ASSESSMENT OF ALTERNATIVE ENERGY SOURCES FOR THE ARECIBO REVERSE OSMOSIS WATER TREATMENT PLANT

Interactive Qualifying Project completed in partial fulfillment
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ABSTRACT

The Puerto Rico Aqueduct and Sewer Authority (PRASA) has proposed the construction of a reverse osmosis water treatment plant in Arecibo. This plant requires a large amount of energy, which can be expensive and harmful to the environment. We evaluated the feasibility of alternative energy by performing site analyses, estimating the costs and amount of energy produced, assessing the environmental impacts, and conducting a cost benefit analysis. We then made a recommendation to PRASA about which renewable energy sources would be most advantageous to implement.

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AUTHORSHIP

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Solar Power- Glenn Amundsen
Wind Power- Christina Ferrari
Hydro-Kinetic Power- Samantha Millar

All other sections were researched, written, and edited by all members of the group.

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EXECUTIVE SUMMARY

The Puerto Rico Aqueduct and Sewer Authority (PRASA) is considering using renewable energy to reduce their operating costs and dependence on fossil fuels. This project evaluated the feasibility of using alternative energies to power a proposed reverse osmosis water treatment plant (RO WTP) in Arecibo, Puerto Rico. Traditional energy has many detrimental impacts on the environment so there is a need to consider alternatives. There are many technologies that produce clean and renewable energy. The alternative energy sources that we assessed are solar power, wind power, waste-to-energy, waste steam power, geothermal power, and hydro-kinetic power.

We determined the viability of the energy sources by conducting an analysis of each option. We performed site analyses of the proposed locations to determine the amount of energy available locally and any physical features of the area. We estimated the costs and amount of energy that each could produce by reviewing case studies, contacting manufacturers, and interviewing experts in renewable energies. To assess the environmental aspects, we established the impacts of each energy option and performed surveys to gauge public opinion. Finally, with our cost benefit analysis, we compared all of the above findings to create a recommendation to PRASA.

We discovered that solar power, wind power, and hydro-kinetic energy are all feasible options to power the RO WTP. The solar radiation, wind speed, and wave heights are all adequate to allow for sufficient energy production. Conversely, the other energy systems do not produce sufficient energy to make them favorable options. Solar power, wind power, and wave power are also cost effective when compared to traditional energy sources. We recommended that a combination of solar and wind power be used. We did not recommend hydro-kinetic energy because it is not developed enough to install on a commercial scale. Although solar and wind power would not be able to power the entire plant, it would be enough to make a significant contribution. Any attempt to reduce reliance on traditional energy would help with costs and reduce environmental impacts. Implementing the use of renewable energy would make PRASA a forerunner in the global trend towards environmental responsibility, which, as the results of our survey show, would greatly improve PRASA's public image.

1. INTRODUCTION

Modern society needs to have a properly functioning and regulated water system to purify and distribute water to the population. As an island, Puerto Rico is self-contained and thus has limited resources and space. In addition, it is surrounded by seawater and therefore many of its water sources are contaminated with salt. For these reasons, Puerto Rico must take careful measures in maintaining water quality and services. The government has agencies in place for the management and maintenance of such systems. PRASA, the Puerto Rico Aqueduct and Sewer Authority, known locally as Autoridad de Acueductos y Alcantarillados, is responsible for these duties.

In June of 2006, PRASA drafted plans to create a water treatment plant in the city of Arecibo on the northern coast of the island. This water treatment plant will use reverse osmosis membrane technology (RO) to produce drinkable water from the brackish water in the area (Rojas, Thompson, & Hobbs, 2006). Reverse osmosis is a process where water is passed through a membrane to remove salt and other contaminants (American Membrane Technology Association, 2007). This method is beneficial because the membranes have a long lifespan and require little maintenance. A downside to the RO system is that the proposed Arecibo Water Treatment Plant will require a large amount of energy to operate, traditionally obtained from nearby power stations.

Power stations generally produce energy through the burning of fossil fuels such as petroleum. Despite the environmental implications fossil fuels may have, the use of these fuels continues to be a staple of modern power plants around the world. The two main problems with this method are that it releases carbon dioxide which contributes to global warming, and that it is non-renewable so it will eventually be depleted. Because the energy consumption of the RO system is costly and detrimental to the environment, traditional sources may not be the best answer. In response, PRASA has decided to investigate alternative solutions.

The goal of this IQP was to assess the feasibility of implementing various alternative energy sources for the proposed plant. These options included solar power, wind power, waste steam power, geothermal power, waste-to-energy, and hydro-kinetic power. We conducted research, consulted experts and performed site analyses in order to compare the environmental impacts and costs associated with each of these options. Finally, we presented the advantages and disadvantages of each choice and made a recommendation to PRASA.

2. LITERATURE REVIEW

There is much to consider when planning water management projects since adequate water is an essential part of any community. In order to meet certain criteria for drinkability, this water is purified at water treatment plants. These plants consume a large amount of energy, which can have adverse effects on the environment if traditional methods are used. Climate change has specific implications for Puerto Rico and the water management sector. To reduce their impact on the environment, the water industry is beginning to look at using various methods of alternative energy to power their water treatment plants. Some of these options include solar and wind power, as well as waste-to-energy incineration, waste steam, geothermal systems, and hydro-kinetic energy.

2.1 Water Requirements

In July 2008, the population of Puerto Rico was at nearly four million (Central Intelligence Agency, 2009). To provide enough water to each of these people, the Puerto Rico Aqueduct and Sewer Authority (PRASA) produces 541 million gallons per day (MGD) of purified drinkable water. In addition to this, PRASA receives 307 MGD of raw sewage that it is responsible for treating (Carey, Jaimes, Song, & Woods, 2008). This services most of the population of Puerto Rico, while the remaining population uses private wells or other non-regulated sources for their water needs. To better meet the needs and requirements of Puerto Rico, PRASA has proposed creating a reverse osmosis water treatment plant in the city of Arecibo. This plant is intended to treat 10 MGD initially, but will eventually expand to produce 25 MGD of drinkable water (Rojas et al, 2006). This will supply quality drinking water that meets the Environmental Protection Agency's (EPA) standards.

The source water for the Arecibo Reverse Osmosis Water Treatment Plant (RO WTP) enters from nearby Caño Tiburones as a combination of freshwater and seawater. The concentrations of salt, chlorine, fluoride, and many other substances need to be reduced in order for the water to be drinkable. PRASA will use reverse osmosis to filter water so that only clean, potable water is distributed to their customers.

2.2 Reverse Osmosis

Reverse osmosis is a procedure that removes pollutants from water. Osmosis is the natural process where materials from a low concentration move through a thin membrane to a higher concentration until equilibrium is met. Reverse osmosis passes water with high concentrations of salt and other contaminants through a membrane and produces pure water. This occurs by pressurizing the source water to a level higher than the osmotic pressure to force it through the membrane (Al Suleimani & Nair, 2000). A typical reverse osmosis membrane configuration can be seen in Figure 2-1. This technique of water purification requires less electricity than other methods, but due to the large quantity of water being processed, it still requires a significant amount of energy (Oh, Hwang, & Lee, 2009).

Figure 2- 1: Typical RO membrane configuration
(Rojas et al., 2006)

The RO membrane is created using a relatively simple and inexpensive process that causes it to have high flux and salt rejection qualities, making it ideal for reverse osmosis (Cadotte, 1974). The water entering this membrane will be pretreated to reduce fouling and increase the lifespan (Shon et al., 2009). There are many factors involved in the damage to the membrane. These include the velocity and chemical composition of the water entering the filter. Contaminants can cause fouling by building up on the surface of the membranes or by clogging pores of the membrane. The membrane itself can also be a factor for its damage because its surface, pore size, and pore distribution all contribute to fouling (Vrijenhoek, Hong, & Elimelech, 2001).

To prevent this fouling, the Arecibo RO WTP will filter the water three times prior to passing through the membrane. These three stages of filtration include coarse, secondary, and fine filters. In addition to the filtration, the water is chemically altered and then passed into an ultrafiltration (UF) membrane (Rojas et al., 2006). It is then pressurized and passed into the RO membrane. When these processes are performed, the membrane remains unfouled and allows the plant to run more economically.

It is expected that the system for the Arecibo RO WTP will have an efficiency of 65% (Rojas et al., 2006). To overcome the 35% loss, more filtration and more energy use will be required to obtain the amounts of water required by the people of this region.

2.3 Traditional Power Methods

Under PRASA's current plan, these energy needs are met by traditional power methods. Normally, the power is supplied by the Puerto Rico Electric Power Authority (PREPA). PREPA accomplishes this through the five power plants in: Costa Sur, Palo Seco, San Juan, Complejo Aguirre, and Arecibo (Puerto Rico Electric Power Authority, 2002). These power stations function by converting the heat energy provided by the combustion of the fossil fuel petroleum into mechanical energy. The oil used for combustion is classified as a residual fuel oil, also known as a RFO. This type of heavy oil, specifically the bunker fuel No. 6, is used as the primary energy source for four out of the five power plants on the island. The fifth power plant, in Arecibo, burns the lighter distillate of bunker fuel No. 2 (Puerto Rico Electric Power Authority, 2002).

