Renewable Energy Analysis and Implementation

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Submitted on November 13, 2019

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Abstract

A renewable energy source needed to be created in order to provide power to a town of 200 households located in Klamath Falls, Oregon. Weather data taken from Klamath Falls International Airport was analyzed to determine which renewable energy source, solar or wind, would be most effective. Wind data was analyzed as well as precipitation and fog data to determine which type of energy would be more effective. Calculations were performed to find how much power could be produced by Siemens Gamesa 2.X 114 m diameter wind turbine and the LG Solar 400 Watt NeON BiFacial Commercial Mono solar panel respectively. A single one of these solar panels could produce 108 kWh per month on its own, and the wind turbine could produce 61,357.2 kWh in the same amount of time. It was determined that either 3 of the wind turbines or 2,000 of the solar panels would be sufficient to power the entire complex. The solar system was determined to be much more effective at producing power than the wind system. It was also determined to be more cost effective, with a total estimated cost of $2,392,000. As such, the solar system was selected as the design to implement into the housing complex.

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1 Introduction

The purpose of this project was to research and design a form of renewable energy that would be most effective based on data collected from Klamath Falls International Airport, Oregon, US given its weather conditions. After researching various types of weather-related renewable energy, weather data collected at Klamath Falls International Airport was evaluated and the most effective renewable energy source for that location was determined. The need for this project was to provide a sustainable amount of energy to a town of 200 households while having less of an impact on the environment.

1.1 Problem Statement

It was determined that a renewable energy source needed to be created that was strong enough to power a town consisting of 200 households in Klamath Falls, Oregon. Weather data needed to be evaluated so the most effective energy source for the location could be determined. The energy source chosen had to use the weather effectively so that the maximum amount of power could be produced given the weather conditions. The type of materials used and their costs also needed to be taken into consideration. The materials needed to be effective in producing the maximum amount of power possible while also being inexpensive. They also had to be durable so that costs due to maintenance were kept to a minimum. Additionally, the energy system would need to have a minimal impact on the surrounding area, to promote the safety and wellbeing of the public.

1.2 Background

1.2.1 Solar Energy

Solar energy was a type of renewable energy that would harness the light energy from the sun to strip its photons of an electron. The electrons would run through a solar cell and flow through the connected circuit to create electricity (Sunpower). The origins of solar energy came from the use of the sun's light rays and a magnifying glass to create heat, which could create fires. This tactic was used as early as the 7th century B.C. The Greeks and Romans were also known to use objects named "burning mirrors" to harness the sun and light religious torches. Later on in 1200 A.D., ancestors to the Pueblo Native Americans used the sun's heat to warm their homes during the cold winter months. They would do this by building insulated rooms that had an open roof during the day to take in heat, and a closed roof during the night to conceal the heat (Richardson). It is clear that the sun's energy and ability was used in many different ways before the solar array was invented. The development of solar cell technology, or photovoltaic (PV) technology, began during the Industrial Revolution when French physicist Alexandre Edmond Becquerellar first demonstrated the photovoltaic effect, or the ability of a solar cell to convert sunlight into electricity, in 1839 (Sabas).

Since solar energy relied on the sun, it produced less power when the sun was not showing. That was just one of many disadvantages to using solar energy over other forms of renewable energy. Nonetheless, there were also many advantages to using solar energy rather than other forms of renewable energy. Some of the advantages included the ability for solar panels to be installed almost anywhere. This allowed the average family the ability to live on their own grid through the power generation of solar panels. This would not have been possible with wind turbines due to the amount of area needed to build them (GreenMatch). The downside to installing them on a home was the amount of money needed to acquire and install the panels. Another advantage was the advancement of solar cell technology and how it now allowed solar panels to generate electricity even when it was cloudy outside. This advancement in solar panels made the usage of the panels much more viable in multiple different situations. The only disadvantages that counteracted this advantage was other types of coverage that solar panels could not generate electricity through, such as trees or roofs (Sepco). Throughout the research conducted, solar energy seemed to be viable when the most sunlight was possible (the least amount of coverage) and when the most amount of area was possible for the placement of the panels.

1.2.2 Wind Energy

Wind energy was created as a type of renewable energy which would harness the kinetic energy generated by wind patterns to create electrical energy. It was considered a renewable form of energy because winds would continue to be generated if the sun's rays continued to heat the planet, according to the US Department of Energy (Office of Energy Efficiency). In other words, wind could not be depleted from the Earth in the same way as fossil fuels such as coal and oil.

