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Evaluating the Potential for Renewable Energy Technology at US Ski Resorts

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Evaluating the Potential for Renewable Energy Technology at US Ski Resorts

by

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Bachelor of Engineering Independent Project

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Evaluating the Potential for Renewable Energy Technology at US Ski Resorts

June 4, 2019

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Abstract

The ski industry is one of the most at risk industries as a result of climate change. Warming temperatures and decreasing snowfall are contributing to a decline in skier visitations, shorter seasons, and higher energy costs. Currently, only 3 of 478 ski resorts in the United States rely on 100% renewable energy sources. The intent of this paper is to understand what the issues and barriers are to renewable energy development at ski resorts, and what technologies are feasible and appropriate for this industry to develop. While the renewable energy industry faces many issues and barriers, the ski industry faces its own unique set of financial, land, and community barriers to implementing renewable alternatives. However, this study finds that three renewable technologies (solar, wind, and hydropower) are feasible and appropriate for ski resorts to implement with considerations to be taken in context of the environment, state policies, and natural resources. Renewable energy development is an option for every ski resort; however there is not a one-size-fits-all solution. Overall, there is an opportunity for ski resorts or a third party to take the lead on renewable development. The ski industry can show that it is possible and that nationally we all must transition.

Acknowledgements

I would like to thank Professor Mark Laser for being an amazing advisor to this project and a teacher who has inspired me throughout the year in coursework and beyond. His depth of knowledge in renewable energy and encouragement throughout the process has been invaluable. I would also like to thank my family and friends for their help and support.

Furthermore, I would like to thank Jim Farrell at Berkshire East and Jim Van Dyke at Jiminy Peak for their time and ideas for this project. Both of them and their ski resorts are inspiring for being so far ahead of the curve in renewable energy development and helping make our future a greener one.

Contents

I Overview

I.1 Background

The ski industry is at a crossroads. Ski lifts and the accompanying infrastructure primarily rely on fossil fuels and electricity generated from fossil fuels. A study by the National Ski Areas Association found that 24 of the most environmentally conscious ski resorts[1] emitted 167,251 MTCO2e in the 2018 [1], equivalent to the emissions for 20,000 American homes. These emissions are part of the overarching problem of climate change which is undermining the industry's future [2].

However, ski resorts have the opportunity to implement renewable energy solutions. Today, three resorts are 100% renewable; Jiminy Peak in Hancock, MA runs on a 1.5 MW wind turbine and a handful of solar farms; Berkshire East in Charlemont, MA runs on a 900 kW wind turbine and a 500 kW solar farm; Wolf Creek Ski Area in Pagosa Springs, CO runs on a 2.75 MW community solar farm. Furthermore, there are many reasons for ski resorts to implement renewable technology.

First, Ski resorts are susceptible to the cost of energy and are bulk buyers of electricity. In interviews with Jiminy Peak and Berkshire East, the primary reason why they developed renewable resources was to hedge against rising utility costs and have better control of their operating costs. Energy costs are typically the second biggest operating expense after labor [3], traditionally 10% to 30% of the total operating budget. Snow making greatly increases these costs with operating costs ballooning from $2,000 a day to $30,000 to $40,000 a day for a mid size resort [4]. Warming temperatures will require resorts to rely more heavily on snow making. Already 91% of ski resorts rely on snow making at some point in the season [5]. Renewable energy help control operating costs for ski resorts in a warmer future.

Second, ski resorts are on the front line of climate change. Warmer winter temperatures and reduced snowfall will shorten ski seasons and reduce skier visitations. These impacts will be acute by 2050; in Figure 1, the percent change in ski season length can be found for selected resorts across the country. An economics study by Protect our Winters, a non-profit organization climate advocacy group for winter sports, found that changes in the winter season caused by climate change were costing the ski industry approximately $1.07 billion in aggregated revenue over high and low snow years in the past decade [6]. It stand to be one of the most highly impacted industries in the world. This makes the shift towards green energy ever more important.

Third, ski resort customers value green renewable energy. Jiminy Peak saw this in customer satisfaction surveys in the seasons after building their wind turbine. Additionally, a compre-

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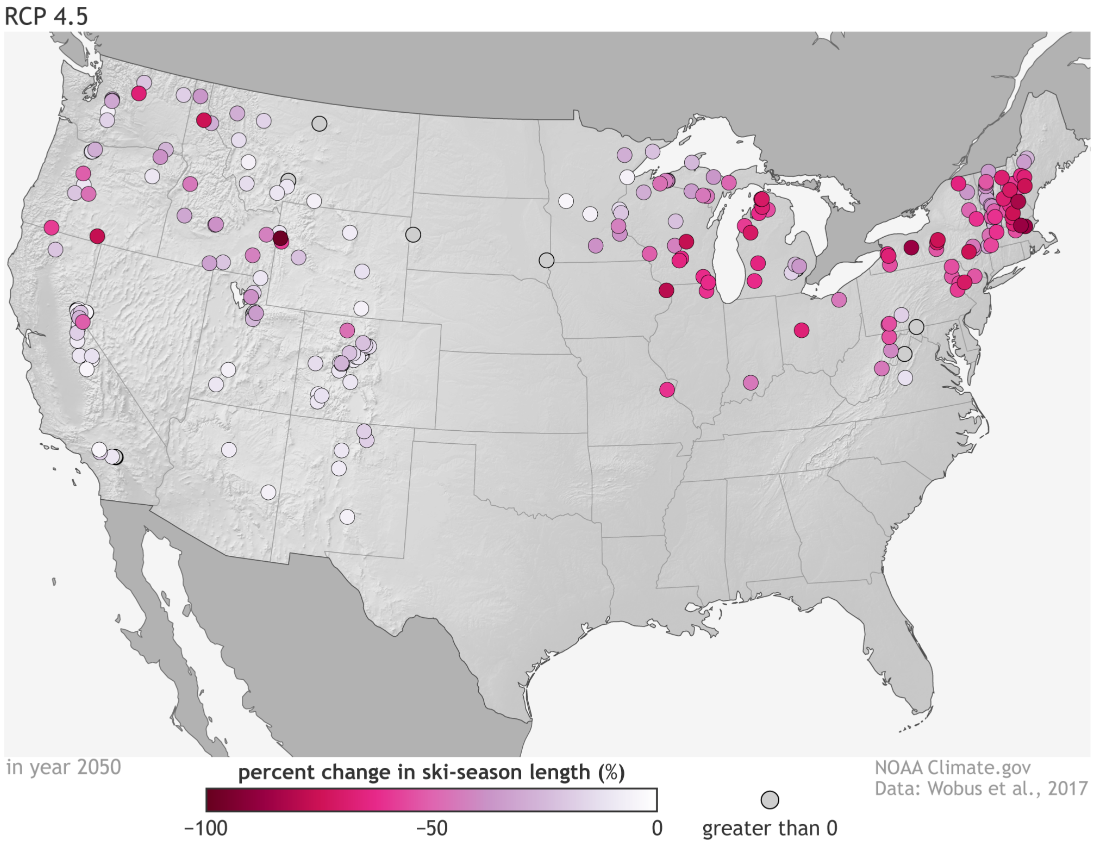
[1] These 24 environmentally conscious resorts are part of the sustainable slopes initiative by the NSAA which helps ski resorts pursue energy efficiency and carbon reduction.

hensive study in Europe found that skiers react positively towards renewable energy and environmental projects at ski resorts [7]. A similar study in Oregon found that skiers were more likely to return to a ski resort if they knew about the environmental programs going on at the resort [8].

Finally, ski resorts suffer from power reliability issues resulting from severe winter storms, which renewable energy plus storage can solve through grid islanding. Although there is no quantitative data on power outages for ski resorts, it is a costly problem [9]. Most ski resorts are located in remote areas where it could take hours to repair transmission lines. These are valuable hours and wasted days for a ski resort operating on a short 100- to 200-day season. Storage may not be a cost-effective solution now; however, Berkshire East and Squaw Valley are both set to install Tesla Power Packs for their respective resorts in the next two years. This will both optimize their renewable off take and increase resilience.



NOAA Climate.gov
Data: Wobus et al., 2017

Figure 1: This figure illustrates the impacts of the IPCC RCP 4.5 scenario on ski season length in 2050. [10].

I.2 Ski Industry Overview

In the US, the ski industry is made up of 478 ski resorts spread across 40 states, see Figure 2. In 2015-2016, skiers participated in a total of 52.8 million skiing and snowboarding days

[6] . They contributed to a total of \$2.6 billion in direct added economic value and an additional \$3.7 billion in indirect value [6]. These indirect effects arise from supply chain links, and spending in other local industries such as hotels and restaurants.

Figure 2: A map of all 478 ski areas in the United States.

I.3 Ski Industry Energy Consumption

Energy consumption for ski resorts can vary widely between small mom-and-pop resorts with a couple lifts and a day lodge to mammoth resorts such as Vail with 31 lifts, 165 hotels, and multiple lodges spread across the mountain. One of the largest contributions to electricity consumption at ski resots is snowmaking. To produce 1 m^3 of snow it requires 1-14 kWh of electricity [11]. In the US, 91% of ski resorts use snowmaking to supplement natural cover and it can consume up to 50% of resort energy costs [5] [3]. A breakdown on energy usage for a typical Northeast resort can be found in Table 1. Table 2 presents the electricity consumption per year for selected resorts. Energy data for businesses is usually proprietary, so data presented is what data could be found publicly. Overall, electricity loads range from 1,000 MWh to 32,000 MWh per year.

Table 1: Typical Northeast Ski Facility End Use Breakdown. Sourced from ACEEE [12]

Electrical End Use Data	**MWh**	**Percent**
Snow Making Compressed Air	5,490	53%
Snow Making Pumps	2,090	20%
Ski Lifts	2,061	20%
Lighting	354	3%
Miscellaneous	217	2%
Space Heating	176	2%
Total	10,390	100%

Table 2: Electricity Consumption for Selected Ski Resorts

Resort	**Number of Lifts**	**Size (Acres)**	**Electricity Load (MWh)**	**Source**
Whistler Blackcomb, BC	37	8,171	32,000	[13]
Vail, CO	31	5,289	16,790	[14]
Jiminy Peak, MA	9	167	7,000	[15]
Sugar Bowl Ski Resort, CA	12	1,650	4,300	[16]
Boreal Mountain Resort, CA	8	380	2,166	[17]
Berkshire East Ski Area, MA	6	180	1,200	[18]

I.4 Problem Statement

Ski resorts should develop renewable energy technology to maintain and grow the industry into the future. Currently, only 3 of 478 ski resorts in United States rely on 100% renewable energy sources. This paper seeks to investigate what issues and barriers US ski resorts face in implementing renewable technology, and what technologies and resources are appropriate.

US ski resorts are the focus of the study because as this report will explain renewable energy is very dependent on its context and environment. Limiting the context and environment to the US allows the paper to dive deeper into the issues and barriers facing a similar set of ski resorts. The findings however could be extrapolated to other regions such as Europe, Canada, and Japan.

II Issues and Barriers

This section will discuss the unique issues and barriers to ski resorts considering renewable energy development including land use issues, financing issues, social and community issues, and state and federal renewable energy policy.

II.1 Land Use Issues

Ski resorts in the United States operate on land leased from the federal government (U.S. Forest Service), land leased from state governments, and/or private land. Each type of ownership position presents different challenges and limitations for developing renewable energy. Across the country, ski resort land usage and issues are very different and regionalized. The distribution of land usage for Vermont, Montana, and Michigan can be found in Table 3. This section will evaluate the constraints and issues within each ownership scenario.

Table 3: Distribution of Land Usage for Vermont, Montana, and Michigan

State	**Vermont**		**Montana**		**Michigan**	
	N	%	N	%	N	%
Federal Lease	3	17.64	12	80.00	1	2.04
State Lease	8	47.05	0	0.00	0	0.00
Private	6	35.29	3	20.00	48	97.95
Total	17	100	15	100	49	100

II.1.A Federal National Forest Service Land

In 2019, there were 122 downhill ski areas in the U.S. operating under special use permits on National Forest System (NFS) lands. The ski areas occupy 182,095 acres, or about .09% of the 193 million acres of NFS land [19]. The leases return $26 million to the NFS annually and are determined using a progressive rental charge system based on gross revenue.

The National Forest Service describes its relationship with the ski industry as an enduring partnership because ski resorts connect more Americans to the outdoors and the revenue generated from the leases funds programs throughout the park system. However, the ski industry has faced harsh criticism from environmentalist because of the high concentration of visitors in a relatively small area of the park system. Habitat fragmentation, water use, waste disposal, greenhouse gas pollution, and sprawling developments are a few of the issues facing the NFS on leased land. These issues are especially prevalent in areas with high concentrations of ski resorts such as White River National Forest in Colorado where 12 ski resorts are located, including Vail and Aspen. These issues have made any development and expansion on public lands contentious issues. Public criticism and extensive litigation has defined most development of ski resorts since the 1990s [20] and would most likely face ski resorts in developing renewable energy.