Once the fuel has been consumed, the resulting mechanical energy is converted into electrical energy through an electrical generator (Nave, 2006). The electrical energy produced by the power plants is distributed to satisfy the energy demands of the island. According to PREPA, the electrical needs of 1.4 million clients are met by these current electrical systems and stations of PREPA (Puerto Rico Electric Power Authority, 2002). The high electrical demands of the island can be costly and result in the high consumption of non-renewable natural resources. One way in which higher costs are prevented is through the use of the less expensive, heavier oils. These RFOs require specialized refineries for their burning, transport, and storage as opposed to the lighter distillates. In conjunction with these qualities, the toxins released upon heating allow for the residual oils to be priced lower than most other oils on the market. This continues their use as a cost effective and primary fuel source (U.S. Government, 2006).

2.4 Environmental Consequences

The above methods of powering the RO treatment plant, while proven and convenient, do pose some problems. The first issue concerns global warming. The burning of fossil fuels releases carbon dioxide (CO_2), which is a greenhouse gas, into the earth's atmosphere. When the earth absorbs the sun's energy, much of it is emitted as radiation back into outer space. However, some of this energy is absorbed by the gasses in our atmosphere, which then radiate the energy back down onto the earth. Some greenhouse effect is natural and necessary, but as we continue to increase this effect through the emission of CO_2 and other greenhouse gasses, the resulting climate change can be severe (EPA, 2009).

Evidence of these changes can be seen in the fact that over the past century the earth's average surface temperature has risen by between .6 and .9 degrees Celsius and the rate of this increase has almost doubled in the last 50 years. This temperature increase has caused the sea level to rise by more than half a foot (Riebeek, 2007). These changes can also cause inconsistent weather patterns and precipitation. As these climate changes continue to increase, so will the consequences, many of which have special significance to Puerto Rico. As an island, it will be severely affected by the rising sea level. Furthermore, the inconsistent weather patterns will mean longer droughts that will put a strain on the already limited fresh water supply. These droughts will be interrupted by more severe rainfall and storms that will increase the rate of sedimentation in the reservoirs, which will again put more strain on the water supply (US Global Change Research Program, 2004).

The second problem is that they are "capital energy sources," so they cannot be replenished. Fossil fuels account for 83% of the world's energy consumption and will eventually be depleted (Neville, 1995). The finite nature of fossil fuels will become a very real problem before the end of the century.

2.5 Energy Alternatives

There are many strategies to combat these issues, such as reducing the amount of energy consumed or finding more efficient means of energy conversion. The implementation of alternative energy systems is one of the most effective means of change. There are several alternatives to fossil fuels that can be used and they all have their benefits, whether it is through cost savings, natural abundance, or environmental friendliness. Here we present some of the primary alternative energy sources including solar and wind power, as well as waste-to-energy incineration, waste steam, geothermal systems, and hydro-kinetic energy.

2.5.1 Solar Energy

One of the most promising sources of alternative energy is solar power. Solar power takes advantage of the photovoltaic effect to convert the sun's energy into useful electricity. Solar energy, unlike fossil fuels, is not in danger of being depleted. As Riebeek notes in his book on the subject, "the solar energy falling on the earth's surface each year is over 20,000 times our current needs," (Riebeek, 2007). All of this energy cannot be converted into electricity due to space requirements and current conversion efficiencies. However, even with strict assumptions about the amount of land devoted to solar power and the efficiency of the photovoltaic cells, solar power could be the exclusive provider of energy to the global population. The "technical potential" of solar energy is 1575 exajoules/year while the current primary global energy demand is only 402 exajoules/year (Luque & Hegedus, 2003).

In addition to its capability to continuously meet global energy needs, solar power has other benefits. In contrast with other energies, it does not emit harmful green house gasses that contribute to global warming, and there are little to no hazardous waste products. Although there is some waste associated with the production of solar cells, this can be reduced by adopting environmentally friendly methods of production.

Solar power comes in many forms but this study will consider photovoltaic (PV), solar cells. Solar cells are made from semiconductors, usually some type of silicon. A typical solar panel is shown in Figure 2-2.

Figure 2- 2: Solar panels
(Solar Navigator, 2008)

When a photon from sunlight hits the silicon it knocks free an electron. This produces an electrical direct current (DC) running through the solar cell. Among other things, the current's magnitude is dependent on the intensity and frequency of the light as well as the angle at which it hits the solar panel. In addition, the cell's output is affected by any shading on or corrosion of the cell. This DC current is then either pumped into a battery for storage or run through an inverter, transforming it into alternating current (AC) which can then be used to power whatever application the system is connected to. If solar panels are the only method of power, some of the sun's energy can be stored in a battery for later use. If the system is connected to the power grid, it can consume all the energy it needs during the day, and then still get its power from PREPA when sunlight is limited. Any excess can be sold back to the power company.

There have been studies that address the issue of using solar power for water treatment in remote areas of the Middle East, including one in Saudi Arabia (Alawaji, Smiai, Rafique, & Stafford, 1995) and one in Oman (Al Suleimani & Nair, 2000). In these studies, small scale, experimental water treatment plants pump brackish water out of the ground and treat it with RO technology. The Saudi Arabian system produces 3,772 gallons per day of drinking water using PV panels that have a peak power of 11.2 peak Kilowatts (kWp). These panels have an adjustable tilt angle to ensure they are always capturing the maximum amount of sunlight

(Alawaji et al., 1995). The Oman system produces 1,320 gallons of drinking water during the five hours it operates each day, using solar panels at a constant tilt angle that produce 3.4 kWp (Al Suleimani & Nair, 2000).

In both systems, the PV modules were the largest component of the capital costs, accounting for more than 50% of the total expenditure (Al Suleimani & Nair, 2000, Alawaji et al., 1995). These large capital costs, however, were justified by the extremely low operating and maintenance costs of the solar power system. Unlike conventional energy systems, solar power generation needs almost no maintenance or spare parts, consumes no fuel, and its efficiency remains relatively constant throughout its lifetime (Al Suleimani & Nair, 2000). Both studies concluded that solar powered RO water treatment can be an effective means of providing water to remote rural areas. The Oman study even indicated that solar power would be 25% less expensive than the traditional diesel generators over a 20 year lifetime (Al Suleimani & Nair, 2000).

These plants are significantly smaller than the proposed Arecibo RO plant that is expected to initially produce 10 and then ultimately 25 million gallons a day. The Arecibo plant will need much more energy to operate, and thus require a very large initial capital investment for the solar panels. In addition, Arecibo has convenient access to traditional power, so some of the advantages of the system are reduced when compared with the remote locations in the Middle East. Nevertheless, these studies do show that solar power has the potential to be successful when used in conjunction with RO technology. We performed further analysis to determine whether the environmental and long term economic benefits can outweigh the high initial capital costs.

2.5.2 Wind Energy

Wind power is another alternative energy source with possible application to the proposed Arecibo RO WTP. Windmills have been used for hundreds of years with the purpose of utilizing another natural resource to provide power. The modern revival of the windmill is a wind turbine, shown in Figure 2-3, which consists of a few thin blades that maximize the percentage of kinetic energy extracted from wind mass.

Figure 2- 3: Wind turbine
(Minnesota State University, 2008)

Wind turbines are capable of using the converted kinetic energy to generate electricity that can be used for residential needs as well as for businesses and other establishments (American Wind Energy Association, 2009). These turbines consist of a vertical tower with a rotor, which usually consists of three blades responsible for the initial conversion of the wind's kinetic energy. The rotor can have either a vertical or horizontal axis on the tower (American Wind Energy Association, 2009). Turbines on a horizontal axis require less design features but also produce more noise. Both of these qualities make horizontal axis turbines less expensive than the turbines on a vertical axis (Clean Energy Ideas, 2008).

The energy carried in wind increases with wind velocity. The direct conversion of wind energy into kinetic energy is completed by the turbine blades. The area of wind passing through the blades at any given time correlates to the amount of mechanical energy that can be obtained. Therefore, larger blades with a greater surface area will harvest the largest amount of power from the wind and are the most efficient in converting the wind's energy into electricity (World Wind

Energy Association, 2006). Because this method directly harvests power from the wind, it has many environmental and social advantages.

One of the greatest benefits of using wind turbines instead of traditional fuel is its availability. Unlike fossil fuels, wind energy is a renewable source of energy. Also, the energy resulting from the extraction of wind power does not harm the environment, which will elicit a positive social and political response from the community. In addition to the benefits, the technical aspects of its efficiency and appearance on a particular site were studied carefully.

The feasibility of wind electric turbines supporting the base load of the RO Treatment plant was also researched. The founding physicist of wind turbines, Albert Betz, first proposed Betz' Law in 1919. This law theorizes that in ideal conditions a wind turbine could extract up to 59% of the kinetic energy in wind (Cleveland, 2006). However, wind turbines tend to have a lower efficiency due to variables in wind, environmental conditions, and their placement.

Wind turbines can be utilized as either individual harvesters of energy or as collective harvesters in systems. Individual placement of wind turbines is not very conducive to generating large amounts of energy and therefore would be better suited for minor energy demands. Aside from the quantity of wind turbines, the location of their placement is also critical in obtaining energy (Muljadi, 2006). Wind turbines can be constructed on land or offshore. Generators on land tend to have problems with the geography hindering the wind from flowing at maximum velocity. Onshore turbines, however, can be constructed on agricultural land so that the neighboring land can still be used. This is helpful in areas where space is limited. Conversely, offshore turbines can be constructed to extract power from higher wind velocities and allow for less physical obstructions. Therefore, offshore turbines can result in the production of more energy and electricity (Rowlands & Jernigan, 2008).

