Wind Energy Use at Bridger Bowl

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Introduction

Earth's ever increasing human population is driving a rapid increase in energy consumption and has created the issue of whether humans should increase renewable energy consumption to offset negative aspects of traditional energy sources. Anthropogenic pressure on the environment from the use of carbon-based fuels has become a great ecological concern due to driving climate change, habitat loss, or species displacement. Hence, safer and more renewable forms of energy are needed (Park et al. 2013). Many forms of renewable energy are available and new methods are still being researched. Wind power is a continuous renewable resource that has been utilized for thousands of years. Wind turbines were first developed either in Persia around 500A.D. or in China in 1219A.D. for water and grain production, and wind turbines are currently are used as a source of renewable electricity generation (Figure 1; "Early History," 2001).

Bridger Bowl is a non-profit ski resort located 20 miles northeast of Bozeman, MT. The motto of Bridger is to be environmentally sustainable, which is reflected in their recycling and access to free transportation to and from the ski resort. Investment in wind power energy would help solidify their sustainability motto while maintaining themselves as a non-profit ski resort.Utilization of an essentially free energy source such as wind would decrease the dollars spent on energy, dollars that could be used to reinvest in the resort. However, certain geomorphological characteristics need to be analyzed to determine whether wind energy is the best suited and most cost effective way to generate electricity. The north facing aspect of Bridger Bowl would not allow for enough solar energy generation to power the ski resort. Hydroelectric energy generation has a low potential at Bridger Bowl due to the lack of large water sources and infrastructure to produce electricity. Based on the local geomorphological characteristics, wind power could have the greatest potential for energy generation at Bridger Bowl.

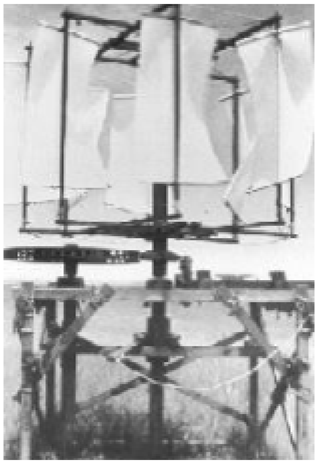

Figure 1: Early Persian wind turbine design

The design of wind turbines has changed substantially through the years to meet new production requirements, reduce maintenance and repair costs, and meet rising social concerns regarding wind energy. As a result, 2.5% of the world's energy needs are supplied by wind energy, an amount equivalent to about 197 gW of power (Minderman et al. 2012). The rapid development of wind energy has major potential for phasing out nonrenewable carbon based energy sources. The size, scale, and design of wind turbines vary greatly. Design improvements involving the turbine blades have led to a greater efficiency in harnessing wind energy.

Blade designs have to consider the whole length of the blade from tip to base and the loading effects on each part. Low blade tip speed ratios tend to increase wake rotation. Based on the three basic Newtonian physics principals, every force on an object has an equal and opposing force on it. The wind causes torque on the turbine blades and the rotating of the turbine blades causes the wind force to rotate as it passes the blades. The flow passing the turbine blades causes torque on the blade axis in addition to torque tangent to the blade axis's. The tangent or perpendicular torque exerted on the turbine blades is the wake rotation and is unavailable for energy use. Changing the blade design and incorporation of airfoil technology can change the propulsion generated by the lift to drag ratio of the blades thus reducing wake rotation (Schubel et al. 2012). Reducing the angle of twist on the blade, linearization of chord width within the blade material and reduction of different airfoil profiles on the blade are methods for achieving max wind turbine efficiency. Blade designs vary depending on desired electricity output level and wind condition.

Wind turbines are classified into two general categories, horizontal and vertical axis as illustrated in Figure 2a. Horizontal axis turbine blades rotate parallel to the ground where as vertical blades rotate perpendicular to the ground ("Types of wind turbines," 2006). Based on turbine type, the blade design is separated into either straight or swept (curved) edge designs as seen in Figure 2b (Amano et al. 2012). At low wind speeds, the swept blade design has a more even pressure distribution along the whole length of the blade and experiences less blade vibration and pressure on the leading edge of the blade. But in areas that experience high wind speeds, straight blades are more efficient due to less pressure being transferred to the root of the blade (Amano et al. 2012). Blade design is chosen based on max energy conversion efficiency and current designs only allow for 59.3% of potential wind energy to be harnessed for electricity generation (Schubel et al. 2012).

