FEASIBILITY STUDY OF ALTERNATIVE ENERGY SOURCES AND CONSERVATION TECHNIQUES FOR IMPLEMENTATION IN El YUNQUE NATIONAL FOREST

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Submitted to:

Professor Ingrid Shockey
Professor Robert Kinicki
Professor John Delorey

In cooperation with:

Pedro Rios, Ecosystem Management and Forest Planning Team Leader

Kevin Arruda
Steven Baldwin
Alexander Quinn

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CHAPTER 1: INTRODUCTION

The global community's dependence on fossil fuels (coal, oil, and natural gas) as a primary energy source has created a need for alternative energy. Two major concerns surrounding this issue are financial instability of energy costs, and the environmental consequences of burning fossil fuels. In the United States, 85% of all energy consumed is provided by fossil fuels. This accounts for about two thirds of the electricity that is produced each year, and nearly all of the transportation fuels that are used (Department of Energy, 2010). Data collected by the United States EIA (Energy Information Administration) on the average cost of fuel throughout the world shows extreme inconsistencies over the past 5 years, and a general upward trend in the price per barrel of crude oil over the past 10 years. Environmental ramifications of burning carbon-based fuels include the contamination of soil, air and water (Energy Information Administration, 2010). As these issues concerning sustainability continue to grow it is becoming clear that changes must be made in the way we live and generate energy.

More sustainable, renewable methods of producing energy exist and are being implemented around the globe to address the aforementioned issues. These renewable sources of energy have been more commonly classified as alternative energy. The most common alternative energy sources include wind power, solar power, geothermal power, hydroelectric power, and biodiesel fuel. These types of energy sources perpetually generate energy over their lifetimes by converting natural resources present throughout the environment into more useful forms of energy. After an initial investment and the costs of maintenance, energy that is produced by alternative methods is untied to the fluctuating costs of non-renewable fuels. As result, energy produced by alternative sources is produced at a more financially stable rate than energy produced by conventional means. Furthermore, these alternative methods of producing energy yield far fewer harmful byproducts such as green house gases than conventional methods of generating energy. This is important because according to the U.S. DOE (Department of Energy) the "rising level of [greenhouse] gases contributes to global climate change, which contributes to major environmental and human health issues" (National Renewable Energy Laboratory, 2009). For these reasons, these alternative energy sources provide a sustainable solution to areas dependent on imported, nonrenewable, and carbon-based fuel sources.

Puerto Rico has limited traditional fuel resources. This limitation has caused and continues to propagate a reliance on foreign oil as the primary energy resource throughout Puerto Rico; accounting for over 98% of its energy production (Energy Information Administration, 2010). As a result, almost all of the energy produced in Puerto Rico is non-sustainable. The proposed site, El Yunque National Forest is maintained by the United States Forestry Service and is no exception to Puerto Rico's reliance on non-renewable energy sources.

El Yunque National Forest in Puerto Rico's Luquillo Mountain Range is the only tropical rainforest in the National Forest System and is a worldwide model of tropical land management. The reserve offers tours, hiking trails, and environmental education to its 1.2 million visitors per year. El Yunque is also part of the United Nations Man and Biosphere Program, a collection of reserves around the world,

> "which innovate and demonstrate approaches to conservation and sustainable development. They … share their experience and ideas nationally, regionally and internationally within the World Network of Biosphere Reserves" (United Nations Educational, Scientific and Cultural Organization, 2010).

The Forest Service wants El Yunque be an example of responsible land management and conservation not only to visitors, but also to other parks around the world. Thus it is important that the forest has a responsible and sustainable energy program. Not only is sustainability vital to the survival of the rain forest, but the responsible use of resources and land also affects the worldwide image of the forest, Puerto Rico, and the United States Forestry Service.

The tropical rainforest setting is subject to conditions that make many energy solutions difficult to implement. The Luquillo Mountain Range receives 200 inches of rain every year, and has regular flooding and hurricane seasons. Energy solutions such as windmills and solar panels can be damaged by these natural phenomena. Information, ideas, and technologies that prove applicable in El Yunque will be of great value to tropical rainforests and reserves worldwide with similar problems.

El Yunque National Forest is faced with the problem of supplying power to its 28,000 acre infrastructure which includes office buildings, vehicles, recreation areas, and communication outposts. El Yunque Forest currently depends on the island's electrical grid and backup diesel electric generators to produce electricity. The Forest's dependence on high priced energy reduces the funds available for natural resource management and creates concerns for its sustainability. The El Yunque Forest staff is exploring techniques to reduce the cost of operating the forest's facilities and create a more sustainable system in which the land and resources of the reserve are managed responsibly.

This paper will research and outline recent developments in alternative energy and conservation solutions. Solutions that appear to be feasible and potentially beneficial will be further investigated as a means to increase sustainability with regards to energy in the El Yunque National Forest. This investigation will include site research and analysis, and conclude with an estimation of energy production and cost analysis to determine the feasibility and of integrating alternative energy and conservation technologies into the existing infrastructure in the El Yunque National Forest. Using this information, the most effective solution or solutions will be determined and presented in a proposal to the sponsor.

CHAPTER 2: LITERATURE REVIEW

This literature review is a compilation of current research and relevant topics in the field. It summarizes the processes and requirements of the energy sources and conservation methods that will be investigated. It also reviews pertinent case studies in which the outlined alternative energies and conservation techniques have been implemented. Case studies dealing with national parks and tropical climates were selected and reviewed for their relevance to the project.

2.1 Traditional Power Methods

Traditionally, electrical energy is made in facilities that use fossil fuel as their initial source of energy. Coal or oil is burnt and the heat energy that is released is transferred into water in a boiler to make steam. Next, the pressurized steam is forced through a turbine, converting the heat energy into mechanical work. The steam turbine is connected to an electrical generator that converts the mechanical work into electrical energy that is then wired into the electrical grid that the power plant serves. This method of generating electricity is convenient because fossil fuels are readily available and the power plants are able to produce a large amount of energy, the issue is that this convenience comes at an environmental cost (Beer, 2008).

The combustion of fuel releases many harmful vapors into the environment; including the oxides of nitrogen and sulfur, carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). These gases are categorized as greenhouse gases. When these fuels burn, the resultant gases are released directly into the atmosphere where they continually collect along with other greenhouse gases. Sulfur and carbon oxides contribute to acid rain and contaminate air and rainwater. The other greenhouse gases mentioned above contribute to global warming (Environmental Protection Agency, 2010).

Global warming is attributed to the presence of greenhouse gases in the upper atmosphere that allow light and solar radiation to pass through them on the way through the atmosphere. However the radiation reflected off the surface of the earth bounces back off the greenhouse gases on its way out and becomes trapped. It is likely that the increased concentration of greenhouse gases in the atmosphere contributes to global temperature and weather changes. However the EPA (Environmental Protection Agency) states, “these features of the climate also vary naturally, so determining what fraction of climate changes are due to natural variability versus human activities is challenging” (Environmental Protection Agency, 2010).

Puerto Rico currently produces electricity using six petroleum fired power plants, one coal fired power plant, one natural gas powered plant, and six hydro-electric plants. The fossil fuel plants accounted for 99.4 percent of the overall electrical production on the island in 2007. The Puerto Rico Electrical Power Authority plans to begin producing 20 percent of the island's electricity using alternative energy sources by 2015 (Energy Information Administration, 2010). Considering its current state it is clear that Puerto Rico has concerns with sustainability, and that agencies are working to rectify these issues.

2.2 Conservation Techniques

Conservation by analyzing and streamlining existing infrastructure is one of the cheapest and easiest ways to cut down energy costs. Reducing, reusing, recycling, implementing passive energy systems, using efficient appliances and lighting, using green roofing and following efficient building codes are all ways to conserve energy, and reduce overall cost.

In the last 50 years, the amount of solid waste the average American generates in a day has nearly doubled. The best way to address this issue is to try to discard fewer items. There are many economic and environmental advantages to be derived from reducing the amount of waste generated and reusing the materials that need not be thrown away. From an economic stand point, this is beneficial because less money is spent purchasing materials as well as disposing of solid waste. The U.S. EPA (Environmental Protection Agency) website states that "source reduction also conserves resources and reduces pollution, including greenhouse gases that contribute to global warming" (Environmental Protection Agency, 2009). Even though every facility will generate some waste, it is important to recycle as much as possible and discard only what cannot be reused or recycled. Recycling is the act of taking material that would have otherwise been thrown into a land fill or incinerated and reprocessing it into another useful form. Recycling material reduces the energy costs of processing virgin materials. Another benefit to recycling is that there are recycling centers that pay per weight for recyclables. Organic waste such as food scraps and yard trimmings can be composted and later re-used, again cutting down on volume of wasted materials and therefore reducing costs (Environmental Protection Agency, 2009).

Old appliances and lighting systems in buildings that are out of date consume far more energy than similar modern devices. Recently the U.S. government has implemented a rating system to help consumers purchase more environmentally friendly appliances. The energy star tag appears on appliances that meet efficiency requirements established by the DOE (Department of Energy) and the EPA. Rebates may be offered to consumers who replace existing appliances with those that have received an energy star rating. There are currently many modern lighting options available to suit any need. Some include CFL (compact fluorescent lamps), straight tube fluorescent, tungsten halogen and light emitting diode lighting options. Although most of these options are significantly more expensive than standard incandescent lighting, they require less energy to produce more light, and bulb life is much longer (Department of Energy, 2010).