With both offshore and onshore turbines, environmental conditions can still be one of the biggest problems with the implementation of wind turbines. The variability in the weather patterns, temperature, and resulting wind velocities can all affect the rate at which the turbine blades extract wind power. Changes in wind direction and velocity can affect the consistency and efficiency of its energy conversion (Rowlands & Jernigan, 2008). This problem has two possible solutions that we explored to determine the feasibility of using wind turbines. The first option is to create a form of storage for the energy converted by the wind. This would address the problems that variable wind patterns create when the wind has stopped and no electricity can be generated. If the energy were stored, it would be able to provide for disruptions in power and act as a backup generator in those types of situations. The wind is also variable from day to night, with higher and more consistent velocities during the day as opposed to at night, so the storage system would also be effective for overnight and slowed velocities (Rowlands & Jernigan, 2008).

The second method is to connect the turbine system directly into the electrical grid of the power plant to prevent the need for any type of storage system. This proposed method is referred to as the "Danish Concept" and has been used across Europe (World Wind Energy Association, 2006). The electricity flows directly to the grid to provide for any possible disruptions to consistently meet the base load (Danish Wind Industry Association, 2003). However, one case study reported a downside to this method. According to a 2008 case study of wind energy in Ontario, Canada, if the turbines were directly connected to the power grid and wind production fluctuated, it could have damaging effects on the power plant's electrical grid. The load-following requirement, which is the amount that generators change their power output in response to power demands, could possibly be altered as a result of these fluctuations. The same problem could also occur with the operating reserves requirement, which is the back-up capacity stored for when power disruptions occur. Both of these requirements could be altered and therefore affect the entire electrical grid and system (Rowlands & Jernigan, 2008). Both methods were explored in determining the most effective and feasible operating system for wind turbines.

Another problem is the potential for social and environmental opposition. Some environmentalists oppose wind turbines because the birds in the vicinity can be killed by flying into the turbines. The number of birds killed by turbines is very small, however. One study observing the fatalities of birds in the United States found that less than one percent of all avian deaths occur as the result of wind turbines (World Wind Energy Association, 2006). Nevertheless, this can be problematic when endangered species are involved. Also, the presence of a wind turbine system may not be visually pleasing and perhaps even upsetting in a social context. There is also a substantial amount of noise produced from the machinery that can negatively impact the surrounding neighborhoods. These factors would most likely vary based on the location of the turbines.

In addition to the aforementioned weather and environmental problems, cost is another concern in implementing wind turbines. There are high installation fees for both the turbines and their transmission lines. With a high capital investment and high-energy demands for a large system like the RO water treatment plant, wind energy can be initially very costly but overtime produce relatively cheap energy. There is also a certain amount of operation and maintenance costs for wind turbines.

There are currently no completed industrial scale wind farms in Puerto Rico, but one project has been proposed and is in the stages of permitting and other legalities (J. Benitez, personal communication, March 31, 2009). The developer, Windmar, has proposed a wind farm in the town of Guayanilla that would consist of 25 large-scale wind turbines to produce approximately 40 MW of power. This project is facing serious environmental opposition, however, due to its location and possible detrimental impacts on the surrounding ecosystem (Rust, 2007). This current project reflects the possible conflicts when assessing the construction of wind turbines in Puerto Rico. We have therefore evaluated this alternative source of energy technically and in terms of the impact it may have economically, environmentally, and socially.

2.5.3 Waste-to-Energy

Another possible alternative to the traditional energy sources is the waste-to-energy incineration. This method first shreds garbage into a combustible fuel that is burned in specialized waste-to-energy plants to produce a heat energy that can be used to generate electricity (Integrated Waste Services Association, 2009). Power plants usually burn fossil fuels such as petroleum or coal to generate energy, but the waste-to-energy incineration of garbage could aim to replace these environmentally damaging and nonrenewable materials. A point to consider, however, is that the incineration of waste releases less heat than the incineration of coal. According to the Energy Information Administration, the combustion of 2,000 pounds of garbage will release the same amount of heat as the combustion of 500 pounds of coal (Energy Information Administration, 2006). Although the amount of waste needed to equal the heat energy of burning coal is significantly higher, this can be beneficial for Puerto Rico, where the excess garbage in landfills is a serious problem.

The overcrowded landfills of Puerto Rico are a big concern for its residents. The island's size limits the availability of land to convert into disposal sites for garbage. The relatively low

10% recycling rate on the island also contributes to this issue and foreshadows Puerto Rico's need for addition landfills (Quintanilla, 2007). The EPA has taken action by forcing the landfills of Santa Isabel, Toa Baja and Vega Baja to close after health concerns arose from the nature in which the landfills were operating (Cahill, 2007). These are just the first of many out of the total 29 landfills in the country to close. Studies have predicted that 25 of these landfills will reach the capacity limit for waste in the next decade (Cahill, 2007). The current accumulations in the landfills of Puerto Rico make the reduction of garbage the greatest benefit of the waste-to-energy alternative.

A landfill located in Arecibo was also recently closed due to its proximity to the wetlands of the Caño Tiburones State National Reserve (F. Quinones, personal communication, January 28, 2009). It was discovered in 2003 by the *Solid Waste Characterization Study* that this facility "received primarily municipal solid waste (93%) with minor composition of auto wastes (2%), construction debris (3%), and yard wastes (2%)." The study also calculated the weekly amount of garbage received to be 4,000 tons (Wehran, 2003). This amount of waste could potentially be directed to a waste incineration plant to yield electrical energy. In addition to reducing the amount of waste, this new facility could generate enough energy to power the RO WTP and sell the excess to PREPA. This would be a financial advantage, considering the initial capital and operation and maintenance costs. Although potentially financially beneficial, this alternative does have environmental hazards to consider, and while addressing waste disposal concerns, it is not strictly considered an alternative energy.

The previous alternatives discussed have the reduction of greenhouse gas emissions as the greatest advantage to their implementation. Although waste-to-energy incineration emits fewer pollutants than traditional fuel burning methods, it is not as environmentally considerate as wind and solar alternatives. Byproducts of garbage incineration include carbon dioxide and nitrogen oxides. The carbon dioxide emissions can be controlled by several devices, such as dry scrubbers, selective non-catalytic reduction, and fabric filters (Energy Information Administration, 2006). These devices function in many different types of facilities with the same purpose of removing pollutants from the air. They are used in combination with waste-to-energy incineration plants but still do not address the ash that accumulates from the incineration (Integrated Waste Services Association, 2009). The problem is then focused on where to dispose of the ash, which can contain numerous metals and dangerous compounds. The amount of contaminated ash can be reduced by removing garbage items bound to release toxic metals upon combustion. The ash is then tested to see if it is safe to re-use in the construction of various materials such as pavement and cement. Every ton of garbage burned creates about 300-600 pounds of ash that needs to be disposed of in specialized landfills (Energy Information Administration, 2006). Other problems incurred with waste to energy systems include the reduced incentive to recycle, as well as the high costs of waste-to-energy processes.

Preliminary data with the waste-to-energy solution seems to have many disadvantages to its application with a few very significant advantages. The potential environmental harm that could result from this alternative was considered, as was community opposition in terms of social and political interests. In addition, the economic benefits of selling excess energy were compared with capital investments as well as maintenance and operational costs. All of these factors were considered when evaluating the feasibility of implementing this alternative.

2.5.4 Waste Steam Energy

Another option for fueling the RO plant is the use of waste steam. The nearby power plant, Cambalache, is a simple cycle gas turbine plant that produces steam as a waste product; this steam can be converted into useful energy (F. Quinones, personal communication, January 28, 2009 and L. Pagan, personal communication, March 17, 2009). In fact, most traditional power plants already use steam to convert the chemical energy in fossil fuels into electrical energy. The plants burn fossil fuels to heat water, thus creating pressurized steam. This steam is then passed through a steam turbine, which is what generates the electricity, and then condenses back to water and begins the process again as shown in Figure 2-4.

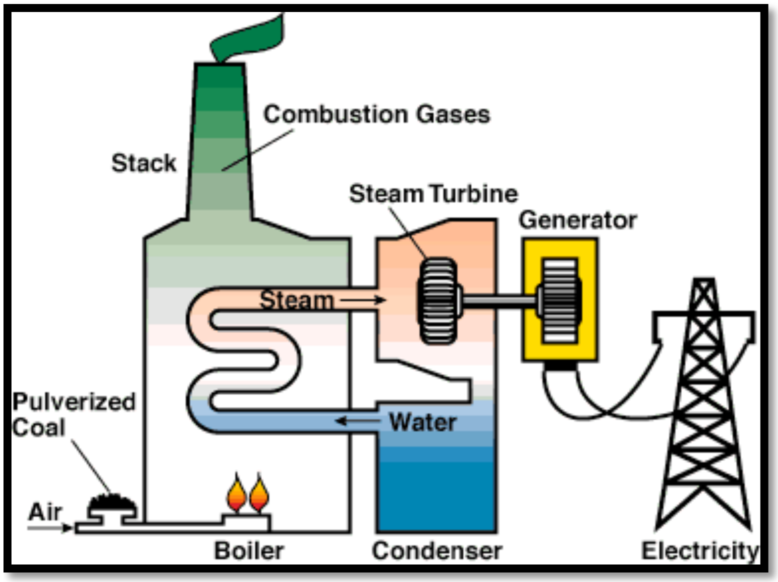

Figure 2- 4: Traditional electricity generation using steam turbine
(ONCOR, 2009)

The steam turbine consists of hundreds of angled blades that convert the steam's mechanical and thermal energy into rotation of a magnetic rotor. This rotation then generates a current through the law of magnetic induction (Edmonton Power Historical Foundation, 2007).