So far no ski area located on NFS land has developed on-site renewable energy. After talking with the NFS, there would be regulatory and permitting barriers similar to other ski area development projects. However, there is no steadfast barrier to implementing renewables on leased land. In fact, the NFS, in conjunction with NREL, has extensively studied the renewable potential on National Forest and Grassland units [21]. Their findings were that 119 National Forest units have high potential for solar and wind power production. This includes units with high concentrations of ski resorts such as Arapaho-Roosevelt National Forest (8,245 MW) and White River National Forest (318 MW).

Overall, on NFS leased land there are high barriers to on site development due to public criticism, regulatory issues, and extensive litigation. However, the NFS is interested in the potential for renewables on their land. The development of each project will have to weigh the risks and limitations of the development process with the gains of renewable energy for on-site development.

II.1.B State Land

In some states, ski resorts lease state-owned land through a department of parks and recreation. A notable example of this is Vermont where almost half of all ski resorts lease land from the state of Vermont. The leases are structured similarly to federal leases with a portion of the gross revenue going towards the state. State land endures similar environmental consequences to land leased by the NFS and subsequently any development is highly critiqued by the state and the public. Overall, barriers to renewable energy development are likely to be similar to developments on federal land; however, this will vary from state to state.

II.1.C Private Land

Ski areas operating on private land have lower barriers for development. Depending on the state, and municipality development requires a building permits and other red tape but otherwise is a fairly simple process. Both Jiminy Peak and Berkshire East developed on private land, had similar experiences with permits. Some issues with the permitting process and the community and social barriers will be discussed in section Section II.3.

It is also important to understand that there are a number of resorts where the resort's land is partially on private land and partially on state or federal land. In this case, it is common that the base area is privately owned and the runs are on state or federal land.

II.2 Financing Issues

II.2.A Ski Resort Business Climate

The ski industry is facing major challenges including an aging and declining customer base, a infrastructure, and climate change. Furthermore, it is undergoing a transition away from local small and medium ski resorts towards mega conglomerates such as Vail's Epic Pass and Alterra's Ikon Pass [22]. Bill Jensen, a former Vail executive and CEO of Intrawest, categorized the US's 470 resorts into 5 tiers:

1. Uber (10)
2. Alpha (35)
3. Status Quo (125)
4. Survivor (150)
5. Sunset (150)

The Vail and Alterra conglomerates make up a majority of the uber and alpha tier. These resorts combine for less than 10% of ski resorts but generate over 40% of all ski business. The status quo and survivor resorts are small and medium independent resorts. Jensen predicts that these resorts will continue on for the next few decade but have flat revenue. Additionally, he says that sunset resorts are expected to close in the coming years due to declining revenue, reliance on natural snow, and limited tourist traffic [23]. Small resorts have been in this predicament for a very long time with 76 resorts closing since 1991.

All of this echos what I heard from people in the industry. Most small- and medium-sized ski resorts in the Status Quo and lower tiers do not have the financial capital to spend money and will continue to operate as ”status quo”.

On the other hand, Uber and Alpha resorts are primed for large investment. In the past decade the Vail Resorts corporation has invested \$1.2 billion into their ski resorts and will invest \$175 to \$180 million in the 2019/2020 ski season alone [24]. These investments include chairlifts, snowmaking infrastructure, restaurants, and lodging.

Resorts in each tier will require different financing models to develop commercial scale projects depending on their financial considerations. Commercial scale projects are projects where electricity off take is going to a commercial consumer. There are two predominate financing strategies used in the US renewable energy industry, Power Purchase Agreements (PPAs) and self purchase. A third strategy for developing renewable energy is community scale projects, which are renewable facilities shared by multiple community subscribers. Many of the insights below were drawn from discussions with ski industry experts and a technical report from the National Renewable Energy Laboratory [25]. A full quantitative analysis of financing for ski resorts would require proprietary data and therefore this analysis was limited to insights gathered.

II.2.B Ski Resort PPAs

A Power Purchase Agreement (PPA) is a contract for the purchase of power and associated renewable energy certificates from a specific renewable energy generator to a purchaser of renewable electricity. The agreements typically spans 10 to 20 years and can carry many terms. It allows the developer to secure long-term financing and build the project. The customer agrees to purchase the power at a set price over the span of the contract with a price escalator. Today, both the price and price escalator are typically below the default utility supplier [26]. The physical renewable energy generation can be located on or off site with the electricity being delivered by the grid to the buyer. At the end of the contract, the buyer can either sign a new agreement with the seller or purchase the system [27]. PPAs with corporations are widely used in the renewable energy industry. In 2018, 6.43 GW of PPAs were signed by non-utility buyers [26]. Many of these buyers are similar to ski resorts in that they are energy-intensive customers switching their loads from fossil fuels and the grid to renewables.

For ski resorts, especially ”status quo” tier and below, PPAs enable them to clear potential financial hurdles involved with self-financing. Unlike purchases of renewable energy systems, PPAs are off-balance sheet transactions which suits ski resorts with low capital and high debt to equity ratios, as it allows them to circumvent the liability of a loan on their balance sheet. The biggest challenge is guaranteeing the off-take of the power for 10 to 20 years. For many sunset resorts, this may not be possible to arrange with a developer because of bad credit and high risk. Further benefits from PPAS include reducing exposure to risks related to under-performance, unanticipated O&M costs, and delays in the project and incentives.

II.2.C Ski Resort Self-Financing

Corporations that can assume more risk often self-finance their own renewable energy projects [25]. By taking this risk, it enables companies to reap the benefits of a long-term, high quality asset and cut out the 3rd party developer [25]. This way, the owner can capture more of the savings. Additional benefits include lower project cost and administrative costs due to the extra sensors and measuring devices required for a PPA.

Jiminy Peak and Berkshire East both chose to self-finance wind turbines, decisions they made because of their respective financial positions at the time. Jiminy Peak had a couple of successful years reducing their debt to capital ratio, which allowed them to get favorable terms for a loan. Berkshire East ownership team had experience in renewable energy development and their expertise lead them to pursue self-financing. Overall for any ski resort, the motivations for self-financing come down to their risk-tolerance and financial well-being.

For alpha and uber tier ski resorts, self-financing will be more favorable as they have a higher risk-tolerance and better financial well-being because they have a large financial backing. Furthermore, they are able to look at 20 to 30 year time horizons with more certainty, while ”status quo”, survivor, and sunset resorts are only trying to stay afloat.

II.2.D Self Financing Compared to PPAs

In evaluating the decision to self-finance or sign a PPA, a ski resort will need to evaluate the economic attractiveness of each option. This section will use a cashflow analysis from NREL [25] adapted for installing a PV system at a ski resort in Colorado to analyze both options in Figure 3. The self-financing option provides a greater payback in the long-run, however is a major liability in the short-term. The PPA agreement offers some return over the time period but does not have any major liability associated with it. A further benefit from both financing mechanisms is that they offer price stability over the long run.

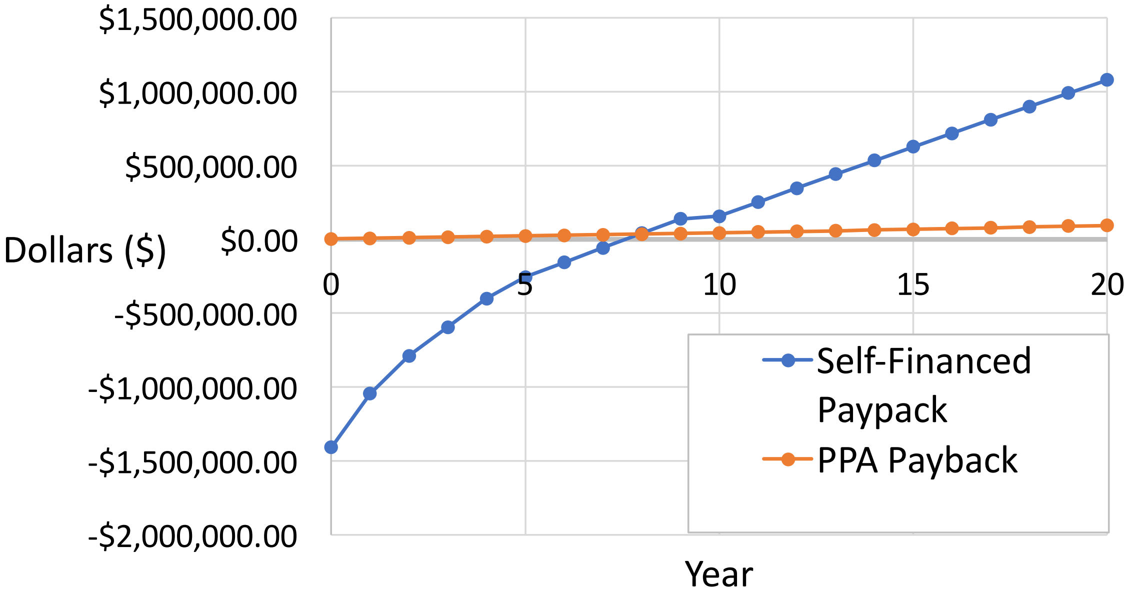


Figure 3: Cashflow analysis for a 1 MW PV system in Colorado. Assumptions and calculations can be found in Appendix A.

II.2.E Ski Resort Community Financing

Community solar is a relatively new financing instrument that bands together groups of residential and commercial consumers to buy or lease part of a larger offsite, shared photovoltaic system. To date, this financing mechanism has generally been applied to solar facilities, although it can be applied to other renewable energy systems, too. The main benefit of community solar is that it gives customers the option to install solar who otherwise would have insufficient roof or land space, who do not own their land, who are located in an area of insufficient solar resources, or who would be unable to finance solar. All four are barriers pertaining to ski, as well.

Jiminy Peak and Wolf Creek Ski area are two ski resorts that participate in larger off-site community solar projects. Jiminy Peak buys power through a PPA with a 2.3 MW facility located on its property but developed by a special purpose entity. Wolf Creek ski area operates under a similar PPA agreement where they purchase 1,000 MWh per year of the 7,000 MWh generated from the Penitente Solar Project. The 1,000 MWh generated offsets 100% of Wolf Creek's energy needs through virtual net metering.

II.3 Social and Community Issues

Ski resorts have always been central aspects to mountain communities, but have recently become more controversial due to conglomeration and corporatization. Renewables have the potential to add to this contention if the community is left out of the planning process. Recent projects such as the Lowell Mountains Wind Project in Vermont, renewable projects in San Bernardino County, and many others have felt the negative backlash of communities against renewables in their backyards [28][29].

When Berkshire East developed its wind turbine, the town was apprehensive about the turbine and its effect on the community. However, growing discussions between the community and the resort lead to a close partnership between the two. The ski resort provides season passes and ski rentals for all the students and teachers in the community. When Hurricane Irene hit the town on August 27 and 28, 2011, it flooded Hawlemont Elementary School, closing it for multiple weeks [30]. The ski resort allowed the school to use the day lodge for classes and provided lunch for the students at no cost to the school board. Furthermore, the ski resort encourages groups and schools in the area to visit the turbine and solar field to learn about renewable energy. These types of connections to the community are essential to developing renewable energy effectively and allowing the company to proceed through the permitting process in a conscientious way.

An important message for ski resorts interested in developing renewables is that the project is not just about economics, and the community needs to be involved with the process, as well.

II.4 State and Federal Renewable Energy Policy

This section will highlight important state and federal policy. State policy varies widely and this report will discuss important policies relevant to ski resorts looking to develop renewable infrastructure. A summary of state by state policies can be found in Appendix D of NREL's Assessing the Potential for Renewable Energy on National Forest System Lands [21].

Federal policies of interest for ski resorts include the Business Energy Investment Tax Credit (ITC),the Modified Accelerated Cost Recovery System (MACRs), the renewable electricity production tax credit, and the solar and geothermal business energy tax credit. All of which can be claimed for solar and wind projects but not hydropower. Furthermore, the production credit and the energy credit cannot both be claimed by one project. The ITC is an investment credit for renewable energy projects based on a percentage of the total investment that declines by year into 2022. MACRS allows for depreciation deductions for the investment over 5 years. The production tax credit provides a tax credit of 1.8 cents/ kWh for 10 years for wind and 5 years for solar. The energy tax credit provides a 10% credit to be carried back to the 3 preceding years and forward for 15 years. More details on these policies can be found in NREL's report [21].