Cooling building space comes at a huge energy cost. The obvious solution is purchasing new and efficient air conditioning units. However this can be prohibitively expensive. Ensuring that your building is properly insulated, and doors and windows are properly sealed to keep cool air in and hot air out. Awnings and landscaping can be used to block direct sunlight from striking windows preventing extreme solar gain. Passive cooling systems reduce cooling costs in buildings. Passive energy collection systems use the design of the component of a building to absorb wanted heat energy, or reflect un-wanted heat energy (Department of Energy, 2010). A study performed by the Florida Solar Energy Center concluded that white roofing materials proved to greatly reduce the attic air temperature within test buildings and therefore reduce the overall cooling costs (Parker & Sherwin, 1998). In the most severe climates evaporative cooling methods work well to cool interior spaces. An effective evaporative cooling method works by pumping a small amount of water over the surface of a roof. As the water runs down the hot roof, it begins to evaporate. The evaporation of water requires a great amount of heat energy that would have otherwise been absorbed by the roof system. For almost every climate and condition there are passive cooling and heating systems that will help in reducing energy costs (Western Solar Utilization Network, 2010). A diagram of a passive solar cooling system is shown in Figure 2.1.

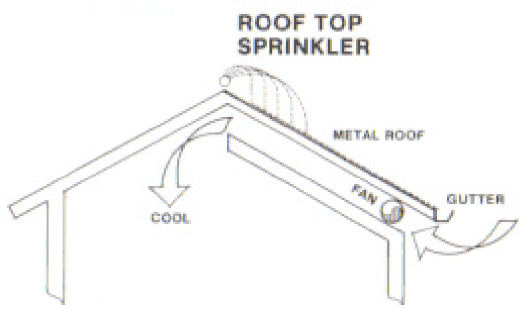

Figure 2.1: Roof top sprinkler, integrated conductive and evaporative cooling (Western Solar Utilization Network, 2010).

Another method of cooling airspaces within buildings is green roofing. The most notable benefit of green roofs in terms of energy conservation is decreasing temperatures in and around buildings in urban settings (Miller, 2009). In urban areas, thermal energy from the sun is absorbed in rooftops, streets, and sidewalks, rather than being absorbed and consumed by vegetation. This causes a substantial increase in temperature at street level and within buildings in these areas and therefore higher cooling costs. This phenomenon is known as the "Urban Heat Island Effect" (Environmental Protection Agency, 2009). Green roofs reduce this effect. However, the facilities in El Yunque National Forest are already surrounded by an entire rain forest bursting with vegetation that is consuming the sun's thermal energy. Therefore, the conservational benefits of adding a green roof on buildings in El Yunque would be negligible compared to the effects of adding a green roof in an urban area.

Yosemite National Park uses a park wide recycling system that collects glass, plastic, paper, and aluminum. Recycling containers are readily available for guest use, and employees use compostable packing peanuts, re-use shipping containers, and use environmentally friendly water based cleaning products. When purchasing products to be used throughout the park sustainability is always considered, from purchasing environmentally friendly paper products, to carpeting made from recycled plastics. They are also in the process of moving toward an entirely paperless office, encouraging employees to carpool, and installing waterless bathroom facilities. Yosemite has partnered with a local waste management facility to construct a composting facility where organic waste is separated and composted and remaining waste is managed responsibly (National Park Service, 2010).

Yosemite National Park also planned a lighting retrofit that is expected to yield a 30 % reduction in the cost of lighting throughout the park. The plan mainly consisted of replacing existing incandescent lighting with CFL. Another component of the lighting retrofit was to install motion sensors on lighting systems and programmable thermostats on heating and cooling devices. As a part of the master plan, park managers "select new equipment based in part on energy efficiency, using 'Energy Star' products for heating … and appliances. [Additionally] an energy-saving variable drive pump motor is also used for the sewer lift station" (National Park Service, 2010). These considerations that have been made by the National Park Service and Yosemite's management have both created a more sustainable business model, and an environmentally friendly image that visitors and employees constantly observe (National Park Service, 2010).

A lodge in the Sukau rainforest, located in Sabah Malaysia, has successfully used passive cooling to cut energy costs and improve public image. Through using passive solar techniques, the Sukau rainforest lodge eliminated the need for air conditioners in guest rooms (Sukau Rainforest Lodge, 2008). As a result, the lodge is able to advertise itself as a desirable destination for tourists that are concerned with green tourism.

2.3 Solar Power

Solar power is harnessed using several different methods and generates energy in the form of electricity or heat. Furthermore, solar power produces no harmful byproducts or greenhouse gases which contaminate the environment. According to 30 years of solar radiation data collected by the National Renewable Energy Laboratory (NREL), the city of San Juan receives an average 5.5 kWh/m^2/day (a measure of energy per unit area per day) for flat plate collectors, such as solar panels, at fixed latitude tilt (National Renewable Energy Laboratory, 1990). These data show potential for sustainable solar energy applications in El Yunque National Forest even though El Yunque receives 50 to 250 inches of rain annually depending on the specific location (US Forestry Service, 2008).This study considers photovoltaic (solar) electricity generation and solar hot water systems applied to El Yunque's energy needs.

2.3.1 Photovoltaic (Solar) Electricity Generation

Photovoltaic cells utilize the photoelectric effect to convert sunlight into electricity. Solar cells are constructed from thin layers of semiconductor materials such as silicone. These semiconductor materials are specially treated with foreign elements to polarize them, (i.e. to produce a positively charged and negatively charged side). When exposed to sunlight, electrons are knocked loose from the atoms of the semiconductor material. The polarity of the semiconductor material causes the electrons to flow from the negative side to the positive side of the solar cell, creating a direct (DC) electric current. A typical monocrystaline silicon photovoltaic cell has efficiency between 12% - 15% (Corkish, 2004; Knier, 2010).

Photovoltaic systems are constructed using arrays of solar cells and can be configured either as standalone systems or connected to an electrical grid. Standalone photovoltaic systems are used primarily in areas without nearby access to an electrical grid. In addition to the solar cells themselves, a standalone system in Puerto Rico requires an inverter to convert the direct current (DC) to alternating current (AC) as well as a battery to store the electricity generated. Furthermore, standalone photovoltaic modules are also used in conjunction with diesel generators in hybrid photovoltaic systems that insure energy requirements are met regardless of the availability of sunlight. Grid connected photovoltaic systems require an inverter to convert the direct current (DC) to alternating current (AC), but are connected to the local electrical grid rather than a battery. Therefore unused electricity is sold back to the power company, while additional electricity is purchased from the power company to meet energy requirements (IEA, 2010). Although photovoltaic systems require a large initial investment, they call for essentially no reinvestment and no maintenance aside from standard cleaning. A typical construction of a grid connected photovoltaic system is shown in Figure. 2.2.

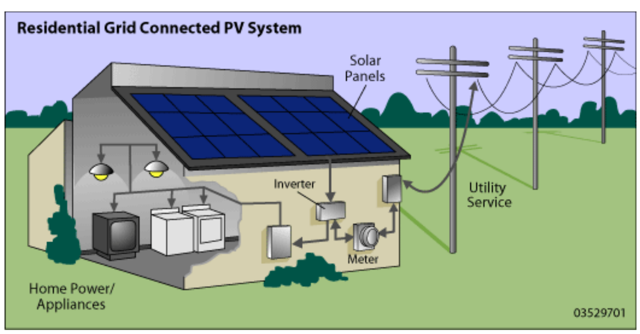

Figure 2.2: Grid connected photovoltaic system (US Dept. of Energy, 2009).

Wayne National Forest in southeastern Ohio has been using photovoltaic solar power to provide electricity to its headquarters building since 2007. The original system consisted of 20 photovoltaic panels and cost $33,000. In 2008, the system was expanded to 50 panels for an additional $35,000. The 50 panel system satisfied about 7% of the building's electricity demand during peak production months. In 2009, Wayne National Forest was granted $7.2 million under the American Recovery and Reinvestment Act. $398,000 of this fund was used to expand the headquarters' photovoltaic system to 302 panels for a total capacity of 59 kW, as shown in Figure 2.3.

Figure 2.3: 59 kW photovoltaic system at Wayne National Forest Headquarters (Sound, 2010)

According to Wayne National Forest engineer Steve Marchi, the system is expected to reduce electricity costs by $5,000 to $7,000 annually at a rate of $0.09 per kWh (Madsen, 2009). Puerto Rico generally has higher electricity prices and receives more solar radiation than Ohio. Therefore, a similar photovoltaic system in El Yunque could save significantly more money annually and bring more sustainability to the region.

On Mona Island, Puerto Rico, there is a small settlement consisting of a museum, several barracks, a rangers' office, and a communications building. Traditionally, energy was supplied to these facilities by means of a diesel generator grid. In 1997, seven standalone photovoltaic systems with a combined capacity of 23.5 kW were integrated into these facilities to fully replace the diesel generator grid and provide a cleaner, more sustainable source of electricity. An aerial image of the 15 kW photovoltaic system used on Mona Island to power the museum is shown in Figure 2.4 (Bing, 1998).

