas House. The basics of using wind power to generate electricity can first be understood as stemming from the process of converting kinetic wind energy to mechanical energy by aerodynamic lift principles. The blades of the turbine "catch" low-pressure pockets in the air like an airplane wing, and cause the rotor to rotate. Small wind turbines can provide up to 100 kilowatts of power to an energy grid, while larger wind turbines can produce up to several megawatts (U.S. Department of Energy).

Modern wind turbines utilize the concepts behind wind technology and windmill designs, and can be divided into horizontal axis and vertical axis turbines (Balat, 2009). Horizontal Axis Wind Turbines (HAWTs) are commonly used for commercial applications, and have two to three blades. HAWTs can have upwind or downwind rotors, although downwind rotor turbines are much louder. Vertical Axis Wind Turbines (VAWTs) have an egg-beater design, and are very easy to repair and service. Another advantage to VAWTs is that the blades are omnidirectional. However, the energy output capacities for VAWTs are smaller than that for HAWTs (Balat, 2009). The tower used to raise the blades to high altitudes can be constructed in several different ways, including lattice, concrete, free standing tubular steel, and hybrid constructions (Hau & Renouard, 2013). The optimum height of the tower is determined by considering economics and wind flow. Typically, there is a 0.7% increase in energy per meter in height, but there is no general standard for economic benefit. The economic factor is more flexible, through use of grants and longer amortization periods (Hau & Renouard, 2013). Depending on the site location, the local community and regulations can be very advantageous to the implementation of a wind turbine.

2.3 Wind Site Analysis and Feasibility

In the past decade, the use of wind power has become increasingly prominent throughout the world, especially in the United States. Large-scale wind farms have been constructed to provide alternative energy. The major factor in harnessing wind energy effectively is finding a site that achieves wind speeds of at least 4 mph at an altitude of 10 meters (Hau & Renouard, 2013). Wind speeds increase with higher altitudes and can be improved at a low cost. Modifying the terrain in the area, such as building a rounded hill for the turbine's foundation will increase wind velocities (Jha, 2011). Figure 1, below, displays the wind patterns across the United States. This map provides a general overview of ideal wind turbine placement to maximize energy output. The darker the blue the stronger the wind power is for the area.

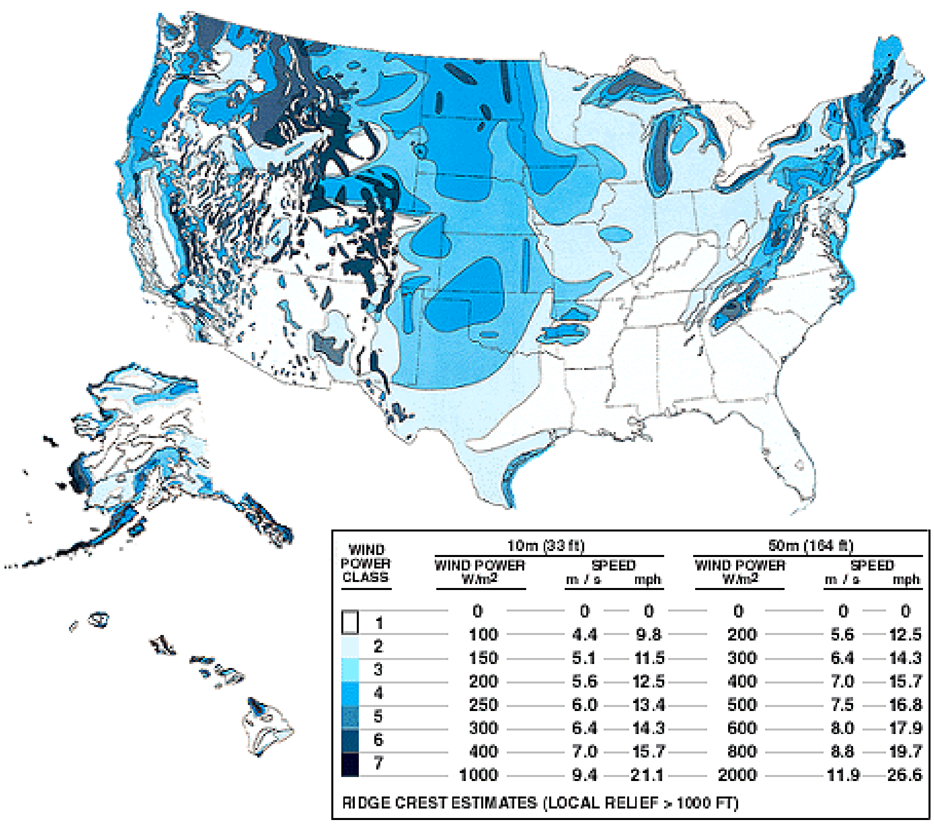

Figure 1: United States Annual Average Wind Power, (Demers-Peel, Dechiara, Brewster, & Mathisen, 2009)

Wind power is the fastest growing energy in the United States and has replaced 42% of all electric capacity (Fischlein, Feldpausch-Parker, Peterson, Stephens, & Wilson, 2014). Many businesses and residents are considering wind energy as a source of power to reduce costs and carbon emissions to the environment.

According to Archer, states including Minnesota, Texas, Montana, and Massachusetts have high potential for wind power. Recently, Massachusetts has begun to develop more wind farms in order to capture the energy across the state. A significant amount of wind energy for the state of Massachusetts can be found offshore, especially from The Cape Wind Project (Archer et al., 2014). However, central and western Massachusetts contains many turbines, which are supplying considerable amounts of power, specifically in Worcester and Gardner. This map shows the layout of wind patterns for the Worcester area (see figure 2).