The most important state policies for ski resorts are net metering, renewable energy certificates (RECs), and state tax credits. Other policies exist and should be understood on a state by state basis. Net metering is a billing mechanism that credit renewable energy owners for the electricity they add to the grid on a 'net' basis. This values each kWh of electricity generated at a higher retail rate in comparison to a wholesale rate. State legislation on net metering varies with some state not requiring utilities to net meter and other states impose capacity limits and enrollment limits. RECs are a instrument that represents property rights to environmental, social, and other non-power attributes of renewable energy generation. RECs are issued when one MWh is generated by a renewable source and it allows the owner to sell the property right to a third party. States can either have voluntary or compliance REC markets. States with compliance markets generally have Renewable Portfolio Standards that utilities need to obeyed by. State tax credits on renewable generation are set up in a similar manner to the federal system and apply on a per energy basis.

III Technology and Resources

This section will evaluate alternative renewable energy technologies appropriate for ski resorts. It will provide an overview of current and future technology, the availability of natural resources near ski areas, issues and considerations for a particular technology, how well that technology matches seasonal and daily consumption and provide the basis for an economic analysis of that technologies.

III.1 Solar

Solar power is currently in use at multiple ski resorts around the United States through PPAs and self-financed investments. Notably, Wolf Creek supplies 100% of their electricity through an offsite solar PPA that provides 1,000 MWh [31]. Using offsite solar helps Wolf Creek maximize their investment as although the ski resort and the solar facility are only 50 miles away apart Wolf Creek is among Colorado's snowiest areas averaging 391 inches a year, while the San Luis Valley is one of the driest only receiving 26 inches. This has large impacts on the solar resources received with Wolf Creek averaging 4.822 kWh/m^2 per day and San Luis valley averaging 5.433 kWh/m^2 per day.

III.1.A Current Technology

In recent years, photovoltaic solar technology has drastically decreased in price as seen in Figure 4, driven by a decrease in the price of modules and inverters. This has allowed solar to grow exponentially in the commercial and residential sector. Costs vary across the country but solar is generally cost-effective with payback periods of 5 to 10 years [32]. In general, photovoltaic commercial system vary from 10kW to 2MW [33]. There are a number of factors and limitations to consider when determining system size which will be discussed in Section III.1.E.

The energy conversion process of photovoltaic panels is defined by Equation (1):

$$\mathrm{P} = A_{\text{Panel}} * \eta_{\text{Panel}} * \mathrm{I} * \eta_{\text{System}}. \tag{1}$$

Where A_{Panel} is the surface area of the solar panels , η_{Panel} is the efficiency of the panels, I is the irradiance of the sun,and η_{System} is the efficiency of the system.

The most important factor for generating solar energy is irradiance from the sun. Over the course of the day it depends on a number of factors including time of day, weather, and shading. A developer can control some of these factors by choosing a location that maximizes irradiance. For instance, Wolf Creek uses offsite solar from the San Luis Valley to maximize irradiance since the weather is drier in the valley and the area is clear of trees. The most common indicator of

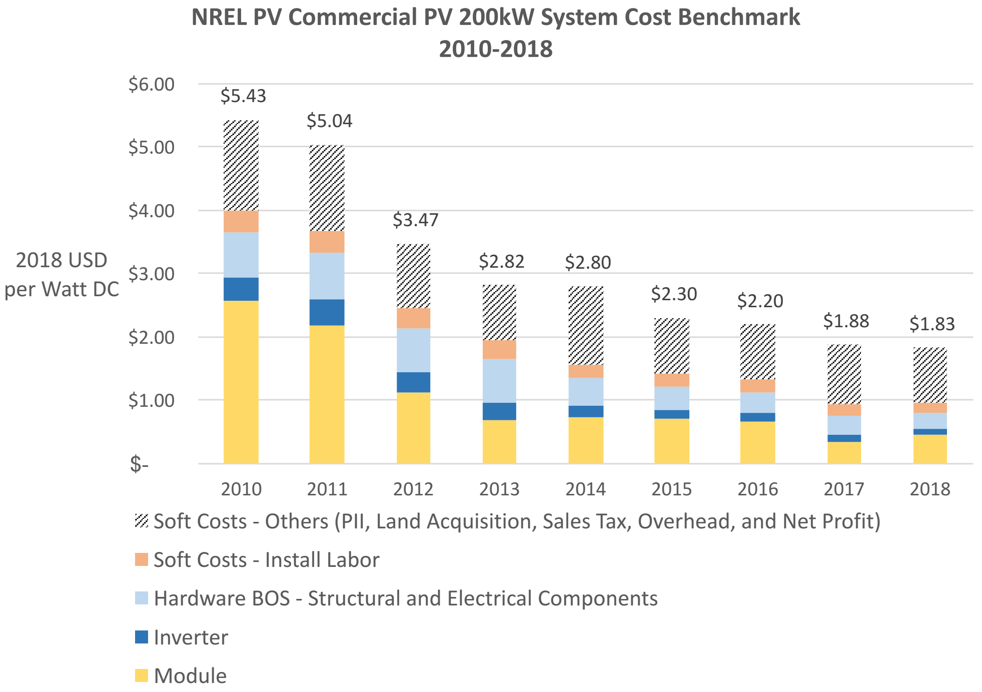


Figure 4: This figure illustrates the benchmarked values for a commercial system of 200kW and drivers of cost decrease. The data is sourced from the U.S. Solar Photovoltaic System Cost Benchmark: Q1 2018 [33].

irradiance at a specific location is Global Horizontal (GHI) and can be found using tools such as Global Solar Atlas. Tracking, orientation, and spacing of the panels can further maximize the irradiance received by the panels. Tracking will be discussed in more depth in Section III.1.B.

The efficiency of the panels and the system are also important factors that deal with solar technology. Currently, the efficiency of panels range from 15% to 17% with the most efficient panels on the market today rated at 22% [34]. The efficiency of the system is also important and takes into account inverter losses, temperature losses, cable losses, shading, and degradation. Typically system efficiency are around 75% but can range from 50% to 90% [34].

III.1.B Tracking Considerations

Within photovoltaic technology there are two forms of sun tracking technology that can be employed to maximize energy production and capacity factors: single-axis tracking and two-axis tracking. A solar tracking system maximizes the electricity production by moving the panel to follow the sun throughout the day, this optimizes the angle that the panels receive solar radiation. Single-axis tracking increases the performance of the system by 25% to 35%, while two-axis tracking increases it further 5% to 10% [35]. However there are drawbacks, the tracking systems have higher installation and maintenance costs as seen in Table 4.

A tracking system is appropriate for ski resorts that either have limited space or are located at high latitudes. Ski resorts with limited space due to land use constraints can utilize trackers to maximize energy production. At high latitudes, fixed solar panels face an issue with the sun's position varying dramatically between the summer and winter months. Trackers resolve this issue although the energy gains from the trackers are highly dependent on the location and specifically latitude. Gains from one axis tracking to dual-axis tracking range from 0.42% to 23.4%, while gains from fixed tracking to dual-axis tracking range from 17.72% to 31.23% [36].

For a ski resort looking at installing panels onsite, a common concern will be snow. Snow buildup does effect the amount of irradiance that is able to reach the panels and effects energy production from the system. Most trackers have a snow mode function which speeds up the snow shedding process and moves the system at night to avoid heavy accumulations. Furthermore, dual-axis trackers are tall enough so that any snow on the ground won‘t impeded the system's function. This is very important for Western ski resorts with greater snow depths.

Table 4: 2013 Cost Benchmarks for McGee, MS [37]

System Type	Installed Cost($/W)	Percent Increase	Annual O&M Cost($/kW)	Percent Increase
Fixed	$2.79	-%	$20.00	-%
One-Axis Tracking	$3.34	19.71%	$22.00	10.00%
Two-Axis Tracking	$3.68	31.89%	$25.00	20.00%

III.1.C Future Technology

The department of energy pursued the Sunshot initiative in 2011 with the goal to reduce the cost of solar by 75% by 2020. This goal was achieved in 2017 at $0.06 per kWh, 3 years earlier than expected [38]. The agency regrouped and set a new goal of $0.03 per kWh by 2030 [38]. This reduction in price will have major impacts on the industry making it amoung the lowest cost generation even competing against existing plants.

The department plans on doing this by investing in research and development into materials and manufacturing costs. The areas of interest include:

1. Materials, interfaces, and high-efficiency cell development
2. Advanced PV manufacturing science and technology
3. System optimization for increased energy yield and lower OM costs
4. Perovskite module manufacturing and long-term durability
5. Low-cost substrates for single-crystal high-efficiency cells

6. PV system recycling and end-of-life management

One of the most exciting area for solar development lies within the perovskite module which are semi-transparent PV modules that could be used on windows or stacked with silicone modules.

III.1.D Resources

The application of solar technology at ski resorts will depend on the solar resources available in the area. As mentioned in Section III.1.A, the power produced by a solar panel is primarily a function of irradiance from the sun. The location of the array is crucial to maximizing the irradiance. There are a number of tools including globalsolaratlas.info, pvwatts.nrel.gov, and NOAA's climate dataset to gather irradiance data for a specific location.

Whether to locate the facility on or off site can be an important determination for irradaince. For some ski resorts, high levels of snowfall and cloudy weather in the mountains may inhibit energy generated from an onsite solar facility. However close by in the plains, the weather is usually dry and sunny. This can be seen in the image on the left of Figure 5. This shows the difference between irradiance received by Wolf Creek Ski Area (4.822 kWh/m^2 per day) and the San Luis Valley plains (5.433 kWh/m^2 per day). This difference can lead to significant annual energy gains from an off site facility. However, with a offsite facility there are additional costs and limitations including land ownership, renewables visibility, and state virtual net metering laws.

For a ski resort locating a solar facility onsite, there is a significant difference between locating the facility on south or north facing slopes. This can be seen in the image on the right of Figure 5. This shows the difference in irradiance on north and south facing slopes of the Gallatin Mountain Range in Montana, where Big Sky Ski Area is located. For Big Sky ski area, the difference in irradiance between south and north facing slopes is 0.375 kWh/m^2 per day.

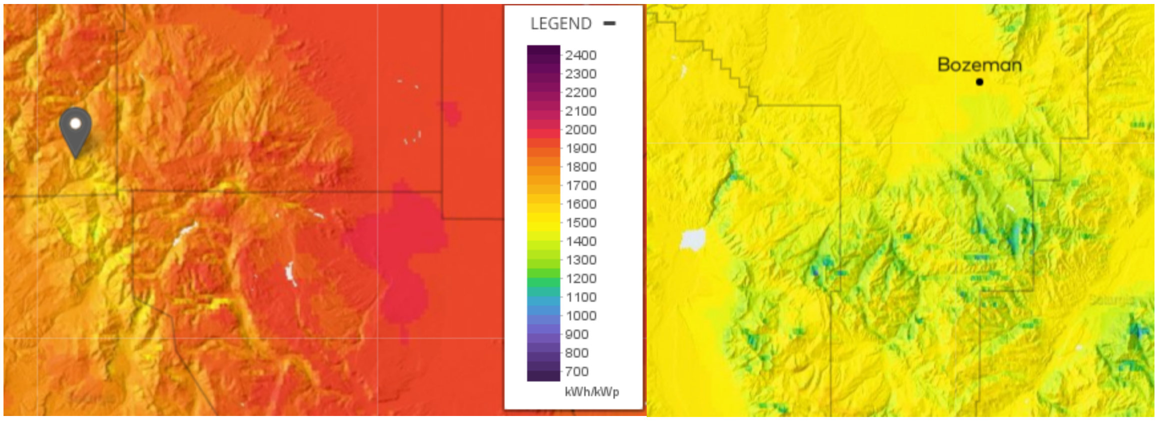


Figure 5: The image on the left illustrates the difference in irradiance data between the mountains and the plains, with the plains receiving more irradiance as indicated by the dark red shading. The image on the right illustrates the difference between the north and south faces of the mountains, with the north faces receiving less irradiance as indicated by the green and blue shading.

III.1.E Issues and Considerations

The most important aspect of developing solar power is the irradiance the system will receive. Irradiance determines the output and capacity factor of the system, which can be seen in Figure 6. Solar is not suitable for all ski resorts with solar irradiance differing dramatically across the country. Figure 7 shows average PV system capacity factors for various states. Solar will not be a compelling technology for ski resorts located in wet climates and high latitudes in the US such as the Pacific Northwest. While, regions with a majority of sunny and dry days such as the Rockies will find solar technology very compelling . Furthermore,to maximize irradiance tracking can dramatically improve capacity factors as seen by the orange line in Figure 6.