The two most common classifications of wind turbines were vertical axis wind turbines (VAWT) and horizontal axis wind turbines (HAWT). VAWTs (**Figure 1**) could spin and collect energy along a vertical axis and have had their origins dated to about 200 BC along the Persian-Afghan borders (Kaldellis 1890). VAWTs were notable for their ability to collect greater amounts of energy at lower wind speeds and from lower altitudes than HAWTs. VAWTs could also collect wind power from any direction, although unfortunately they produced much less power than HAWTs (Thanh). HAWTs (**Figure 2**) originated much later than VAWTs in Europe between 1300 and 1875 AD and spun on a horizontal axis rather than a vertical one (Kaldellis 1891). HAWTs were created to be more efficient than VAWTs, and although they could only collect wind from one direction at a time, they often were designed to spin and face towards the direction of oncoming wind to increase efficiency. The shortcomings of HAWTs, such as its inability to harness winds of lower speeds and its need for higher altitude placement were made up for in the efficiency of its power collection. As such, HAWTs are the more widely used type of wind turbine (Thanh).

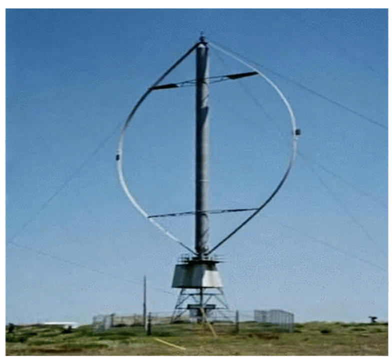


Figure 1. A vertical axis wind turbine located in the Magdalen Islands (Thanh)

Figure 2. A collection of horizontal axis wind turbines (Office of Energy Efficiency)

While wind energy was created to be highly efficient, it also suffered from the variability of wind patterns. The amount of energy produced by wind turbines was dependent on how often the wind blew and at what intensity. Small changes in wind speed could have large effects on the output; if the speed of wind doubled, the amount of power generated would multiply roughly eight times (“How Wind Energy Works”). There have been various strategies implemented in the past in order to address the unpredictability of wind patterns. One such strategy was to place wind turbines throughout a wide area of varying geography in order to increase the chance of collecting wind in some locations (“How Wind Energy Works”). Some collected energy was also kept in reserve in case extended periods of time pass with little to no energy generation (“How Wind Energy Works”). These strategies were implemented successfully, so they have become the core elements of the designs of wind energy plants in the modern era.

Part of the purpose behind the use of wind energy was to reduce human impact on the environment. Wind energy was considered a “clean” energy, meaning that it did not produce greenhouse gases which were believed to contribute to global warming (Saidur 2429). In this aspect, wind energy has a greatly reduced environmental impact compared to fossil fuels. Wind energy was not completely harmless to the environment, as the movement of the wind turbines have led to the deaths of many wild birds and other animals. Furthermore, wind turbines create sound pollution which could disturb the surrounding environment and people living in the vicinity. There have been significant improvements made on the environmental effects in the past through research and development processes, and soon the impact of wind turbines could be close to none (Saidur 2429).

1.2.3 Effect of Location on Wind and Solar Energy

Wind farms tended to be most effective in areas with consistently high wind speeds. For this reason, wind farms could typically be found on mountains and along the shore lines. The midwest has the highest average wind speeds between 7-9 m/s, with mountain ranges following right behind with average winds speeds up to 6.5 m/s (NREL). However, other factors had to be considered when determining the location of wind farms. Wind farms would have to have access to the electrical grid while being in an area that would not affect the residents that lived there. McWilliam et al. found that wind farms were more effective in less populated areas (297).

Like wind farms, solar farms had to be located somewhere that would not interfere with the surrounding population. Solar farms also had to be located in areas that received a lot of sunlight. Because of this, many solar panels were often found in fields and on the roofs of buildings in an effort to reduce shade from surrounding trees and buildings. Panels tended to be tilted to maximize direct sunlight. The use of an active sun tracker would optimize the solar energy collected by changing the tilt of the panels throughout the day in order to maximize direct sunlight; however, the use of an active sun tracker would be expensive and cost energy (Khatib et al. 2867).

1.2.4 Effect of Climate and Weather Patterns on Wind and Solar Energy

Wind farms relied on high wind speeds in order to produce a sufficient amount of energy; therefore, they were most effective in climates that have a lot of wind. However, the air temperature also influenced where wind farms could be located. Wind farms located in areas with warmer air had to be made with materials that would not be affected by the heat of the air;

they also had to have a powerful enough cooling system, so the fluids used for lubrication were not affected (Pryor and Bartelmie 83). Wind farms located in areas with colder air, like warmer air, needed to be made of materials that would withstand it; they would sometimes also need to have gearbox heaters (Laakso et al. 46). In colder air, they were also at risk of ice buildup which, like dust and insect accumulation, could reduce the amount of power produced (Pryor and Bartelmie 84).