The supply of heated steam from the Cambalache plant would eliminate a large portion of this process. Essentially, that steam only needs to be run through a steam turbine to create electricity. However, there may be additional factors to consider. Depending on the temperature, pressure, and flow rate of the steam it may need to be acted on before entering the turbine. If it is not hot enough it will need to be heated; if there is a not enough pressure it will need to be condensed; if the flow rate is not sufficient enough it may need to be supplemented by an outside source. Nevertheless, this system can have a significant advantage due to the pre-heated quality of the steam, and we will perform an analysis of this option to determine if it is economically feasible.

2.5.5 Geothermal Energy

Another source of power that takes advantage of steam turbines is geothermal energy. Inside the earth's surface there are reservoirs of thermal energy in the form of hot water or steam that can be captured and converted into electrical energy. There are three main types of geothermal energy but they all have a similar process. The first form is called “Dry Steam” and it involves pumping hot, dry steam from inside the earth’s surface. This steam is run through a turbine to generate electricity much in the same way that the waste steam was run through a turbine. The second method is called “Flash Steam” and is very similar to dry steam. The difference is that in this method, very hot, pressurized water is pumped up from underneath the earth’s surface into a low-pressure tank. This lower pressure vaporizes or “flashes” the water into steam, which is then run through the turbine in the same way as the dry steam. The last method is called “Binary Cycle”. In this method instead of using the steam/water to power the turbine directly, its energy is used to heat another fluid that runs though a similar turbine system (Nielson, 2007).

Geothermal energy has many benefits. First, it is a clean energy and does not produce any of the harmful waste products of traditional power methods. Furthermore, it is in no danger of being exhausted; “The long-term sustainability of geothermal energy production has been demonstrated at the Lardarello field in Italy since 1913, at the Wairakei field in New Zealand since 1958, and at The Geysers Field in California since 1960,” (Department of Energy, 2008). Unfortunately, like some of the other alternatives considered, geothermal power involves a large initial investment. Even though this is partially balanced by the reduced operating and maintenance cost, this can be a problem. Moreover, this option requires enough space to operate above ground and sufficient, accessible thermal energy below ground, neither of which are always available. We assessed the benefits and feasibility of this option when considering alternatives for use in the Arecibo plant.

2.5.6 Hydro-Kinetic Energy

The Arecibo RO plant will be sited on the northern coast of Puerto Rico so harnessing energy from the ocean is another possible alternative. There are several ways to transform the changing tides into electricity. One way is through a tidal turbine. This concept is similar to the wind turbines except the apparatus is located underwater. As the tide changes on a daily basis, it creates a flow of water, which passes through the turbine causing the blades to turn. A tidal generator such as this exists in Hammerfest, Norway (Freeman, 2004). Another type of generator is called the Stingray as seen in Figure 2-5.

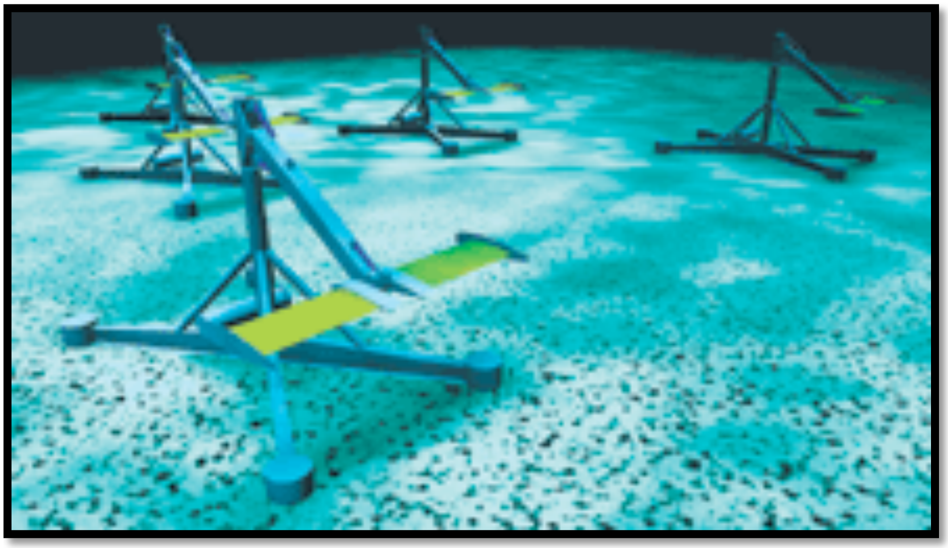

Figure 2- 5: Stingray tidal generator
(Stone, 2003)

This has a hydrofoil that is raised and lowered as the tide changes. The pumping motion creates electricity, and during tests averaged 90 kW (Stone, 2003). Another tidal option is a dam similar to the one created in St. Malo, France. This dam forces water that was trapped by the dam through turbines producing 240 MW of power.

An additional option to harness the energy from the ocean is wave generators, which come in many different forms. One way of utilizing wave energy, called the point absorber, uses a floating buoy attached to a generator. As the buoys change height and direction, the generator creates electricity. Wave energy can also be captured through an oscillating wave column. This design uses a submerged device that has a column of air and water. As waters with greater heights pass into this column the air inside is forced through a turbine and used to generate electricity (EMEC, 2008). These are shown in Figure 2-6.

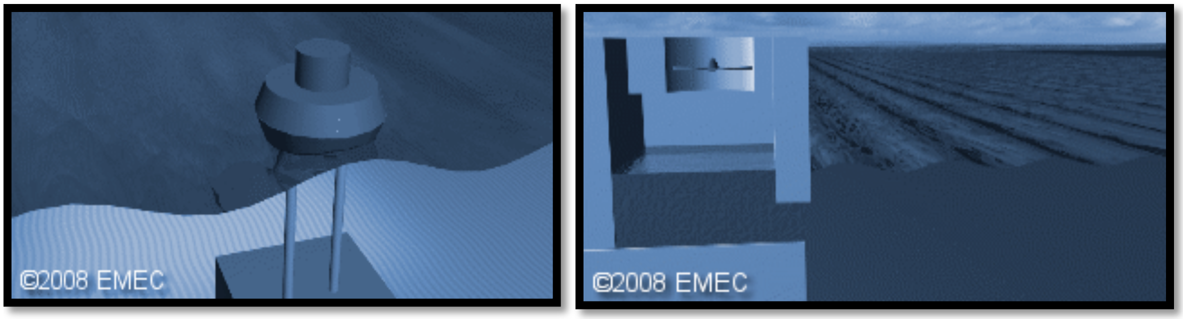

Figure 2- 6: Point absorber and oscillating wave column
(EMEC, 2008)

Marine hydro-kinetic energy is a new technology that has not yet been implemented in Puerto Rico. Tidal generators are not feasible everywhere due to variation in the height of tides and waves. The only states in the US with large enough tidal changes are Alaska and Maine (Tibbetts, 2004). We have evaluated the site to determine the suitability of marine hydro-kinetic energy in Arecibo.

2.6 Summary

Every society needs clean water in order to survive. Puerto Rico has a limited supply of fresh water so some of its needs must be met by water treatment. These processes require a large amount of energy, which can be expensive and have negative impacts on the environment. Therefore, PRASA is looking towards alternative forms of energy.

We have discussed several options including solar and wind power, waste-to-energy incineration, waste steam, geothermal systems, and hydro-kinetic systems. Each alternative energy option has its own problems ranging from high costs to low efficiencies. Despite these challenges PRASA is leading the way for Puerto Rico in the global trend of environmental friendliness. In the next section we will discuss the steps that we took to evaluate the options with the purpose of determining the feasibility of implementing alternate energies.

3. METHODOLOGY

In order to determine the feasibility of using alternative energy sources to power the proposed RO WTP in Arecibo, we examined solar and wind power, waste-to-energy incineration, waste steam, geothermal systems, and hydro-kinetic energy. We performed site analyses, determined the energy potential and cost, assessed environmental concerns, and conducted a cost benefit analysis. We gathered this information through archival research, site analyses, and surveys. Finally, we used these data to prepare a cost benefit analysis to inform PRASA of their options for the Arecibo Plant. The steps required to meet our objectives are outlined below.

3.1 Perform Site Analyses

Site analyses determined to what extent the site was suitable for the installation of solar panels, wind turbines, hydro-kinetic energy, and/or waste-to-energy incineration facilities. There are four proposed sites, as shown in Figure 3-1, with PRASA's top choice depicted in yellow and the three alternate site options in red.