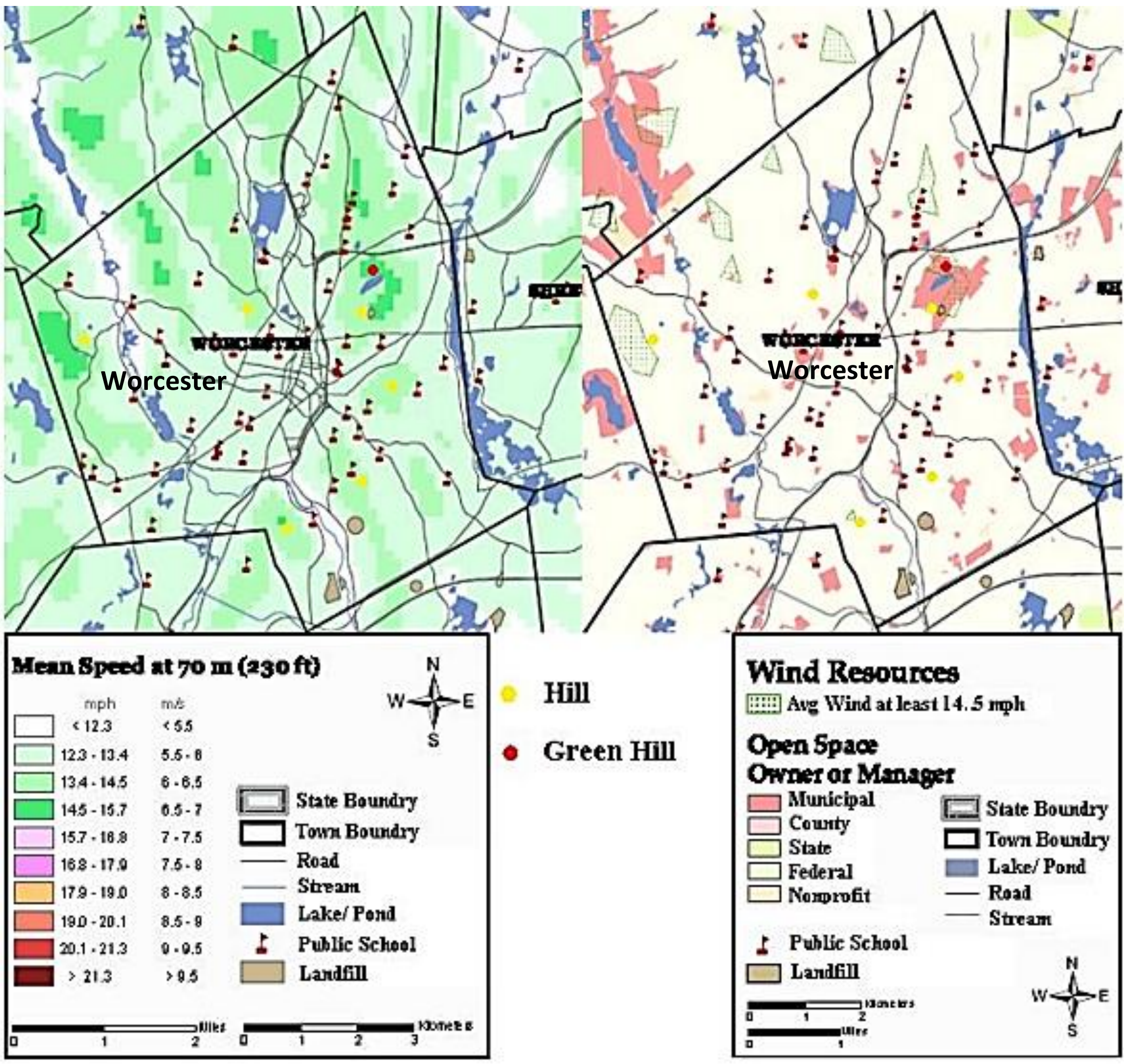

Figure 2: Wind Speeds and Land Ownership in Worcester, (Ghizzoni, Cahill, Low, & Jarvis, 2009)

As shown above, Worcester has several areas where wind speeds average about 15 mph. These average speeds can supply sufficient wind for turbines to produce substantial wind energy. Worcester has installed many wind turbines and will add more throughout the city to utilize the abundant wind speeds.

2.4 Support for Implementation

Since 2008, Worcester has become the "green" geographic focal point of Central Massachusetts in the northeastern United States (McCauley & Stephens, 2012). Through the assistance of a diverse array of stakeholders, the "smokestack" city has begun to reap social benefits (McCauley & Stephens, 2012). These benefits include the creation of jobs, increased energy efficiency, support for research, and progress towards national recognition as a leader in sustainability. Government organizations assist with financial obstacles, while non-governmental organizations aid in navigation of regulations. Locally, the "Green Business Zone" offers permitting, zoning, and tax breaks to energy efficient firms. Reflecting on the multiple sources of support, "firms identify the supportive role of city and state government… as strengths for the sector" (McCauley & Stephens, 2012). This strength was confirmed in 2012 when Worcester was designated a "Green Community" in Massachusetts (McCauley & Stephens, 2012).

This statewide support for green initiatives is observed in the increased installation of wind turbines. In 2008, Holy Name Central Catholic Junior Senior High School constructed the first wind turbine in Worcester, MA (McCauley & Stephens, 2012); (Nicodemus, 2013); (Reis, 2008). The turbine cost approximately $1.7 million in total, but with the assistance from Holy Name's Founding Order the Sisters of St. Anne, the Diocese of Worcester, Worcester Polytechnic Institute students, United States Representative Jim McGovern, the Massachusetts Technology Collaborative, and various private organizations, the cost was reduced (Reis, 2008). The Massachusetts Technology Collaborative alone awarded Holy Name a $575,000 grant, the maximum amount possible, and was connected with the school through Representative Jim McGovern (Reis, 2006). Support from the community and state was critical to the success of this wind turbine implementation.

The town of Gardner, MA has also successfully implemented wind turbines. Following the installation of wind turbines at Mount Wachusett Community College, the town implemented two additional turbines on state prison property to create clean energy for the prison. It is estimated that the clean energy generated by the wind turbines, in addition to increased energy efficiency at the prison, will save the facility approximately $2.3 million per year (Barnes, 2014). This is particularly relevant to our team, as we will be evaluating local and state funding, as well as smaller grants to support micro-wind turbine implementation.

2.5 Challenges for Implementation

When considering wind power, one challenge is the unpredictable nature of wind. As studies on wind energy have increased, evidence has shown weakened wind flows across the Northern Hemisphere, which greatly impact the US, Western Europe, and China (Fairley, 2011). These are heavily populated areas that use a significant amount of power, yet wind energy is unreliable due to its random patterns. Climate change might hinder the capacity for wind turbines in some regions. Therefore, areas with decreasing wind may be reluctant to invest in wind power.

Urban development is also a possible cause of decreased wind flow. As cities grow and buildings rise taller, wind patterns are altered. The growth has created larger buildings that deflect the wind patterns. Due to the population expansion, winds speeds decrease while cities expand. Overall, vegetation has slightly increased as well, which has decreased wind speeds (Milton, 2010). The vegetation has created a rougher surface area. Because of urban development, population expansion, and vegetation growth, decreases in wind speeds might hinder the advancement for wind energy.

The unpredictability of wind power raises concern when considering installing wind turbines. Due to the intermittent wind patterns, wind turbines must be installed in high wind locations to operate efficiently. Wind energy also has a low energy density. Low energy density states that a large energy input results in a minor power output. For example, nuclear power has high energy density because little energy is required to produce a substantial amount of power. Therefore, wind turbines need to rotate with great velocity to produce significant power output. Because of inconsistent wind speeds and low "energy density", wind energy is often overlooked when considering renewable energy (Anonymous, 2010). For the Dismas Family Farm, the wind turbine will be relatively small; therefore, the "energy density" will not affect the power generated by the wind turbine.

Because our project is based on installing a small scale wind turbine, these potential challenges will be minimal or non-existent. The decrease of wind speeds across larger cities will have a diminished effect on smaller wind turbines. This is caused by lower operational wind speeds required for a micro-wind turbine. Micro-wind turbines experience less of the challenges mentioned above due to the smaller scale.