Like wind farms, solar farms were affected by the buildup of dust. The accumulation of dust would not allow for sunlight to properly reach the panel, resulting in a less than optimal amount of power produced. Because of this, solar farms did better in climates with less wind; wind also allowed for debris to damage the solar panels (Pratt et al. 100). Higher temperatures tended to have a negative effect on the amount of energy produced by solar farms. Panels with photovoltaic cells were less efficient in higher temperatures, and stations that used sunlight to produce heat had a problem with their cooling system (Pratt et al. 100).

Both wind and solar farms were affected by precipitation. Wind turbines would sometimes be struck by lightning resulting in damages that would affect the amount of power produced and would be costly to repair. Hail could cause damages to both wind turbines and solar panels. Cloud accumulation would make it so sunlight could not reach the solar panel which, in turn, would not allow for power to be produced. Therefore, both wind and solar farms were more successful in areas with little precipitation.

1.2.5 Prior Costs of Solar and Wind Energy

Cost was a significant barrier in switching to renewable energy. The majority of the costs were from the development of the technology. A solar system for a residence could cost upwards of $3700/kW (kilowatt), and a wind turbine could cost upwards of $1700/kW. In contrast, a new natural gas plant only cost about $1000/kW (Wales). Another factor contributing to the cost of renewable energy was the transportation of it. Say, for example, there was a city that needed electricity, but the city's mayor specifically asked for solar power. A solar system could not be implemented on every block, so a system that transports energy also needed to be built. This system was an additional cost that inflated the cost of renewable energy systems (EERE).

The costs mentioned above only considered the initial implementation of renewable energy; was renewable energy cheaper after time? Lazard said it was. In their 2017 Levelized Cost of Electricity (LCOE) Analysis, there was a continuous decline in the cost/kWh (kilowatt hour) of various renewable energy sources, including solar and wind (Waxler). **Figure 3** and **Figure 4**, below, showed a decline in cost over an 8-year period of both wind and solar energy, respectively.

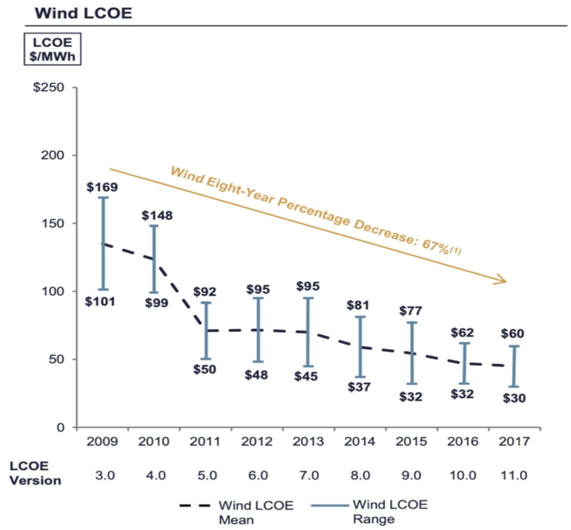


Figure 3. The Levelized Cost of Energy of Wind Energy from 2009-2017 (Waxler 10)

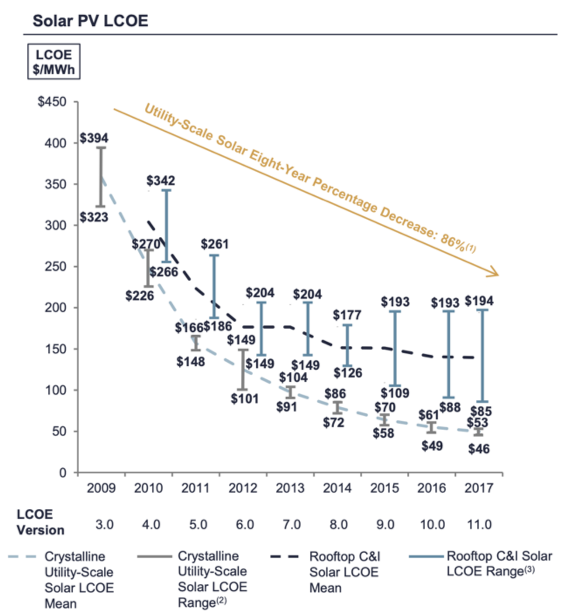
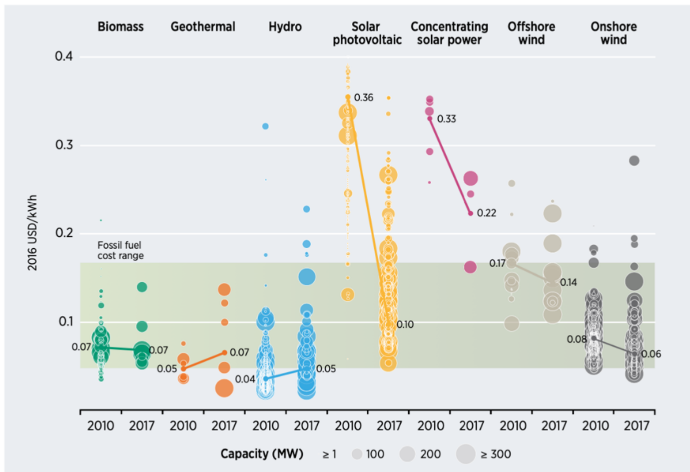