Figure 2.4: 15 kW photovoltaic system on Mona Island, Puerto Rico (Bing, 1998)

In 1998, Mona Island was struck by Hurricane Georges. Hurricane Georges was a category four hurricane meaning that it had persistent wind speeds between 131 mph and 155 mph (National Weather Service, 2009). Only two of the seven photovoltaic systems on Mona Island sustained damage strictly due to the hurricane and one had sustained damage due to poor placement and improper installation (Deering & Thornton, 1999). This case provides evidence that not only can photovoltaic systems provide a sustainable source of energy in a tropical environment, but they can also withstand severe tropical weather conditions.

2.3.2 Solar Hot Water Systems

Solar hot water systems consist of solar collectors and a tank or storage unit. Flat plate solar collectors are the most common type of solar collector used in solar hot water systems. A flat plate solar collector is a box containing a system of small pipes that carry a fluid covered by a translucent cover. The solar collector heats the fluid which is then circulated through an insulated tank; heating the water inside. Therefore, solar hot water systems normally require a pump to circulate the fluid throughout the system, but they can circulate the fluid using gravity. Solar hot water systems require minor maintenance throughout their lifetime that consists mainly of replacement of the electronic components such as the pump, and plumbing repairs related to leaky or broken pipes. A typical construction of an active, pump operated solar hot water system is shown in Figure 2.5 (National Renewable Energy Laboratory, 2009; US Department of Energy, 2009).

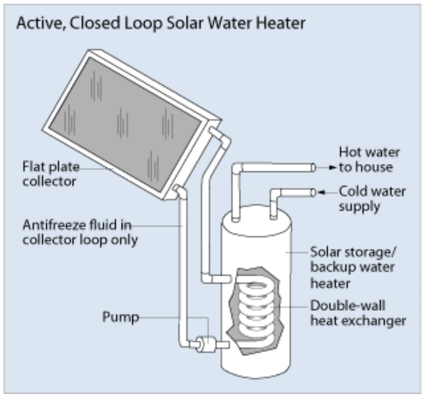

Figure 2.5: Active, closed loop solar hot water system (US Dept. of Energy, 2009)

In 1998, the National Park Service installed three solar hot water heating systems at Buckhorn Campground in Chickasaw National Recreation Area in Oklahoma. The three systems supply all of the hot water to three comfort stations, which provide Chickasaw visitors and employees with hot showers. Two of the systems produce 9,394 kWh per year, and are capable of providing 660 gallons of water per day at 95°F. These small systems cost $18,000 and have a projected payback period of nine years. The third system produces 18,194 kWh per year and is capable of providing 1500 gallons of water per day at 105°F. This larger system cost $24,000 and has a projected payback period of eight years. Each of the systems has a savings to investment ratio of at least 2:1. (US Department of Energy, 1999) The large comfort station solar hot water system at Buckhorn Campground is shown in Figure 2.6.

Figure 2.6: Large comfort station solar hot water system at Buckhorn Campground (National Renewable Energy Laboratory, 1998)

The National Park Service has had success with solar hot water systems at Buckhorn Campground. This case gives promise that similar success with solar hot water systems could be achieved in El Yunque in providing hot water to the US Forestry Service's facilities.

Barbados has taken advantage of solar hot water systems more than any other Caribbean nation. Between 1974 and 1992, 23,388 solar hot water systems were installed in Barbados. In 1992, aggregate energy savings for solar hot water systems in Barbados was approximately 75 million kWh for a total monetary savings of approximately $9.75 million USD (United States Dollars) at $0.13 USD per kWh. That is a savings of approximately $416 USD per system. In terms of foreign oil use, the 23,000 solar hot water systems in place in Barbados saved approximately 188,000 barrels of oil in 1992 (Headley, 1997). Foreign oil and electricity prices have increased rapidly over the past 20 years in Puerto Rico and the rest of the Caribbean region. Therefore, solar hot water systems could save significantly more money per system annually in El Yunque today than was saved in Barbados in 1992, while bringing more sustainability to the region.

2.4 Wind Power

Wind has been used for hundreds of years as a natural source of energy to accomplish many tasks. Wind energy has traditionally been used to propel ships, process grains, and pump water (Hills, 1994). Modern versions of the wind mill are currently being used to transform the kinetic energy of the wind into electric energy, and are commonly referred to as wind turbines.

Albert Bets showed in 1927 that an ideal wind turbine with non-lifting blades is only capable of extracting 16/27ths of the total kinetic energy of a moving air mass due to inherent losses and inefficiencies. It was later discovered that the actual ideal wind turbine with non-lifting blades is only capable of extracting about 25% of the total available kinetic energy from the wind (Heier, 2003; Hills, 1994).

Horizontal axis and vertical axis wind turbines are the two major classes of wind turbines. In a horizontal axis wind turbine, the plane of the spinning blades is perpendicular to the earth's surface, whereas in a vertical axis wind turbine, the plane of the spinning blades aligns parallel with the earth's surface. The two main advantages of a vertical axis wind turbine are that it works equally well in any wind direction without having to design a swivel mechanism, and its blades make far less noise (Hills, 1994). However, it has been proven that over a variety of wind speeds horizontal axis wind turbines have advantages in achieving higher performance coefficients than vertical axis machines. The performance coefficient C_p is described in Equation 2.1

Equation 2.1: Performance Coefficient:

$$C_p = P_w/P_o$$

C_p = performance coefficient
P_w = total power absorbed from the wind column
P_o = total available power

Horizontal axis wind turbines also exhibit more desirable start-up behavior and offer more latitude for the implementation of control options. These benefits come at the cost of noise and complexity (Heier, 2003). Figure 2.7 shows a Horizontal axis wind turbine next to a vertical axis wind turbine.

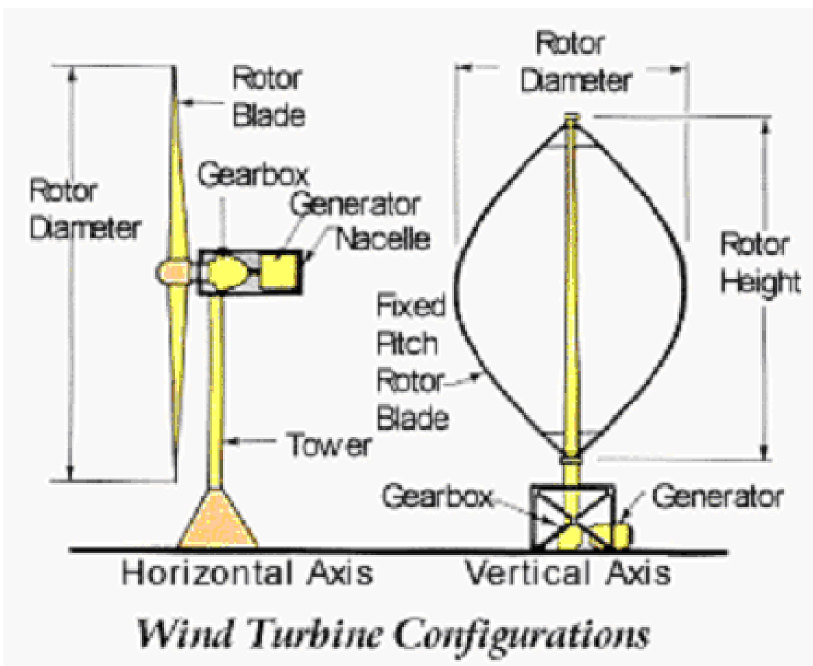

Figure 2.7: Comparison of a vertical axis and horizontal axis wind turbine (85 Twenty First Century Energy 2010).

Wind turbines of both varieties can be developed and optimized to output high torque or high rotational speed. Machines constructed with many blades and slow rotational speeds produce high levels of torque and therefore are best suited to perform mechanical tasks. On the other hand, wind turbines with fewer blades achieve higher rotational speeds and are better suited to achieve high levels of power extraction. For this reason wind turbines with fewer blades are better suited for making electricity. The development of aerodynamically lifting blades for both classes of wind turbines has made it possible to extract nearly 45% of the overall available kinetic wind energy (Heier, 2003).

There are several advantages of using wind to generate electricity over conventional power generation techniques. One notable advantage is that the power generated by wind turbines does not cause direct environmental harm. Moreover, wind energy installation yields minimal site damage. Lisa Daniels describes another advantage derived from wind energy for land owners, “[wind turbines] take less than 2% of the land out of production, so it's not replacing what's there. It is an additional source of revenue” (Gordon, 2004). Other benefits include monetary clean energy incentives and tax breaks offered by some governments (DeCarolis, Keith, Jacobson, & Masters, 2001). Unfortunately, not every aspect of wind power generation is positive.

Since the best areas to position wind turbines are high ground or flat terrain, the turbines are visible from great distances. Some people consider this view undesirable, and believe that property with wind turbine obstructed views is undesirable (Nadaï & van der Horst, 2010) (Pinder, Price, & Smith, 1989). There are also environmental aspects to consider. Sites are particularly damaging to birds, both physically and in terms of habitat damage. High blade tip speeds generate loud turbulence. The final concern is that uncertainties with wind turbine technology such as blade or tower failure make the safety of the public residing near a wind turbine a concern (Berkhuizen & Slob, 1989).