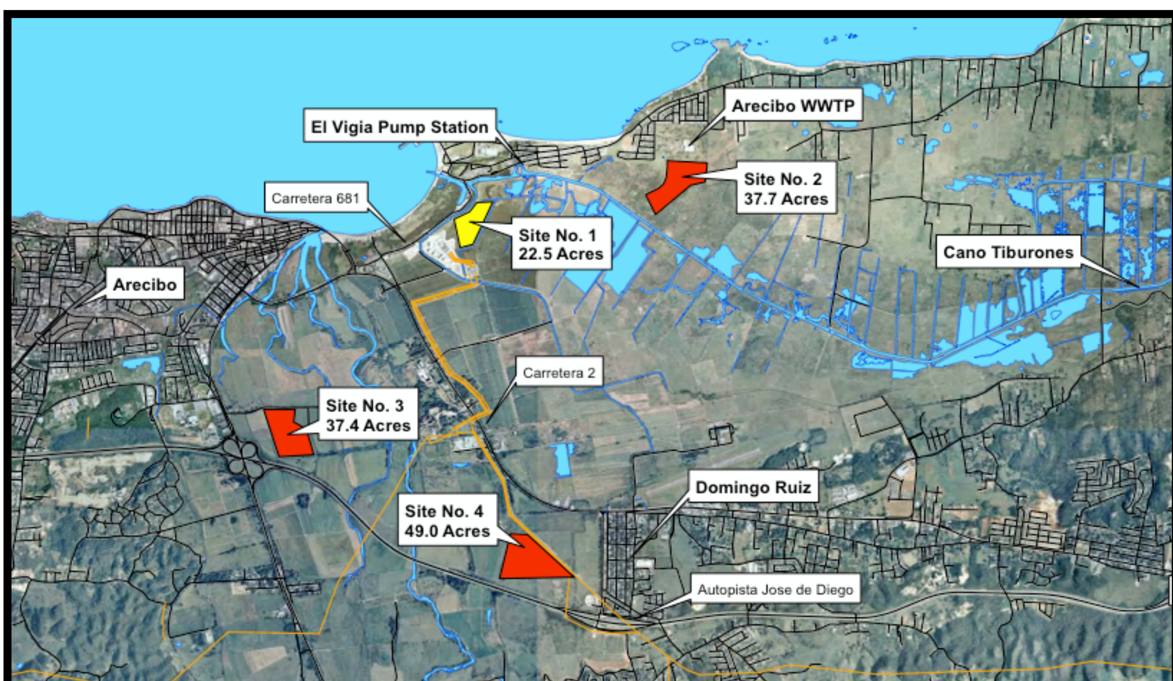

Figure 3- 1: Proposed site locations for the Arecibo RO WTP
(Rojas et al., 2006)

The first and second sites are the only feasible options due to their proximity to the source water and to the wastewater treatment plant. We visited and researched the top two proposed sites to evaluate the environmental conditions such as wind velocities, sun exposure, current strengths, and possible locations for geothermal energy production. Additionally, consultations with a site analysis expert at CSA Group helped determine the best methods for measuring these data. We determined who owned the land of the four proposed sites for the RO WTP in order to obtain permission to visit them. We used a map with various sections of Arecibo gridded and numbered in order to specify the exact locations of the proposed sites and then visited the Centro de Recaudación de Ingresos Municipales to obtain information on land ownership.

3.1.1 Solar Power Site Analysis

Several factors determine the feasibility of using solar power at a specific site. We considered the intensity of the sunlight in Arecibo by consulting 3TIER's Firstlook map of solar radiation. The earth has a variation in length of day due to the axial tilt and rotation of the earth, so we researched the average length of daylight in Puerto Rico at various times throughout the year. Weather also has a significant impact on the performance of solar systems; therefore, we considered average trends in cloud cover as well as the average and extreme temperatures and precipitations. In addition, we assessed the possibility of hurricane damage.

We then conducted site surveys of the various locations to determine the amount of sun they receive each day. Harnessing solar power requires a significant amount of space so we determined the area available for solar power. We also considered to what extent shading would affect the solar panels by observing any large obstructions in the area. If PRASA decides to go forward with this project they should do a more thorough shading analysis using the "Profile Angle Method". This involves calculating the angle to the top of the obstruction (profile angle) and comparing it with the altitude and angles of the sun at the same azimuth angle determined from a sun path chart for Arecibo's latitude. If the profile angle is greater than the altitude angle of the sun at the same azimuth angle then the object will cause shading. These obstructions are then charted on a Profile Angle Diagram.

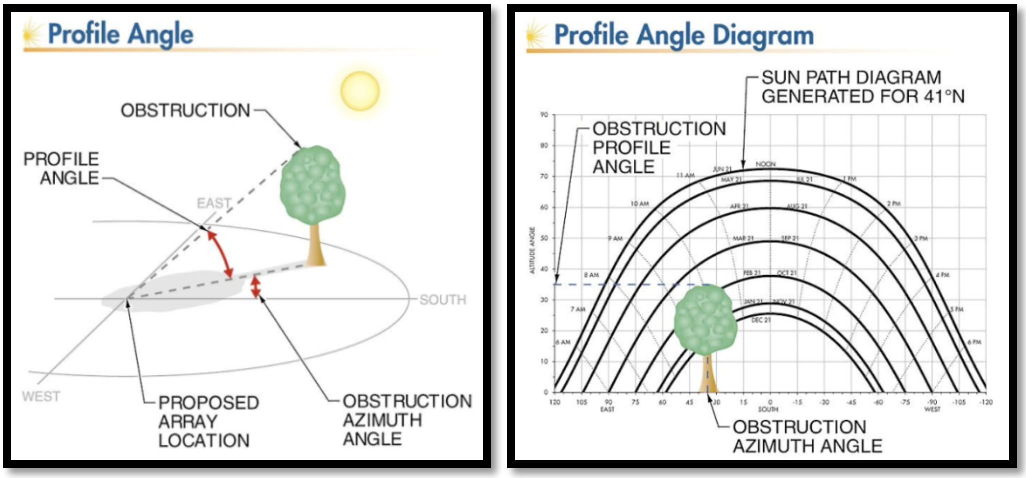

Figure 3- 2: Profile angle and diagram
(Dunlop, 2007)

3.1.2 Wind Power Site Analysis

We considered many technical and economic aspects when assessing the feasibility of wind power at a particular site. Technically, the wind conditions should be measured to determine the energy yield based on the wind velocity. Unfortunately, this was beyond the scope of our project so a wind map, such as Figure 3-3, was used instead to determine the wind velocities of Puerto Rico and surrounding areas (US Department of Energy, 2008).

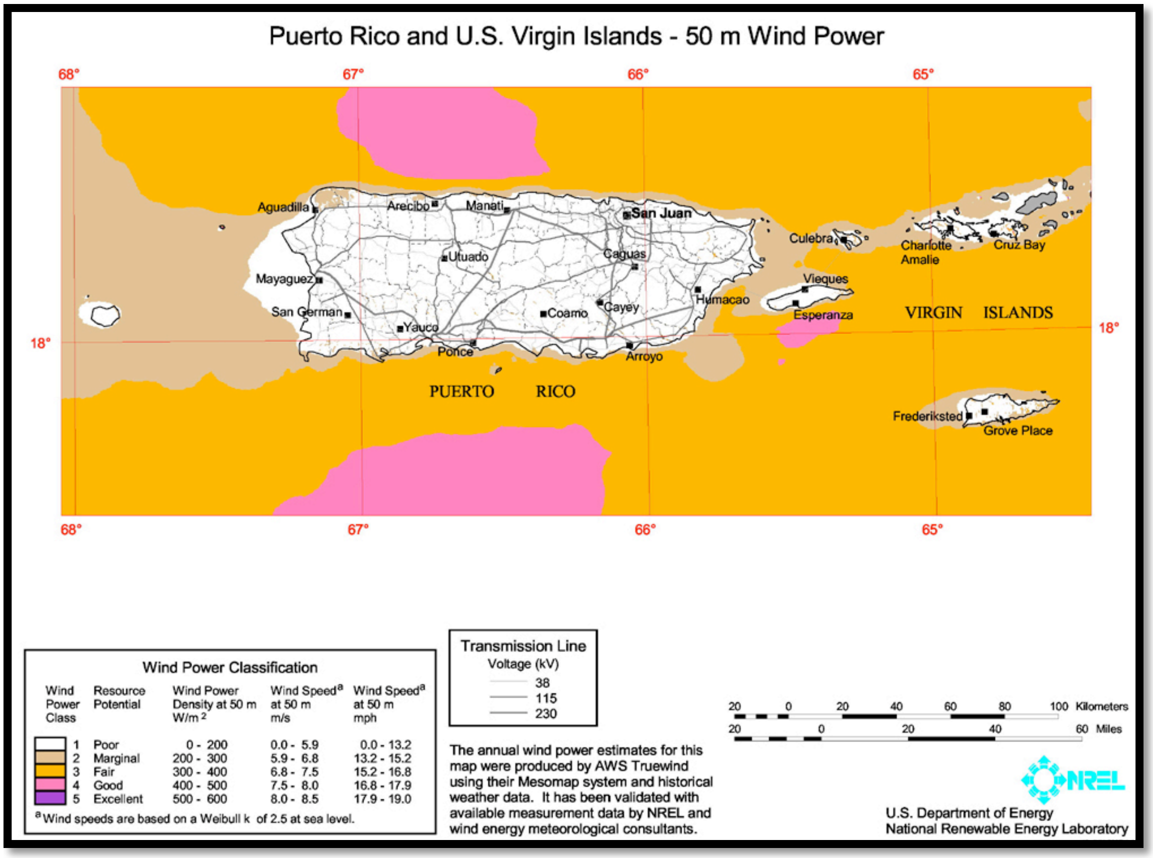

Figure 3- 3: Wind map of Puerto Rico
(Erickson, et.al, 2002)

The wind map classifies the geographical regions by the average wind speed and wind power class from 1 to 7. Wind classes increase directly with wind power with 7 being the highest class and 1 being the lowest (Renewable Resource Data Center, 2009). Many factors, such as latitude and topography, affect wind speed and contribute to the feasibility of wind power. The physical conditions of the terrain impact the local wind velocities and were observed to estimate the wind characteristics present at each site. Figure 3-1 roughly maps the terrain around the possible site locations and neighboring areas. We recorded more detailed observations to evaluate the feasibility of the locations in terms of the current topography. Finally, we observed the neighboring residences and places of interest to determine if they would be disturbed by the noise pollution and visual obstruction of wind turbines. The site analysis provided information such as available land, terrain structures, and wind velocities to help determine the feasibility of implementing wind turbines.