Figure 4. The Levelized Cost of Solar Energy from 2009-2017 (Waxler 10)

Another organization, the International Renewable Energy Agency (IRENA), published *Renewable Power Generation Costs in 2017* in 2018. In this publication, IRENA analyzed the trends in costs of various renewable energy sources (solar power, wind power, hydropower, bioenergy, and geothermal power) over time. **Figure 5**, below, was their findings.



Source: IRENA Renewable Cost Database.
Note: Each circle represents an individual project in the IRENA Renewable Cost Database, with the centre of the circle representing the LCOE value on the Y-axis and the diameter of the circle the size of the project. The lines represent the global weighted average LCOE value for a given years newly commissioned projects, where the weighting is based on capacity deployed by country/year.

Figure 5. Global Levelized Cost of Electricity from Renewable Power Generation Technologies, 2010-2017 (*Renewable Power Generation Costs in 2017* 34)

As seen In **Figure 5**, the cost/kWh of solar photovoltaic energy decreased significantly from 2010 to 2017. This trend was also true for concentrating solar power. The cost/kWh for onshore wind and offshore wind energies both decreased by roughly the same amount from 2010 to 2017. However, the main takeaway from the data was the fact that most renewable energy sources analyzed by IRENA were on the lower end of the cost/kWh spectrum of fossil fuels. In other words, there was not much of a difference in cost/kWh between fossil fuels and renewable energy. It could be assumed that the costs were even lower today because IRENA stated in their

“Key Findings” section of the report that “The results of recent renewable power auctions – for projects to be commissioned in the coming years – confirm that cost reductions are set to continue through 2020 and beyond” (*Renewable Power Generation Costs in 2017* 14). Another study, performed by BloombergNEF (BNEF), found “that the LCOE per megawatt-hour for onshore wind, solar PV and offshore wind have fallen by 49%, 84% and 56% respectively since 2010” (Battery Power’s Latest Plunge in Costs Threatens Coal, Gas).

In early 2019, cost estimates were provided for residential solar and wind systems. The installment cost of a 5-kW solar system for a home varied by state. The cheapest a system could be installed was in North Dakota for $8,196, and the most expensive a system could be installed was in Michigan for $17,147 (White). These 5-kW systems could produce “anywhere from 14.5 and 23 kWh per day on average” (“Solar Estimate”). The cost of a 5-kW to 15-kW wind power capacity wind turbine for a residential home could range anywhere from $15,000 to $75,000 (Thoubboron).

2 Methods and Materials

2.1 Weather Data Analysis

The weather data was received in a spreadsheet in Microsoft Excel. In order to determine the effectiveness of each of the two considered types of renewable energy, the categories Average Wind, Precipitation, Wind Direction, Temperature, 2-minute Wind Speed, 5-minute Wind Speed, and Weather Types were analyzed. In order to evaluate the viability of solar energy, special attention was paid to the Weather Type and Precipitation categories. The built in SUM function in Excel, was used to find the total amount of precipitation throughout the entire year which was then compared to the national average of 32.21 in. The percentage of days in which Klamath Falls experienced precipitation was found; the same was done for the percentage of days Klamath Falls had fog, both heavy and otherwise.

The wind data was analyzed in a similar way to the solar data, however the important categories for this energy type were Wind Direction and all of the previously-mentioned Win0d Speed categories. The average wind speed for the entire year was calculated using the Excel AVERAGE function. The standard deviation of the wind speed throughout the year was also found using the Excel STDEV function. This was then compared to the suggested average speed for wind development of 14.54 mph. The 2-minute Wind Speed average and standard deviation for the year was found, as was the 5-minute Wind Speed average and standard deviation (Khan Academy); average was found using the Excel AVERAGE function and the standard deviation was found using the excel STDEV function. The wind direction was analyzed to find a pattern in which the direction of the wind changes.