2.6 Environmental Impact of Wind Turbines

Major concerns for implementing wind turbines as an energy source are related to negative effects on the environment. These concerns are for avian life, land clearing for installation, and reduction of wind speed after contact with a turbine. Wind turbines can potentially affect avian life through collisions with rotor blades of wind turbines and the displacement from the wildlife's natural habitat. Most birds that nest in the vicinity of a wind turbine are able to observe the new obstacle in the area and are able to avoid it (Hau & Renouard, 2013). Bird deaths are due to variables specific to each site. The variables that must be considered for each location are the local species of birds, bird population, and site topography. These variables should be observed in all locations under consideration for wind turbine development. This concern will be investigated before implementation.

In addition to disruption of avian patterns, wind turbines bring other impacts to the local environment. As part of construction, an area of earth must be cleared to erect the foundation and turbine tower. There are arguments that an area should be cleared for safety purposes in case a propeller were to break off the turbine or if the tower were to collapse. This extra clearing is not necessary because the risk of these tragedies occurring is as likely as a building collapsing (Hau & Renouard, 2013). Additionally, our proposed tower is anticipated to be on a smaller scale. It is likely minimal clearing will be necessary.

2.7 Social Impact of Wind Turbines

Beyond the environment, the social impact related to the installation of wind turbines, often overlooked, can be detrimental to individuals living in surrounding areas if not properly addressed. Many developers view the installation of wind turbines as a cost effective benefit. However, those that neighbor turbines experience two major issues with noise and shadow flicker. From studies conducted in 2007, wind turbine noise has disrupted human patterns, and shadow flickers have caused health issues such as headaches and dizziness. The noise originates from the constant pressure and electromagnetic waves produced when the wind turbine oscillates. Not all sound waves can be heard by the human ear, yet the infrasounds (low frequency resonance vibrations) created by the rotor blades are harmful to the human body

(Havas & Colling, 2011). The vibrations caused by wind turbines have led to a series of reported ailments. Wind turbine syndrome and vibroacoustic disease are two illnesses associated with wind turbines. Vibroacoustic disease (VAD) is “caused by direct tissue damage of a variety of organs from high or low frequency noise” (Bolin et al., 2011). Wind turbine syndrome is due to the pressure waves and low frequencies, and affects the neurological aspect of the human body. Side effects consist of earaches, altered heart rate, nausea, mood swings, and lack of concentration. Wind turbines are not the only causes for these afflictions, but are shown to be more prevalent in heavily populated areas surrounding wind turbines.

To examine these issues, the Massachusetts Departments of Environmental Protection and Public Health commissioned an independent panel of experts to analyze relevant literature. The Panel determined that there was “insufficient evidence” that wind turbines directly cause health problems, including shadow flicker and noise ("Health & Safety," 2011). The Panel did agree noise is a possible cause of annoyance and/or sleep disruption. Noise produced by the wind turbine can be divided into two categories. Mechanical noise is produced by the turbine components, whereas aerodynamic noise results from the blades passing through the air. Multiple factors, including air flow, turbulence, and topography, are affected by the perceived noise volume. Noise is regulated by the Massachusetts Department of Environmental Protection, and limits the increase in ambient sound to a maximum of 10 dB(A) ("Health & Safety," 2011). Shadow flicker is dependent on factors including the weather, wind direction, sun position, and blade motion. With recent technological advances, shadow flicker can now be modeled with computer software, and thus is easily predicted and reduced. Additionally, the range is generally limited to locations within 10 rotor diameters, reducing the areas impacted for micro-wind turbine models ("Health & Safety," 2011).

2.8 Cost Analysis

When considering implementation of a wind turbine, a cost analysis can be performed to estimate the potential cost for a wind turbine to be installed. The cost analysis includes many variables, including turbine cost, maintenance, overall investment, energy savings, scale, and connectivity to the electrical grid. A study from 2006 analyzed the installation of an entire wind turbine, with researchers able to conclude that 80% of the total cost was due to installation (Aso & Cheung, 2014). This percentage includes the price of the turbine, installation, manual labor, and the turbine construction. Maintenance for wind turbines becomes costly over time because the functionality needs to be inspected after 10-20 years. Costs, including maintenance, land rental, insurance, and taxes, accumulate over time (Blanco, 2009). Due to the initial high price of a wind turbine and fees that continue to follow after, it may take 12 years for the wind turbine to profit the landowner. The landowner should evaluate the turbine size and location, and understand the cost commonly takes years to repay. However, the overall benefits from wind turbines are significant, as wind energy decreases energy bills significantly and ultimately helps in reducing carbon emissions. Wind turbines tend to be expensive, but the energy output along with reducing carbon emission are beneficial in the long term.

2.9 Case Studies

The main goal our team addresses is the feasibility of affordable micro-wind turbine implementation on Dismas House Property. For this reason, we have specifically reviewed articles detailing the process and nature of small wind turbines. These two case studies were selected for the insight they provide.

Case Study 1: Implications of the UK Field Trial of Building Mounted Horizontal Axis Micro-Wind Turbines

In 2007, six hundred micro-wind turbines were installed in the United Kingdom. For these wind turbines, manufacturers claimed that turbine performance improved at lower wind speeds. However, the study completed below disproves this claim. A study was completed in urban, suburban and rural areas to determine if building mounted wind turbines were cost effective.

The study fully monitored 33 turbines in the United Kingdom that were mounted to buildings. These micro-wind turbines had anemometers mounted at the same height as the hub of the turbine and the minimum distance away from the blades to avoid distortion and noise. Average wind speed data for these sites was collected using NOABL-MCS, the United Kingdom wind speed database. Each turbine in the trial was rated 2.5 kW for wind speeds lower than 15 m/s (33.5 mph).

Throughout the study, it was observed that power output increased with increasing turbulence at average wind speeds of 5-10 m/s. At some locations, the wind turbines produced negative net energy as energy is required by the turbine to produce electricity. It was also discovered that slightly lowered wind speeds can cause a decrease in power output. For example, a 1 kW turbine surrounded by an average wind speed of 5 m/s is projected to produce 358 kWh/m^2. However, the turbine produced 10% less power due to the average wind speed being 4.8 m/s.

The study concluded that the wind turbine that does not receive high enough wind speeds will not be economically sound. Micro-wind turbines in this study require a minimum average wind speed of 5 m/s to operate efficiently. This case study shows the importance of ensuring that wind speeds at our proposed locations meet or exceed the requirements of the implemented wind turbine to become an economically sound investment(James et al., 2010).

Case Study 2: Small Wind Turbines: The Unsung Heroes of the Wind Industry

Over the last decade implementing micro-wind turbines worldwide has allowed residential areas to benefit from wind energy. When first developing wind turbines, large, high-powered wind turbines were the main focus for an alternative energy source. However, the focus has shifted to small-scale wind turbines that produce less than 100 kW. These smaller wind turbines can be used for village or residential electrification applications and powering small appliances. The space required for a small turbine can be as small as one square yard, but the general standard is to allot a half-acre. Once constructed, the tower height for a 250-watt turbine is suggested to be between 30 to 50 feet high. When constructing a small wind turbine, builders strive to reduce the number of moving parts to minimize required maintenance.