Figure 2a: Two main wind turbine categories

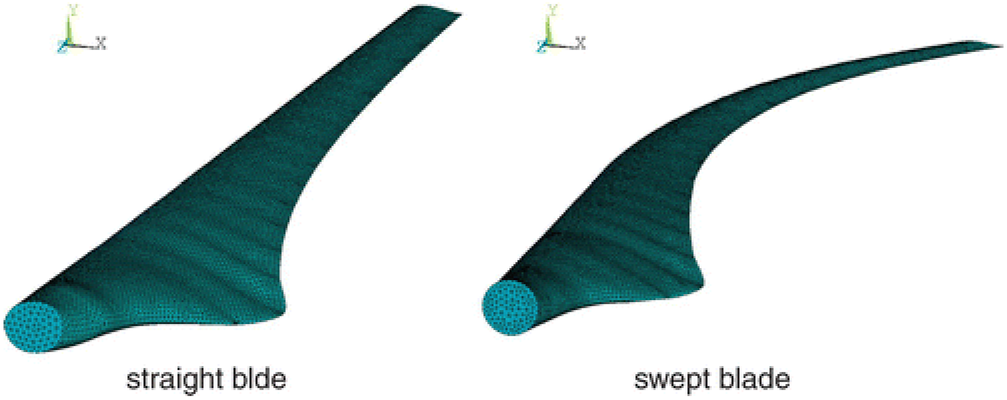

Figure 2b: Two main categories of blade edge design

Figure 3: Large wind farm example

The majority of wind energy development has focused on the development of large scale wind farms where the turbines are densely concentrated in a specific location (Park et al. 2013). Figure 3 illustrates traditional wind farms utilization of large turbines that have straight blades with a length of 100 meters or greater and stand 20 building stories or higher ("Types of wind turbines," 2006). A single large turbine scale can power up to 1,400 homes. Smaller noncommercial turbines utilize a variety of different designs that have blade lengths between 2 and 10 meters in length and can supply the power needs of a single home or small business (windeis.anl.gov). Rapid technological advances have made the implication of small wind turbines more affordable to business and home owners (Minderman et al. 2012). As a consequence, over 150,000 small turbines have been implemented in the United States. Currently there are 54 small turbine models commercially available. Small turbines are used in homes, schools, commercial and industrial facilities, telecommunication, farms and ranches, and communities ("The Cost," 2013). Advances in turbine technology combined with different biological and social risks associated with wind energy would influence Bridger Bowl to install and operate medium to small sized wind turbines.

Aerodynamic, gravity, centrifugal and structural loading caused by varying local climate conditions are all areas of concern for wind turbine design (Schubel et al. 2012). The loading and deterioration rate of wind turbines depends on temperature, humidity, precipitation, solar radiation, lightning and salinity. The different states of precipitation have different loading and deterioration effects. The presence of ice needs special consideration, due to the fact that icing can lead to a 20-50% decrease in energy production (Tammelin 2001). The different variables affecting loading and deterioration of wind turbines is directly correlated with the stiffness of the blade design, composite materials the blade is constructed out of and how the fibers are arranged in the blade. Fiber design determines the stress experienced on the surface of the blade and within the blade (Kensche 2006). Current material inputs are being used to design turbine blades that have the lowest possible weight (Kong et al. 2005). Ice and snow loading would be the major concern for wind turbine instillation at Bridger Bowl. Blade designs that would reduce the buckle and flex failure caused by different loading events would be the best for use at Bridger Bowl. Collection and analysis of weather and meteorological data collected at different Bridger Bowl weather stations can be used to determine the most efficient design for increased electricity generation and minimization of fatigue failure.

In 2013, the Ski Area Citizens Coalition, which provides grades for ski resorts in the western US based on their environmental policies and management, released an annual score card that showed the top ten "green" ski resorts in the United States. Montana was nowhere in the top ten, even though it is home to some of the best skiing and snowboarding in the country. In fact, the only time Montana showed up on the list was in the *bottom* 10, with two "D" scores for Whitefish Mountain Resort and Lost Trail Ski Area (Ski Area Citizen Coliation, 2013). Back in 2009, an economic stimulus bill was passed that rewarded the implementation of renewable energy programs through benefits such as grant programs and tax credits. Although this has helped many ski resorts take action through the purchase of Renewable Energy Certificates, others have remain unchanged in their energy consumption.

One way ski resorts are reducing emissions and energy consumption is through the harnessing of wind power, whether through the purchase of renewable energy credits or through the implementation of their own small-scale wind turbine(s). Whether or not a ski resort qualifies for a small-scale wind turbine depends largely on several factors, including cost of implementation, the availability of storage, social and biological risk factors, and land suitability.

Cost Factors:

Identification of the most cost effective energy source requires a method to generate a dollar amount associated with production of kilowatt hours of energy. The levelized cost of electricity production equation is an example of how wind energy users can compare costs for different energy sources (Jowsey et al. 2009). Levelizing the costs of electricity production allows for a dollar amount to be put on different direct inputs and variables of energy use and for the total cost of production from the different energy sources to be compared (Jowsey et al. 2009).

The largest component of cost analysis for wind turbines is the initial capital cost for building and installing the turbines, which accounts for 70% or more of the overall total cost (“The Cost,” 2013). Discount rates are provided by governments for using clean energy. In the United States, large discount rates tent to lead to lower US$/mWhr costs for electricity producers and create larger saving for consumers. Analysis of nonrenewable resources for electricity production using either a 5 or 10% discount rate reveals a cost spread between 30 to 180 US$/mWhr (Larson et al. 2014). The spread for renewable resources was much larger ranging from 20 to 2000 US$/mWhr (Jowsey et al. 2009). Land based wind power had a cost spread of 50 to 240 US$/mWhr depending of the discount rate (Larson et al. 2014). The cost calculations for electricity production methods do not include external costs associated with greenhouse gas emission fees or the use of backup energy sources for intermittent resource conditions. Costs associated with onshore wind power vary based on location, climate, biological impact and turbine design and abundance. Levelization of the different costs associated with different energy sources will help Bridger Bowl make the most cost effective choice for energy use.

Operation and maintenance costs (O&M) are together another component for levelizing the cost of energy production. The O&M costs for onshore wind power revealed a cost range from 10 to 30 US$/mWhr (Larson et al. 2014). This cost range is slightly higher than the range for hydroelectric power and nonrenewable resources. The O&M cost standard deviation of onshore wind power is smaller than photovoltaic electricity generation. The average life span of wind turbines is 20 or more years to recuperate production costs, meaning that O&M will have to be performed to optimize production efficiency of wind turbines (Kong et al. 2005; “The Cost of”, 2013). The O&M costs associated with wind turbine use at Bridger Bowl could be substantially high due to varying loading and climate factors. The climate variability of the Bridger Mountain range could lead to O&M costs in the upper range of the average O&M costs for onshore wind energy and would require there to be knowledgeable staff onsite to deal with the different O&M factors. But comparison with using off site secondary companies for O&M costs would need to be made to determine the lowest cost solution.