2.2 Energy Calculation

The average amount of energy used in a normal household was about 914 kWh per month according to the US Energy Information Administration ("U.S. Energy Information Administration - EIA - Independent Statistics and Analysis"). The size of the town was roughly 200 households, so if each household required an average amount of power, the amount of power required for the entire town would be 182,800 kWh per month. This amount of power would be used to determine the required scale of each of the two types of renewable energies.

$$E = 0.75pt \quad \textbf{(Equation 1)}$$

The energy (*E*) of the solar panels could be found using **Equation 1 (**"How to Measure Solar Panel Output"). The solar panel power (*p*) could be found labeled on the solar panel. The average hours of sun (*t*) referred to how long the sun was out in any given day. The 75% (0.75) was meant to account for the lost power of the solar panels when converting from light to electrical energy. The values were substituted into the above equation in order to determine the power output of the entire designed solar energy complex.

$$P = (0.5)(p)(A)(Cp)(V^3)(Ng)(Nb) \quad \textbf{(Equation 2)}$$

The calculation of the power generated by a wind turbine required the use of **Equation 2** (Sarkar and Behera 3). In this equation, *P* stood for the power generated, *p* stood for air density, *A* stood for rotor swept area, *Cp* stood for coefficient of performance, *V* stood for wind velocity, *Ng* stood for generator efficiency, and *Nb* stood for gear box bearing efficiency. The air density was determined for use in the equation using the air pressure of Klamath Falls, and the average temperature as determined with the AVERAGE function in Excel and the Max and Min Temperature columns. The rotor swept area was calculated using the formula for the area of a circle with the radius being the radius of the wind system's turbines. The wind velocity used was the average speed as calculated with the AVERAGE function in Excel when used on the column of average daily wind speed. For simplicity of the calculation, it was assumed initially that efficiency was 100%, giving a value of 1 to *Cp*, *Ng*, and *Nb*. Efficiency was, however, taken account for after the calculations. The results of this calculation were used to determine the power output of the potential wind energy system.

2.3 Energy Systems and Cost Analysis

When determining the size and scale of the wind and solar systems, the main considerations were the power outputs for each unit of the system and the final cost of the full system.

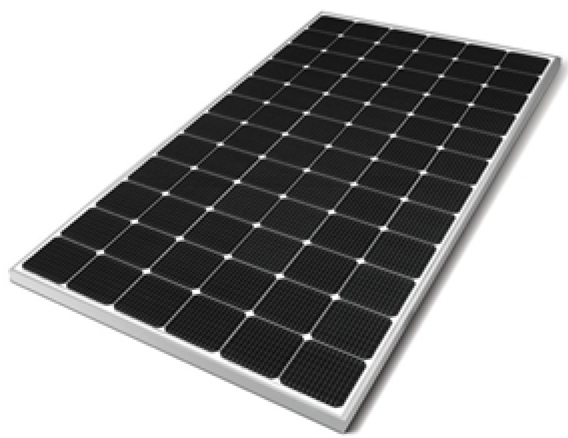


Figure 6. The LG Solar 400 Watt NeON BiFacial Commercial Mono Solar Panel

The solar panel which was selected for use in the solar system was produced by LG, and was pictured in **Figure 6**. In order to determine the number of the above solar panels that would be required for each house in the 200 household complex, **Equation 1** was first used to calculate the amount of power in kWh produced by a single solar panel in a month. Then, the total amount of power used by a standard household in a month was divided by the amount of power for each produced by a solar panel in order to calculate the amount of solar panels each house would need. The cost was then calculated from this amount by multiplying the number of solar panels times the cost of one LG Solar solar panel, then by 200 to account for the entire 200 household community.

Figure 7. A Siemens Gamesa 2.X 114 m diameter wind turbine optimized for low-medium wind conditions

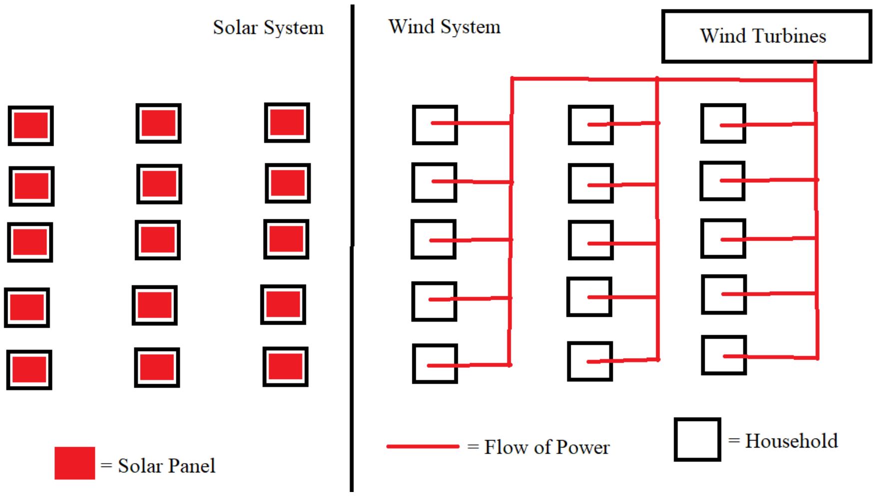


Figure 8. A representation of the difference between the wind and solar system designs