This study indicates that micro-wind turbines provide a considerable amount of energy and can also be cost effective. Our team strives to provide three cost effective micro-wind turbine model options for Dismas House. This study, in addition to others, validates the effectiveness and application of wind energy devices (Bergey & Kruze, 2002).

2.10 Concluding Summary

In sum, our assessment of the literature addressed the interface of environment, technology, and society through discussion and exploration of harnessing wind power. Considering these three overarching themes, the impact caused by wind turbine implementation was viewed from multiple angles. Research has addressed economic feasibility, technological design, wind study demographics, social and environmental impacts and the current position of Worcester, Massachusetts on wind energy. Review of case studies has also yielded valuable insight to guide our process as we move forward.

Chapter 3: Methodology

The project determined the feasibility of installing an affordable micro-wind turbine on Dismas House property. There were three objectives:

1. Examine the proposed sites to determine the optimum site location with respect to wind speeds, environmental impact, and social influence.
2. Review funding opportunities to aid in feasibility and implementation of a micro-wind turbine.
3. Identify favorable characteristics of micro-wind turbines and evaluate models based on feasibility and economic options.

3.1 Objective 1: Site Baseline and Suitability Analysis

The first objective required a site analysis of the Dismas House property. The analysis included photographic documentation, town bylaws, and structured interviews. Collectively, these methods determined the feasibility of a micro-wind turbine.

Site Baseline

To better understand the location, photographic documentation was used to observe the immediate surroundings. Photographs documented potential areas for implementation on the farm (Garrett, 2014). Research concerning Massachusetts zoning laws for Oakham, MA verified that a wind turbine can legally be installed.

A baseline assessment was conducted to ensure that the location met minimum requirements for successful implementation. The baseline assessment consisted of wind speed measurements collected from archival data. This data was taken from surrounding weather stations to analyze wind speeds. The data collected dates back as far as ten years prior.

Environmental Effect

The major concerns for implementation were the removal of trees and death of avian life. As our sponsors focus on a micro-wind turbine, concerns for avian life and land clearing are minimized. To meet our first objective, we utilized a mapping method and photographic documentation to approximate the open area for implementation.

A wind turbine requires an open area to ensure that the blades do not collide with objects. The size of this area is dependent on the wind turbine size (Cochrane, 2014). During the data collection period between the months of January and March, we observed that the avian population was relocated due to migration patterns. To address this, our team collected information on the avian population near the Dismas Family Farm throughout the year through interviews with residents. Additionally, interviews with local turbine owners were conducted to better understand the effect of wind turbines on avian life.

Social Impact

Interviews were conducted with Dismas residents, personnel, and owners of installed wind turbines. Dismas House residents were interviewed concerning their perceptions of wind turbines. In interviews with turbine owners we noted any obstacles that were encountered and determined potential solutions to avoid similar difficulties. These interviews supplied our team with information including cost, energy usage, size, and labor. Sample questions from our interview with residents who have installed a wind turbine can be found in Appendix A and B. All interviews provided important feedback concerning the turbine.

3.2 Objective 2: Funding Opportunities

In order to complete objective two, our team conducted archival research and research on external funding opportunities. Research of Dismas House archives provided the team with knowledge of previous energy usage trends from Dismas House. Research of current funding opportunities provided Dismas House with financial options to aid in the overall process for installation. Data was obtained about the financial distribution throughout the association. Previous records provided hard copy documents that assisted in economic distributions (Ward, 2014). Implementation of this method depended on the permission of Dismas House and availability of records.

Further research was conducted on current external funding opportunities for a micro-wind turbine, specifically available in Massachusetts. The state of Massachusetts will support organizations with grants and rebates that propose a plan to reduce carbon emissions (U.S. Department of Energy). There are several energy conservation programs throughout the state that provide funding to commercial and residential locations. We also evaluated grant opportunities provided to Dismas House by Associated Grant Makers. Our team identified funding options that will support the installation of the micro-wind turbine.

3.3 Objective 3: Comparison of Micro-Wind Turbine Models

To meet objective three, research was reviewed on micro-wind turbine models. Research considered vertical axis wind turbines (VAWTs) and horizontal axis wind turbines (HAWTs), size, wind speed requirements, and energy output of the models. Models were actively reviewed through archival research of wind turbines implemented in Worcester, and the online resource allsmallwindturbines.com. This source compared professional micro-wind turbines based on manufacturer, model, power output, and cost. Micro-wind turbine models that did not fit to site specifications were not considered. Site specifications were determined through objective one in the methodology.

Model candidates were also eliminated based on sponsor specifications. Sponsor specifications included, but were not limited to, preferences on tower height, maximum cost, and power output. These sponsor specifications depended on all variables, and were negotiable. Sponsor specifications were determined through discussions with our sponsor. Specifics about financial contributors and the amount of power produced were discussed as well as the "ideal" wind turbine (i.e. height, size and design). Discussions were conducted in person as a collective group.

These findings were compiled into a feasibility study. This sample of turbines was ranked to offer design options for the Dismas House. The ranking consisted of characteristics including, but not limited to, axis design, turbine size, wind speed requirements, and power output. These characteristics served to offer three distinct micro-wind turbine models to Dismas House. The characteristics were determined through our methodologies, including research of model designs, site specifications, and the sponsor's specifications.

3.4 Data Management

Our team encrypted documents and files in order to keep information for the Dismas House private. Similar measures were taken in order to secure data backups.

Chapter 4: Findings

For this chapter our team will explain our project's findings.

4.1 Site Baseline

In order to determine the feasibility of installing a micro-wind turbine on the Dismas Family Farm our team completed a site baseline assessment. The assessment used photography, mapping, wind speed data, and a review of the Oakham Zoning Laws.

Photography

Photographs of the farm were used to depict the layout of the different buildings and open areas on the farm. The photographs below show possible locations for the installation of a wind turbine.

Figure 3: Dismas Family Farm (a), (Photo credited: Andrew Kenyon)

Figure 4: Dismas Family Farm (b), (Photo credited: Andrew Kenyon)

Figure 5: Dismas Family Farm (c), (Photo credited: Andrew Kenyon)

Figure 6: Dismas Family Farm (d), (Photo credited: Andrew Kenyon)

The three panoramic images above depict the three open areas on Dismas Family Farm property. It was observed that the open field behind the main house in Figure 5 was at a higher elevation than Figures 3, 4, and 6. It was also noted that the area in Figure 3 had the lowest elevation and is used for livestock to graze. The areas in Figures 4 and 5 are used for farming. The barn, in Figure 6, provides an elevated platform that can serve as a possible installation site. The photographs indicate that there are prospective installation sites at the farm.

Mapping

A topographical map (Figure 7) of the farm's location was reviewed to determine the best location for a micro-wind turbine. As wind speeds generally increase with elevation, areas of higher elevation on the farm property were identified as potential implementation sites. In the topographical map below, the area of highest elevation was identified as the open area 1,200 feet north of the main house.

