Sustainability of Artificial Snowmaking

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15 June 2018

Abstract

The sustainability of artificial snowmaking is becoming less and less each year as more and more water and air is needed to supply the needed snow due to unpredictable weather patterns and warmer temperatures throughout the world. Our current energy consumption is mainly through the use of hydrocarbon based fuels like oil and gasoline which releases tremendous amounts of carbon dioxide, nitrogen oxides, and many other harmful pollutants that contribute to the Greenhouse Effect. Not only does energy use affect the environment but so does taking water out of ecosystems like artificial snowmaking does. As water is removed, ecosystems are altered and are usually harmed as a result. Snowmaking is currently an unsustainable practice and will continue to be unless ski resorts begin to use more water efficient systems and use renewable energy instead of fossil fuel based systems.

This paper examines three possible alternatives to the current situation and are solar, wind, and biomass based energy sources. Solar is renewable and is also a viable option in Vermont's landscape but is a bit more expensive than biomass and wind energy. Biomass is by far the least expensive but still releases carbon dioxide and many other harmful pollutants into the atmosphere and environment. Wind energy is also relatively inexpensive and a clean energy source with no atmospheric emissions. This research and calculated data show that wind energy is the most viable alternative to current energy efforts as wind energy is both affordable for ski resorts and has a very neutral impact on the surrounding environment. Although wind seems to be a clear winner, each situation is different and each of these alternatives are viable options to supply renewable energy to ski resorts. All offer major cost savings which scale up to hundreds of millions of dollars over 25 years for all of Vermont's ski resorts.

On top of becoming more renewable energy dependent, more efforts can be taken to ensure the least environmental impact. These include using high efficiency snow guns, installing more efficient lighting, maximizing snow output by using the correct type of snow gun on certain areas of a mountain, using Energy Star appliances throughout the resort, and to make use of passive solar building designs. These efforts are in hope to reduce the environmental impact of the ski industry in order to keep skiing alive for generations to come by protecting the environment.

Introduction

The purpose of this research is to look at viable alternatives to the current energy uses at ski resorts in Vermont. Vermont is one of the leading states in renewable energy production and use. Currently 25.8% of the energy in Vermont is produced from renewable sources, mainly biomass and hydroelectric production(U.S. Energy..., 2017). The Vermont Comprehensive Energy Plan has goals of being 90% renewable by 2050(Silverman, 2017). This would be a major success if this is accomplished in the future and would have many environmental benefits. Current energy use is about 64.8% hydrocarbon fuel based which is better than average energy consumption countrywide but should be reduced in all areas as combustion of these fuels releases CO_2 and other harmful pollutants. These pollutants catalyze the greenhouse effect and cause many harmful environmental effects such as acid rain, ocean acidification, and unpredictable weather patterns.

Ski resorts on average use around 10.4 million kWh per year of energy which is then multiplied by sixteen when looking at all sixteen ski resorts in Vermont(Efficiency Vermont, 2004). Though, these numbers are just averages and were taken in 2004 which may not reflect recent changes in ski resorts such as upgraded lifts, upgraded snow making fans and guns, more energy efficient technology, and other changes. These alterations are not taken into account in this report and while there may not have major differences in numbers and energy use, there may be slight discrepancies in current energy use versus energy use in 2004.

Snowmaking has an environmental impact not only as producing an artificial environment but also as using fossil fuels in many of the activities that take place. One of the main goals of this report is to offer alternative energy sources that will not only have a positive impact into the future on global energy use and environmental effects, but also cost savings in using renewable energy sources. It will be shown that most renewable energy sources have a low payback period and offer millions of dollars of savings over the lifespan of these renewable sources as opposed to current energy consumption that relies on electricity production from hydrocarbon based fuels (gas, oil, coal, LPG, etc.). The current status of the environment demands that action be taken in reducing carbon dioxide emissions and ski resorts can be an industry that paves the way into the future.

Other ways to save energy will also be explored, mainly the different types of snow guns that are currently on the market and how the ratio of energy to the amount of snow produced can be maximized based on the type of gun whether it be a traditional, tower, or a fan snow maker. There are also many other ways in which energy use can be reduced such as using efficient lighting systems, low energy appliances in cafeterias, and even placing windows directed at the sun as to improve efficiency and use direct heating less, a.k.a. passive solar building design. While these energy saving ideas won't be further elaborated upon, they are all viable options in reducing energy use across all ski resorts.