The cost of the wind energy system was calculated in a similar way to the solar system. The wind turbines that were used for calculation were by Siemens Gamesa, pictured above in **Figure 7.** To determine the size and cost of the wind system, **Equation 2** was used to determine the amount of energy that was outputted by one turbine of this type. While the solar panel system was created to have solar panels at each individual house, the wind turbines were much more powerful and only a small amount were intended to provide power for the entire community. **Figure 8** shows the system which would transfer power from the wind turbines to each household, and how it differed from the solar energy design, which was spread out throughout the houses. The total required average monthly power for the entire residential community was divided by the amount of monthly generated power of each individual turbine. This gave the amount of turbines which would be required to power the entire community. The cost of the entire wind power system was calculated by multiplying the cost of a single wind turbine by the total amount required to power the entire community. To account for the transfer of power to each individual household, a cost was determined for the system to transfer power to each household of the community, and this was added to the total cost of the wind system.

2.4 Deciding Between Wind and Solar

A number of factors were considered when determining whether to use wind or solar power as the final design. First, and most notably, the weather data was analyzed in Excel in order to determine which energy type would be more effective. For solar power, factors that were most heavily considered were lower amounts of precipitation and inclement weather. For wind, the most important factors were the consistency and speed of the wind on average. The cost of each of the two systems was viewed as a secondary consideration, in order to distinguish the two types of power in the event that they have similar levels of effectiveness in the weather conditions. Lastly, the impact on the residents was considered, and the more desirable option in this category was seen as the one which produced the least noticeable impact on the community.

3 Results

3.1 Weather Analysis Results

Table 1. Displayed are the amounts of precipitation and fog in Klamath Falls for the year

Total Annual Precipitation	Days without Precipitation	Days with Fog	Days with Heavy Fog
9.10 in	77.53%	43.56%	9.31%

The first data to be analyzed was the data related to weather patterns other than wind. **Table 1** shows the amount of precipitation as a total cumulative amount and as a relation of the amount of days without rain. Fog, another significant weather type, was represented in a similar way, as a proportion of the amount of days with fog to the total amount of days in the year.

Table 2. Displayed is the average wind speed for the year and the frequency of days with certain amounts of wind

Average Wind Speed	Days Over 10 mph Avg	Days Over 15 mph Avg
5.95 mph	11.23%	1.37%

The calculated wind data is shown in **Table 2**. The amount of days with wind speeds of over 10 mph and over 15 mph are represented as percentages of the entire 365 day year. In addition, the standard deviation of the average wind speed was 3.27 mph. The 2-minute wind speed average for the year was 18.21 mph with a standard deviation of 6.58 mph, and the 5-minute wind speed average was 22.84 mph with a standard deviation of 8.76 mph (Khan Academy). The wind direction was found to change in a fairly predictable fashion, but no significant patterns were immediately apparent.

3.2 Energy Output

Table 3. Displayed are the power outputs of a single unit of solar and wind power, as well as the amount of energy consumed in a month by 200 households

Solar Power Generated	Wind Power Generated	Power Consumed
108.0 kWh	61,357.2 kWh	182,800 kWh

The power outputs of a unit of each of the two tested systems were shown in **Table 3**. More specifically, a single unit of the solar system was a single 400W solar panel, whereas a single unit of the wind system was a 114m diameter wind turbine. The power consumed was how much power would be required to supply energy to the 200 homes on average. The power levels shown were the amount of power that would be produced in a month of 30 days.