3.1.3 Site Analyses for Other Energy Options

There are additional factors that we considered in the site analysis for waste-to-energy incineration, steam power, hydro-kinetic power, and geothermal power. For all four options, we discovered whether there was an appropriate location for the respective power elements by consulting maps of Arecibo and calculating geographic area. Waste-to-energy requires a specialized facility that takes up large amounts of space. In addition to the incineration plant, waste-to-energy also requires enough space for a specially designed landfill. For steam power, we consulted a Professional Engineer about the potential for waste steam in Arecibo. Hydro-kinetic energy requires a location with enough current and wave height change to function, so we researched the tidal and wave changes in the area. Finally, we analyzed a map of the thermal energy available near the proposed sites to determine if geothermal power is feasible.

3.2 Estimate the Amount of Energy Each Option Can Produce

In order to assess the feasibility of replacing traditional energy methods with alternative sources, we combined the data collected from the site analyses with the potential output of the alternate energy sources. We accomplished this by contacting manufacturers and determined the actual energy yield by reviewing published theoretical output and approximate operating losses.

To determine the amount of solar power that could be produced at each site, we applied size and power ratings obtained from Puerto Rico's website on acceptable solar devices to the information on available space discovered during the site analyses (Administración de Asuntos Energéticos de Puerto Rico, 2009). We used Equation 3-1 to compute the amount of energy that a system could generate (W. Pedreira, personal communication, April 2, 2009).

Equation 3- 1: Energy production formula

$$E = C \cdot DR \cdot SH$$

E = Energy/Day

C = Capacity

D= Derating Factor = .84

SH = Sun-hours/Day

To estimate the amount of available wind energy, we used published wind velocities in conjunction with power curves and turbine capacity factors. The basic formula to calculate the theoretical annual output at any site is shown in Equation 3-2.

Equation 3- 2: Wind annual energy output formula
(US Department of Energy, 2008)

$$E = 0.01328 \cdot D^2 \cdot V^3$$

E = Energy Output (kWh/year)

D = Rotor Diameter (ft)

V = Average Wind Speed (mph)

However, because turbines cannot extract 100% of the wind energy, we used wind power curves and published measurements to compute a more accurate estimate.

Wind power curves are provided by turbine manufacturers as the result of measured field data. They graph the electricity produced at varying levels of wind velocities (Danish Wind Industry Association, 2003). We used these power curves to estimate the efficiency that would result at different velocities at the possible sites for the RO WTP. We also determined the average wind velocities with the use of published wind maps of Puerto Rico. The average wind velocities, when combined with a specific turbine's power curve, aided in estimating the power output to be expected at various locations. We also considered the capacity factor, which is the value resulting from the actual power production divided by the theoretical power production running constantly and at full capacity (American Wind Energy Association, 2009). This factor takes into account any operating losses that may occur and how many additional turbines may need to be constructed to make up for this possible loss. Although these data are only estimates they still provide a general idea about the feasibility of wind power. In order to gather accurate data, professional site analyses and precise measurements will need to be conducted.

We considered the most recent trends in renewable energy research to determine any new beneficial technologies and to assess their long-term reliability by consulting manufacturer information and case studies of current hydro-kinetic and waste energy projects. In addition, we consulted with experts in the fields of alternative energy sources. We met with a Professional

Engineer from the engineering consultation company, CSA Group, in Puerto Rico to discuss energy production in regards to solar power, wind power, and waste steam. We also communicated with experts currently working on hydro-kinetic projects. We then compared these data with the environmental conditions of the possible site locations in order to estimate the actual amount of energy each option is capable of producing.

3.3 Estimate the Costs of Each Energy Option

To compare the benefits of the alternative energies, we determined the cost of each option. This cost estimate includes the price of the initial installation of required materials, as well as the cost required to operate and maintain each energy source for the life of the plant. We also evaluated the lifetime of each energy source to account for any replacements that will need to be performed in the future and considered the change in price over time. We estimated the costs of installation and operation and maintenance fees by performing research and interviewing experts. To determine the cost of each system's components, we contacted manufacturers and reviewed published prices. We also interviewed a CSA Group Professional Engineer, who recently completed a feasibility study on solar and wind power, about the cost associated with these energy options and any extraneous costs. In addition, we consulted case studies of various hydro-kinetic implementations to help estimate the costs. We also discovered federal and local government incentives for using alternative energy sources using an online database (North Carolina State University, 2009). The estimated cost of each option provides PRASA with one key factor in their overall assessment of alternative energy.

3.4 Assess the Environmental Impacts

Switching to less environmentally harmful means of producing power will have many advantages for agencies such as PRASA. Many of the methods considered are better for the environment, while others need more careful evaluation. As we have previously established in our review of the literature, solar and geothermal systems do not have any significant environmental impacts. Therefore, we considered the impacts of wind, waste steam, waste-to-energy and hydro-kinetic power.

We determined the environmental impacts of the various energy systems and reviewed case studies to assess how these impacts apply to Puerto Rico. For wind and tidal power, we determined the effect of the turbines on their respective local species and environment. This was accomplished through the use of an environmental sensitivity map that documents the various species and concerns of the Arecibo region. For the waste-to-energy system, we determined the effects of the ash and pollutants. In addition, we researched an alternative waste-to-energy technology that does not involve incineration that has been proposed in Caguas, Puerto Rico.

We also ascertained how the use of each of these alternatives would impact the Puerto Ricans' opinion of PRASA. We created a questionnaire that asked for public opinion on each of the proposed energy alternatives, their attitudes concerning traditional power methods, and their current opinion of PRASA (see Appendix C and D). We obtained participants in a sample of convenience throughout various public areas of San Juan by inquiring if they would be willing to partake in our study. This information contributed to the overall cost benefit analysis by weighing the social implications of switching to these energy alternatives.

3.5 Conduct Cost Benefit Analysis

Finally, we determined the feasibility of each option for PRASA. Using the data discussed above we formulated a comprehensive cost benefit analysis. This includes financial, as well as social and environmental implications for the various options.

We considered the economic aspects by performing a life cycle cost comparison. This method compares all of the capital costs associated with each option and all of the operating and maintenance costs over the entire life of the system. The sum of these two costs is known as the life cycle cost (Markvart, 1994). We also calculated the payback period by dividing this initial cost by the annual electricity savings. By comparing these numbers, we determined which option makes the most sense financially, but we also considered the social and environmental factors. We used the surveys discussed above to determine how each option will change the public's opinion of PRASA. This information was finally used to present the advantages and disadvantages of each option to PRASA and make a recommendation as to which option or options would be best suited for them.

The feasibility of alternative energy sources for the Arecibo RO WTP was determined by gathering information about the energy production, cost, and environmental implications of the various methods through archival research, site analyses, and surveys. We then prepared a cost benefit analysis using the collected data. This allowed us to determine if solar power, wind power, waste steam, waste-to-energy, geothermal, or hydro-kinetic energy would be viable, and which would be the best option for PRASA.

4. RESULTS AND ANALYSIS

In determining the feasibility of using alternative energy to run the Arecibo RO WTP, we evaluated solar and wind power, waste-to-energy incineration, waste steam, geothermal systems, and hydro-kinetic energy. We performed site analyses, determined costs and available energy, and assessed the environmental impacts for each option. Finally, we combined the data in a cost benefit analysis to determine which energy option will work best for PRASA.

4.1 Solar Energy

For solar power, we determined the energy density in Arecibo to be 4.64-5.65 kWh/m^2 per day, which corresponds to the number of hours of peak sun received daily. See Figure 4-1.

Figure 4- 1: Solar insulation in Puerto Rico
(3TIER: First Look, 2009)

From the map of Arecibo, we identified that the possible sites ranged from 22.5 to 49 acres (Rojas et al., 2006). According to the Puerto Rico website on acceptable solar panels, the 205 W Kyocera solar panels occupy 16 ft^2 (Administración de Asuntos Energéticos de Puerto Rico, 2009). Using these data, we determined that to reach the required capacity of the Arecibo water treatment plant over 64 acres of solar panels would be needed. This is not possible given the sizes of the sites but solar power could be used to power part of the plant. Depending on the site, between 12.5 MW and 27 MW of solar panels can be installed. Using Equation 3-1 we found that this corresponds to an output of 19.7 to 42.2 million kWh/day. Furthermore, during our site analyses we discovered that, for the most part, the sites do not have any large structures nearby that would shadow the solar panels. The first choice is adjacent to a power plant with tall smoke stacks directly to the west, but these are far enough away that they would only be an issue late in the day when the solar power density is already relatively low.

In an interview with Walter Pedreira, the president of Caribbean Renewable Technologies, we discovered that the initial cost for a large solar project is $7000-$8000/kW (W. Pedreira, personal communication, April 2, 2009). At this rate the system would cost between $94 and $204 million. Fortunately, there is a government incentive for 50% of the total initial costs under the industrial incentives law. This means that the new cost of the system would be between $47 and $102.5 million. In addition, there are operation and maintenance costs that include cleaning of the solar panels, insurance, and a new inverter after about 15 years. These costs are about $0.05 per watt annually which, for this system, would be between $0.627 and $1.366 million every year. Furthermore, solar panels only last about 25 years, so during the lifetime of the plant the whole system will need to be replaced. This means that the total cost of the system over the 50-year lifetime of the plant would be between $125.5 and $273 million. This information for each site is shown in Table 4-1. However, it does not take into account that a supplemental power system would also have to be installed because the solar system will not supply 100% of the plant's energy needs.