Methodology

This research was conducted using a 2004 report from Efficiency Vermont that detailed average energy use in Vermont ski areas. This data is reported in table I in the raw data index. Conversions were then used to convert these energy values to btu and then converted to a cost at the average price for commercial electricity in Vermont today. These numbers were then scaled up to reflect all sixteen ski resorts in Vermont currently. This data is reflected in table II. The energy sources were then analyzed in Vermont and the percent breakup of energy usage was recorded in table IV. Table III reflects the energy needed in order for ski resorts to be 100% renewable energy dependent. This was calculated by taking 75.8% of the total energy since 75.8% of energy used currently is non renewable. This other 24.2% is considered to come from renewable sources and is not accounted for in further calculations. Tables VI, VIII, and IX reflect the above calculation where different energy producing systems are analyzed using the data calculated in table III.

Table V shows the percent of energy that ski resorts consume in Vermont's commercial sector. All energy related calculations that refer to different percentages were calculated using data off of the EIA's website using most recent data profiles. Tables VII and X describe the cost analysis for different energy systems and their return on initial investment periods.

All data is calculated using average pricing and average energy consumptions. Pricing is taken from most recent estimates while energy is assumed to have stayed consistent since 2004. This does leave room for error as recent renovations and upgrades to many ski resorts may affect energy consumptions and current efficiency. There have also been many efforts recently at ski resorts worldwide to decrease the impact on surrounding environments and become more renewable energy dependent. Some of these efforts will be discussed later in the research. Energy estimates are only taken as estimates. There may be some variation in current numbers but the values used should accurately reflect current ski resorts.

Discussion

Snowmaking accounts for about 73% of all energy used at ski resorts. Air needs to be constantly compressed and water needs to be constantly pumped uphill which takes much energy especially when considering the volume of both that are used in this process. In past years, these systems have become more efficient due to technological advancements and also due to scientific analysis which has determined the most efficient ratios of water to air in this system which maximizes snow output to energy efficiency. There are also multiple types of snow guns that can be used during this process which all have different benefit and drawbacks depending on humidity, temperature, and area in which snow is being made. The two categories of snow guns are internal and external mix snow guns. There are also snow fans that are widely used which uses both an on board air compressor and a fan which propels the snow forward and mixes with water particles to disperse the produced snow.

Internal mix snow guns mix the compressed air and water inside of the chamber before it is expelled out into the air. External mix guns rely on the mixing right outside of the chamber and snow fans use high powered fans and compressed air to mix the water particles and air. On average, snow fans use about 25% of the electricity that internal mix guns use and also can produce snow in the widest range of temperatures and conditions and produces snow over the widest area (Blanchard). Each system has its benefits and drawbacks and each should be analyzed to determine maximum efficiency for specific situations. Snow fans are the most energy efficient of each system, produces snow over a wide area, and is generally suitable in most snowmaking conditions. Internal mix guns are resistant to wind, are light and portable, and generally cover a wide trail area. External mix guns are more energy efficient than internal mix guns and they are quieter and easier to operate (Peaks to Prairies).

Making the best use of each type of snow producing system will maximize efficiency and reduce yearly cost for electricity. It would also increase efficiency in water consumption which would have positive effects on surrounding ecosystems. Increasing efficiency in lighting systems has the ability to save 20-60% of energy used on lighting. Energy Star appliances also have the ability to reduce electricity consumption and should be taken into consideration when looking for ways to decrease electricity use and increase efficiency (National Ski Areas Association). Also, new lift systems have the ability to reduce electricity consumption but also do pose significant initial costs which may outweigh the investment.

When analyzing efficiency and sustainability, the source of electricity production also has to be taken into account. Currently in Vermont, 74.2% of energy consumed is derived from fossil fuels and hydrocarbon based fuels. Disregarding all current clean energy programs at ski resorts in Vermont, only 25.8% of energy consumed is derived from renewable energy sources (U.S. Energy Information Administration 2017). Therefore to be 100% renewable energy based, 74.2% of current energy consumption must be provided by renewable energy sources. The rest of this paper is focused on different ways to provide this needed energy and the cost analysis that is included with each energy source. The sources analyzed include biomass, solar, and wind energy. More data on energy sources can be obtained from tables IV and V.