The values found in **Table 3** were calculated using **Equation 1** and **Equation 2**. The solar system was calculated using **Equation 1** and data from the LG Solar 400 Watt NeON

BiFacial Commercial Mono. A value of 400W was used for *p*, and a value of 12 hours was used for *t*, which was an estimation of the amount of hours in the average day. For the calculation of wind energy, the air density *p* was calculated to be 1.0772 kg.m^3 by using the average temperature of 47.70 degrees Fahrenheit in Klamath Falls (Haponiuk). The rotor swept area was calculated using a radius of 57m, and was found to be 10,207.035 m^2. The wind velocity used was 5.65 mph, which was roughly equivalent to 2.66 m/s. For simplicity of calculation, efficiency was initially assumed as 100%, giving a value of 1 to *Cp*, *Ng*, and *Nb*. The calculated power of the wind system at this point was 103,469.146 kWh, however this did not take efficiency into account. As such, this number was multiplied by a theoretical efficiency for wind turbines known as Betz Limit, which was 59.3% (Sarkar and Behera 3). The final energy output of a unit in the wind system is shown in **Table 3**.

3.3 Energy Systems

Table 4. Displayed are estimates of the amount of units for each system as well as the estimated cost for each system as a whole

	Number Units in System	Cost for All Units ($)
Solar System	2,000	2,392,000
Wind System	3	11,025,000

Table 4 showed an estimate of the amount of units which would be required for each of the collective systems, as well as the cost for the entire system of all of the individual units. The units for each system are the same as defined in the previous subsection. The cost of a single

solar panel unit was on average \$2.99 per watt (Matasci). This meant that a single 400W turbine would cost about \$1,196. The cost per MW of power in a wind turbine was determined to be about \$1.75 million, meaning a single 2.1 MW turbine unit would be about \$3.675 million ("How Much Do Wind Turbines Cost?"). The final total system costs were shown in **Table 4**.

4 Discussion

4.1 Weather Data Evaluation

The evaluation of the weather data started with the analysis of the given data for Klamath Falls, Oregon. The solar related data that was given for the location of Klamath Falls included precipitation per day, as well as the fog weather type. With this data, the total amount of days with clear weather and sunlight could be found and used to determine the effectiveness of the solar panels. Unfortunately, as seen in **Table 1**, there was a high frequency of days with fog, decreasing the effectiveness of the solar panels. To counteract this issue, the LG Solar 400 Watt NeON BiFacial Commercial Mono solar panel was specifically chosen for its known effectiveness in lower light levels. The wind related data shown in **Table 2** included wind speed per day, which was used to decide when higher wind speeds were more prevalent and the average wind speed over certain time periods. This showed that the wind speed in Klamath Falls was far below the ideal average wind speed of 9 mph for wind energy collection (American Wind Energy Association). Unfortunately, the climate of Klamath Falls was not ideal for either solar or wind energy generation. However, the solar panels were able to generate some energy even through the frequent fog. In contrast, the wind turbines, despite being optimized for low to medium wind speeds, would have trouble generating much power at all most days.

4.2 Energy Output and System Rationale

The potential solar and wind systems differed significantly in their designs. As shown in **Table 4**, the solar system consisted of about 2,000 individual units, while the wind system only consisted of 3. This was counterbalanced by the fact that the solar units were much smaller and cheaper than the wind turbines. In addition, the solar units were intended to be mounted on each house, with 10 panels per house. On the other hand, the wind turbines would need to be located near the residential complex, but would also require a means of transporting the collected power, an additional cost which was not included in the calculation because cost differences were already very clear.

The solar panels used in the system were selected for their ability to work well in low light levels, which would optimize the amount of power generated in the frequent foggy weather. This prevented the need for an increased amount of solar panels and made the entire system more efficient. Likewise, the Siemens Gamesa 2.X turbine was selected for its ability to work in low to medium wind levels as the wind speed in Klamath Falls was lower than typical wind farm locations. Unfortunately, although the wind turbines were rated at 2.1 MW and were supposed to be able to provide much more power, the poor wind conditions of Klamath Falls prevented them from producing power at any level near their capacity. As such, they were underutilized in the design, and the price for the wind system became very inflated. The solar panels in the solar system were used much more efficiently. The sectioning of solar panels onto each individual household decreased costs by eliminating the need for a means of power transportation, and increased power output in conditions that were less than ideal.

4.3 Deciding Between Wind and Solar Power

When it came to deciding between wind and solar power for Klamath Falls Oregon, there were many factors that were important to analyze. The first and most important factor was the amount of energy each of these systems would generate in this region. From the given data, it was determined that a system of 2,000 solar panels could generate a total of 216,000 kWh of energy in the Klamath Falls area. The cost of these solar panels came to a total of $2,392,000, which was significantly cheaper than a system of 3 wind turbines in the same area which cost $11,025,000. On top of the solar system being much cheaper than the wind system, the wind system only generated around 184,000 kWh of energy per 3 wind turbines. Because there were more individual units in the solar system, the power generation was able to be more customizable, allowing for additional energy in case residents of the complex use more than average. After considering the weather of the region and the total cost of each system, it was found that a solar system would be much more appropriate for this location. A system of solar panels could also be placed on the roofs of buildings all around Klamath Falls, while a wind system would need a significant amount of open space to operate. The addition of wind turbines would also be disruptive to the public if placed too close to the city. After considering public safety and welfare, it was once again found that the solar system would be the more advantageous choice for Klamath Falls.