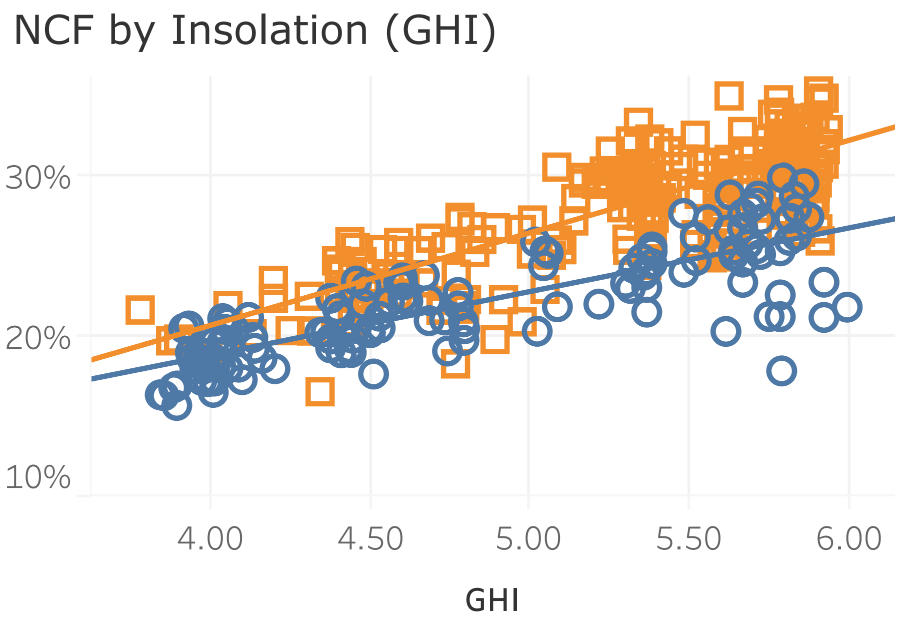


Figure 6: This figure illustrates the net capacity factor for PV systems based on Global Horizontal Irradiance (GHI) [39].

Land use requirement for solar PV projects can be significant issue. The average land use of a small PV project is 7.6 acres/MW for a fixed system, 8.7 acres/MW for a 1-axis system, and 13 acres/MW for a 2-axis system [40]. For an offsite development this may result in a significant increase in costs to purchase or lease land not owned by the ski resort. For onsite development, this represents a space that needs to be repurposed. For ski resorts there are a number of options for onsite land development for solar. Utility lots are often seldomly used and can offer a large area for a solar field. Most ski resorts have large parking lots, which could partially or fully be converted to solar roofed parking. Finally, ski resorts often have sections of land that are wooded and too flat to be developed into ski runs. This land is ripe for solar development as solar benefits in construction cost from flat areas.

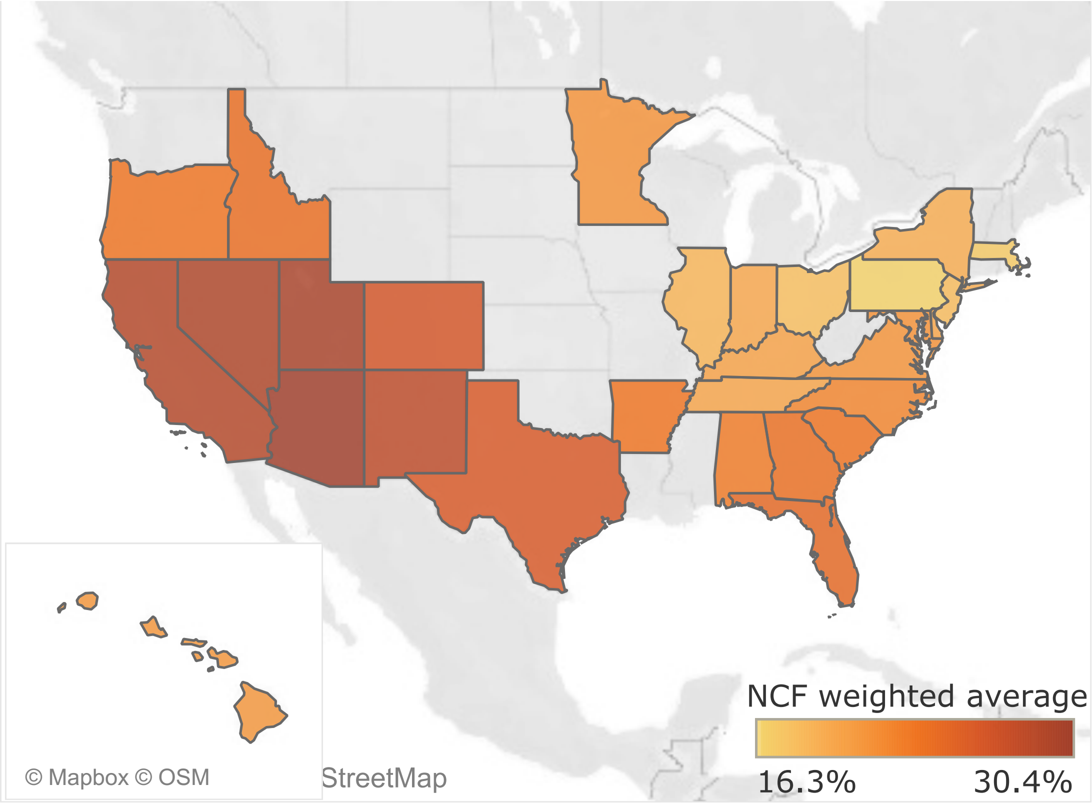


Figure 7: This figure illustrates the net capacity factor for PV systems for various states. The value is a weighted average based on capacity [39].

Finally, system sizing will depend on whether they want to maximize self reliance or be net zero on an annual basis. For example in Figure 8, Wolf Creek ski area is maximizing it's self-reliance for average generation for each hour of the day using a 3.5 MW system. However, that 3.5 MW system generates 6,000 MWh of electricity on an annual basis which is almost 3 times the electricity consumption of the lifts per year (2,300 MWh [41]). If Wolf Creek wanted to be net zero on an annual basis, they could use a 1.5 MW system to meet their electricity demands.

III.1.F Generation-Consumption Match

Solar offers a unique advantage for ski resorts in that the timing of when the energy being generated matches when energy is being consumed by ski lifts. Ski resorts have unique load profiles where the lifts generally operate between 9 am and 4 pm and solar has a unique simultaneous parabolic generation profile. These are both modeled for an offsite 35kW photovoltaic system for Wolf Creek ski area located in the San Luis Valley, which can be seen in Figure 8. Both profiles complement each other to maximize self-consumption and minimize interactions with the grid. This is advantageous for ski areas operating in states with conservative net metering policies. Coupling solar with storage could enable ski resorts to be entirely self-reliant.

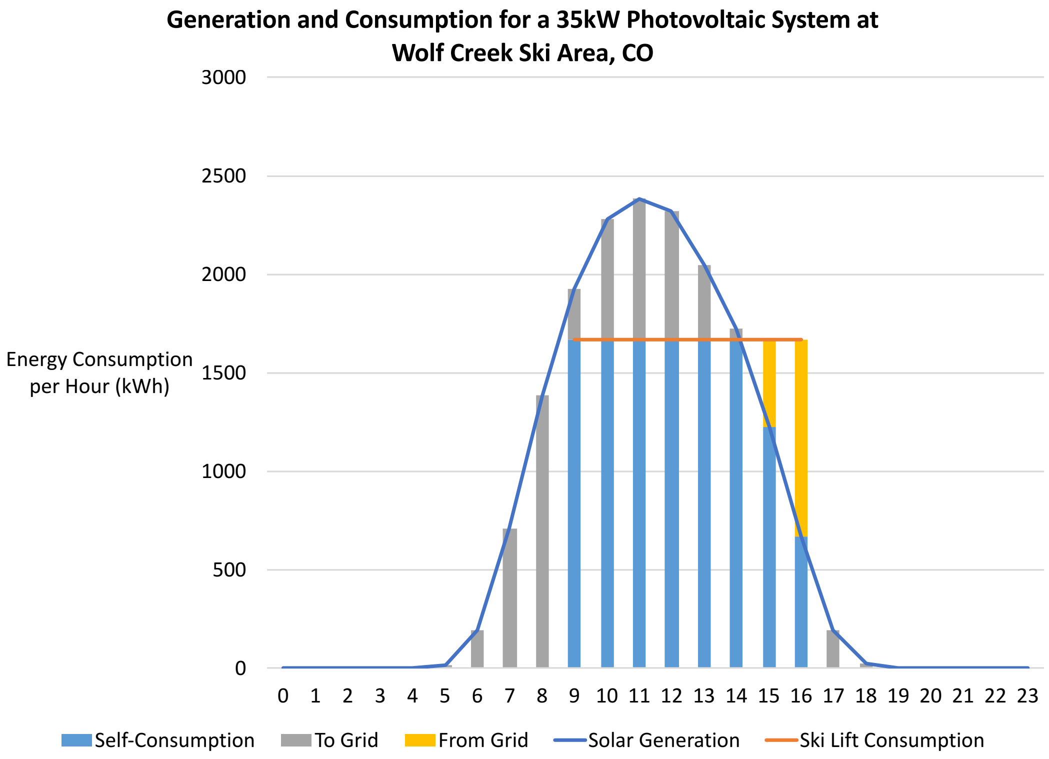


Figure 8: This figure illustrates a model for an offsite 35kW solar system for Wolf Creek ski area located in the San Luis Valley. Generation data was averaged for each hour over the entire year. Ski lifts were assumed to run consistently during operating hours (9am to 4pm) at their rated horsepower from liftblog.com [41].

Although solar matches daily consumption well, solar has seasonal mismatches with overall demand.In Figure 9, the seasonality of solar generation and Vail ski resort's electric power demand are plotted for the year. If a resort was aiming to maximize self reliance, solar would be mismatched to the demand over the course of the year. Producing excess energy during the summer months and insufficient energy during the winter months.

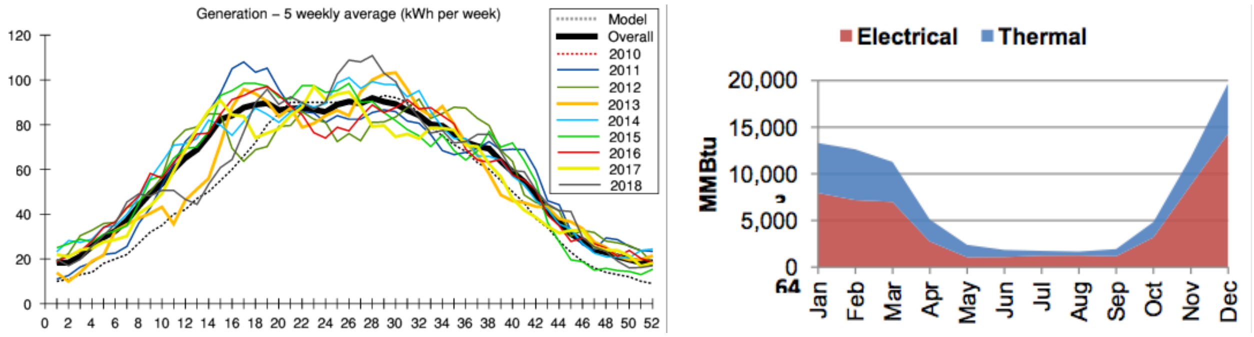


Figure 9: The image on the left illustrates the seasonality of solar generation [42]. The image on the right illustrates seasonality of electricity demand from ski resorts [14].

III.1.G Economics

To evaluate the economics of solar there are two major determinants: capacity factor and cost per watt. Capacity factor can be determined based off the amount of energy produced by the array over the course of the year. This will depend on location through insolation (GHI), tracking, and efficiency of the panel and the system. The cost per watt can be location dependant but according to NREL is approximately $1.83 per watt [33]. One-axis tracking costs 20% more and two-axis tracking costs 30% more [33].

Other minor determinants include the annual degradation rate of the panels and operation and maintenance costs. Estimates for all determinants for solar can be found below in Table 5.

Table 5: Economics determinants

Determinate	Range of Values
Capacity Factor	16.3% - 30.4%
Cost per Watt	$1.83 / W
Annual Degradation Rate	0.3% to 1% per year
Operation and Maintenance	$18 /kW-year ($8-$25)

III.2 Wind

Two wind turbines are currently operational onsite at ski resorts in the United States, Jiminy Peak and Berkshire East. They are 1.5 MW and 900 kW respectively. The Zephyr turbine at Jiminy Peak produces 4.7 GWh of electricity annually, which covers 66% of their electricity demands [15].

III.2.A Current Technology

Modern wind turbines fall into two basic groups: Horizontal-Axis turbines (HAWT) and Vertical-Axis Turbines (VAWT). HAWTs are traditional turbines with 3 blades operating upwind with the turbine pivoting to face the wind. VAWTs come in a number of different forms and operate omnidirectional, meaning they don‘t need to be adjusted to point into the wind. Utility-scale HAWTs can range in size from 100kW to several MW [43]. VAWTs are traditionally smaller scale and are technologically lagging in comparison to horizontal-axis. Traditional VAWTs range in size from a couple hundred watts to 20kW, although larger VAWTs have been built up to 4MW. Both turbine designs follow the same general energy conversion process defined by Equation (2). However, a more complete understanding of the generation potential of a turbine comes from a power curve, illustrated in Figure 10.

$$\mathrm{P} = \frac{\pi}{2} * \mathrm{r}^2 * \mathrm{v}^3 * \rho * \eta. \tag{2}$$

Where r is the radius of the turbine, v is the wind speed, ρ is the density of air, 1.2 kg/m^3, and η is the efficiency of the turbine. The efficiency factor is the amount of kinetic energy from the wind that is converted to mechanical energy and then to electricity. The average efficiency is 35-45%, the maximum theoretical efficiency is 59.6%. Air density changes with altitude and temperature and this will be discussed in Section III.2.D.