It is important to consider the number of wind turbines that are placed on a specific site when planning a wind project so the desired amount of electricity can be generated. Individual wind turbines are capable of producing electricity on a small scale. Depending on site requirements it may be necessary to construct a wind farm, or a single site that employs multiple wind turbines that work together to produce electricity. Recently there has been a shift in individual ownership of small wind turbines to a commercial ownership of wind farms. This trend correlates directly to the economic benefits, and the efficient nature of larger scale projects

(Nadaï & van der Horst, 2010). Deciding the location that the wind turbines will stand is the next step in constructing a successful wind farm.

The two main categories for site choices are land based sites and off shore sites. Off-shore wind farms are desirable because issues with noise, visual obstruction, and safety are avoided. Additionally, off shore wind patterns are more consistently sustained and therefore turbines can be constructed on a larger scale. However the forces of waves and currents and the logistical issue of getting the electricity from the off shore site back onto land is problematic (Byrne & Houlsby, 2003). When considering sites on land, altitude is important. As a rule of thumb, wind speeds increase in a given area with height above the surface of the earth. This phenomenon is described with boundary layer theory, a topic in fluid mechanics. Landscape also can interrupt the linearity of the wind flowing over the land and generate turbulence. Due to the irregularity of turbulent flow, wind turbines are relatively ineffective at extracting energy from turbulent flows (Simmons, 1975). Because flow consistency is proportional to a wind turbines overall efficiency, weather patterns are also important to site selection.

Weather patterns that typically include a sufficiently strong and relatively steady wind are perfect for a wind turbine site (Cheremisinoff, 1978). Other site data that can be used to determine the energy yield of a site include the number of hours per year that relevant wind speed occurs (Heier, 2003). Wind gusts are useful on start up as wind turbines generally can continue to operate at a wind speed that is lower than the speed required to start them spinning. Occasional slow wind speed is acceptable, as there is some energy stored in the spinning blades of a wind turbine. As a result the rotational inertia of the system is sufficient to keep the blades spinning when there is a short period with low wind speeds.

Depending on whether electricity will be fed into a grid or stored on site, the electricity generated by a wind turbine may pass through a rectifier or an inverter. A rectifier takes one or three phase AC into DC, and an inverter converts DC into one or three phase AC. This is necessary because the electrical current needs to be compatible with the storage system it is used with (Heier, 2003). This process is similar to the grid integration and standalone power section outlined in section 2.2.

There are currently several wind projects underway to supplement Puerto Rico's dependence on fossil fuels as a primary energy resource. Wind data has been collected for sites along the northern and eastern coasts and throughout the high ground in the interior of the island.

A 50 megawatt wind project is currently under construction and is slated to be completed by August 2012. Additionally, there are two more wind projects in the development stages. As stated by the EIA, "the use of renewable energy is growing and the Puerto Rico Power Authority plans on generating more than 20 percent of electricity demand from renewable sources by 2015" (Energy Information Administration, 2010). Despite the social concerns that revolve around wind energy, there is currently a movement in Puerto Rico toward employing more wind energy, and addressing the issue of sustainability.

The Boston Harbor Islands National Recreation Area is operated by the National Park Service and is planning to use wind as a resource. The area is very windy and as a result a wind turbine was constructed on the mainland in Hull. This wind turbine is responsible for generating all of the electricity that the street lights use in Hull, and has been so successful that a second larger turbine is currently being constructed at a second site. The Park Service is planning to place their own wind turbines throughout the islands to help power their infrastructure (National Park Service, 2008). Wind energy is one component of the plan that the park service has to use alternative energy throughout the Boston harbor islands to address the issue of sustainability and create an energy conscious public image.

2.5 Transportation and Alternative Fuels

Biodiesel fuel is a renewable fuel produced from various biomass materials including animal fat and vegetable oils. It is used as a replacement for conventional petroleum diesel because it combusts in a very similar fashion and has like properties. Bio and petroleum diesel are often combined to produce a biodiesel blend. These fuels are classified by the percentage of biodiesel present in the mixture. A diesel blend with 20% biodiesel and 80% petroleum diesel is classified as B20, and pure biodiesel is listed as B100. B20 is the most commonly used biodiesel blend in vehicles today, as its use requires little or no modification to traditional diesel engines.

Biodiesel is most widely used for transportation, though it also generates electricity. Most biodiesel blends provide a similar performance to that of traditional diesel fuel. In a test both of both on and off road biodiesel applications, it was determined that biodiesel shows "similar fuel consumption, horsepower, torque, and haulage rates as conventional diesel fuel" (National Biodiesel Board, 2010). As the price of petroleum rises, so does the demand for biodiesel. The national production of biodiesel in the United States grew from 2 million gallons in 2000 to 491 million in 2007 (National Biodiesel Board, 2010b). Yet the prices of biodiesel blends rise with the petroleum prices as well. In October 2009, the price of B20 was listed at $2.88 per gallon, and B100 at $3.19 per gallon, both more than regular gasoline and petroleum diesel. When compared to reports from July 2009, both prices had increased considerably. B20 prices increased by $0.19, and B100 increased by $0.11. Though biodiesel prices rose, gasoline and diesel prices rose by $0.20 and $0.26, respectively (US Department of Energy, 2009). However, each fuel type does not produce the same amount of energy per gallon, so we must look at the amount of energy produce per unit price. On an "energy equivalent basis" in units of dollars per million BTU, gasoline cost $22.90, diesel; $21.69, B20; $22.77, and B100; $27.21 (US Department of Energy, 2009).

Biodiesel is used in place of fossil fuels because it is less damaging to the environment. Biodiesel is known to release considerably fewer harmful emissions than gasoline and traditional diesel fuels. Emissions of hydrocarbons, nitrogen oxides, and carbon monoxides are known to adversely affect the environment. According to the National Biodiesel Board, B100 emits about 48% less carbon monoxide than traditional diesel fuel, and 67% fewer hydrocarbon pollutants. B20 fuel reduces carbon monoxide and hydrocarbon emissions by 20% and 12%, respectively. However, both B100 and B20 blends have shown an increase in nitrogen oxide emissions, by 10% and 2% respectively (National Biodiesel Board, 2010a).

In efforts to protect wildlife by reducing emissions, the United States National Park Service has been using pure B100 fuel to power vehicles in Yellowstone National Park for over 10 years. Use of biodiesel in Yellowstone began as a test, but has since become popular in the National Park Service. According to NPS Environmental Leadership Program Coordinator Shawn Norton, biodiesel fuel is now used in "more than 1,000 different biodiesel applications" in "at least 50 …national parks." In 2005, the NPS used over 80,000 gallons of biodiesel fuel in various applications, and is still ambitious to use biodiesel in more of its parks (Kotrba, Ron 2006).

2.6 Hydropower

Hydropower systems produce mechanical energy and electrical energy (Gulliver & Arndt, 2004). Compared to burning fossil fuels, hydropower systems emit a negligible amount of harmful byproducts and greenhouse gases. Additionally, since hydropower is a renewable energy source and will remain a sustainable source of energy indefinitely. Hydroelectric power generation will be included in this study.

Hydroelectric power systems exist in many different sizes. The United States Department of Energy classifies hydroelectric power systems by their electrical capability. Under this classification scheme, large hydroelectric power systems have a capability of over 30 MW of power, while small hydroelectric power systems have a capability of 100kW to 30MW. Hydroelectric power systems having a capability less than 100 kW are known as micro hydroelectric power systems (US Department of Energy, 2005).

There are three major types of hydroelectric power generation. The most common type is an impoundment hydroelectric power plant. Impoundment hydroelectric power plants dam a river to create a reservoir of water which is then released through the dam, rotating turbines as it passes through. The turbines are connected to a generator which turns to produce electricity (US Department of Energy, 2005). However, impoundment hydroelectric power plants usually have severe ecological and environmental effects. These types of plants can prevent migratory fish from travelling upstream, while fish and other organisms travelling downstream can be pulled into the dam's intake and forced through the turbine causing them to sustain physical injury or death. Furthermore, impoundment hydroelectric water plants severely alter the flow of water in a river. Upstream from the dam, a reservoir forms which may flood and force any land abiding species on shore to displace. Water in the reservoir may also become stagnant or inert causing undesirable growth of algae and the prevention of important nutrients from flowing downstream. This leads to chemical imbalances in the water and malnourishment of aquatic plants and animals in areas downstream from the dam (Brookshier, 2004; Cada, Sale & Dauble, 2004).

The ecological and environmental consequences of impoundment hydroelectric power plants can be reduced at the expense of electrical output. Such measures include adding passages for fish to travel through both upstream and downstream, and providing a means for a sufficient amount of water to flow to areas downstream to maintain the health of aquatic animals and plant life in these areas. However, these methods are not completely effective and require a significant amount of monitoring and maintenance which makes them less sustainable (Cada, Sale & Dauble, 2004). Therefore, in a National Forest Reserve such as El Yunque, impoundment hydroelectric power plants are not an appropriate means of electricity generation because of the ecological and environmental consequences associated with them.

The second type of hydroelectric generation is a diversion hydroelectric power plant. Diversion hydroelectric power plants can be constructed using one of two techniques. First, a diversion hydroelectric power plant is constructed by channeling off a section of a river and damming it rather than the entire width of the river. The water in the channel is guided through one or more turbines connected to generators which they turn to produce electricity (US Department of Energy, 2005). Since this type of diversion hydroelectric power plant alters the flow of the river to a certain extent, it has similar environmental and ecological consequences as impoundment hydroelectric power plants but at a lesser degree. The second type of diversion hydroelectric power is a run of the river hydroelectric system, and is used mostly in micro hydroelectric systems. Run of the river of hydroelectric power systems simply diverts water from a location upstream through a pipeline or channel and a turbine which is connected to a generator, back into the river at a location downstream. A typical construction of a run of the river hydroelectric power system is shown below in Figure 2.8 (US Department of Energy, 2009).