Storage Factors:

Due to their reliance on environmental conditions to produce energy, renewable energy sources are intermittent. Manufacturers have developed conversion turbines that depend on wind power and blade rotational speed. Conversion turbines provide power smoothing methods for intermittent periods of wind patterns based on the use of storage devices for excess energy storage. Non-storage designs are the most cost effective due to the high upfront cost for excess storage devices (Howlader et al. 2013). US investment in wind power and wind conversion systems is projected to be the dominant method for increasing renewable energy consumption accounting for 5-25% of total US energy use in the near future. Models and equations are used to simulate different wind conditions and also to analyze wind patterns and determine max power output values based on turbine design. Maximum power output values allow for the calculation of potential cut in or cut out levels of wind speed based on a wide variety of variables (Xie et al. 2011). The cut in level is the minimum wind speed that wind turbines can operate at and cut out level is the maximum wind speed that wind turbines can operate at efficiently without experiencing structural failure. There are large pulses of energy generation, which cause these systems to fail to provide consistent energy for consumer needs, and so other forms of traditional energy are necessary for those power demands. Cut in and cut out levels for wind conversion turbines will provide insight on whether storage devices for excess energy is needed to meet consumer needs when wind power is intermittent. Given the variability in energy production, energy storage is a crucial aspect for renewable energy to be an effective energy source (Hadjipaschalis et al. 2008).

Energy storage technologies are available for renewable energy systems in all forms of energy: chemical, mechanical, and thermal (Ibrahim et al., 2007). Each of these technologies has specific features which make their uses applicable in certain situations (Hadjipaschalis et al. 2008). Some storage systems are for short-term storage versus long-term storage, while other systems can be portable (Ibrahim et al. 2007). These energy storage systems are for both small-scale systems needing low to medium power needs as well as large-scale systems needing larger inputs of power supply. The types of storage systems described in this paper are pumped hydro storage, compressed air energy storage, battery energy storage, and flow battery energy storage.

Pumped Hydro Storage:

The hydro storage system is unique in that this energy storage system uses water held in two reservoirs of varying heights to generate electricity. The system works by using electricity to pump water from the low elevation reservoir to a high elevation reservoir when energy demands are low (Ibrahimet al., 2007). Conversely, when energy demands are high, water is released to the lower reservoir, and the flow of water activates turbines, which generate electricity in the same method as a hydropower station (Pumped Hydroelectric Storage n.d.). The amount of electricity that this system can store is dependent upon the distance between the top and the lower reservoirs as well as the volume of water (Ibrahim et al. 2007). This system can respond to a peak in energy loads in a matter of seconds, making it able to rapidly respond to any inputs of energy into the system (Pumped Hydroelectric Storage n.d.).

A downfall of this system is the need for reservoirs, or an existing site with water at varying elevations (Ibrahim et al. 2007). Currently in the US there are 24 pumped hydro storage systems in operation, which were implemented about 30 years ago. Presently, about 8 states have proposed projects to implement pumped hydro storage systems, making this type of energy storage system a viable option for the future (Cherry 2014). The lack of large scale water sources and infrastructure limitations would provide a major challenge to Bridger Bowl. Implementation of pumped hydrologic storage would require a large investment to build the necessary storage facilities to meet energy production. The large investment cost of pumped hydrologic storage would likely outweigh the benefits that it would provide to Bridger Bowl.

Compressed Air Energy Storage:

Compressed air energy storage systems use natural geologic formations such as aquifers and constructed salt and rock caverns, which act as storage systems for air. Air is pumped into these caverns when energy needs are low. The air is pressurized and when energy is needed, the air from these caverns is heated and slowly released, which activates turbines to generate energy. It is possible to use tanks for air storage, but the cost associated with engineering these tanks makes this option unlikely for most situations (Hadjipaschalis et al. 2008).

Currently there are only two compressed air energy storage systems in use worldwide—one in Germany and the other in Alabama (Díaz-González et al. 2012). There was an attempt in Iowa to implement a compressed air energy storage system with a wind farm, but the project was eventually rejected due to the geologic limitations in the area (Shulte et al. 2012). The lack of ideal geologic formations for air compression at Bridger Bowl rules out the use of a compressed air storage system.

Energy Storage with Batteries:

Batteries can be used for energy storage with the use of electrolytes. The batteries have single or multiple cells and the reactions creating energy occur in those cells. Inside these cells are anodes, cathodes, electrolytes, and separators. The anodes provide a negative charge, which supplies electrons to the load. The cathode provides a positive charge, which accepts the electrons. The electrolyte solution allows these electrons to flow back and forth from the anode to the cathode. The separator insulates the electrical reactions occurring within the cell. These cells are sealed in a container and connected to an outside source. There are three types of battery systems used for renewable energy storage: lead-acid batteries nickel batteries, and lithium-ion (Hadjipaschalis et al. 2008).

The lead-acid batteries involve reactions with lead dioxide, lead and sulphuric acid. The lead dioxide acts as the cathode, the lead acts as the anode, and the sulphuric acid acts as the electrolyte. These types of batteries are efficient, have easy installation, need very little upkeep, and are a low cost solution. A negative aspect of lead-acid batteries is that they have a short life cycle, lasting between 5 and 15 years (Hadjipaschalis et al. 2008). Also, these batteries tend to not function properly at high and low ambient temperatures (Díaz-González et al. 2012). The short life span of lead-acid based batteries combined with the variable temperature conditions at Bridger Bowl would make this a poor choice for capturing excess energy generated.

Nickel batteries are composed of nickel and cadmium, nickel and metal hydride, or nickel and zinc. The anode in these batteries is nickel hydroxide and the electrolyte is composed of a solution of potassium hydroxide and lithium hydroxide. The cathode composed of cadmium hydroxide, a metal alloy, or a zinc hydroxide depending on the nickel battery combination. These types of batteries have a much longer life cycle than the lead based batteries but cost up to 10 times more than lead batteries (Hadjipaschalis et al. 2008). In addition to having high costs, nickel and cadmium are toxic metals and initiatives to make energy storage systems with batteries that more environmentally friendly makes the future use of nickel-cadmium batteries uncertain (Díaz-González et al., 2012). High up front cost and toxicity of nickel-cadmium batteries is a huge deterrent for use at Bridger Bowl.