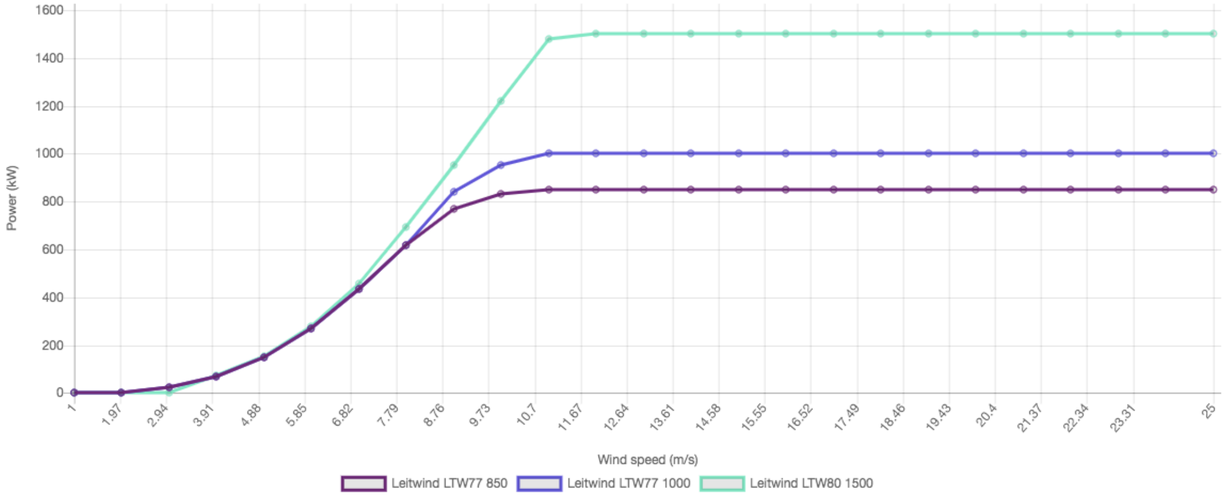


Figure 10: The image illustrates the power curves for 3 different Leitwind turbines: 850kw, 1MW, and 1.5MW. [44].

The most important factor for generating wind energy is wind speed. Consequently, it is what makes HAWTs turbines superior to VAWTs. HAWTs are typically 60 or 80 meters above ground capturing higher wind speeds and can be built with larger swept areas, πr^2. VAWTs are traditionally located lower to the ground and cannot harness the higher wind speeds. Furthermore, both turbines need smooth laminar air flow. VAWTs are typically built close to the ground where the air is more turbulent making them less efficient and increasing maintenance costs.

Although VAWTs produce less energy and can have higher maintenance costs, they come with other advantages for ski resorts. They can still produce energy in non-laminar and variable winds, which can be common in mountains [45]. In addition,they are less obstructive and quieter than HAWTs owing to their smaller size and height. This can be a particular decisive factor when applying for permits and discussing a renewable energy project with the community. They can also be clustered together, whereas HAWTs need space separation to reduce turbulence and maximize efficiency.

Overall, however, HAWTs are technically and economically superior. A single HAWT of 1MW, similar to Jiminy Peak or Berkshire East, is equivalent to 100 10kW VAWT. Furthermore, early VAWTs had significant maintenance issues due to the higher tip speeds encountered with the VAWT design. The main deciding factor is how large the barriers to building HAWTs near communities and in potentially environmentally sensitive areas.

III.2.B Future Technology

The Wind Energy Technologies Office within the Department of Energy have worked on lowering the cost of wind power. They have done this by working with turbine developers to create longer, lighter rotor blades, taller towers, more reliable drivetrains, and performance-optimizing control systems. All this has increased efficiency from 22% in 1998 to 35% today and lowered the cost of wind from over 55 cents per kWh in 1980 to under 3 cents per kWh today [46]. This work continues today making wind power one of the cheapest sources of energy available.

Icing is a major issue for wind turbines located in harsh winter weather. In Section III.2.D, icing problems will be investigated in more detail. Many companies are researching new technologies to fix the issue and expand into Northern markets. Vestas has an inhouse solution which uses an electro-thermal heating elements embedded in the laminate directly below the blade's surface. The control system has different operational modes that allow the heating elements to separately create the optimal heating level, increasing effectiveness and minimizing energy consumption [47]. The system will reduce energy production losses by 90% [47].

III.2.C Resource

The application of wind technologies is entirely dependent on wind speeds. Luckily, wind speeds are readily available at weather stations around the country and most ski lifts have anemometers. Furthermore, NREL publishes high resolution maps of wind resources at 30, 50, and 80 meters above the ground for the United States and offshore [48]. NREL classifies wind power density into 7 classes for utility-scale wind turbine applications based on abundance and quality of wind, complexity of the terrain, and the geographical variability of the resource. Considering ski resorts are likely to build on a small scale, the most important aspect of the scale is abundance and quality of the wind which can be measured using Table 6. Class 3 or greater are generally suitable for wind turbine applications, although class 2 are marginally suitable dependent on context.

Table 6: NREL Wind Classes[49]

Height	10m		30m	
Wind Power Class	**Wind Power Density** (W/m^2)	**Average Speed** (m/s)	**Wind Power Density** (W/m^2)	**Average Speed** (m/s)
1	0-100	0-4.4	0-200	0-5.6
2	100-150	4.4-5.1	200-300	5.6-6.4
3	150-200	5.1-5.6	300-400	6.4-7.0
4	200-250	5.6-6.0	400-500	7.0-7.5
5	250-300	6.0-6.4	500-600	7.5-8.0
6	300-400	6.4-7.0	600-800	8.0-8.8
7	400-1000	7.0-9.4	800-2000	8.8-11.6

III.2.D Issues and Considerations

The biggest barrier to overcome when developing wind power is permitting and red tape. Wind turbines are inherently obstructive especially HAWTs and communities are hesitant to allow them. These social and community issues can be dealt with if ski resorts engage with the community early and openly. Both Jiminy Peak and Berkshire East contended with these issues and were successful in implementing their respective turbines. Albeit, Berkshire East limited the size of their turbine to 900kW in response to community input. VAWTs are less obstructive and may have an easier time in navigating these complex legal and social pathways.

Turbine icing is a major consideration for ski resorts in areas with harsh winter weather. The reason why Jiminy Peak and Berkshire East are both practical locations for wind turbines is because they lie on the southern end of the Green Mountains where the weather is more suitable for turbines. Both resorts stated that they had minimal down time, 3 to 5 days per season, for icing issues. However, for locations on the higher peaks of the Green Mountains, the Rockies and the West Coast, we would expect more down times over the course of a season. These downtimes can contribute to significant energy loss over the course of a season. A study on a wind farm in Norway found that icing events contribute to a production loss of 14% to 22% [50]. The actual loss will be a function of how harsh the weather is onsite, however these losses can be significant. To mitigate the impact of icing there are a number of solutions. When locating the project, icing should be a consideration in the locating process. Maximizing wind speeds on a high elevation ridge may not result in maximizing energy production if the weather is too harsh. Rather locating the turbine on a lower ridge or plain with lower wind speeds may result in higher energy production. Addtionally, there are technologies for deicing. Wicetec WIPS blade-heating elements provide a 0.5mm heater along the outside of the blade that sheds any build up of ice. The heater can acheive 70% to 80% energy recover of icing losses.

Balancing the height of the turbine between energy production and visual obstruction can be difficult to balance. The most typical turbine today is a 1.5 MW GE turbine which sits on a 212 feet tower with a 116 feet blade. This makes the turbine a total of 328 feet high with a blade sweep of almost an acre. Overall, this is great for energy production, however it needs to be weighted with the community input in mind. Berkshire East originally wanted to install a 1.5 MW turbine but settled for a 900kW turbine to minimize the visual obstruction for the town.

The power produced by wind turbines is reduced when the density of air drops; this occurs at high elevation and cold temperatures where many ski resorts are located. For every percent decrease in density of air, there is an equal percent decrease in the power produced for a given wind speed. For every 5°C drop in temperature there is approximately a 1.5% decrease in the density of the air. For every 1000ft of elevation gained there is approximately a 4% decrease in the density of air. These are significant factors, however the impact of wind speed is much greater. Where these factors may make a difference is deciding to locate a turbine onsite or offsite at a lower elevation. The combination of elevation and temperature differences could impact power production by 11% if you consider a 2,000 foot elevation and 10°C difference, which would be quite usual for a ski resort in the West region.

Wind turbines suffer from a bad reputation about killing birds. However, the myth that turbines kill millions of birds is often overblown [51][52][53]. Only 150,000 to 500,000 birds are killed each year by turbines which is significantly less than other causes such as cats (3.7 billion), tower collisions (6.5 million), window collisions (300 million),and power line collisions (25 million) [51]. If the ski resort is located in an area with specific bird migration routes or endangered species, specific mitigation techniques can be employed to minimize bird collisions [54] including temporary shutdowns, night lighting, and radar bird and bat monitoring.

The footprint of a wind project is not significant. The average land use of a wind turbine is 1.5 acres/MW for the permament base and clearing [55]. The average ski resort will only require a couple MW of power which means that the footprint of the site is quite small. Furthermore, the site is just cleared of shrubs and trees so it can still be used for skiing and other activities.

III.2.E Economics

To evaluate the economic of wind there are two major determinants: capacity factor and cost per kilowatt. Capacity factor can be determined based off the amount of energy produced by the array over the course of the year. It will depend on the considerations made and location of the system but is usually between 26% to 52%; the average capacity factor in 2015 was 42% [56]. Installation costs for land-based wind power projects are broken down to 67.3% turbine costs, 22.9% soft costs, and 9.7% financial costs. The actual cost will vary but HAWTs are between $1,500 and $2,000 per kW in capital expenditure and $20 to $30 per kW per year in operational expenses [43]. VAWTs tend to have higher capital costs 2,742$/kW and similar operational expenses [57]. However, VAWTs tend to have lower capacity factors.

III.3 Hydro

While not in the US, Whistler Blackcomb Ski Resort in British Columbia, Canada is a great example to demonstrate hydropower. The Fitzsimmons hydro project is a 7.5 MW run-of-river power plant located on site between the resorts two mountains. The plant produces 32 GWh of electricity annually [13] covering the resorts annual energy consumption for it's 38 lifts, 17 restaurants, snow-making, and other buildings and services.

III.3.A Current Technology

There are two types of hydropower facilities: impoundment and run-of-river. Impoundment facilities are typical large power plants with dams that store river water in a reservoir. While run-of-river facilities channel a portion of the river through a penstock and may not require a dam. Both types of facilities could be used in the context of ski resorts and follow the same energy conversion process defined by Equation (3).

$$\mathrm{P} = \rho_{\text{Water}} * \mathrm{g} * \mathrm{H} * \eta * \mathrm{Q}. \tag{3}$$

Where ρ is the density of water, 1000 kg/m^3 , g is the acceleration of gravity, 9.8 m/s^2, H is the head of the dam, the height between the intake and the generator, η is the efficiency of the system, and Q is the flow rate of the intake.

The deciding factor between the two types of facilities is maximizing the amount of head. Since head is a multiplier for factors of nature like density, flow rate, and efficiency, developers of hydro projects will try to maximize the head of the facility by using a dam. Furthermore, a dam allows for more control of power because it allows energy to be stored and released for the operator. Although dams provide improve head and control, they come with controversial environmental effects such as degraded water quality, restricting fish passage, and destroying riparian ecosystems [58]. These environmental effects may not be palatable to mountain communities and lead to delays and permitting issues with state and federal fish and wildlife agencies. Overall, impoundment facilities may only be feasible in a select number of cases such as rivers with existing non-powered dams or snow making reservoirs.

Diversion hydropower minimizes environmental damage because they stores little or no water and can allow for fish passage [59]. This makes it more appealing for ski communities and regions concerned about watershed health. For this paper we will look at micro and small scale diversion hydro. Micro-scale hydro is defined as $< 500kW$ and small scale hydro is defined as $500kW$ to $10MW$. Both sizes are capable of meeting ski resort load.

Capacity depends on the flow rate and head. For diversion facilities, both depend on the engineering design of the dam. The flow rate will depend on the water resources available from the river but will also depend on the percent of water diverted from the river's flow rate. The percent of water diverted would be determined based on environmental limitations from state regulators or the engineering design. The head will be dependant on the limitations of the topology and amount of land available for a penstock.