Table 4- 1: Solar power data for each site

Location	Size (acres)	Power (MW)	Average Sun Hours/ Day	Energy/ Year (kWh)	Capital Costs After Incentive ($million)	Operation and Maintenance Costs ($/year)	Total Life Cycle Cost ($million)
Site One	22.5	12.55	5.12	19702491	47.07	627551	125.51
Site Two	37.7	21.03	5.15	33173813	78.86	1051496	210.30
Site Three	37.4	20.86	5.03	32174236	78.23	1043129	208.63
Site Four	49.0	27.33	5.03	42153412	102.5	1366666	273.33

In addition, solar power has no environmental concerns. It does not pose a threat to the local ecosystems nor are there any harmful pollutants so there will not be any social opposition to a solar project in Arecibo. In fact, in a survey of residents in San Juan (shown in Appendix C and D) 77% of participants said that it would positively affect their opinion of PRASA if they used solar power. See Figure 4-2.

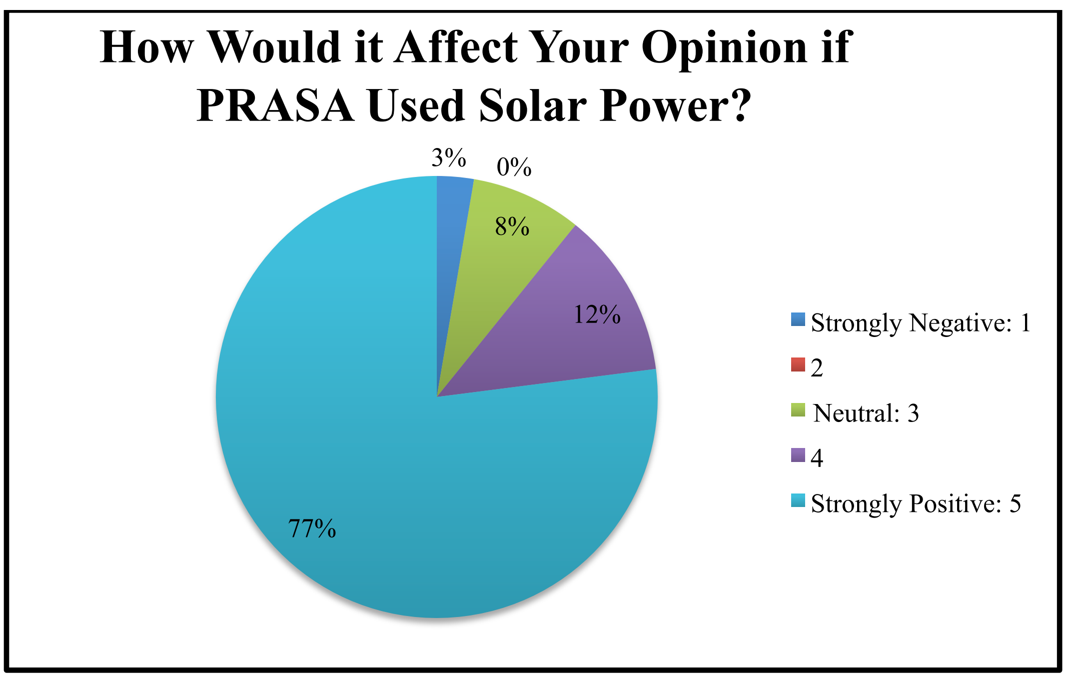

Figure 4- 2: Survey results, question 8

With all of these things considered, solar power is a good candidate for powering the Arecibo plant. In section 4.7 we compare this option with the alternatives to determine whether or not the costs outweigh the benefits.

4.2 Wind Energy

The feasibility of wind power as an alternative energy source for the Arecibo RO WTP was analyzed using the site analyses and the amount of wind energy available. The location was critical to assessing whether wind turbines would effectively convert the kinetic energy of the wind into electricity. As previously mentioned, a quantitative site analysis was beyond the scope of our project, and only published data were applied in determining the wind energy available. The wind map in Figure 3-3 shows the central area of Arecibo to be between a class I and class II wind candidate. This indicates that the city experiences wind velocities of up to 6.8 m/s at a measured height of 50 meters. Figure 4-3 shows another map that evaluates onshore wind energy for Arecibo, with the average annual wind speed measured at a height of 30 meters.

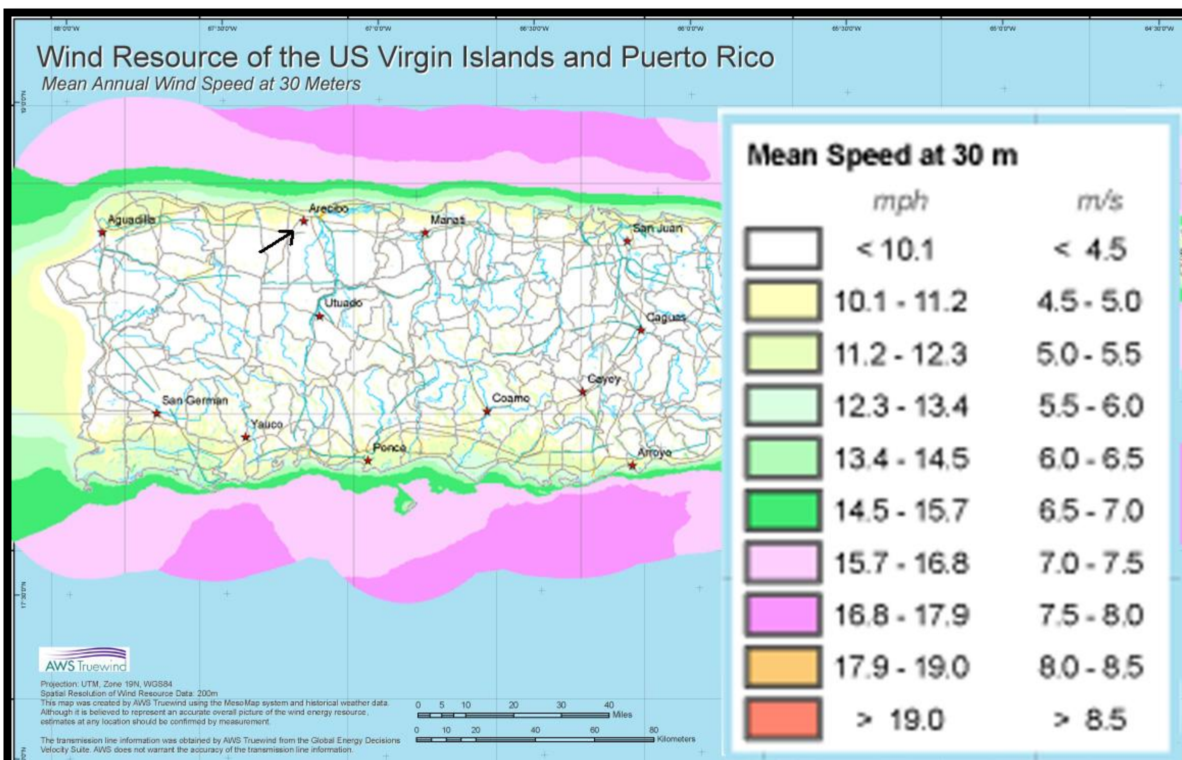

Figure 4- 3: Alternative wind map of Puerto Rico
(AWS Truewind, 2009)

This map displays the central areas of Arecibo with velocities of up to 5.0 m/s and coastal areas of Arecibo with wind velocities between 5.0 to 6.0 m/s. These mean wind speed values are indicative of class II wind power. A wind power classification of III or greater indicates a potential for industrial wind energy through the implementation of wind turbines (Renewable Resource Data Center, 2009). Alternate publications found that exposed points along the entire northern coast of Puerto Rico appear to have class III annual wind power (Renewable Resource Data Center, 2009). The proposed RO WTP locations in Arecibo are considered exposed points on the northern coast due to their proximity to the Atlantic Ocean. Therefore, the data classifying central Arecibo as class I and class II wind power may not apply to the coastal locations of the proposed sites. In addition, the primary choice for the RO WTP is situated less than a half a mile from the coast of Arecibo and the secondary site just less than a mile from the coast, so they are both likely to experience the velocities of class II or class III winds (Google Earth, 2009).

Although offshore turbines would most likely experience higher wind velocities than onshore turbines, many more problems arise. Offshore turbines need to be placed in shallow waters less than 30 meters deep, which is difficult to accommodate with the rapid increase in depth off the northern coast of Puerto Rico (Sovacool & Hirsh, 2007). However, if the turbines were to somehow be installed at 30 meters depth, then they would be fairly close to the shore, which could create marine disturbances affecting sea life, shipping routes, fishing habits, and coastal erosion (American Wind Energy Association, 2009). Expert consultation also deemed that offshore turbines would not be feasible due to their necessity for shallow waters, the higher cost associated with them, and the environmental oppositions that arise (L. Pagan, personal communication, March 17, 2009). For these reasons, offshore turbines were not a feasible option to power the RO WTP, so we further investigated onshore turbines proximate to the coast.