Lithium-ion batteries exist in two types, either lithium-ion or lithium-polymer cells. Within these cells, there are anolytic and catholytic plates that are filled with electrolytes. Lithium ions are transferred through a permeable structure consisting of either polyethylene or polypropelyne. The anolytic material is made up of graphite and the catholytic material is made up of a lithium metal oxide. The electrolyte in this battery is an organic liquid such as Phosphatidyl Choline. Lithium-ion batteries are highly efficient and need little maintenance. A downside to lithium-ion batteries is the lifetime is dependent on temperature. Lithium-ion batteries are not ideal for short term energy back up and because of the poor performance at high temperatures, these batteries have the potential to completely be drained of all energy (Díaz-González et al. 2012). High efficiency and low maintenance cost of lithium-ion batteries is a good indicator for use at Bridger Bowl. But determination of the ideal operating temperature for Lithium-ion batteries and comparison with Bridger Bowl temperature data would need to be made to see if the local conditions are ideal for using this excess energy storage device.

Energy Storage with Flow Batteries:

Flow batteries operate similarly to that of regular batteries but the electrolytes are stored in tanks. There are different forms of flow batteries including Vandium redox, zinc-bromide, and polysulphide flow batteries. To generate reactions, the electrolytes contained within the tanks are pumped to an electrochemical cell where reduction and oxidation reactions occur. Flow batteries can be scaled by changing the size of the tanks of electrolytes, an advantage for this type of energy storage system, and they last about 15 years (Díaz-González et al. 2012). The scaling abilities along with long life span make flow batteries an ideal choice for storage of excess energy generated by wind energy.

Ecological and Social Factors:

The current change of the global climate has promoted increased use of renewable resources to mitigate future changes to planet earth. The benefits of wind power have been estimated to benefit humans, the environment and the climate anywhere from 10 to 1000US$/mW/hr (Siler-Evans et al. 2013), but there are potential ecological and social risks that must be considered before implementing small turbines in any type of setting, specifically Bridger Bowl. The installation of wind turbines provides 60% more benefit than purchasing wind tax credits from offsite sources but can create unwanted ecological and social risks (Siler-Evans et al. 2013). In this study, the risks associated with small turbines were broken down into two main categories—ecological and social. The ecological risks were further broken down into sub categories including, bird and bat habitat displacement and disturbance effects and more specific to Bridger Bowl, raptor displacement and disturbance effects. The social aspect was divided into two main categories, audio and visual effects, but health concerns were also addressed.

Ecological Risks

Ecological risks associated with wind turbines vary with the location. Bird and bat populations are potentially at risk to wind turbines through collisions with turbine blades and displacement through the elimination of viable habitat where turbines are located (Pearce-Higgins et al. 2009). Displacement can result in lower breeding bird densities, lower numbers of foraging birds and reduced flight activity around wind turbine sites (Park et al. 2013). Lower populations of birds around turbines is a result of individuals abandoning otherwise suitable habitat (Pearce-Higgins et al. 2009). Behavioral avoidance is similar to displacement but only affects the flight path of birds causing them to fly around or above turbines. Avoidance results in less collision mortality but does not occur in all bird species (Garvin et al. 2011). The effect on bird populations varies with site topography, habitat type, and the species present (Minderman et al. 2012). An understanding of the effects of displacement and behavioral avoidance are necessary to predict whether a population is at risk to incur losses at a rate that the population cannot sustain.

Preliminary studies are necessary before the installation of a turbine because the amount of risk incurred by birds is site specific. Studies should focus on determining which species will be affected and how they will be affected. Measurements can be taken to determine population densities, carrying capacity of the habitat, and the height, direction, and frequency of the use of flight paths. Population density will determine the likelihood that displacement will occur. At higher population densities more habitat is needed. A decrease in the amount of viable habitat will decrease the carrying capacity of an area and most likely cause displacement within the species whose habitat was affected. At higher population density the risk for collision mortality increases due to increased activity and competition for space (Minderman et al. 2012).

Identifying the amount and type of flight activity is important in determining the risk for collisions. High flight activity does not automatically infer that a species is more likely to experience collision mortality, but it is the combination of the location, the amount, and the height at which it occurs (Park et al. 2013). Many species of birds have reoccurring flight paths that should be considered before the implementation of a small turbine. A flight path is defined as a reoccurring route that birds use as a corridor to other viable habitats or recurring migration routes (Marques et al. 2014). Flight paths can be determined by observing the sites to record the frequency of flights, the species of bird, and the height at which the flight occurs throughout all of the seasons (Minderman et al. 2012). Building a turbine in an established flight path could cause large amounts of collision mortalities. Some species of birds avoid large turbines completely creating displacement but avoiding deaths due to collisions (Pearce-Higgins 2009).

Bats experience the same risks as birds to the presences of wind turbines but have different behavioral traits. Bats are nocturnal animals and utilize echolocation to prey on insects and guide them through the night. Bats have been found to not avoid large wind farms but to actively forage around and investigate turbines. The increased presence of bats around turbines increases the likelihood of collision mortality (Horn et al. 2008). A study of bat interactions with small turbines revealed that activity decreased while turbines were running. It was hypothesized that the rotating blades cause reflection of the echolocation, which may cause avoidance and decrease the amount of collision mortality. Though collision mortality is lower with small turbines, it is still important to consider habitat loss where available suitable habitat is low (Minderman et al. 2012).

The Bridger Mountain Range is part of the Rocky Mountain Flyway for various raptor species during the fall migration. Peak migration activity occurs around mid-October each year and is noted for the largest concentration of Golden Eagles in the lower forty-eight states. At times there can be 200 eagles per day and in general there are between 1,200 -1,900 migrant eagles per season. Seventeen additional raptor species utilize the flyway each season, creating an additional 1,500 migrants passing through (“Hawkwatch International” n.d.).