Each of these sources reduce the carbon footprints that ski resorts have and this is important as the environment is the most vital aspect of a ski resort. Global warming is having harmful effects throughout the world but within the ski industry, cold temperatures and high rates of snowfall are depended on to have a thriving business. With increased atmospheric CO_2 concentrations, global warming is having an effect on the ski industry. Ski seasons are becoming shorter and are more unpredictable due to changing weather patterns. This has caused an increase reliance on snowmaking which takes more water out of natural ecosystems and disrupts natural cycles. As more energy is used in these processes, more fossil fuels are burned to supply this energy. As more carbon dioxide is released into the air, these weather patterns become more unpredictable and climate warms. This leads to a positive feedback loop which keeps requiring more and more energy to upkeep the current conditions and length of ski seasons (Hughes). Because of the increase energy needed into the future, it is necessary to begin to phase out fossil fuel based electricity and phase in renewable energy sources in order for ski areas to maintain the smallest carbon footprint. In a world where ski resorts rely on cold and steady weather patterns, it is necessary that they try to prevent the Greenhouse Effect that is currently changing the world's climate.

Current energy efforts only include about 25.8% of renewable energies and the rest are hydrocarbon based fuels. While this is not only bad for the environment it is also hurting the checkbooks of ski areas across the nation. As will be shown, renewable energy sources are much more affordable on a large scale than current energy efforts are. Each ski resort in Vermont pays about 1.5 million dollars per year in energy costs. This amounts to about 37 million dollars over the span of 25 years. All other sources analyzed offer significant savings while also having a positive impact on the environment. More data and specific numbers on energy usage can be obtained from tables I, II, and III.

The first source of energy that was researched is solar based energy systems. Solar systems capture energy from the sun and convert the solar energy into electrical energy. While Vermont is not the most ideal state to capture energy from the sun, it still does have potential to generate much electricity from the sun throughout most of the year. Ski resorts use on average 10,390,510 kWh of energy per year on operations which is mostly derived from water pumping and air compression. Since Vermont's electricity is already derived from 25.8% clean energy, only about 7,709,758 kWh are needed to be generated per year per ski resort to be 100% renewable energy dependent. When looking at all of Vermont's 16 ski resorts, about 123,356,135 kWh are needed per year to be 100% renewable based. When researching the amount of solar systems that are needed to supply this energy per year, 10kW solar systems are used in calculations.

With these systems, four hours of direct sunlight per day for the entire day are assumed which would produce electricity at full potential for four hours a day. This equates into 40 kWh per day or 14,600 kWh per year. To supply the needed energy to be 100% renewable energy based, this system equates into 8,450 solar systems. The current average price of these systems is about $21,500 which makes the total around $181,675,000 (Matasci).

When comparing this price to the current price of energy, there is about $260,000,000 worth of savings in investing in solar panels. This is calculated over a span of 25 years as this is the average lifespan of a solar system currently. These savings equate into about $16,000,000 of savings per ski resort over 25 years. These systems not only save money but are also cleaner sources of energy as once they are up and running, there is no carbon dioxide emissions being released into the atmosphere. More data of solar energy systems can be obtained from tables VI, VII, and X

Biomass was also analyzed as a viable solution to the current hydrocarbon based fuel problem. In analyzing biomass derived energy, hardwood was the main energy source of biomass that was looked at. Although there is a bit more variance due to btu values of different types of wood, average btu was about 30,000,000 btu per cord of wood (World Forest Industries). Table VIII sums up most of the findings and costs included with using biomass as a fuel. Over the span of 25 years, biomass is the cheapest alternative to hydrocarbon fuel which prices out to $63,000,000 for all ski resorts or about $4,000,000 per ski resorts over 25 years. When including the cost of the already renewable energy, the total cost comes to about $217,000,000 for all ski resorts or $14,000,000 per ski resort over 25 years. This incurs about $380,000,000 worth of savings for all ski resorts over the span of twenty years. Per ski resort that number is about $24,000,000 of savings over 25 years. This is a substantial amount of savings but there are also drawbacks to this type of energy. More data of biomass energy can be obtained from tables VIII and X.