4.4 Considerations of the Design

When considering which renewable energy source would be most beneficial for the area, the safety of the public as well as global, cultural, social, environmental, and economic factors were all considered. The use of either renewable energy source would have positive social and cultural impacts. One of Oregon's primary energy sources was hydroelectric power, so the use of more renewable energy sources would be more readily accepted by the public as opposed to other areas that rely more heavily on nonrenewable energy sources. It would also provide jobs for the region; a solar farm would provide more jobs than a wind farm as there would be more solar panels than wind turbines, meaning a solar system would require more maintenance than a wind farm.

Some global factors that had to be considered were imported and exported goods between countries. Use of renewable energy would mean less imports of nonrenewable energy sources such as oil and gas. Solar panels utilized rare metals, of which, China has the highest production rate. Renewable energy sources generally had positive impacts on the environment as they would not have as many harmful products as the nonrenewable alternatives allowing for cleaner air and water in the area. Solar and wind energy were both clean and sustainable energy sources, however, they both also had negative effects on the environment. Wind turbines were a danger to birds and other animals that could get caught within the turbines. The manufacturing of solar panels includes the use of hazardous materials. Both wind and solar farms take up a lot of space, which could lead to deforestation and destruction of habitats.

Economically, solar panels were more effective than wind turbines. The wind speeds in Klamath Falls, Oregon were not strong enough to justify using wind turbines, as they were more expensive than solar panels and, due to the low wind speeds, did not produce energy efficiently. The area's low precipitation allowed for solar panels to be used effectively. The use of wind turbines could possibly have some negative effects on nearby residents' health. Reflections of light from the turbines could have a strobe effect, which could lead to seizures. There was also speculation that the vibrations in the air caused by the turbines could cause health problems such as sleep deprivation and headaches. The main health concern for solar farms are burns due to the heating of the panels.

5 Conclusion

After analysis of the weather data for Klamath Falls, Oregon, it was determined that the proposed solar system would be a better renewable energy system for the region. The wind speeds in the region were too low to generate enough energy to power the 200-home complex. In addition, there was little precipitation in the region, which justified the choice of a solar system. The decision to choose a solar system was justified further when the costs of both the solar and wind systems were analyzed. The solar system was significantly cheaper and more cost-effective than the wind system.

The solar system also had significantly fewer negative effects on residents' health. The only safety concern with solar panels was potential burns due to their heating, which would not be a major concern, since the panels in the proposed system would be placed on the roofs of the houses. The wind turbines were much more disruptive. The reflection of light off of them could lead to seizures, and air vibration changes could have caused headaches and sleep problems.

The objectives for the project were met. The weather data was successfully analyzed, and the solar system was determined to be more efficient than the wind system. Cost analysis was performed, and the materials chosen were successfully able to be durable and keep costs low, without sacrificing the efficiency of the system. The proposed system also did not pose a risk to the public.

5.1 Future Work

Future research could be done in the optimization of the arrangement of the solar panels to maximize the amount of sunlight absorbed. Calculations for the optimal angle of the panels, as well as the best angle for the panels to be built, would have to be performed. In addition, further research could be done in figuring out the best type of solar cells to use to convert sunlight into energy, as to minimize the amount of energy lost during the conversion. Also, different materials for the panels to be built from should be tested to determine the cheapest material, without sacrificing the quality of the system. Research could also be conducted in other forms of renewable energy. The only renewable energy systems considered were solar and wind, but there are many other forms of renewable energy, such as geothermal, hydroelectric, and biomass.

If this project were completed again with these new parameters, then the cost would need to be updated to include the new solar cells and material cost. An additional factor that would contribute to the [annual] cost would be the maintenance of the panels. Leaves and other debris could cover them, which would reduce their efficiency, so the panels would need cleaned regularly. After these basic principles of the system were optimized, it could be used on larger or smaller sales to provide sustainable energy to industries or corporations or individual homes, respectively.

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7 Appendix

The idea to mount the solar panels on the houses rather than at a separate location came about early in the project. It was believed that this would be a superior means of utilizing the panels, as they would take up less land, and they would not require a potentially expensive wiring system to be built throughout the complex. A similar design was considered at one point with much smaller wind turbines, however it was determined that the average amount of wind was so low that this design would produce little to no power on most days. This is why the wind design requires power to be transported from the location of the large commercial turbines.