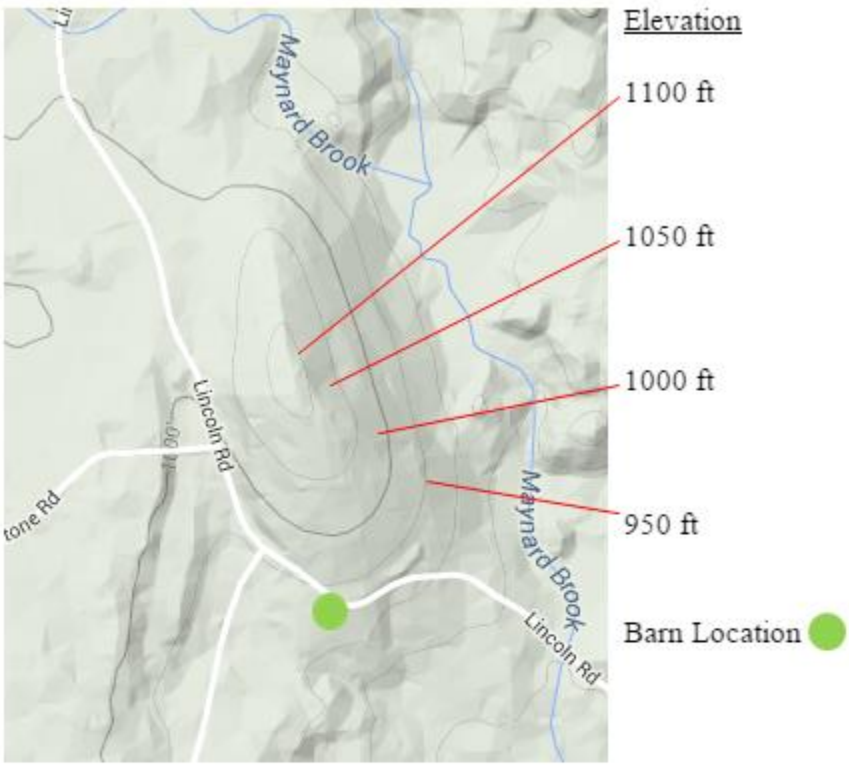

Figure 7: Map A: A Topographical Map of Dismas Family Farm, the green circle marks the location of the barn and farm house.

A satellite image of the farm property was used to identify potential locations for a micro-wind turbine. The land is divided between the Dismas House property and property owned by the Massachusetts Division of Fisheries and Wildlife. The latter is leased to the farm for agricultural use but it is not available for building. Below are two maps of the farm property. The land shaded in blue is leased to the Dismas Family Farm.

Figure 8: Map B - Satellite of Dismas Family Farm.

Figure 9: Map C - Image of Dismas Family Farm Tree Line Shaded Red, Leased Land Shaded Blue, Buildings Shaded Orange

Through mapping, the top of the hill was identified as the area of highest elevation and assumed to have access to the highest wind speeds. However, this land area is not available for the construction of the micro-wind turbine. Based on the information gathered, our group decided the optimal location for implementation of a micro-wind turbine is on the barn's roof. This conclusion was made due to the higher elevation of the barn in comparison to the remaining available land. This will provide a wind turbine with higher wind speeds leading to more energy produced.

Wind Studies

Wind speed data specific to the farm was not available. To make an estimate of the wind speeds on the farm, wind speed data was collected from six local weather stations surrounding the Dismas Family Farm. These wind speeds were compiled to provide a general estimate for average and maximum wind speeds. The wind speeds are higher from October to April than from May to September. Figure 10 shows the average wind speeds throughout 2014.

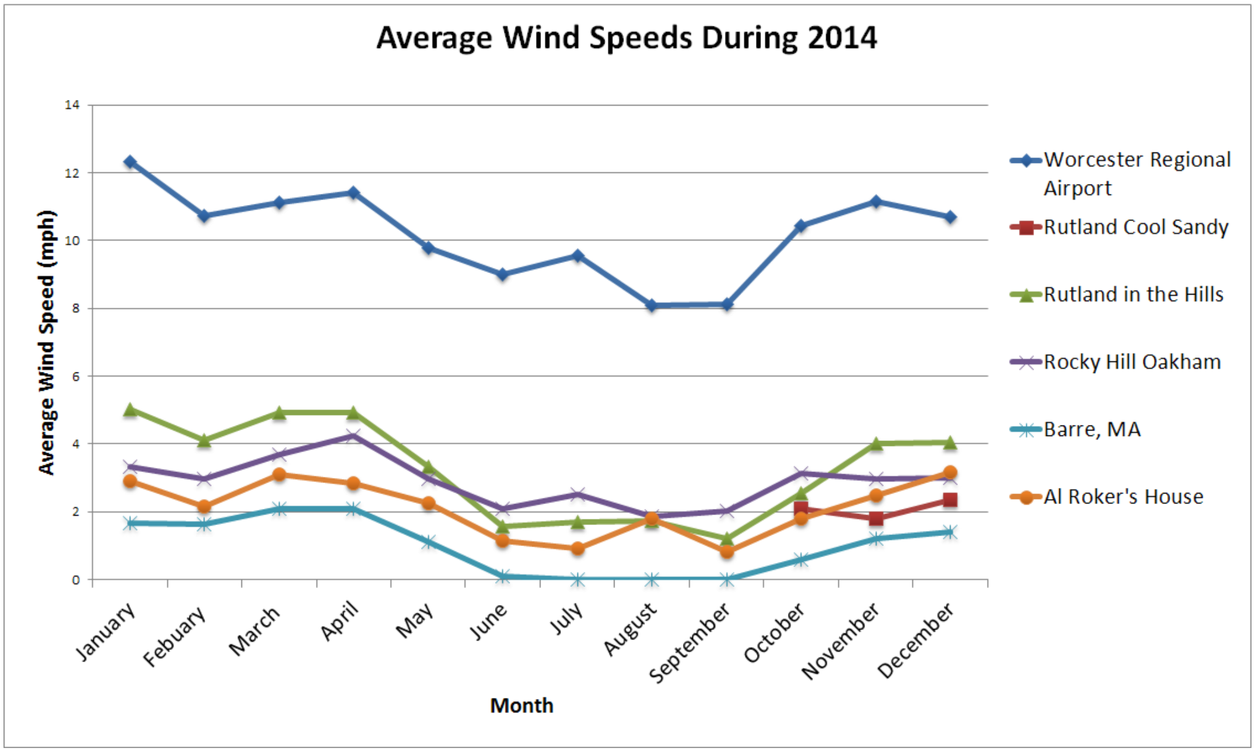

Figure 10: Average Weather Station Wind Speeds

The average wind speeds excluding the data from Worcester Regional Airport (WRA) range from 0 mph to 5 mph. One reason for the lower wind speeds may be the case of less than professional equipment. For example the WRA may have more accurate equipment to measure wind, while Al Roker's House may not. Anemometer implementation will ensure accurate wind speed data at the Dismas Family Farm.