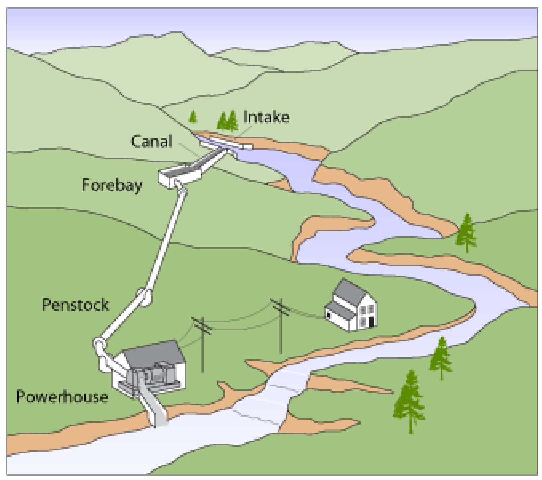

Figure 2.8: Typical Construction of a Run of the River Hydroelectric Power System (US Dept. of Energy, 2009).

Since run of the river hydroelectric power systems do not require a dam be constructed on the river, they do not prohibit the movement of fish and other organisms within the river nor severely alter the flow of the river unless too much water is being diverted out it. Therefore if constructed correctly, the environmental and ecological impacts are negligible compared to those of impounded hydroelectric power plants **(**Egré & Milewski, 2002). In a National Forest Reserve such as El Yunque, run of the river hydroelectric systems are the most appropriate means of electricity generation as the negative environmental effects associated with them are limited. However, this does not mean that these environmental effects will be acceptable.

The third type is the pumped storage hydroelectric power generation. These systems provide more electricity than is available during peak electricity usage. In a pumped storage hydroelectric system, water is pumped by an electric pump to a reservoir of high elevation during periods of low electricity demand. During periods of high electrical demand, water is released from the high reservoir through a turbine connected to a generator and back into the low reservoir (US Department of Energy, 2005). However, pumped storage hydroelectric systems use more energy to pump the water to the upper reservoir than they can generate. Therefore, these systems are not a sustainable source of electricity **(**Egré & Milewski, 2002).

2.7 Geothermal Power

Geothermal energy refers to the heat generated by the motion of earth's inner layers and core. This energy can be collected by using the steam created from water heated beneath the earth's crust to turn turbines and generate electricity. This method of harvesting geothermal energy is effective in areas where the earth's crust is thin enough to allow ground water to be heated by the earth's core. Such areas exist all around the world, but are located mostly on or near tectonic plate lines. Most geothermal energy plants require a deep well dug to reach the hotter layers of the earth, which can cost millions of dollars (depending on the depth and width of the well).

Geothermal energy is hailed as an ideal source because it relies only on the heat of the earth. It is also less harmful to the environment than traditional sources of electricity generation such as burning coal or oil. Drilling wells and pumping steam to the surface releases gases into the air. Gases contained in the earth's crust include carbon dioxide, hydrogen sulfide, methane, hydrogen, sulfur dioxide, and ammonia, though carbon dioxide and hydrogen sulfide are the only two found in enough abundance to be considered a threat to the environment. Burning coal emits over 35 times as much carbon dioxide, and almost 30 times as much sulfur dioxide, as a flash geothermal plant (per mega watt hour of electricity produced) (Wilcox, 2006). There is also concern for water pollution in the process of harvesting geothermal energy. Minerals dissolve in the high temperatures of the steam and water used to generate power, and eventually poison both surface and ground water. Precautions must be taken to prevent harmful minerals in water from being released back into the ground.

There are other methods used for harnessing the heat energy of the earth's core. The term "direct use" describes the use of geothermal energy without converting it to electricity. These uses include but are not limited to; bathing, swimming, space heating and cooling, agriculture, and heat pumps (Lund, 2004). The most common direct use of geothermal energy in the world is space heating, which is accomplished through water to air or water to water heat exchangers. While geothermal heat pumps are very useful for heating buildings, they are less efficient for cooling and require a higher water temperature to be effective, usually above 100°C (Lund, 2007).

Another geothermal application, called ground source heating/cooling, consists of the pumping of air or water through an assembly of piping buried underground. The air or water is either heated or cooled (depending on its original temperature and the ground temperature) by the soil. The water or air is then pumped to an above ground point where it is used for heating or air conditioning. Evaluating the effectiveness of this method requires knowledge of the characteristics of the soil, including its thermal conductivity and heat capacity, k_s and $\rho_s C_s$ respectively (Hepbasli, 2004). Similar to ground source cooling systems, so systems use piping laid underneath or in bodies of water to cool air. Ground source heating and cooling are generally used on small scale applications such as private residences. Figure 2.9 shows a schematic of ground source heat recovery system.

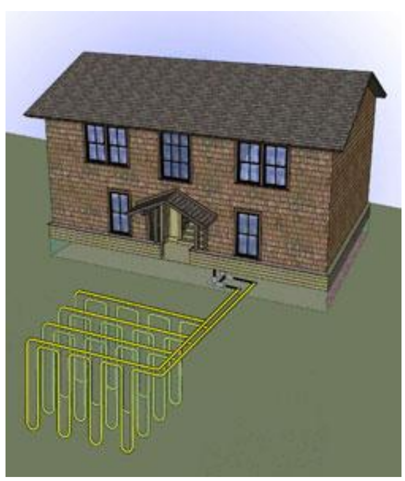

Figure 2.9: Schematic of typical ground source heat recovery system (National Park Service 2010).

Yosemite national Park utilizes a GSHP (ground source heat pump) system to control the temperature of its employee housing in Curry Village. The system pumps a mixture of glycol and water through pipes buried in the ground. In the winter the cold refrigerant is forced (by electric pumps) from within the building through the loops pipes in the ground. As the mixture travels it collects heat from the earth, and then returns to the building heated. Once inside, air is passed over the pipes containing the hot mixture. The air is heated by the pipes, and is then dispersed into the building to heat it. (National Park Service, 2010) Though a GSHP in El Yunque would be used for cooling rather than heating, the principle idea remains the same. Hot air would be collected from the building, and then cooled by the ground as it passes through piping.

2.8 Summary

There is a constant demand for energy all around the world, and El Yunque National Forest is no exception. There is a need to produce and conserve energy in a more cost effective manner, as well as to exhibit an environmentally friendly image. We have introduced many ways to do this, including practicing different conservation techniques and harnessing solar, wind, biomass, hydro, and geothermal energies. Each of these constituents will be investigated, and their advantages and drawbacks will be evaluated. These findings will be used to develop an energy plan addressing cost, sustainability, and land management in El Yunque National Reserve.

CHAPTER 3: METHODOLOGY

The goal of this project is to evaluate the possibilities and advantages of using alternative energy sources and energy conservation methods in El Yunque National Forest. Since the team did not have the benefit of first seeing the forest, it is prepared to examine the feasibility of many alternative energy sources including solar power, wind power, geothermal power, hydropower, and biodiesel fuel. Once on site, the most feasible alternative energy sources will be chosen and further investigated. All other alternative energy sources will be deemed unfeasible, and no further investigation will follow. Site analysis will be performed in order to determine which methods show the greatest potential benefits for El Yunque National Park

3.1 Site Analysis

A site analysis will assess the feasibility of each proposed solution. The social issues that each of the solutions present, including visual intrusion, noise pollution, and general public opinions, will also be considered. Site analysis includes data collection in the forms of research, interview, and field work. Using this data, the amount of energy potentially produced or conserved using each method will be estimated. Cost analysis will then be performed by evaluating the total cost of each method. Comparison of the energy production and costs of each method with those of El Yunque's current system will determine the best solution(s) for the sponsor. The desired deadline for data collection will be within five weeks of arrival on site.

3.1.1 Conservation Analysis

The project will consider the energy and overall cost savings potentially produced by conservation techniques. This analysis will begin by uncovering major energy wasting habits at the park. Some examples may include: using non-programmable thermostats, using inefficient lighting and appliances, the improper insulation of walls, ceilings, and windows, wasteful policies, etc. Next, the current recycling plans in El Yunque will be studied, as well as the level to which they are carried out. A study will determine whether or not El Yunque has a recycling plan implemented and how successful it is, by observation and photographical evidence. From the information on the current situation, an estimate will be made of the amount of energy wasted, and the amount of materials being thrown away or purchased without reason. Finally, a proposal outlining conservation, recycling, and reuse techniques that may save energy and reduce total operating costs, will be made to the sponsor.

3.1.2 Solar Power Site Analysis

The most significant factor in the feasibility of capturing solar power is the intensity of the solar radiation at the site in question. The National Renewable Energy Laboratory's "Solar Radiation Data Manual for Flat Plate and Concentrating Collectors" will be used to evaluate the solar radiation in El Yunque (National Renewable Energy Laboratory, 1990). This manual contains average daily solar radiation statistics for San Juan based on thirty years of data collection. Weather is another significant factor on the productivity of solar power systems, and weather trends must be studied, including cloud cover and precipitation in El Yunque. Information from El Yunque's weather station will be used to investigate weather conditions as well as solar radiation statistics. As hurricanes are common to the Caribbean region, the possible extent of damage to solar units due to hurricanes will also be examined by reviewing case studies of solar power applications in Caribbean nations. After reviewing solar radiation and weather data, several potential sites in El Yunque will be analyzed in terms of how much sun each receives. Analysis will also include an observation of any obstructions that block sunlight, such as trees, buildings, mountains, and so forth. These observations will allow the team to propose sites best suited for solar energy collection.