III.3.B Future Technology

One of the Department of Energy's areas of hydropower technology development is in low-head hydropower and run-of-river technology. The DOE has targeted this area as an opportunity for simple, robust and economical development[60]. An example of innovation in this area is the U.S's first Archimedes Hydrodynamic Screw System seen in [60].

There are also a growing number of companies looking into micro and small scale hydro such as Turbulent, a Belgian hydropower developer. The company develops 5kW to 150kW turbines that use a vortex to produce power for low head environments (1.5 to 3.5m). Their design is fish friendly, low maintenance, easy and cheap to install, and has a long operating life (30+ years). Currently, they have 3 turbines operating in low head off grid conditions one might find at a ski resort [61].

III.3.C Resources

The application of hydro technology at ski resorts will depend on the water resources available in the area. As mentioned earlier, the power produced from a run-of-river facility is a function of two factors of nature: head and flow rate. Head can be designed around topology and the type of technology employed. Although dams are traditionally the method to maximize head, run-of-river plants can also maximize head using piping and topology, such as Whistler's project which gains 250 meters of head. On the other hand, flow rate is dependent on nature and how much of the river can be diverted into a turbine. The percentage of the river diverted can be designed based on the capacity of the turbine but also environmental regulations at the state and federal level. To predict generation potential Equation (3) can be used in conjuncture with flow data from the USGS and topology data from a GIS source.

III.3.D Issues and Considerations

Many ski resorts are located in mountain range watersheds near rivers and streams. This makes hydro a compelling technology to deploy for the industry. However, there are a number of things to consider when addressing the water resources.

Variations in flow rate can cause low capacity factors for the facility if the turbine is designed for higher flow rates. Therefore, to maximize the utility of the facility, one should design the turbine to operate at a mean flow rate for the year.

There are many water resources, especially at high altitude, that have no flow during the winter. The Fitzsimmons project can be shut down for periods at a time when flow rates drop. To maintain power production over the course of the year, a ski area could locate the facility at a lower elevation in the watershed. The example below shows the flow rates for various locations, see Figure 11, in the Gallatin Watershed near Big Sky, Montana. Table 7 shows the average and peak flow rates for these locations. At higher elevation the flow rate is lower but increases quickly as you fall in elevation. If one were to locate a facility at a lower elevation location, it would see a more consistent flow rate for power production over the course of the winter. Albeit, it may require a ski resort to build offsite.

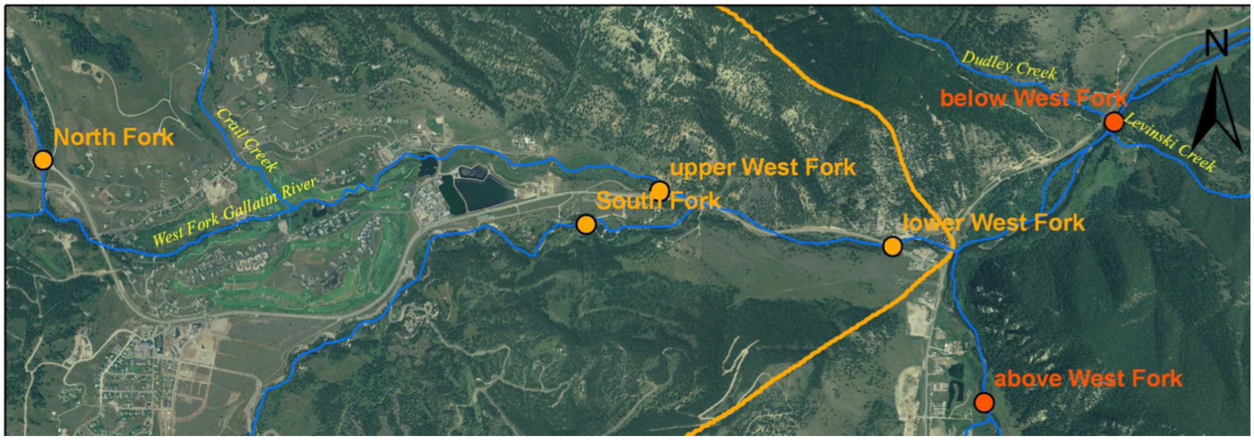


Figure 11: The image illustrates an offsite 1 MW facility for Big Sky Ski Area in Montana. It is modeled on the Gallatin river UGIS flow site with a 25 m head, a 40% diversion, and a 60% efficiency for three days.

Table 7: Gallatin River Flow Rates

Location	Elevation	Peak Flow	Mean Flow
North Fork	6414’	60cfs	35cfs
Upper West Fork	6108’	400cfs	100cfs
Lower West Fork	6030’	900cfs	300cfs
Gallatin River	5193’	2700cfs	758cfs

Periodic drought conditions must also be considered when evaluating hydro projects. California’s 2007 to 2009 drought reduced hydroelectric generation by 20% and the 2011 to 2015 drought reduced hydroelectric generation by 40% compared to average [62]. This can be costly for ski resorts because it makes them more susceptible to drought conditions as droughts are also correlated with declines in skier visitations.

III.3.E Generation-Consumption Match

Unlike large downstream rivers, rivers located in mountainous regions are highly variable on a daily and seasonal basis. On a daily basis, the flow rate is variable based off the snow melt, which means that similarly to solar, the power generation is parabolic with time. This matches the unique load profile of ski lifts. In Figure 12, a offsite 1 MW facility for Big Sky, Montana is modeled on the Gallatin river for three days. As you can see the load and generation profiles can be designed to match over the course of the day. Overall, run-of-river hydro continuously produces even at night, which means that there is lots of excess generation with a hydro plant.

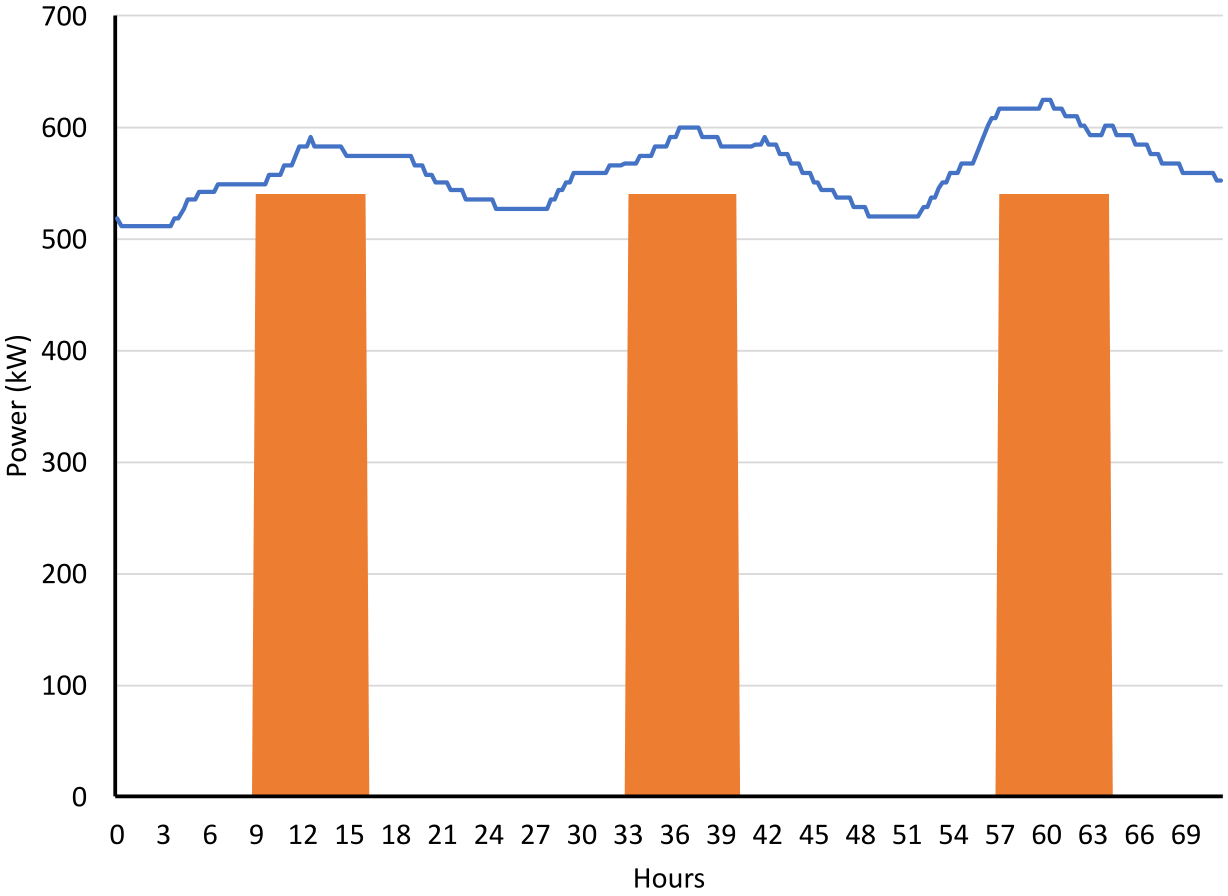


Figure 12: The image illustrates an offsite 1 MW facility for Big Sky Ski Area in Montana. It is modeled on the Gallatin river UGIS flow site with a 25 m head, a 40% diversion, and a 60% efficiency for three days.

On a seasonal basis, water resources at high elevations are extremely variable corresponding to spring runoff with high flow rates during the spring and summer months and little to no flow during the fall and winter. This creates a mismatch between when the energy is being generated and when it is consumed. The flow rate for the Gallatin River USGIS site can be found in Figure 13. If you compare the flow rate in Figure 13 to the consumption profile for a ski resort, such as Vail's in Figure 9, you will find they are mismatched over the course of the year. When accounting on an annual basis or net metering this is not an issue. Although, these rules vary from state to state, see Section II.4.

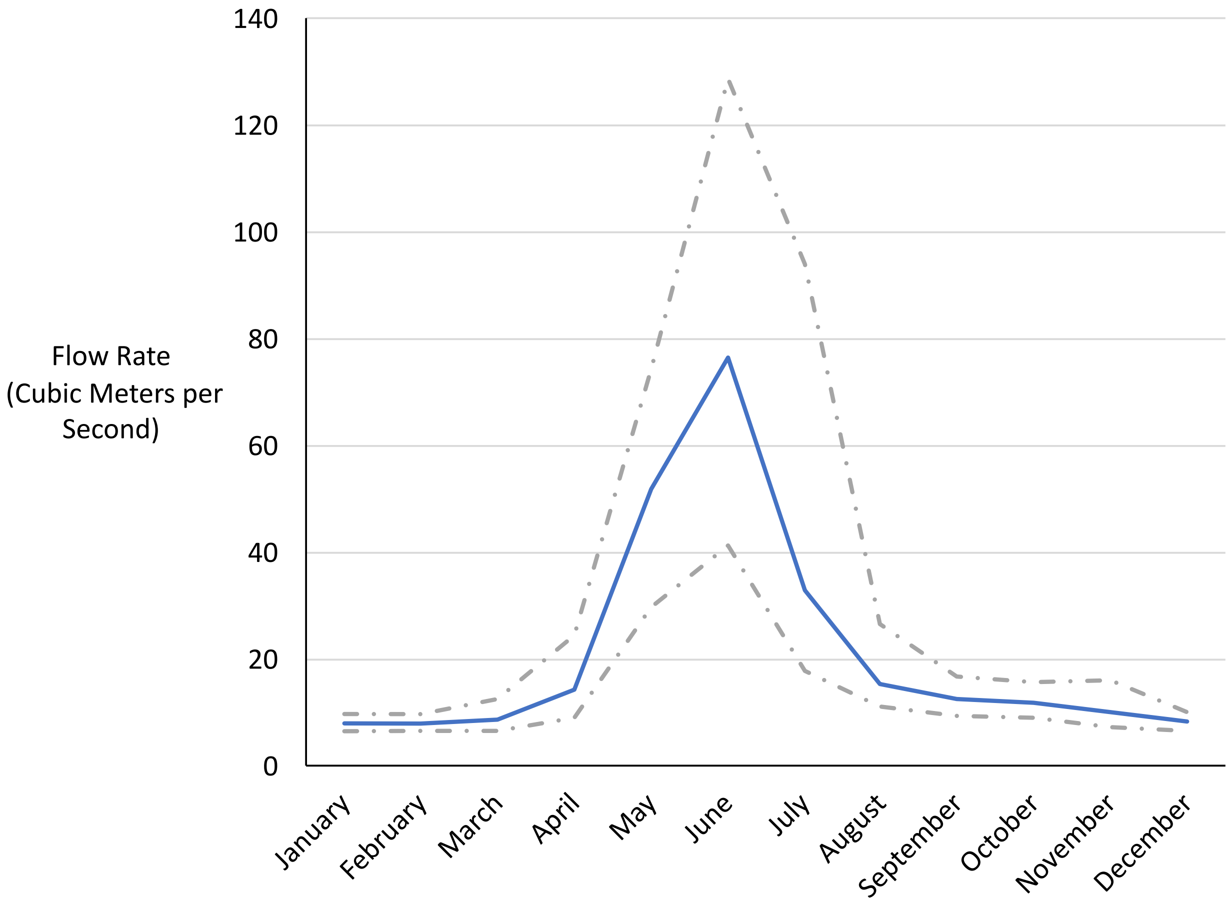


Figure 13: The image illustrates the average monthly flow rate for the Gallatin river UGIS flow site. The upper and lower grey lines illustrate the maximum and minimum average monthly flow rates for each month between 2000 and 2018.