The final step of our site assessment was to research the zoning laws in Oakham, Massachusetts. The Oakham Town Bylaws requires a permit for a structure that exceeds the height of 35 feet. The size and location of the wind turbine will determine the requirement for a zoning permit. No other bylaws affected the implementation of a micro-wind turbine.

4.2 Environmental Effect

Avian Life

After interviews with Holy Name High School and Stevens Farm, our team concluded avian life has not been proven to be affected by wind turbines. Both turbines have been installed for at least five years, and neither owner has noticed effects on avian life by the rotating blades.

In particular, Stevens Farm has a prevalent hawk and eagle population surrounding the farm, yet avian life still remained unaffected by the turbine.

Shadow Flicker and Noise

In discussion with representatives from Holy Name High School and Stevens Farm, both wind turbines were noted to produce shadows. However, these shadows do not impact citizens neighboring the turbine. The Stevens Farm micro-wind turbine is positioned away from neighbors and agricultural buildings; therefore, the shadow flicker and noise do not affect everyday lives. At the Holy Name High School, the wind turbine casts a shadow on the academic buildings. No student, neighbor, faculty member, or any other visitor has experienced any negative impacts from the shadow produced by the turbine. Also sound emitted by the turbine cannot be heard from inside the school, and does not affect the surrounding neighbors. In conclusion, it is not anticipated that shadow flicker and noise will affect the lives of the Dismas residents and surrounding neighbors.

4.3 Social Impact

During in-person interviews with Dismas Family Farm residents, our team acquired a positive response with respect to the green energy movement at the farm. Residents do not have any concerns about installation of a wind turbine on the farm. Generally the farm is quiet and neighbors are distant; therefore, potential noise from a turbine raises little cause for concern. Many residents mentioned the strong winds on the farm, and believe harnessing that energy would be beneficial. This feedback suggests that a wind turbine will be welcomed at the farm.

4.4 Financial Savings

The Dismas House makes a concerted effort to reduce its energy bill. Our team preformed an extensive cost analysis after receiving energy usage data from the past five years. First we reviewed the total energy cost for the Dismas Family Farm through analysis of their WeGoWise account. WeGoWise logs energy data consisting of electricity and fuel oil usage along with cost. Our team examined total energy usage, electricity usage, and cost.

Total Energy Analysis

Since 2010, the Dismas Family Farm total energy cost has varied significantly due to changes on the farm. Figure 11 illustrates the total energy cost, which includes both electricity and fuel oil since 2010.

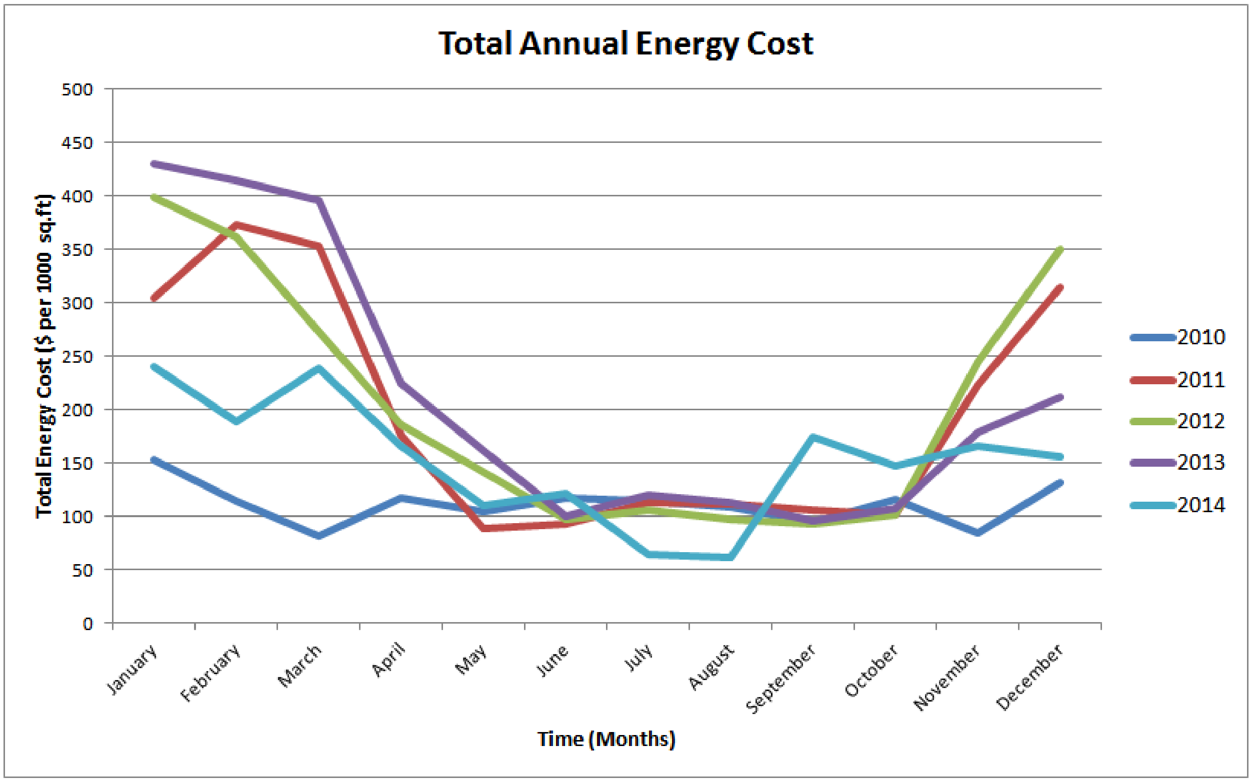

Figure 11: Total Annual Energy Expenses

As shown in the graph above 2010 and 2014 portray the lowest energy costs. Additions on the farm such as a woodshop, greenhouse, and other updates caused energy expenses to increase from 2011 to 2013. However, May 2013 solar panel installation caused a reduction in total energy cost. The winter months require more energy usage; therefore, the energy expenses from November to April were greater than May to October. After total energy cost analysis on the farm, our team investigated electricity cost.

Electricity Analysis

Through comparison of energy usage on the farm, it was found that the farm mainly utilizes electricity from the grid. Figure 12 illustrates the Dismas finances allocated towards electricity since 2010.