3.1.3 Estimate the Production of Solar Energy

The electrical production of a photovoltaic system depends on the size of the system, a performance ratio, and the amount of solar radiation per unit time. The performance ratio takes into account losses in the system due to inverters, cables, and temperature. Mono and polycrystalline silicon solar cells typically have a performance ratio around 0.75. To calculate the electrical production of photovoltaic systems we use Equation 3.1 (Dunlop, Huld, Ossenbrink & Suri, 2007).

Equation 3.1: Annual Electricity Production of Photovoltaic Systems:

$$E = P \cdot PR \cdot SR$$

E = Annual Electricity Production
P = Peak Unit Power
PR = Performance Ratio = 0.75
SR = Annual Solar Radiation

The amount of energy that will be collected by a flat plate solar panel is determined by the Hottel-Whillier equation. The Hottel-Whillier equation is a function of the available solar radiation and several dimensions and characteristics of the system. (Geros, Karatasou & Santamouris, 2006)

Equation 3.2 Hottel-Whillier Equation for Energy Collection:

$$Q_u = AF_R(I_T(\tau a) - U_L(T_i - T_a))$$

F_R = Heat Removal Efficiency Factor of the Collector
A = Area of Collector
τa = Effective Product of Transmittance
I_T = Solar Radiation / Unit Area
U_L = Energy Loss Coefficient
T_i = Inlet Fluid Temperature
T_a = Ambient Temperature

These equations will be used along with collected data to estimate the power that can be produced by harnessing solar power in El Yunque. This type of analysis will be used to evaluate potential energy collection at each possible solar site. This information in conjunction with weather observations will determine the most favorable solar collection site.

3.1.4 Wind Power Site Analysis

Site analysis will consider the technical, economic, and social issues associated with potential site locations of wind turbines. Landscape, altitude, and weather patterns all influence the quality of a wind turbine site. In order to make site recommendations, topographical maps will be used to find the highest and most uniform landscape, observe typical on site weather patterns, and utilize wind velocity maps and recorded wind data. The negative impact that a wind turbine could cause in specific sites will be recorded in the form of a check list developed for this purpose. The check list will be developed around points that include environmental effects, noise pollution, visual intrusion, and the destructive impacts of site preparation and construction. After assessing possible negative impacts, wind speed data will be collected on the most viable specific sites.

This data will be collected to verify that the generalized data presented by wind maps is in fact accurate. At this point it is uncertain if necessary instrumentation such as anemometers will be available to us to use for data collection. Considering this, it is understood that actual collected data is very useful when selecting a site, but data from the weather station in El Yunque and research-based data such as wind maps may need to be used instead. Figure 3.1 is an example of a wind map that describes velocity and direction.

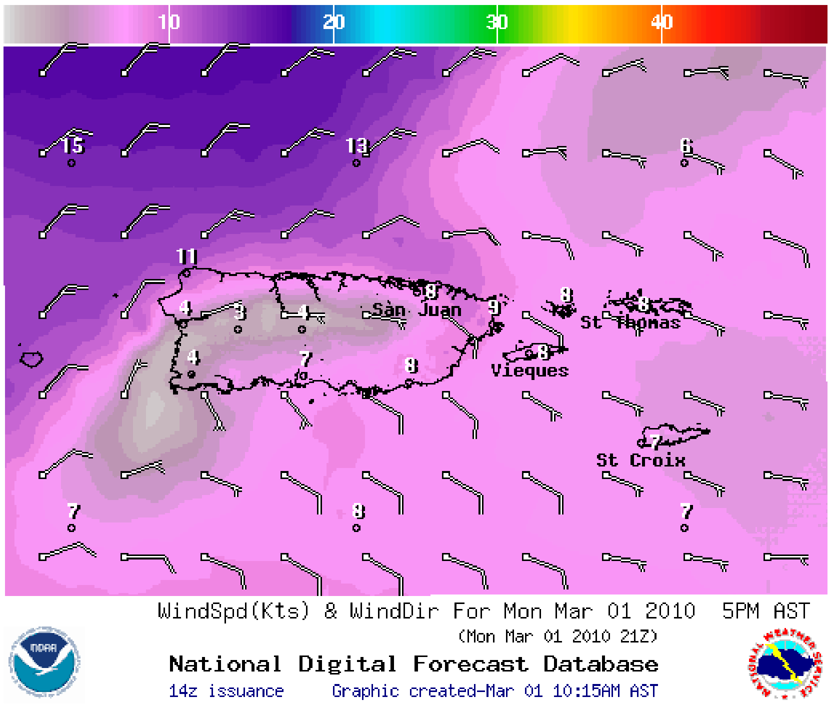

Figure 3.1: Example of Puerto Rico wind map (National Weather Service, 2010).

After collected qualitative and quantitative data is compiled, a report will be drafted, including the locations of the most appropriate sites based on altitude, surrounding landscape, highest average wind speeds, most consistent winds, and possible negative environmental effects. It will be recommended that El Yunque management perform a long term site analysis of each site, as time limitations will prevent us from conducting a more thorough analysis.

Site analysis will provide sponsors with the coordinates of the sites that offer the best energy potential, while impacting the environment and the visitors to the park as little as possible. These sites will be selected as outlined above. A proposal will also recommendation that the park follow through with a long term wind velocity analysis of each proposed site, and will include a summary of the proper methods and instrumentation to use when conducting a wind site study. A properly conducted long term data survey on the sites help El Yunque management to effectively determine the feasibility of using wind turbines as an energy resource.

3.1.5 Estimate of the Production of Wind Energy

The energy produced by a wind turbine is entirely dependent upon the local wind conditions. According to Albert Betz, a theoretical physicist, the maximum wind turbine power output for a wind turbine with lifting blades can be calculated using Equation 3.3 (Heier, 2003).

Equation 3.3: Maximum extracted power for a wind turbine at a given wind speed.

$$P_{W\text{-}max}=16/27*A_R*\rho/2*V^3$$

$P_{W\text{-}max}$ = maximum power that can be generated
A_R = the area of the rotor disk
ρ = the density of the air
V = the Velocity of the air

Betz's equation considers the optimal case and will be used to calculate the best possible results. Performance data that is made available by wind turbine manufacturers will offer us a way of generating more accurate estimates.

Once the total energy need is assessed, appropriate wind turbines will be recommended based on data provided by their manufacturers. Wind turbine manufacturers provide graphs that relate the actual power extracted by a wind turbine to the nominal wind speed. These extraction curves, in conjunction with available wind mapping data and possibly with wind speed data that the team will collect, will be used to estimate yearly power output of various wind turbines at each proposed site. Calculations will provide a general idea of how much energy wind power can produce in El Yunque. After a thorough long term site analysis has been completed as recommended, the expected power for each site can be easily re-calculated to provide more realistic results.

3.1.6 Transportation and Alternative Fuels

To examine the potential benefits of biodiesel or electric vehicles, data concerning the prices of gasoline, diesel, and biodiesel fuels, as well as biodiesel and electric powered vehicles on the market will be collected. Additional information, such as the make and model of the vehicles in the park's fleet, and the model of biodiesel generator currently in use, will also be gathered.

Prices and availability of fuels and vehicles are available online, while information regarding the park's current assets and expenditures will be gathered from utility records and interview of the sponsor. Analysis will consider the difference in environmental impact between biodiesel, diesel, gasoline, and electric vehicles. Projected changes in the biodiesel market must also be considered in proposing a long term plan. Once this information is gathered, an estimate of the amount of money potentially saved or lost by changing fuel uses will be calculated.

3.1.7 Hydropower Site Analysis

When determining which specific site on a river is most feasible for small scale run of the river hydropower systems, one must consider the difference in elevation between the starting point and the end point of the system (natural head) and the flow rate of the river at the proposed site. Other factors to be investigated in planning the implementation of a small scale hydropower system include soil compositions and precipitation runoff; however these variables are not necessary for determining the economic impact of the system. The flow rate or discharge is the volume that flows past a point per unit time. GIS database technology along with other topographical resources will be used to evaluate which sites along rivers in El Yunque have the highest natural head and flow rate.

3.1.8 Estimate the Production of Hydropower

The electrical production of a small scale, run of the river hydropower system depends on the efficiency of the system components, the natural head, and the flow rate at the given site. To calculate the electrical production of small scale run of the river hydropower systems we use Equation 3.4 (Bureekul, Chaisomphob & Rojanamon, 2009). This will allow us to estimate the amount of electricity that could be produced by a run of the river hydro-electric system.