To reduce energy costs during long migrations, raptors rely on different types of lift from wind created by thermals or topography. The Rocky Mountains create conditions favorable for large raptors looking to conserver large amounts of energy. During strong head winds raptors often fly closer to the ground because high winds reduce the amount of thermal lift available. The flight habits of raptors make them susceptible to collision mortality at high altitude turbine sites (Johnston et al. 2014).

To mitigate the risk to raptors at Bridger Bowl, the turbines could be located in areas which are not part of their established flight paths. If it is not possible to locate turbines away from flight paths, wind turbines could be turned off during the heavy months of migration since that is a low power use time for Bridger Bowl. When the turbines are off raptors and other bird species are at lower risk for collision mortality because the blades are more easily detected.

Social Risks

A restriction to the implementation of small turbines is that they are perceived to be noisy and are considered an annoyance (Pedersen 2004). Wind turbine noise is divided into four categories—broadband, infrasound, low frequency, and impulsive. Broadband noise is produced by the blade’s interactions with wind turbulence and is a swishing noise with a frequency higher than 100 hertz. Infrasound occurs at frequencies below which people can hear but have been associated with a tension type arousal in people who have long term exposure (Kasprzak et al. 2014). Low frequency noise occurs at levels between infrasound and broadband and is suspected of causing irritation in people. Impulsive noise occurs at varying frequencies in short acoustic impulses and is created by the interaction of the blades with disturbed air flow.

Surveys have been conducted relating differing types of traffic noise and noise from wind turbines to the percentage of people who are highly annoyed. Noise from wind turbines, though occurring at lower decibel levels, are considered more annoying than other sources of noise (Mollasalehi 2013). The wumphing noise generated by wind turbine blades can be reduced by changing the geometry of the blade through regulation of blade width and thickness combine with incorporation of airfoil technology on the blade surface (Schubel et al. 2012).

Visual effects of wind turbines also exist. The spinning blades of a large wind turbine rotates at a rate between 30 and 60 revolutions per minutes causing a light flicker at a rate of ≥3 hertz (Hz) or 3 flickers per second. Small turbines spin at more variable rates ranging from 30 to 300 rotations per minute causing the flicker frequency to jump between 3 and 30 Hz (Harding et al. 2008).

Photosensitive epilepsy, which occurs in one of every four thousand people, may be affected by flicker from the rotating blades of a turbine. Flicker rates above 3 Hz are known to cause epileptic seizures in susceptible people. Flicker effects have proven to occur only within ten rotor diameters of a turbine (Smedley et al. 2009). Therefore, if the blades have a diameter of ten meters, shadow flicker can have an effect on a susceptible person from a maximum distance of one hundred meters. Altering the spin rates, or placing turbines so they are not readily viewable could reduce the risk for people who are susceptible to photosensitive seizures (Harding et al 2008).

The intensity of the landscape change produced by the addition of a turbine is variable depending on height and visual disruption. Wind turbines can stand from 10 to 150 meters tall potentially interfering with visual aesthetics. Once installed, turbines are immobile and permanently disrupt the landscape. The change in landscape provides a sense of discomfort to some people changing what is thought to be unchangeable in a lifetime. The change in the visual aesthetics of the landscape can be mitigated by turbine design. Turbines can be painted to better blend in with their environment and monopole style construction can be used in place of larger lattice structures (Pasqualetti 2011). Communication between the community and the developer are key to insure public approval of the installation of a wind turbine.

The few risks that exist to humans, whether visual or audio, are countered by many environmental benefits. The main benefit provided from wind power is the reduction of greenhouse gas emissions such as CO_2, SO_2 and NO_x. Emission reduction lowers biotic susceptibility to respiratory illness and reduces the negative impact humans are having on the earth's climate. Setting a goal of increasing global wind power electricity generation to 20% by 230 would reduce CO_2 emissions by 825 million tons (Siler-Evans et al. 2013). A secondary health concern associated with wind turbines is increased radar interference. Large turbine blades affect radar signals by deflecting some of the signal away from the designated radar towers and decreasing the radar signal reflectance on the desired target. Current blade designs would be a critical factor when considering Bridger Bowl due to its close proximity to the Gallatin County airport (Jang et al. 2014). The current increase of wind power energy use by 27% annually since 2009 (Jang et al. 2004) has led to design improvements to greatly reduce radar influence. The reduction of greenhouse gas emissions and reduced radar interference by wind turbines is a tradeoff between the different visual and audio effects caused from blade rotation (Schubel et al. 2012).

Social and Biological Community Factors

In addition to the approval of the general public regarding turbine installation, it may be important to look at the aesthetic impact turbine placement has on surrounding areas. Turbines can produce shadows as well as other optical distortions (Wagner 2013). They tend to be tall and are therefore visible for great distances. Wind turbines can either be seen as a symbol of sustainability or as a giant metal disturbance to an otherwise pristine habitat. It all depends on the attitude of locals. In a ski resort environment, where most customers are avid outdoorsmen, it would likely be a beacon of environmental awareness. It is also of utmost importance to determine the impact of turbine placement on the biological community. Studies should be done prior to building to make sure the site is out of the way of bird migration paths/nesting grounds and that it doesn't affect local flora at ground level (Wagner 2013).

Other Factors

Other factors that affect turbine location include access to the site, wind direction and connection to the grid. The proximity to Bozeman could allow for offsite maintenance and repair teams depending on the most cost effective method. But the accessibility to the different turbine sites at Bridger Bowl would be a big concern. Turbines located near the ridge could be accessed via helicopter for installation and turbines located lower down the ridge could be accessed via automobile. Continual monitoring and maintenance could be accessed via the existing trail and road systems. Wind direction would play a big role in determining site locations due to the turbines needing to face into the wind the majority of the time in order to utilize the wind the efficiently. The location and accessibility of the turbines would greatly affect how easy it would be to connect to the grid for dispelling excess energy or for receiving energy during low wind power time periods.