Vermont is full of forests and with that comes the accessibility to hardwoods for burning and transforming into usable electrical energy. Vermont is currently adding about 166.6 million cubic feet of new forest growth per year which is equivalent to 2.1 million cords of new wood growth (Schlossberg). This new growth is high compared to what is being used which makes the harvesting of timber for energy a sustainable practice. Even though this is currently a renewable resource, it does have some drawbacks that can cause damage to the environment. Trees are one of our best ways to filter carbon dioxide out of the atmosphere as trees use it in photosynthesis. This is one of our best ways to combat the greenhouse effect. Although, when trees are burned for energy they do release high amounts of carbon dioxide and also other pollutants like carbon monoxide, VOC's, particulate matter, nitrogen oxides, sulfur dioxide, and dioxin. These are harmful to the environment and do contribute to the greenhouse effect unless certain precautionary measures are taken. While biomass is the least in terms of cost, it does pose a threat to the environment if handled in the wrong way.

Wind energy was the last type of renewable energy to be researched. Although Vermont doesn't achieve the highest wind values, there are many places throughout Vermont that experience high winds constantly due to elevation and topography. The wind turbines used in calculations were assumed to be 2MW wind turbines that operate at full capacity for 6 hours per day, every day of the year. This system then would produce 4.38 million kWh per year and this system is averaged to cost 2.8 million dollars per turbine. When looking at the amount of turbines it would take to supply this energy, only 29 in total would be needed to supply this energy every year. This total cost comes out to 81.2 million dollars and wind turbines have similar life spans to solar systems being about 25 years. These numbers translate into about 22.5 million dollars worth of savings per ski resort over this span of 25 years. Wind has been noticed as a viable alternative to current energy so much so that its use has increased by twenty times in the past eight years (Silverman). More specific data about wind energy can be obtained from tables IX and X.

Although each source has benefits and drawbacks, it is logical to conclude that they have a much less impact on the surrounding environment than hydrocarbon based fuels do.

Conclusion

The purpose of this research was to analyze energy usage in the ski industry and to explore different viable options to replace current energy efforts. Wind, solar, and biomass were all researched and analyzed for their viability. When looking at all of the factors of each type of energy, wind energy seems to be the best viable option to replace current energy efforts. Wind energy offered about 22.5 million dollars of savings per ski resort over their lifespan, doesn't release any carbon dioxide or other pollutants into the atmosphere when producing electricity, and offers reliable production values since Vermont has many windy areas that can be used to produce electricity.

Vermont ski areas already have initiated many clean energy and sustainability programs that utilize wind, solar, and even Cow Power used at Killington resort. Cow Power utilizes manure from local farms in Vermont where the farms capture methane gas from the manure and use different chemical and anaerobic processes to convert the methane into biogas. This gas is then used in a natural gas engine to create electricity. This electricity is then used to power the K1 Express Gondola and the Peak Lodge at Killington Ski Resort (Killington). The goal of using these energies at ski resorts should be to better manage and create a more robust, flexible and sustainable energy cycle. This doesn't have to be accomplished through large scale projects like the ones described in the above paper and data but can solely be small scale projects meant to lessen the impact on the environment and to create a more renewable energy dependent society and world (Nolt-Helms).

The focus of this project was to broaden the scope of energy used today and to evaluate the validity of each type of energy source. This report can be used to evaluate and implement different energy sources at ski areas throughout the world and should be used to enact change within our society to become a renewable energy dependent world.

Raw Data Tables

I

Energy Use for Average Ski Resort Yearly	kWH	Btu	Cost at $0.1432/kWh
Compressed Air	5,490,373	18,733,930,295	$786,221.41
Water Pumping	2,090,195	7,132,041,381	$299,315.92
Additional Used Energy	2,809,942	9,587,920,085	$402,383.69
Total	10,390,510	35,453,891,760	$1,487,921.02

*These numbers reflect data collected from 2004. These numbers are only rough estimates of the average energy usage at a typical Vermont ski resort. This data may over or underestimate energy usage at ski resorts as in the past 14 years technology has changed and ski areas are upgrading many of their technologies to better cater to skiers today.