III.3.F Economics

To evaluate the economics of hydro there are two major determinants: capacity factor and cost per watt. The capacity factor depends on the capacity, flow rate, head, and other consideration discussed in this section. The costs depend on the head and capacity of the facility as seen in Figure 14. The actual cost will vary but generally range between $1,300 and $6,000 per kW [63]. OM costs typically vary between 1% and 4% [63]. Major advantages of hydro over other renewables are the consistency of energy and low levelized cost of energy.

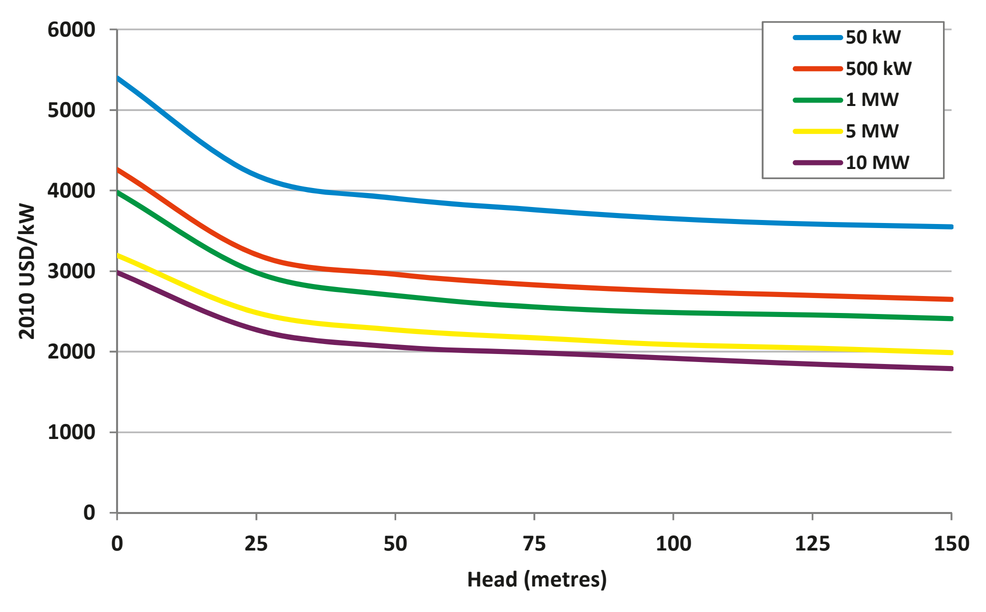


FIGURE 4.3: INVESTMENT COSTS AS A FUNCTION OF INSTALLED CAPACITY AND TURBINE HEAD

Source: Based on Kaldellis and Kondili, 2005.

Figure 14: The image illustrates the cost of building a hydro facility for a variety of capacities and head. Sourced from Kaldellis and Kondili, 2005.

IV Economics and Market Analysis

This section will explain a step by step process to evaluating renewable energy potential at a general ski resort and use that process for two example resorts, Cranmore Mountain Resort New Hampshire and Big Sky Resort in Montana. The resorts were chosen to evaluate two ends of the spectrum of ski resorts and the availability of data. The two resorts were also chosen because they lie on different ends of Bill Jensen's tiers; Big Sky is more closely related to an Alpha resort and Cranmore a Status Quo resort. It was also important to highlight the differences in renewable resources between the East and West coast, their locations are illustrated on the map in Figure 15. At both resorts, weather data was available.

Figure 15: The map illustrates the locations of both resorts. The red label is Big Sky Resort, MT and the purple label is Cranmore Mountain Resort, NH.

The central aspect of this economic analysis will be the levelized cost of energy for the various renewable technologies in order to meet their annual generation needs. The levelized cost of energy (LCOE) can be calculated using Equation (5).

$$\mathrm{LCOE} = \frac{\sum \frac{I_t + M_t}{(1+r)^t}}{\sum \frac{E_t}{(1+r)^t}}. \tag{4}$$

where I_t is the investment expenditures in year t including financing, M_t is the maintenance expenditures in year t, E_t is the electricity generation in year 5, and r is the discount rate. For this analysis we will use a discount rate of 8% based on the USA results from Grant Thorton's renewable energy discount rate survey in 2017 [64].

IV.1 East Coast Example: Cranmore Mountain Resort NH

Cranmore Mountain Resort, New Hampshire has a vertical rise of 2000 feet with 8 lifts, of which 5 are chairs and 3 are surface lifts. There are 4 buildings at the base of the mountain and the resort relies heavily on snowmaking. An estimate for energy usage for the resort is 7,000 MWh; This puts it on par with similar medium size East Coast resorts with snow making. A breakdown of renewable energy resources and lands available can be found in Table 8.

Table 8: Cranmore Renewable Energy Resources and Land

Attribute	**Cranmore Mountain Resort**
Solar Potential GHI (kWh/m^2 per day)	
On-Site	3.75
Off-Site	3.81
Wind Potential (V_{avg} at 30m)	
On-Site	4.0 to 4.5 m/s
Off-Site	5.0 to 5.5 m/s
Hydro Potential (H, Q_{avg})	
On-Site	None
Off-Site	1m to 100m+ , 28.3 m^3/s
Land (acres)	
Parking Lot	8.92
Building Roofs	1.75
Open Space	0-2.42+

Table 9, displays the economic results from the LCOE analysis. Each resource was sized to meet the annualized energy demand of Cranmore Mountain Resort, 7,000 MWh. The commercial rate of electricity in North Conway, NH is 12.88 ¢/kWh. All the resources except on-site wind and off-site hydro fall below this threshold making them cost-effective.

All solar options are economically viable for development. The biggest barrier for development is the amount of land required to supply the resort for energy. Onsite development could be possible if more open space is created through clear cutting forests owned by the resort. This type of land reclamation was not included in Table 8. However, 40 to 50 acres is a lot of land to develop. On the other hand, offsite development provides better solar resources and could be more practical by reclaiming a plot of unused open land. This is the biggest uncertainty in costs for off-site development. This model assumed $3,000 per acre which was sourced from property listings in rural areas of Conway, this number could be higher depending on the site chosen. Two-axis tracking is the best system and maximizes collection of the weak solar resource. Two-axis tracking also mitigates any snow shedding issues.

The wind estimates were created using mean wind speed data from NREL and a Weibull wind distribution with a standard deviation of 5.452 mph. This is because location specific public

Table 9: Cranmore Mountain Economic Results

	LCOE 20yrs ($/kWh)	**LCOE 30yrs** ($/kWh)	**Capacity Required** (MW)	**Total Capital Cost** ($)	**Land Usage** (Acres)
Solar (Fixed)					
On-Site	0.1079	0.1045	5.2	9,516,000	39.51
Off-Site	0.1074	0.1039	5.1	9,450,351	38.76
Solar (1-Axis)					
On-Site	0.1173	0.1144	4.65	10,211,400	40.45
Off-Site	0.1163	0.1134	4.55	10,096,495	39.58
Solar (2-Axis)					
On-Site	0.1026	0.1008	3.7	8,802,300	48.1
Off-Site	0.1016	0.0997	3.6	8,704,800	46.80
Wind (HAWT)					
On-Site	0.1662	0.1630	7.5	11,250,000	11.25
Off-Site	0.0921	0.0903	4.5	6,750,000	6.75
Hydro					
On-Site	-	-	-	-	-
Off-Site	0.1254	0.1190	1.70	10,158,000	4 km

wind speed data was unavailable for Cranmore Mountain Resort. Unfortunately this made the results very sensitive to changes in the granular data from NREL. The NREL wind speed map can be found in Figure 16. The onsite results represent a mean wind speed of 4.0 m/s and the offsite results represent a mean wind speed of 5.0 m/s. Should the actual onsite wind speeds correspond closer to the offsite speeds, the results would be adjusted to a more economic outlook.

Understanding these sensitivities, wind is the most economic option. However as the resort is located near National Forest Land and pristine White Mountain Wilderness, it would not be hard to foresee significant resistance to a wind development in this region, either onsite or offsite. They would need to work with the community from the start of the process to help them understand the benefits and create a meaningful relationship between the resort and the region. Furthermore, a more comprehensive understanding of icing risks should be studied.

Finally, Hydro is both not cost effective nor feasible. There is no onsite water resources because the stream located by the resort does not have sufficient flow rate. The offsite water resources are not particularly favorable either. The Saco River, located along the valley where the resort is located, is a meandering river with little vertical drop. Assuming a diversion rate of 30%, it would require a penstock 4km long to achieve a head of 12m, which would meet the energy demands of the resort. To create a 4km penstock, huge amounts of land would need to be purchased or a right of way for the penstock would need to be established. Both would require extensive costs and meet administrative barriers.

Overall, Cranmore resort could develop renewable energy using either wind or solar power or a combination of the two. Each face moderate barriers. Solar faces extensive land usage

Figure 16: The image illustrates the mean wind speeds around Cranmore Mountain Resort.

barriers. While, wind faces redtape and permit issues within the community. Both are surmountable obstacles through either offsite development or a strong community relationship, respectively.

IV.2 West Coast Example: Big Sky Resort MT

Big Sky Resort, Montana has a vertical rise of 4,350 feet with 36 lifts, of which 24 are chairs and 12 are surface lifts. There are many buildings and hotels at the base of the mountain and the resort minimally relies on snowmaking. An estimate for energy usage for the resort is 7,000 MWh; This puts it on par with similar large size West Coast resorts without significant snow making. A breakdown of renewable energy resources and lands available can be found in Table 10.

Table 11, displays the economic results from the LCOE analysis. Each resource was sized to meet the annualized energy demand of Big Sky Resort, 7,000 MWh. The commercial rate of electricity in Big Sky, MT is 9.79 ¢/kWh. On-site 2 axis solar tracking, wind, and hydro are all cost-competitive with the utility electricity rate. Wind and hydro are significantly cost-competitive with the utility.

Fixed and 1-axis solar are both close to being cost-competitive with the utility rate. Even though they are more expensive today, Big Sky resort should still consider developing 1-axis and fixed solar for specific uses such as solar covered parking and rooftop solar. This will lessen the burden of land development of other renewable technologies.

2-axis solar tracking was cost competitive with the utility rate. The biggest barrier for

Table 10: Big Sky Resort Renewable Energy Resources and Land

Attribute	**Big Sky Resort**
Solar Potential GHI (kWh/m^2 per day)	
On-Site	4.112
Off-Site	4.969
Wind Potential (V_{avg} at 30m)	
On-Site	4.5 to 6.5 m/s
Off-Site	6.0 to 7.0 m/s
Hydro Potential (H, Q_{avg})	
On-Site	1m to 40m, 3m^3/s
Off-Site	1m to 100m+ , 21.5 m^3/s
Land (acres)	
Parking Lot	11.44
Building Roofs	3.32
Open Space	3-11+

Table 11: Big Sky Resort Economic Results

	LCOE 20yrs ($/kWh)	**LCOE 30yrs** ($/kWh)	**Capacity Required** (MW)	**Total Capital Cost** ($)	**Land Usage** (Acres)
Solar (Fixed)					
On-Site	0.1013	0.0981	4.8	8,784,000	36.47
Off-Site	0.1088	0.1042	4.55	9,474,465	34.58
Solar (1-Axis)					
On-Site	0.1073	0.1046	4.2	9,223,200	36.54
Off-Site	0.1127	0.1089	3.95	9,670,785	34.36
Solar (2-Axis)					
On-Site	0.0947	0.0931	3.35	7,969,650	43.55
Off-Site	0.1032	0.1000	3.15	8,681,400	40.95
Wind (HAWT)					
On-Site	0.0745	0.0731	3	4,500,000	4.5
Off-Site	0.0629	0.0617	3	4,600,000	4.5
Hydro					
On-Site*	0.0402	0.0382	0.635	2,540,000	1.8 km
Off-Site	0.0643	0.0610	1.24	5,053,652	2.4 km

development is the amount of land required to supply the resort for energy. On-site development could be possible if more open space is created through clear cutting forests owned by the resort. This type of land reclamation was not included in Table 10. This type of land reclamation will add to the cost of developing on-site solar. Off-site solar provides some advantages for developing. The site chosen for off-site developing near Big Sky is the West Yellowstone region. In this area there are numerous areas of unused open land for sale that could be developed for solar. This model assumed a value of $29,000 per acre based off property listing in the West Yellowstone region for large lots. Two-axis tracking maximizes the collection of solar energy and also mitigates any snow shedding issues.