Land Suitability Factors

When choosing a site for small-scale turbine placement, it is important to look not only at the economic implications, but at the social and physical aspects as well. It is also of importance to make sure there are no regulations placed on the area being studied, i.e., if the area is located on state land. Wind speed and power are major factors when considering turbine design and location. Different models of turbines have been designed to analyze wind patterns in order to operate under variable wind conditions. Energy use and production models are generated based on the use and needs of electricity consumers and depend on the wind speed variability at the specific site combined with the aerodynamics of the turbine blades. Identifying wind speed rating and wind power length and intensity will indicate the maximum load levels that different turbine designs can handle in varying environments before failure occurs (Han et al. 2014). Winds with higher wind power density class (defined below) combined with high wind speeds are generally more costly for harnessing for electricity production (Eminoglu et al. 2014). Current turbine designs are being made to deal with variable wind patterns. Manufacturers have begun to develop smart wind turbine blades that essentially act like an airplane wing. The shapes of the blades adjust to wind conditions, allowing for increased energy conversion efficiency (Schubel et al. 2012). The following parameters are to be taken into consideration when choosing a site, with special focus on alpine implementation.

Wind Speed

Wind speed is the most important factor for turbine placement. The physical properties of wind can make turbine placement extremely difficult. For example, wind blows faster at higher altitudes due to the reduced influence of drag at the surface and lower viscosity (Geogroup, n.d.). This influences turbine tower height, as surrounding tree heights may provide turbulence and affect power generation, requiring tower height to rise above the tree line. Other features, such as hills or valleys, could also affect wind speeds by complicating wind flow and producing turbulence, which makes the wind too complex for wind power generation (Wagner 2013).

The optimal wind speed for wind generators is 4.5 m/s (16 km/hr) or greater at 10 meters above ground. At high wind speeds, power generation increases until 25 m/s, at which point it ceases due to turbine stress (GeoGroup, n.d.). If no consistent meteorological data can be found for average wind speeds, the possible turbine site will have to be monitored for at least a year to determine whether average wind velocity is significant enough for harnessing.

Wind Power

Available wind power is proportional to the wind speed cubed (Badran et al. 2009). It also depends on the diameter of the blade. The smaller the blade, the less power that can be extracted. Air density, which is a function of air pressure and temperature, also has an effect on wind power and is directly proportional to it. Wind power increases with increasing pressure or decreasing temperature. This should be taken into consideration with placement on alpine sites, where both temperature and air pressure have decreased (Badran et al. 2009).

Wind power density (WPD), which takes into account velocity and mass, is commonly used by planners to determine how much energy is available for conversion through a wind turbine (Haluzan 2012). Once calculated, the site can be placed into a class based on its WPD. The higher the class, the higher the availability of wind power for conversion. Usually, sites with classes of 3 or higher are considered for turbine placement.

Cost

Cost is the number one factor on most landowners' minds when they consider implementing renewable energies, and for good reason. Besides the initial purchase of equipment and monitoring, costs arise from annual maintenance of the turbine and its components. Turbine fatigue, which is a gradual damage that results from continual stress to the components (Malhortra 2010), is the main cause of the need for maintenance. The rest of the cost, including that of parts and transportation/installation, can have payback periods of less than 7 years, due to the amount of energy wind can produce. In terms of the energy used to produce and transport the material for turbine installation, the payback period can be as short as 3 years (Karamanis 2013).

Past/Current Uses of Wind Power in U.S. Ski Resorts

With temperatures on the rise due to global warming, ski resorts have been impacted with shorter seasons and loss of snowpack at lower elevations. However, ski resorts themselves contribute significantly to the effects of global warming. Take into consideration the fact that powering one high-speed chairlift for one season is equivalent to flying all the way from San Francisco to Tokyo and back again—*25 times* (Schendler & Michelson 2009).

In the United States, several ski resorts have taken action to reduce emissions through the use of wind power. Perhaps the most well-known resort is Jiminy Peak Mountain Resort in Hancock, Massachusetts. In 2007, the resort built a 250-foot tall 1.5mW turbine to offset high energy costs ("Green Jiminy" n.d.). The resort received funding for the project through grants, the sale of renewable energy credits, and bank loans. In total, the project cost a whopping 4 million dollars. However, the payback period was only 8 years. In all, the reduction of carbon emission as a result of turbine use at the resort is equivalent to driving 75,000,000 fewer miles each year the turbine operates, or planting 83,000 trees. The turbine produces an average of one third of the electricity needed by the resort, with higher production during winter months than summer months. In the summer months, excess electricity provides power to the local community. The turbine is designed to shut down during icing conditions until the blades and tower thaw in order to ensure safety and efficiency. Other resorts that have installed turbines include Bolton Valley Resort and Burke Mountain Ski Area, both in Vermont, and Grouse Mountain in British Columbia. Some of these resorts use the turbines to contribute to overall efficiency, and some use them to power lifts or specific buildings on the mountain.

No ski resort produces 100% of their own electricity through wind power, partly due to energy grid allocations and needs. However, several ski resorts have started purchasing renewable energy credits. This ensures that the electricity the resort is using has been harvested through renewable methods, such as wind power. Sugar Bowl Ski resort in Truckee, CA was the first U.S. resort to rely completely on wind power through renewable energy credits (Handwerk 2007). Several followed, including Park City Mountain Resort in Utah. The resort not only uses a turbine to power one of its chairlifts, but also offsets 100% of their electrical consumption through credits. These purchases have so far avoided the release of 55,451 tons of carbon dioxide emissions and have reduced the resort's carbon footprint by 67% since 2005

(“Save Our Snow” n.d.).

Other resorts that have taken to buying renewable credits from wind farms include Lake Tahoe ski resorts, Aspen Skiing Company, and Steven’s Pass Ski Resort. Steven’s Pass Resort’s actions are equivalent to taking 2,878 cars off the road for a year. Aspen Skiing Company purchases roughly 5% of their electricity from local wind farms, which contributes to the local economy as well as being environmentally sound (“Innovative Ways” 2012).