Equation 3.4: Electricity Production of Small Scale Run of the River Systems:

$$P = g \times \eta_t \times \eta_g \times Q_d \times (H_d - (0.001 L_h + 0.005 L_p))$$

P = Power Output (kW)
g = Acceleration due to Gravity = 9.81 m/s^2
η_t = Turbine Efficiency
η_g = Generator Efficiency
Q_d = Flow Rate or Discharge (m^3/s)
H_d = Gross Head (m)
L_h = Length of Head Race (m)
L_p = Length of Penstock (m)

3.1.9 Geothermal Energy Site Analysis

Ground source cooling will be considered for air conditioning in the park's buildings. To estimate the effectiveness of ground source cooling, site data including the sizes of the buildings and their ambient air temperatures throughout the day will need to be collected. The density and temperature of the ground around the buildings at varying levels beneath the surface will also be tested.

Most information on the buildings will be provided by our sponsor, including sizes and blueprints. Temperature data will be collected using a thermometer to take readings inside and outside of the buildings. Ground temperatures and densities will be gathered from provided information by the sponsor or online research if it is not available. Coupling this data will thermodynamic analysis will allow us to assess the effectiveness of using ground source cooling to lower the temperature within the buildings in question, and by doing so evaluate the electric energy that can be saved as a result.

3.2 Environmental Impacts

It is important to the United States Forestry Service that EL Yunque National Park has a positive sustainable and environmental image. Alternative energy sources should have a positive impact, as they are perceived to be beneficial to the environment. For example, solar power and direct use geothermal applications have minimal negative effects on the environment save for construction. Conversely, wind power, hydropower, and biodiesel fuel can negatively affect the environment to different degrees. Potential threats to the environment must be carefully analyzed, as sustainability and environmental conservation are integral to the park's agenda. Pertinent case studies and online information will be reviewed in order to analyze the potential harmful environmental effects that each potential solution may present to the forest.

3.3 Cost Analysis

A major factor in accessing the feasibility of implementation, and benefits that each alternative energy source offers is their overall cost. In order to estimate the total cost of each alternative energy source, as much information as possible will be collected regarding the costs of components, installation, site preparation, maintenance, replacement, and operational fees. Manufacturers will be contacted to determine component, installation, and maintenance, and operation costs. The costs of maintenance and component replacement will also be determined by case studies and factored into our long term cost analysis. We also must consider rebates and incentives that are applicable to each alternative energy option. An accurate estimate of the actual cost of each option will help us to provide El Yunque management with a realistic and specific proposal.

3.4 Conclusion

Data and information concerning each method will need to be collected in order to determine their feasibility**.** Cost analysis will be performed for the methods discovered to be the most feasible. Once all necessary information is collected and evaluated, a proposal will be made to the sponsor recommending the most advantageous energy sources and conservation methods, as well as their respective installation and maintenance costs.

CHAPTER 4: CONCLUSION

Review of alternative energy sources, conservation methods, and case studies of the implementation of both has provided valuable knowledge as well as good ideas to be used in solving the problem presented by this project. Energy solutions used in other national parks and recreation areas could prove effective in El Yunque National Park. Studying these cases has also alluded to adaptations that will have to be made for compatibility with the tropical climate of the project site. Having knowledge of the previous implementations of energy solutions will aid in choosing those most suitable for El Yunque National Park.

Conservation and solar power have appeared to be the most promising energy solutions at this point in the project. Replacing light bulbs and applying recycling plans are cheap, easy ways to conserve energy. If park management can ensure employee and guest participation, conservation could prove to be one of El Yunque's best options. Additionally, the geographic location of the project site makes it a prime candidate for harnessing solar power since it is located near the equator. Barring the potentially adverse effects of cloud cover and sunlight obstruction, solar power could help solve El Yunque's energy problem.

Executing the proposed methodology will answer these uncertainties, and allow the team to find the best energy solution for El Yunque National Park. Not only will a successful solution help reduce energy costs within this forest, but they will be applicable to other tropical forests or reserves. Creating a solution to stand as a model of sustainability and responsible land management that can be replicated around the world is a rather exciting notion, and one that will continuously considered in the execution of this project.

REFERENCES

3 TIER. (2010). *3 TIER FirstLook-wind, solar, hydro.* Retrieved February 21, 2010, from http://www.3tier.com/firstlook/

Anagnostopoulos, J. S., & Papantonis, D. E. (2007). Optimal sizing of a run-of-river small hydropower plant. *Energy Conversion and Management*, *48*(10), 2663-2670.

Beer, J. (2008). *Fossil fuel power plant.* Retrieved February 10, 2010, from http://www.eoearth.org/article/Fossil_fuel_power_plant

Berkhuizen, J. C., & Slob, A. F. L. (1989). The impact of environmental aspects on wind energy in the netherlands. In D. T. Swift-Hook (Ed.), *Wind energy and the enviornment* (First ed., pp. 6-7-13). London, United Kingdom: Peter Peregrinus Ltd.

Bing, J. (1998, Nov/Dec). P.V. in paradise. *Solar Today Magazine*, Retrieved February 9, 2010, from http://www.newenergyoptions.com/magazine.php?d=1

Brookshier, P. (2004). Hydropower technology. In Cutler J. Cleveland (Ed.), *Encyclopedia of energy* (pp. 333-341). New York: Elsevier.

Byrne, B. W., & Houlsby, G. T. (2003). Foundations for offshore wind turbines. *Philosophical Transactions: Mathematical, Physical and Engineering Sciences, 361*(1813, Mathematics, Physics and Engineering), 2909-2930.

Cada, G., Sale, M., & Dauble, D. (2004). Hydropower, environmental impact of. In Cutler J. Cleveland (Ed.), *Encyclopedia of energy* (pp. 291-300). New York: Elsevier.

Cheremisinoff, N. P. (1978). *Fundamentals of wind energy* (first ed.). Ann Arbor Michigan: Ann Arbor Science.

Corkish, R. (2004). Solar cells. In Cutler J. Cleveland (Ed.), *Encyclopedia of energy* (pp. 545-557). New York: Elsevier.

DeCarolis, J. F., Keith, D. W., Jacobson, M. Z., & Masters, G. M. (2001). The real cost of wind energy. *Science, 294*(5544), 1000-1003.

Deering, A., & Thornton, J. P. (1999). Applications of solar technology for catastrophe response, claims management, and loss prevention. *National Renewable Energy Labratory*, Retrieved February 2, 2010, from http://www.nrel.gov/docs/fy99osti/25866.pdf

Department of Energy. (2010). *Energy savers.* Retrieved February 10, 2010, from http://www.energysavers.gov/

Department of Energy. (2010). *U.S. department of energy.* Retrieved February 9, 2010, from http://www.energy.gov/energysources/fossilfuels.htm

Egré, D., & Milewski, J. C. (2002). The diversity of hydropower projects. *Energy Policy, 30*(14), 1225-1230.

Energy Information Administration. (2010). *Puerto rico-independent statistics and analysis.* Retrieved February 10, 2010, from http://tonto.eia.doe.gov/state/territory_profile_pr.html

Energy Information Administration. (2010). *U.S energy information administration, independent statistics and analysis.* Retrieved February 9, 2010, from http://tonto.eia.doe.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=WTOTWORLD&f=W

Environmental Protection Agency. (2009). *Reduce, reuse, recycle.* Retrieved February 10, 2010, from http://www.epa.gov/

Environmental Protection Agency. (2009). *What is urban heat island effect?* Retrieved February 9, 2010, from http://www.epa.gov/hiri/about/index.htm

Environmental Protection Agency. (2010). *Climate change.* Retrieved February 10, 2010, from http://www.epa.gov/climatechange/

Farahat, S., Sarhaddi, F., & Ajam, H. (2009). Exergetic optimization of flat plate solar collectors. *Renewable Energy, 34*(4), 1169-1174.

General Motors, C. (2005, June). GM's hybrids: Beyond the urban environment. *Automotive Design and Production, 6*, 40. Retrieved February 3, 2010, from http://find.galegroup.com/gps/start.do?prodId=IPS&userGroupName=mlin_c_worpoly

Gordon, K. (2004). Harvesting the wind. *Rangelands, 26*(2), 23. Retrieved from

Gulliver, J. S., & Arndt, R. E. A. (2004). Hydropower, history and technology of. In Cutler J. Cleveland (Ed.), *Encyclopedia of energy* (pp. 301-314). New York: Elsevier.

Headley, O. (1997). Renewable energy technologies in the caribbean. *Solar Energy, 59*(1-3), 1-9.

Heier, S. (2003). *Grid integration of wind energy conversion systems* [Siegfried Heier: Windkraftanlagen. 3. Auflage /Grid Integration of Wind Energy Conversion Systems] (Rachel Waddington Trans.). (Second ed.). Wiesbaden: B.G Teubner Verlag.

Hepbasli, A. (2004). Ground-source heat pumps. In Cutler J. Cleveland (Ed.), *Encyclopedia of energy* (pp. 97-106). New York: Elsevier.

Hills, R. L. (1994). *Power from wind, a history of windmill technology* (first ed.). Great Britain: Cambridge University Press.

Hybrid Cars. (2010). *Hybrid terms.* Retrieved February 5, 2010, from http://www.hybridcars.com/types-systems/hybrid-terms.html

International Energy Agency. (2010). *Basics of PV.* Retrieved February 9, 2010, from http://www.iea-pvps.org/pv/index.htm

Karatasou, S., Santamouris, M., & Geros, V. (2006). On the calculation of solar utilizability for south oriented flat plate collectors tilted to an angle equal to the local latitude. *Solar Energy, 80*(12), 1600-1610.