The wind estimates were created using mean wind speed data from NREL and a Weibull wind distribution with a standard deviation of 5.452 mph. This is because location specific public wind speed data was unavailable for Big Sky Resort. Unfortunately this made the results very sensitive to changes in the granular data from NREL. The NREL wind speed map can be found in Figure 17. The on-site results represent a mean wind speed of 5.0 m/s and the off-site results represent a mean wind speed of 6.0 m/s. The off-site results assume a offsite facility in the Madison River Valley, to the west of Big Sky. The results also assume a power curve corresponding to a GE 1.5 MW wind turbine [65]

Wind is a very cost-effective option. Although, the resort is located at a high elevation in a mountainous region so icing problems and community and social issues due to obstructed views should be considered. At the offsite location, the Madison River Valley is fairly rural and the weather is less harsh making it more feasible for wind development.

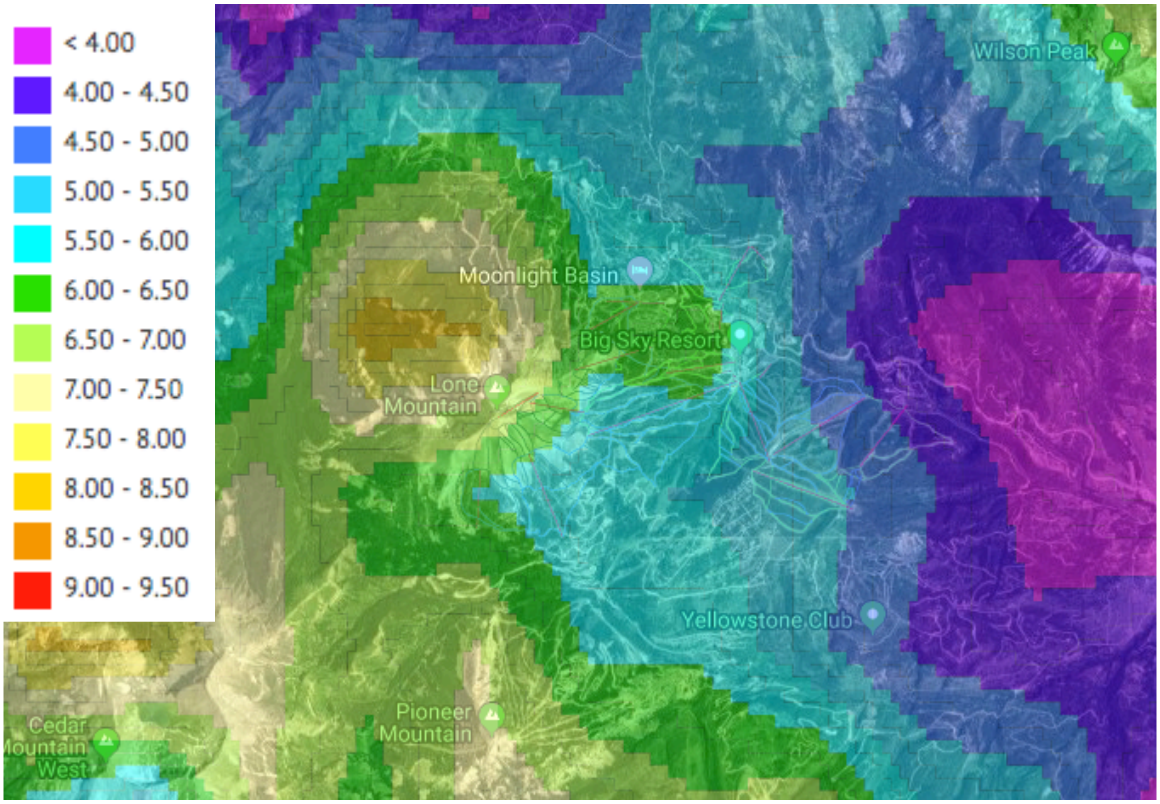


Figure 17: The image illustrates the mean wind speeds around Big Sky Resort.

Finally, hydro is the most cost effective option and fairly feasible for both onsite and offsite development. The onsite development would be located at the Big Sky golf course on the West Fork Gallatin River with the intake at Lone Mountain Trail road and the discharge near the water treatment plant. The only obstruction to the golf course would be the penstock running along side the river. Figure 18 illustrates the route. The facility would divert 80% of the mean flow rate and have a head of 40 meters. A caveat to the hydro development is that it could not meet the needs of the resort do to limitations in land ownership and the water resources available; the facility would produce 5.5 MWh per year. The facility could be extended farther down the river increasing the head and power production if more land is purchased or right of way for the penstock is secured.

Figure 18: The image illustrates the route of the penstock.

The offsite facility was assumed to be located at the USGIS Gallatin River monitoring site. The development would have a head of 25m, a penstock of 2.4km, and a diversion rate of 40% of the mean flow rate. The facility would produce enough energy to meet the energy needs of the resort. The offsite facility would be slightly more expensive because of it's increased size and the need for land.

Both hydro projects face different barriers to development The onsite hydro facility diverts a significant amount of water to maximize power generation, this may cause issues when facing the scrutiny of state and federal water agencies. The offsite hydro facility diverts a moderate amount of water, however recreational activities and fish should have no problems navigating the resulting flow. Land will be the primary issue for developing the offsite facility, acquiring the appropriate land for the development may be difficult depending on who owns the land by the river.

Overall, Big Sky resort could develop renewable energy cost-effectively using either wind, solar, or hydro power or a combination of the three. Each face moderate barriers. Solar facing extensive land usage barriers. While, wind faces redtape and permit issues within the community for onsite and offsite development and icing problems for onsite development. Hydro seems to have little barriers, however state and federal regulations and land usage issues may delay or prevent development. All are surmountable obstacles through either offsite development or a strong community business relationship.

V Conclusion

Renewable energy is important for ski resorts to maintain and grow the industry into the future. There is a great opportunity for ski resorts to lead the way to a green future. The report finds that all three renewable technologies (Solar, Wind, and Hydro) are feasible and appropriate for implementation at ski resorts with individual considerations to be taken in context. There is a renewable energy option for every ski resort, however there is not a single solution for all in the context of barriers and technologies. Overall, there is an opportunity for ski resorts or a third party to take the lead on renewable development.

V.1 Conclusion for Ski Resorts

The majority of ski resorts may not feel the brunt of climate change today, however they will in the future. Both Berkshire East and Jiminy Peak have demonstrated that renewable energy can not only help in the fight against climate change but when the effects of it come renewable energy will be the key for survival. Both resorts stand alone in Western Massachusetts as success stories as resorts around them fall to shorter seasons, higher snow making costs, and the lack of energy security. Every ski resort has the potential to implement renewable energy and many are in prime regions for development. It takes foresight but the benefits far out weight a new chairlift,lodge, or groomer in the long run.

V.2 Conclusion for Skiers and Snowboarders

Ski resorts need to take action on their emissions, however we too as skiers are responsible for our actions. A report from the French NGO Mountain Riders found that your mode of transportation is responsible for 73% of your carbon emissions for a day of skiing [66]. This study was done in France and assumed many of the visitors were flying from places like Paris, Germany, and England. Albeit, our actions on how to get to the resort is a big piece of the puzzle. There are many alternatives including carpooling, electric cars, and public transportation that bring down your carbon footprint and help protect our winters. To learn more about the effects of climate change on the ski and snowboard industry please read the POW annual report and join the organization at www.protectourwinters.org. There is also a responsibility for skiers to support the ski resort’s in the process of developing renewable technologies by helping convince the community to go green, sign ”petitions” to support development, and learn about green energies through education.

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Appendices

Appendix A Financing Calculations

The financing calculations were made using a model from NREL's To Own or Lease Solar:Understanding Commercial Retailers' Decisions to Use Alternative Financing Models. The model was adapted from a example in San Diego, California to Wolf Creek Ski Area, Colorado. This effected assumptions such as state and federal combined tax rate, capacity factor, and price per watt. These assumptions can be found in Table A.0.

Table A.0: Model Assumptions

Characteristic	Value
Installed PV price	\$2.39/WDC
Inverter Replacement Cost	\$0.13/WDC
Location	Center, CO
Size	1 MW
Capacity Factor	21%
Annual Degradation Rate	0.50%
O and M Costs	0.50%
Inflation Rate	2.00%
Project Lifetime	20 years
Incentives	30% Federal tax credit
	5-year Modified Accelerated Cost Recovery System (MACRS) depreciation schedule
	No State incentives
Total Tax Rate	40.2%
Project Lifetime	20 years

The calculation for the cash flow analysis can be broken up into positive annual cash flows, negative annual cash flows, and one time expenses. The positive cash flows are revenue from energy sales/savings, depreciation tax credit, and tax cost deductions. The negative cash flows are operation and maintenance costs and taxes on revenue from energy sales/savings. One time expenses are the initial capital cost and the cost of replacing inverters at year 10.

The revenue from energy sales and savings is the quantity of energy produced in one year multiplied by the commericial rate of electricity. It should be noted that the amount of energy produced degrades from year to year over the lifespan of the project. The depreciation tax credit is the tax savings from the MACRS depreciation schedule. More information on the MACRS depreciation schedule can be found onlin. The tax cost deductions are typical coporate deductions one can take on costs for the company, in this case it's on the cost to maintain the project each year.

The operation and maintenance costs each year are a function of the cost of the entire project. Using the assumptions from NREL, the OM costs are 0.50% of the project cost annually.

The taxes on revenue of the energy sold or saved are simply taxes you would pay on any revenue. It should be noted that energy savings are treated in the same manner as energy sales because by savings energy you are not entitled to the tax deduction if you were to buy that energy.

The initial capital cost is the cost of the project minus the savings from the federal tax incentive. The federal tax incentive savings are tax deductions on 30% of the value of the project. The inverter replacement occurs in year 10 and is a one time cost in year 10.

Appendix B LCOE Calculations

The levelized cost of energy calculations were made using Equation (5). The assumptions for cost of each component of I and M were made dependent on the type of technology from the economics section of Section III. This section will evaluate how the calculations for expenses and energy were made for each technology.

$$\text{LCOE} = \frac{\sum \frac{I_t + M_t}{(1+r)^t}}{\sum \frac{E_t}{(1+r)^t}}. \tag{5}$$

B.1 Solar

The investment cost calculations were made using NREL's commericial benchmark report [33]. The cost per watt was $1.83 for fixed, $2.20 for one-axis tracking, and $2.38 for two-axis tracking. The maintenance cost were simplified to 0.5% of the systems cost [25]. The offsite property costs were estimated using zillow.com to find the average property cost for lots and land in the location of interest. For Cranmore Mountain Resort the location of interest was south of Conway,NH and for Big Sky Resort this was the West Yellowstone region.

The energy calculations were made using globalsolaratlas.com and finding the average energy production per day. For one-axis and two-axis tracking options, we used PV watts to estimate a percentage increase for the area. The reason why global solar atlas was used for the calculations in comparison to PV watts is because global solar atlas can more accurately model large facilities.

B.2 Wind

The investment cost calculations were made using the Department of Energy's 2017 Wind Technologies Market Report [43]. The cost per kW was estimated at $1,500. The maintenance costs were estimated at $20 per kW. The offsite property costs used the same methdology as the solar resourcees. For Cranmore Mountain Resort the location of interest was in the North Conway, NH area. For Big Sky Resort, the location of interest was Ennis, MT in the Madison River Valley.

The energy calculations were made using NREL's wind prospector [48]. Find average wind values for where turbines could be built. The average wind values were distributed into a Weibullwind distribution with a standard deviation of 5.452 mph. This distribution outputted a frequency distribution which was scaled to the number of hours per year for each wind speed. This was then imposed onto the power curve of a GE 1.5 MW turbine to generate energy potential.

B.3 Hydro

The investment cost calculations were made using the Kaldellis and Kondili 2005 cost curves Figure 14. For Big Sky resort, since the penstock and facility was shorter and more feasible a lower installation cost of \$4,000 per kW was used. While for Cranmore Mountain Resort, the long penstock and less feasible outlook meant that a higher estimate was needed of \$6,000 per kW. The maintenance for both facilities was estimated at 1% of the system cost.

The energy calculations were made using the average flow rate and topological limitations to size the facility to meet the ski resort load. For onsite developments, the diversion rate was allowed to be a maximum of 80% of the flow rate. For offsite developments, the diversion rate was limited at 40% because these were larger public waters. The flow rate data was gathered from the USGIS or independent flow rate studies online. The topology data was gathered from caltopo.com and using property lines to map out the limitations on how long a penstock could be and therefore how much head could be gained.