Bridger Bowl Land Suitability

With dozens of ski resorts taking action against high emissions, it must be asked whether the same can be done on our own home turf: Bridger Bowl Ski Area. In a college town that promotes environmental sustainability and the importance of being “green”, one way that Bridger could contribute to the cause is through the implementation of wind power. However, the question is whether or not Bridger is suitable for wind development based on its location. To take a brief look at land suitability for wind development, an interactive display that uses the wind power density class system (described above) was used, which was developed by the Natural Renewable Energy Labs (NREL 2012). The analysis that was done to organize this data was originally completed in 2010, with the wind data mostly being collected at an 80 meter height in accordance with today’s advanced wind technology. The data not only takes into consideration wind power, but also excludes incompatible land use such as urban areas. The considerations are then used to represent the available wind resource. Using this display, the image below was obtained (Figure 4).

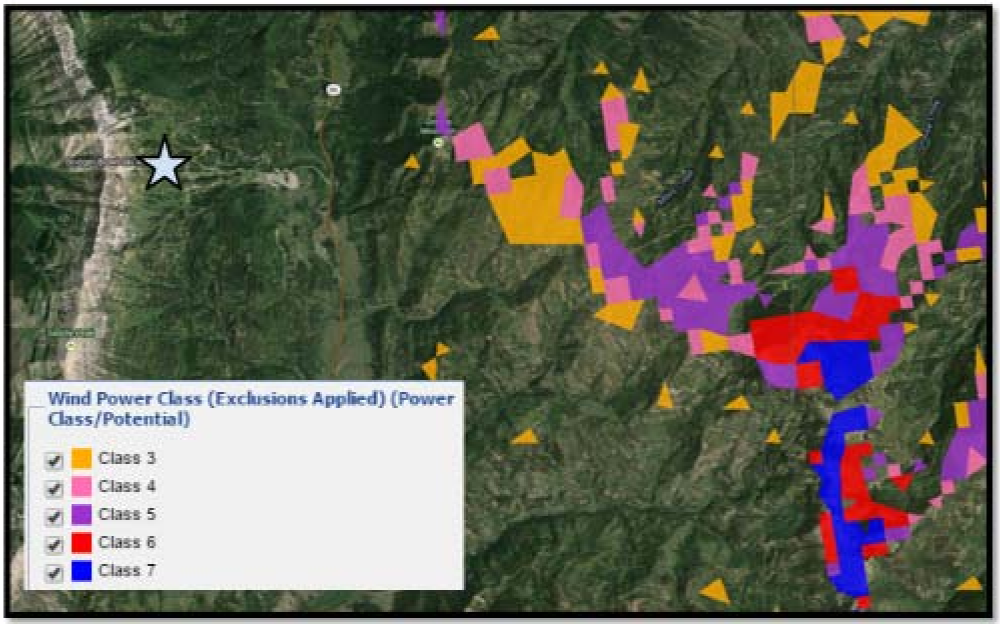

Figure 4: NREL map showing wind power density class for Bridger Bowl (indicated by white star)

As the NREL image shows, Bridger Bowl may not be suitable for wind energy development based on wind power density alone. The colored areas are classified as wind power class 3 or above, with orange areas being class 3, pink areas being class 4, etc. As stated earlier, areas with a wind power class of 3 or higher are best suited for turbine development. Since the area surrounding Bridger Bowl (shown by the white star) are not in class 3 or above, the image suggests it may not be suitable for wind energy harnessing. This may be due to factors such as terrain slope, obstructions, or canopy density.

To take a more in-depth look at how well wind power class can predict land suitability for turbine development, wind power class was assessed at the Jiminy Peak site in Massachusetts. In Figure 5, the Zephyr 1.5 mW turbine is marked with a white star. The placement of the turbine falls directly on top of an area with a wind power class of 3. Again, an area of class 3 would usually be interpreted to be sufficient in wind velocity and density for turbine development. So, according to this image, the area that Zephyr was built on was in fact suitable for harnessing wind power.

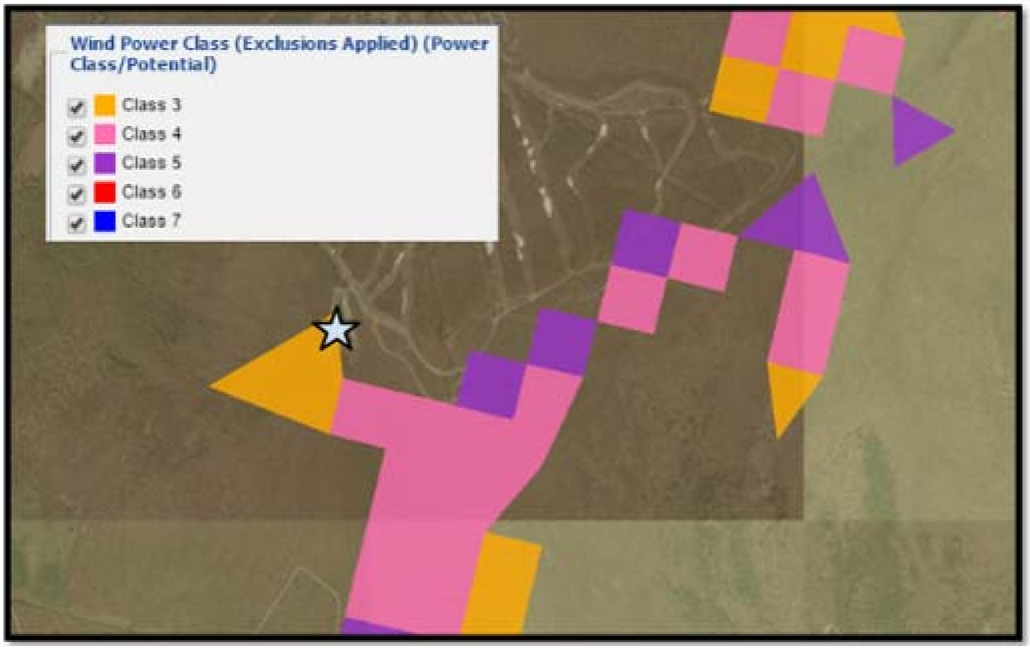

Figure 5: NREL wind power density class for Jiminy Peak, with the Zephyr turbine marked with a white star