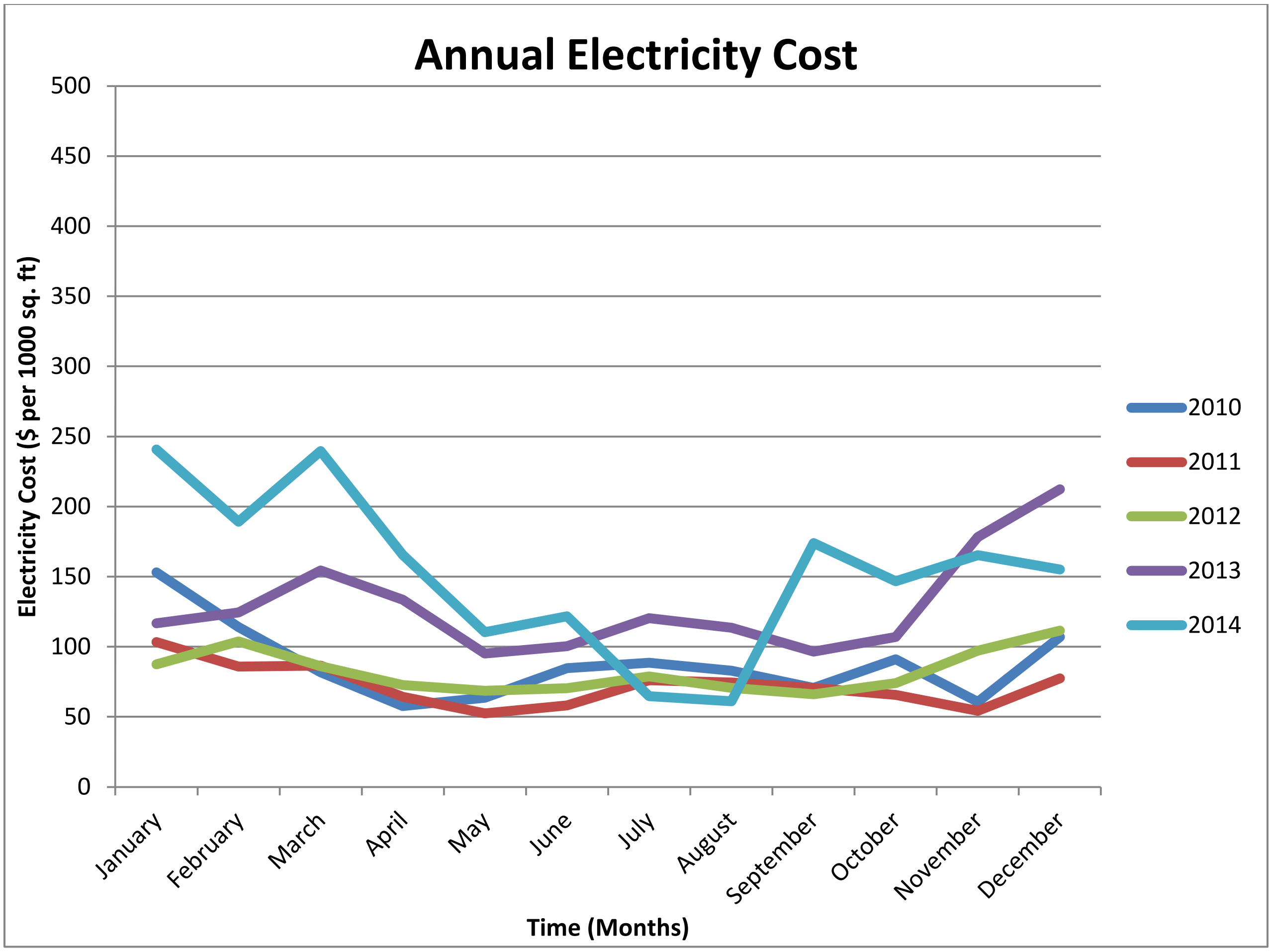

Figure 12: Annual Electricity Expenses

Although the electricity cost in both 2013 and 2014 increased, the overall energy expenses have decreased. From 2010 to 2012, electricity consisted of approximately 40 percent of the total energy cost. Since May 2013, the total energy and electricity cost are the same due to green initiatives. As the Dismas Family Farm plans to implement alternative energy systems, the electricity costs will continue to be reduced.

Financial Analysis Overview

After analysis of the total energy and electricity costs, our team believes the Dismas organization is on pace to continue energy cost reduction. Green energy alternatives on the farm have already been proven to reduce total energy costs, and a wind turbine will continue financial savings. Energy savings will provide greater financial allocation toward resident programs.

4.5 Associated Grant Makers

Our team reviewed 169 potential grant opportunities from Associated Grant Makers. The raw data included information such as the grant title, sponsor, and contact information. To prioritize grants, ranging from those best suited for Dismas House to those that do not match the organization's needs, grants were ranked from 0 to 3 in a variety of categories, with 0 being the best score. Categories were determined based on the provided grant information, the sponsor need, grant focus, geographic influence, limitations, and application style. Grants that could not be readily accessed through research were not reviewed due to the scope and timeline of the project. The decision grid appears in Table 1.

Area	**0** **Excellent**	**1** **Above Average**	**2** **Average**	**3** **Below Average**
Grant Focus	Wind Energy Non-Profit Rehabilitation	Renewable Energy Community	Environment Civic	Other Related groups
Geographic Reach	Worcester Area	Central Massachusetts	Massachusetts	New England National
Limitations	None	1-2 potential	3-4 potential	Known Limitations
Application Style	Ongoing Applications, 1-5 Needed Items	Multiple, Deadlines per year 5-10 Needed Items	One Deadline, 10+ Needed Items	Invitation Only

Table 1: Grantmaker Scoring Grid

Through review, the top 20 grants were identified and suggested to Dismas House directors.

In particular, our team reviewed the Massachusetts Clean Energy Center (CEC) Micro-Wind rebate program. This program interests Dismas House, and provides "rebates through a non-competitive application process for the installation of wind projects by professional, licensed contractors at residential, commercial, industrial, institutional, and public facilities" ("Health & Safety," 2011). For Dismas House purposes, the micro-wind initiative for turbines that produce less than 100 kW could provide funding in the form of rebates. Any size and design is applicable, and up to two rebate applications can be awarded for a combined power output sum of 99 kW. However, first time turbine installers can only apply for a single rebate application. The program outlines the expectations for selected turbine models, installer requirements, power output criteria, and installation requirements. Key expectations require the installation to be conducted by a licensed professional electrician, that the turbine “meet the minimum rated capacity of 1 kW at 11m/s”, and that 50% of generated power will be used directly on-site ("Health & Safety," 2011). The rebate program also requires that a basic feasibility study be conducted. The Massachusetts CEC clearly outlines the program expectations and provides all documents for potential applicants. The significance of this grant is the ease of application and the focus of the grant. As this grant has an open application process, is specifically focused on the implementation of micro-wind turbines, and applicants in Massachusetts, it fits the majority of criteria.