II

Energy Use for all 16 Ski Areas in Vermont Yearly	kWh	Btu	Cost at $0.1432/kWh
Compressed Air	87,845,968	299,742,884,800	$12,579,542.62
Water Pumping	33,443,120	114,112,662,100	$4,789,054.78
Additional Used Energy	44,959,072	153,406,721,400	$6,438,139.11
Total	166,248,160	567,262,268,300	$23,806,736.51

*Cost in the above two tables reflect the current average for commercial energy cost in Vermont.

III

Energy Use	Energy in btu needed to be 100% Renewable per Ski Resort	Energy in btu needed over all of Vermont's Ski Resorts
Compressed Air	13,900,576,280	222,409,220,500
Water Pumping	5,291,974,705	84,671,595,280
Additional Used Energy	7,114,236,703	113,827,787,200
Total Needed Energy	26,306,787,690	420,908,603,000

*The above chart assumes 25.8% of energy used at ski resorts is renewable. This other 74.2% comes from nonrenewable sources. Therefore, the above numbers are based on the amount of energy it would take to in order for this other 74.2% of energy to be renewable. These numbers do not include the 25.8% of already renewable energy used in Vermont.

IV

Vermont Energy Breakup
14.3%-Biomass
8.32%-Hydroelectric
12.58%-Other
64.8%-Hydrocarbon Based Fuel

V

Energy Use	% of Total Commercial Energy in Vermont Consumed by Ski Resorts
Compressed Air	1.12%
Water Pumping	0.43%
Additional Used Energy	0.57%
Total	2.12%

VI

Energy Use	Solar Systems needed to Supply Needed Energy for all Resorts	Cost of Systems at $12,000 per System
Compressed Air	4,465	$95,997,500
Water Pumping	1,700	$36,550,000
Additional Use	2,285	$49,127,500
Total	8,450	$181,675,000

*The above results are calculated using a 10kW solar system receiving on average 4 hours of direct sunlight per day, every day of the year. The cost of a single system is taken to be $21,500.

VII

Cost Analysis for Solar Panels	
Energy Savings Per Year for all Ski Resorts	$17,664,598.35
Saving Over 25 Years	$441,614,958.80
Net Savings Over 25 Years	$259,939,958.80
Net Savings per Ski Resort over 25 Years	$16,246,247.43

*The above chart assumes that 74.2% of the cost of current energy is the savings per year as 25.8% is renewable and already accounted for.

VIII

Energy Use	Biomass Cost per Year for All Resorts	Cost over 25 Years for all Resorts	Cords of Wood Per Year Needed
Compressed Air	$1,338,903.51	$33,472,587.75	7,414
Water Pumping	$509,723.00	$12,743,075.00	2,822
Additional Use	$685,243.28	$17,131,082.00	3,794
Total	$2,533,869.79	$63,346,744.75	14,030

*Biomass is based on hardwood which is taken to contain on average 30 million btu's of energy per cord of wood. These numbers only reflect the cost that would be incurred for biomass only. These cost amounts do not include the 25.8% of already renewable energy.

IX

Energy Use	Needed Wind Turbines to Supply Energy	Cost of Wind Turbines
Compressed Air	15	$42,000,000
Water Pumping	6	$16,800,000
Additional Use	8	$22,400,000
Total	29	$81,200,000

*The above numbers assume 2MW wind turbine systems that are fully operational 6 hours per day, every day of the year. This amounts to 4,380 MWh per year per wind turbine. Each wind turbine at this capability is taken to cost 2.8 million per wind turbine.

X

Type of Energy	Total Cost Over 25 Years per Ski Resort	Total Cost Over 25 Years for all Ski Resorts	Years to Return on Investment
Current Energy	$37,198,025.50	$595,168,408.00	-
Solar	$20,951,778.08	$335,228,449.30	8 Years
Biomass	$13,556,262.13	$216,900,194.10	-
Wind	$14,672,090.58	$234,753,449.30	4 Years

*The above numbers assume that 25.8% of the energy already being used is renewable. Therefore, some of the cost is derived from a portion of current costs. The other 74.2% of the total cost is calculated using alternative energy sources described in the tables using above information from other tables.

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