As previously discussed, several other factors go into the consideration of an area for wind energy development besides wind power class. The fact that Bridger Bowl does not meet the wind power class criteria for wind development based on NREL's analysis doesn't necessarily exclude it from possible development. For example, Zephyr is a huge turbine and would need a higher wind density and occurrence compared to the smaller turbines that might be implemented at Bridger Bowl. Smaller turbines operate with less wind velocity. NREL's interpretive display should be used to get a basic idea of renewable energy sources, not as a management or planning tool. To provide further evidence, Bridger Bowl has a moderate average monthly wind velocity (Fig. 6). However, high winds do exist on site, according to the figure below. As the figure shows, maximum winds can get as high as 93 km/h during winter months. Therefore, there is no question that Bridger has the high wind velocities to turn turbine blades. The question is whether or not these high wind velocities are sustained throughout the year in order to make turbine generation as efficient as possible.

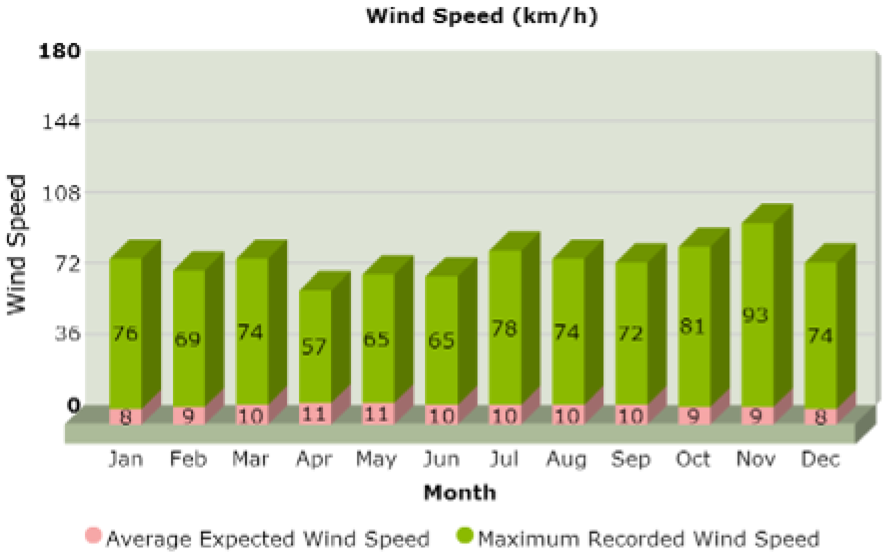

Figure 6: Wind data for Bridger Bowl

Discussion/Conclusion

Although data have shown that Bridger Bowl may not be suitable for wind turbine placement based on wind power density, the ski area may have the opportunity for other ways of offsetting energy consumption and emissions. Bridger Bowl already participates in the movement towards green ski slopes by purchasing green energy that is created through zero emission heat exhaust that is captured from gas pump turbines in North Dakota. It also is very active in recycling endeavors and even purchased and refurbished an old chairlift from another resort, instead of letting the chairlift go to waste ("Sustainabilty", n.d.). Of course, if the management team at Bridger truly wanted to see if a site was capable of harnessing wind for electricity, it could hire somebody to conduct a year-long wind speed study in order to precisely determine wind resources at the ski area. Examination of brand new turbine designs could prove to be efficient enough to satisfy Bridger Bowl's energy demand. Three new designs are being developed to increase wind turbine efficiency while mitigating or completely eliminating all the risks associated with traditional wind turbines. First, an augmenter could be used to increase the amount of wind passing through the turbine blades of current turbine designs ("Types of wind turbine," 2006). Completely altering the turbine design either to a jet engine style of design or to a bladeless design could increase turbine efficiency and mitigate associated turbine risks. Jet engine turbine designs are smaller and sleeker, addressing social and biological risks and has the ability to harness a wider range of wind conditions ("Our Work," 2006). On the other hand, turbine blades can be completely removed and replaced with bladeless technology. Bladeless wind turbines are still being developed, but current tests show that they double efficiency while eliminating all risks associated with wind turbines ("Zero-blade technology", 2014). Analysis of all the costs attributed to wind energy including the use of excess energy storage devices combined with social and biological surveys will indicate whether the benefits outweigh the costs of wind energy. Finally site location characteristics can be calculated to determine where it is actually feasible to use wind energy. Ski resorts such as Bridger could also benefit from looking into other renewable energies, such as solar power. Regardless of the method used, ski resorts that aim towards a greener future are not only saving money in the long run, they are ensuring the future of their existence in the process.

Figure 7a: Bladeless wind turbine design

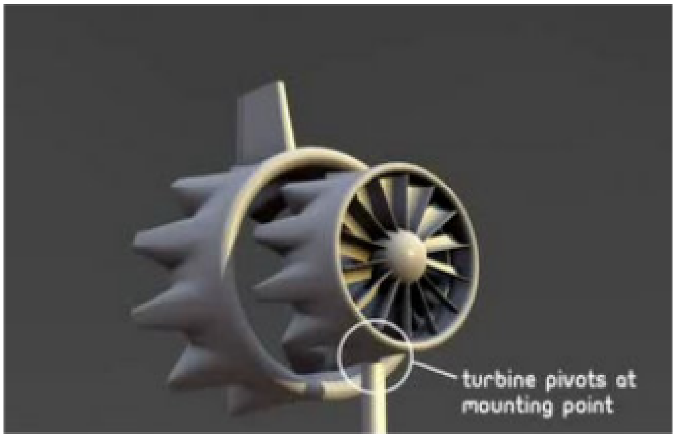

Figure 7b: Jet engine wind turbine design

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