4.6 Model Comparison

Utilizing the online resource allsmallwindturbines.com, 39 micro-wind turbines were reviewed. The models reviewed were limited to those with a rotor diameter of 6 meters or less. This limit was selected to account for the assumed placement of the turbine on top of the barn structure. Following the compilation of data, all 39 models were ranked according to the summation of rated power output, rotor diameter, swept area, area affected by shadow flicker, and cut-in wind speed rankings. Here are the overall rankings:

Model Names	Turbine Axis Design	Scores Sum
Aeolos-V 10kW VAWT	VAWT Darrieus	37
Aeolos -V 5kW	VAWT Darrieus	41
Maglev VAWT CXF-2000	VAWT	42
WTT 2000	HAWT Upwind	47
FDQ4-2/9	HAWT Upwind	48
Aeolos-V 3kW	VAWT Darrieus	52
2kWh Rotating tail design	HAWT Upwind	55
Aelos-H 2kW	HAWT Upwind	61
Vertical Generator	VAWT Savonius	62
Wind turbine generator	HAWT Downwind	64
FDD4-2/9	HAWT Upwind	65
WTT 3000	HAWT Upwind	66
Antaris 2.5 kW	HAWT Upwind	67
Aerocopter 450	VAWT Darrieus	68
Zephyre 1.2 kW	VAWT Darrieus and Savonius	71
3kW VAWT SAWT	VAWT Darrieus	73
BTPS6500	Other	81
Maglev VAWT CXF-3000	Other	83
5kW VAWT SAWT	VAWT Darrieus	88
1.6 kW small wind	HAWT Upwind	89
Maglev 3kW	VAWT Darrieus and Savonius	90
ComSpin C 4000	HAWT Upwind	93
ComSpin C 4000 small wind turbine	HAWT Upwind	93
Windspot 3.5 kW	HAWT Upwind	98
3.2kW Cyclone	HAWT Upwind	100
PWPY-1500L	HAWT Upwind	100
Aeolos-H 3kW	HAWT Upwind	101
1000 kw VAWT	VAWT Darrieus	102
Newmeil 1500w wind generator X2000	HAWT Upwind	103
Ampair 6kW	HAWT Upwind	108
SNT 10	HAWT Upwind	108
FDD5-5/10	HAWT Upwind	111
SNT - 35	HAWT Upwind	112
Tuule E200	HAWT Upwind	120
FDQ5-5/10	HAWT Upwind	121
10kW VAWT SAWT	VAWT Darrieus	125
4.8kW Cyclone	HAWT Upwind	125
S&W 5.5	HAWT Upwind	135
Maglev VAWT CXF-1000	HAWT Upwind	136

Table 2: Micro-Wind Turbine Rankings

To provide a variety of model designs for Dismas House, the top HAWT, VAWT Darrieus, and VAWT Savonius models were considered. These models should not be interpreted as final recommendations for Dismas House, but instead serve as examples to aid in the selection of an appropriate turbine for their site.

	Model		
	Aeolos-V 10kW VAWT	WTT 2000	Vertical Generator
Turbine Axis Design	VAWT Darrieus	HAWT Upwind	VAWT Savonius
Price	n/a	1250 EUR	n/a
Rated Power (W)	10000	2000	2000
Cut-In Wind Speed (m/s)	1.5	2.5	2.5
Rotor Diameter (m)	3	2	2.4
Swept Area (m^2)	7.1	3.1	4.5
Distance Affected by Shadow Flicker (m)	30	20	24

Table 3: Top 3 Models

When price is considered, it would be very important to work with professional contractors to arrive at a reliable estimate. Of the three example models, the WTT 2000 is the only model which a supplied price, of 1250 EUR or $1,425. Considerations would need to be made for any costs incurred to transport the turbine, be it within the United States or international. The rated power relates the maximum power output generally produced at a manufacturer specified wind speed. With the goal of producing energy, a turbine with a higher power rating is preferred. The Aeolos-V 10kW VAWT offers a power rating of 10kW while the other examples offer 2kW of rated power.

The cut-in wind speed requirements for a turbine model can greatly limit the models for implementation at a site. If the average wind for the proposed site does not meet or exceed the cut-in wind speeds for the desired model, the turbine will not be economically efficient and will generate a minimal amount of electricity. Thus, lower cut-in speed requirements are desired to maximize energy production. Of the three model examples, the Aeolos-V 10kW VAWT requires the lowest wind speeds of 1.5 m/s or 3.35 mph. The two other models require winds of at least 5.59 mph to generate electricity.

A proposed site will limit the maximum size allowed due to zoning bylaws, safety considerations, and physical space available. The rotor diameter, swept area of the turbine blades, and area affected by shadow flicker take this physical aspect into account. The Massachusetts CEC estimates that an area within 10 rotor diameters of a turbine can be affected by shadow flicker. Under the assumption that a smaller turbine is desired, the WTT 2000 model has the smallest rotor diameter, swept area, and area affected by shadow flicker.

When any micro-wind turbine model is considered, all factors are important. These factors will vary between models, and site specifications will aid to narrow the search for the ideal turbine for a specific site.

Chapter 5: Recommendations

Through our feasibility study, it was determined that there is not enough information to support the immediate implementation of a micro-wind turbine. Specifically, there is no wind speed data for the farm's location. To gather this data, Dismas House should install an anemometer on top of the barn structure. An anemometer will collect wind speed data particular to the farm location. This will aid in future feasibility studies and grants.

The roof of the barn at the Dismas Family Farm is believed to be the ideal location for wind turbine implementation due to the increased elevation and close proximity to the electrical grid. We recommend that Dismas House hires a professional structural engineer to evaluate and ensure that the barn's structure will be able to support the weight and vibrations caused by a turbine. This is crucial to prevent collapse of the barn.

We also recommend that Dismas House hires a professional to conduct another feasibility study after the collection of wind speed data. This will provide the professional detailed information for further analysis and research into implementation. This hired professional will aid in the pursuit of grants, such as those through the Massachusetts CEC.

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+ECE&rft.au=Low,+Jonathan+K.+Student+author+--
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Appendix A: Sample Interview Questions for Stevens Farm and Holy Name High School

- Why did you decide to construct a wind turbine?
- Did you consider other green energies? Solar? etc.
- Who did you consult/contact for installing/building a wind turbine?
- Did you do it yourself?
- How did you determine the location for the wind turbine?
- How long did it take you to build the wind turbine?
- What concerns did you have with the installation of a wind turbine?
- How did you decide what model to select?
- How many other options did you consider before selecting and building this micro-wind turbine? And what model did you select?
- What is the wind turbine powering?
- Is it powering the milk operating systems on the farm?
- How much did the overall process cost you to construct the micro-wind turbine?
- Does the wind turbine produce any shadows?
- How much noise does the current wind turbine produce?
- What problems did you encounter while you built the micro-wind turbine?
- What are your general thoughts about the micro-wind turbine and wind energy?

Appendix B: Dismas Family Farm Resident Interview Questions

- Are you aware of the effort to install a micro-wind turbine on the farm property?
- How much do you know about wind turbines?
- Through past observation, where have you observed the most avian activity throughout the course of a year?
- What are your general thoughts about the micro-wind turbine and wind energy?
- What concerns did you have with the installation of a wind turbine?
- How much noise is there normally on the farm?
- What are the most active areas of the farm?
- What do you expect the wind turbine to power?
- Where on the farm do you mostly work?
- Do you use a lot of electricity on the farm? For example inside the woodshop? Or most of the tasks performed with other appliances, such as tractor, farming equipment, etc.
- What are your thoughts about the solar panels?
- Do you think the farm is windy?
- Where in the red outlined area would you say is the windiest area on the farm?
- Is there anyone else you believe we should speak to?
- General ideas of the farm? Likes/dislikes