Knier, G. (2010). *How do photovoltaics work?* Retrieved February 9, 2010, from http://science.nasa.gov/headlines/y2002/solarcells.htm

Kotrba, R. (2006, October 2006). National park power. *Biodiesel Magazine,* Retrieved February 6, 2010, from http://www.biodieselmagazine.com/article.jsp?article_id=1184&q=National Park power&category_id=11

Leavitt, W. (2007, October 2007). Green ride in a great park. *Fleet Owner, 102* Retrieved February 10, 2010, from http://find.galegroup.com/gps/infomark.do?&contentSet=IAC-Documents&type=retrieve&tabID=T003&prodId=IPS&docId=A169840973&source=gale&srcprod=ITOF&userGroupName=mlin_c_worpoly&version=1.0

Li, G. (2000). Feasibility of large scale offshore wind power for hong kong — a preliminary study. *Renewable Energy, 21*(3-4), 387-402.

Loftness, V., Hakkinen, B., Adan, O., & Nevalainen, A. (2007). Elements that contribute to healthy building design. *Environmental Health Perspectives, 115*(6), 965-966-970.

Lund, J. W. (2004). Geothermal direct use. In Cutler J. Cleveland (Ed.), *Encyclopedia of energy* (pp. 859-873). New York: Elsevier.

Madsen, A. (2009). *Wayne national forest - now greener than ever.* Retrieved February 23, 2010, from http://www.fs.fed.us/r9/ssrs/story?id=4672

Meyer, T. (2004). Photovoltaic energy: Stand-alone and grid-connected systems. In Cutler J. Cleveland (Ed.), *Encyclopedia of energy* (pp. 35-46). New York: Elsevier.

Miller, C. (2009). Extensive green roofs. *National Institute of Building Sciences,* Retrieved February 2, 2010 from http://www.wbdg.org/resources/greenroofs.php

Nadaï, A., & van der Horst, D. (2010). Wind power planning, landscapes and publics. *Land use Policy, 27*(2), 181-182-184.

National Biodiesel Board. (2010). *Biodiesel fact sheet-emissions.* Retrieved February, 5, 2010, from http://www.biodiesel.org/pdf_files/fuelfactsheets/emissions.pdf

National Biodiesel Board. (2010). *Biodiesel fact sheet-production.* Retrieved February 05, 2010, from http://www.biodiesel.org/pdf_files/fuelfactsheets/Production.PDF

National Biodiesel Board. (2010). *Biodiesel fact sheets-performance.* Retrieved February 05, 2010, from http://www.biodiesel.org/pdf_files/fuelfactsheets/Performance.PDF

National Park Service. (2008). *Boston harbor islands - renewable energy on the islands.* Retrieved February 21, 2010, from http://www.nps.gov/boha/parkmgmt/renewable-energy-installations.htm

National Park Service. (2010). *Yosemite national park - park planning.* Retrieved February 19, 2010, from http://www.nps.gov/yose/parkmgmt/planning.htm

National Renewable Energy Laboratory. (1990). *Solar radiation for flat plate collectors: San juan, PR.* Retrieved February, 9, 2010, from http://rredc.nrel.gov/solar/pubs/redbook/PDFs/PR.PDF

National Renewable Energy Laboratory. (1998). *Large comfort station solar hot water system at buckhorn campground* Retrieved February 6, 2010, from http://www.nrel.gov/data/pix/Jpegs/06719.jpg

National Renewable Energy Laboratory. (2009). *Green house gas program overview* (Plan for Federal Energy Program No. DOE/GO-102009-2946)

National Renewable Energy Laboratory. (2009). *Solar hot water.* Retrieved February 9, 2010, from http://www.nrel.gov/learning/re_solar_hot_water.html

National Weather Service. (2009). *The saffir-simpson hurricane wind scale.* Retrieved February 9, 2010, from http://www.nhc.noaa.gov/aboutsshs.shtml

National Weather Service. (2010). *Graphical forecasts - puerto rico.* Retrieved March 2, 2010, from http://www.nws.noaa.gov/forecasts/graphical/sectors/puertorico.php

Ohlrogge, J., Allen, D., Berguson, B., DellaPenna, D., Shachar-Hill, Y., & Stymne, S. (2009). Driving on biomass. *Science, 324*(5930), 1019-1020.

O'Neill, N. (1989). Legal aspects of wind energy in the netherlands. In D. T. Swift-Hook (Ed.), *Wind energy and the enviornment* (First ed., pp. 14-15-22). London, United Kingdom: Peter Peregrinus Ltd.

Paish, O. (2002). Small hydro power: Technology and current status. *Renewable and Sustainable Energy Reviews, 6*(6), 537-556.

Parker, D., & Sherwin, J. (1998). *Comparative summer attic thermal performance of six roof constructions* No. FSEC-PF-337-98). Toronto, Canada:

Pinder, J. N., Price, M. A., & Smith, M. G. (1989). Propagation of noise from wind turbine generators. In D. T. Swift-Hook (Ed.), *Wind energy and the enviornment* (First ed., pp. 59-60-63). London, United Kingdom: Peter Peregrinus Ltd.

Popiel, C. O., Wojtkowiak, J., & Biernacka, B. (2001). Measurements of temperature distribution in ground. *Experimental Thermal and Fluid Science*, *25*(5), 301-309.

Rojanamon, P., Chaisomphob, T., & Bureekul, T. (2009). Application of geographical information system to site selection of small run-of-river hydropower project by considering engineering/economic/environmental criteria and social impact. *Renewable and Sustainable Energy Reviews, 13*(9), 2336-2348.

Shaahid, S. M., & El-Amin, I. (2009). Techno-economic evaluation of off-grid hybrid photovoltaic–diesel–battery power systems for rural electrification in saudi Arabia—A way forward for sustainable development. *Renewable and Sustainable Energy Reviews, 13*(3), 625-633.

Simmons, D. M. (1975). *Wind power* (First ed.). Park Ridge, New Jersey: Noyes Data Corporation.

Singh, P. P., & Singh, S. (2010). Realistic generation cost of solar photovoltaic electricity. *Renewable Energy, 35*(3), 563-569.

Sound, C. (2010). *Wayne national forest headquarters* Retrieved February 4, 2010 from http://www.waymarking.com/waymarks/WM82D1_Wayne_National_Forest_Headquarters

Sukau rainforest lodge. (2008). Retrieved February 10, 2010, Retrieved February 6, 2010 from http://www.sukau.com/components.php?comp_id=19

Šúri, M., Huld, T. A., Dunlop, E. D., & Ossenbrink, H. A. (2007). Potential of solar electricity generation in the european union member states and candidate countries. *Solar Energy, 81*(10), 1295-1305.

Swift-Hook, D. T., & Lindley, D. (1989). The technical and economic status of wind energy. In D. T. Swift-hook (Ed.), *Wind energy and the environment* (First ed., pp. 1-4-5). London, United Kingdom: Peter Peregrinus Ltd.

Twenty First Century Energy. (2010). *Our wind turbine technology.* Retrieved March 1, 2010, from www.tfcenergy.com

U.S. Department of Energy. (1999). *Showering with the sun at chickasaw national recreation area.* Retrieved February 23, 2010, from http://www1.eere.energy.gov/femp/pdfs/25376.pdf

U.S. Department of Energy. (2005). *Types of hydropower plants.* Retrieved February 10, 2010, from http://www1.eere.energy.gov/windandhydro/hydro_plant_types.html

U.S. Department of Energy. (2009). *Active, closed loop solar hot water heater* U.S. Deptartment of Energy. Retrieved March 3, 2010 from http://www.energysavers.gov/your_home/water_heating/index.cfm/mytopic=12850

U.S. Department of Energy. (2009). *Microhydropower systems.* Retrieved February 9, 2010, from http://www.energysavers.gov/your_home/electricity/index.cfm/mytopic=11050

U.S. Department of Energy. (2009). *Residential grid connected PV system* U.S. Dept. of Energy. Retrieved February 6, 2010, from http://www.energysavers.gov/your_home/electricity/index.cfm/mytopic=10720

U.S. Department of Energy. (2009). *Solar hot water heaters.* Retrieved February 9, 2010, from http://www.energysavers.gov/your_home/water_heating/index.cfm/mytopic=12850

U.S. Forestry Serivce. (2008). *El yunque national forest: Frequently asked questions.* Retrieved February, 9, 2010, from http://www.fs.fed.us/r8/caribbean/faq/index.shtml#01

UNESCO. (2010). ***Biosphere reserves: Reconciling the conservation of biodiversity with economic development***. Retrieved January 31, 2010, from http://portal.unesco.org/science/en/ev.php-URL_ID=4801&URL_DO=DO_TOPIC&URL_SECTION=201.html

Western Solar Utilization Network. (2010). *Passive solar heating and cooling manuel.* Retrieved February 10, 2010, from http://www.azsolarcenter.org/tech-science/solar-for-consumers/passive-solar-energy/passive-solar-design-manual-consumer/passive-solar-design-manual-intro.html

Wilcox, G. (2006). *The future of geothermal energy* (Energy No. INL/EXT-06-11746). Idaho Falls, Idaho: Idaho National Library. . (Geothermal Energy)

Yi, C., Lee, J., & Shim, M. (2010). Site location analysis for small hydropower using geo-spatial information system. *Renewable Energy, 35*(4), 852-861.

APPENDIX A: GANTT CHART TIMELINE