Due to the differences in both the published wind maps and mean annual wind velocity data, more detailed and accurate measurements should be taken that are specific to the site of interest. The best way to accomplish this is through the installation of a wind tower, usually at the 60 to 80 meter planned hub height of the turbine, to obtain data measurements for at least one year (L. Pagan, personal communication, March 17, 2009). The tower can use an anemometer to measure wind velocity and a wind vane with a potentiometric transmitter to measure and record wind direction (World Wind Energy Association 2006). Until these more detailed measurements are made, the most feasible option in terms of available wind energy and environmental conditions would be the construction of coastal, onshore turbines on the top two proposed sites.

The amount of energy produced can vary depending on the type of turbine used. As mentioned previously, the power curves provided by turbine manufacturers provide information on the power output at varying wind velocities. The graph of a power curve for General Electric's (GE) 2,500 kW model is shown in Figure 4-4.

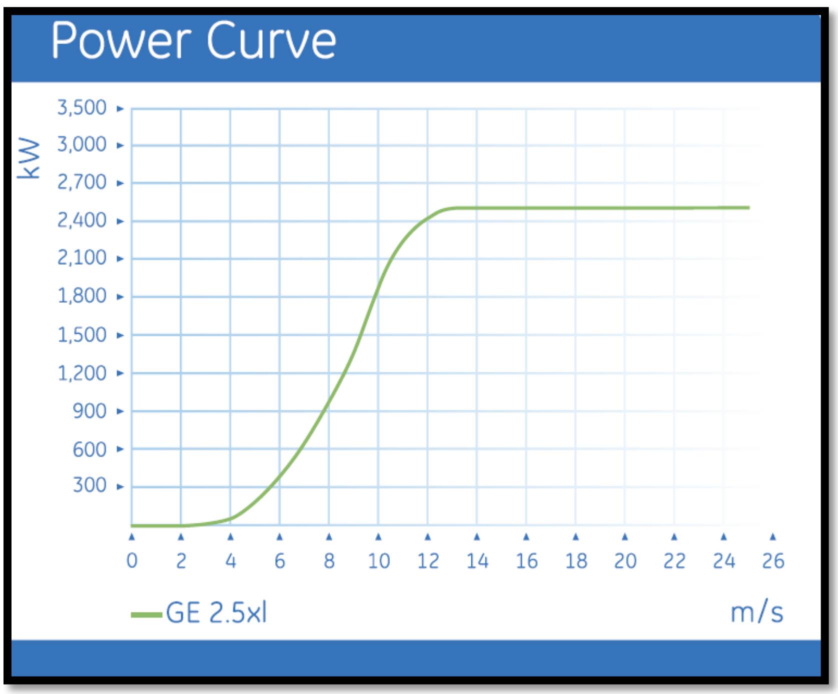

Figure 4- 4: Power curve for GE 2.5xl wind turbine
(GE Energy, 2008)

The power curve in Figure 4-4 displays the power output in kilowatts against the wind velocity in meters per second. This graph can be used to estimate the electricity produced at the average wind speeds in Arecibo to yield a site-specific wind power. Although we are lacking historical data for Arecibo wind values, 3TIER's First Look map of wind velocity calculated the 2003 average speed for the top site choice of the proposed RO WTP in Arecibo as 6.25 m/s (3TIER: First Look, 2009).

The power outputs were then estimated according to the power curves of the different turbines available, which gave an approximate idea of the wind energy available and the efficiency of different models and brands of turbines. Walter Pedreira, the president of Caribbean Renewable Technologies, provided a list of the manufacturers of wind turbines commonly used in Puerto Rico (W. Pedreira, personal communication, April 2, 2009). In Table 4-2 we compiled the turbine models from these manufacturers along with the power curve data estimated at different wind speeds.

Table 4- 2: Power output approximations for popular turbine manufacturers
(Vestas, 2008; Gamesa, 2008; GE Energy, 2008)

Wind Speed (m/s)	Power Output Approximations (kW)										
	Vestas					Gamesa			General Electric		
	V82-1650	*V100-1800*	*V90-1800*	*V90-2000*	*V90-3000*	*G80-2000*	*G87-2000*	*G90-2000*	*2500xl*	*1500 xle*	*1500 sle*
0	0	0	0	0	0	0	0	0	0	0	0
5	200	250	215	215	250	152	181	197	260	130	75
10	1400	1760	1550	1685	1750	1296	1528	1633	1900	1160	970
15	1660	1800	1815	2015	3000	1995	1999	1999	2550	1500	1500
20	1660	1800	1815	2015	3000	2000	2000	2000	2550	1500	1500
25	1660	1800	1815	2015	3000	2000	2000	2000	2550	1500	1500

We approximated the power outputs from graphs provided by the manufacturers' websites with the exception of the Gamesa power curves which were the exact power outputs found in table format on their website. These power curves were applied to the 5-7 m/s wind categories, which would most likely be the normal range of the wind speeds found near the proposed sites (3TIER: First Look, 2009). The GE 2.5xl produced the most energy at around 5 m/s wind speed when compared to the other popular turbine models. Therefore, we continued to use this model as the example turbine to power the proposed RO WTP.

The annual energy output was estimated using two different methods. The first approximation used Equation 3-2. From this formula, we found a yearly output of roughly 3.9 million kWh. The power curve in Figure 4-4 can alternatively be used to estimate the annual energy production. The 425 kW obtained at wind speeds of 6.25 m/s yields the theoretical power production of approximately 3.7 million kWh per year. These power outputs consider the capacity factor to account for any operational losses. We discovered that turbines operate at a capacity factor between 25-60% but most function at 30-40% (American Wind Energy Association, 2009).

The annual power output values are very similar in value. This validates the accuracy of the estimates from the power curves, which can therefore be used to approximate the energy that wind would supply to the proposed RO WTP.

The desired energy production affects the number of turbines that need to be placed on site. However, the land available on each site is a limiting factor, since the proposed sites range in size from 22.5 to 49 acres (Rojas et al., 2006). The turbines require specific spacing layouts that differ based on the direction of the prevailing winds and the diameter of the rotors. It is generally advised to space neighboring wind turbines in each row the length of 3-5 rotor diameters apart if the winds are unidirectional and up to 7 diameters apart if the winds are multidirectional. There should also be a distance of 7-10 rotor diameters between each row of turbines (Wind Power Project Site, 2005).

We continued to use the GE 2.5xl model and its 100 m rotor diameter as the example model turbine. Since we were not able to take or recover any actual wind direction measurements for the site locations in Arecibo, we assumed a horizontal spacing between turbines of 4 rotor diameters. This would result in 500 m of horizontal distance occupied. If the turbines were placed on opposite sides of the proposed plots of land, they would be spaced exactly the recommended distance apart. More than one row of turbines would not be possible due to space limitations on all four sites. In addition, since the direction of the prevailing wind is not known, the distance allotted between each turbine may be further restricted. Therefore, given the parameters limiting the available space of the proposed sites and lack of site specific data, only one turbine would be feasible. If one GE 2.5xl turbine is used, wind energy would provide the predicted annual energy output of 3.7 million kWh.

Another factor affecting the feasibility of implementing turbines is the cost associated with wind energy. This includes the price of installation as well as operation and maintenance. Expert consultation revealed that current, industrial wind turbines are installed for approximately $2,500/kW (L. Pagan, personal communication, March 17, 2009). For a 2,500 kW wind turbine, the initial costs would be $6.25 million. Once properly installed, sources estimate wind energy at larger sites to cost approximately $0.03-0.05 per kWh (American Wind Energy Association, 2009). This estimate includes government tax incentives such as the production tax incentive, which provides industries investing in wind energy with $0.021 per kilowatt-hour credit for the first ten years in operation (Clean Energy, 2008). Puerto Rico can also receive the property tax exemption, which allows for complete tax exemption from all equipment used to produce wind energy (North Carolina State University, 2009). Additional costs throughout the plant's lifetime include turbine replacement every 20-25 years as well as operation and maintenance fees. The operation and maintenance costs are estimated to be 1.5 to 2.0% of the initial investment every year. If we take into account the increasing damage due to daily operation, we can estimate the yearly operation and maintenance costs to be $0.01 per kWh output (Danish Wind Industry Association, 2003). Combining initial and replacement costs, operation and maintenance fees, and tax incentives over the 50-year life time of the plant, the total cost of the wind system is $13.6 million.

Finally, the environmental and social considerations regarding wind energy were evaluated. The noise produced, as well as the visual disturbance of wind turbines are common deterrents to their implementation. This is especially relevant since the top choice of the RO WTP is situated less than a mile from densely populated areas in Arecibo, and the second site is less than a quarter of a mile away from populated areas. The incidents of local birds fatally flying into the rotor blades are also a big concern and have created fierce environmental opposition for other wind projects, such as the proposed wind farm in Guayanilla. This wind farm was opposed for many significant environmental impacts, two of which were the concern for the threatened Puerto Rican Nightjar and the Brown Pelican. We photographed a Brown Pelican shown in Figure 4-5 during our visit to the pump house in Arecibo located close to the top two site choices for the RO WTP.

Figure 4- 5: Brown Pelican in Arecibo area

The close proximity of the birds' natural habitats in Guayanilla to the turbine blades had created much concern (Rust, 2007). The actual amount of avian deaths due to turbines is relatively low, however. For example, we viewed a small turbine at the Polytechnic University of Puerto Rico, shown in Figure 4-6, which has not harmed any birds or other animals in its one year of operation.

Figure 4- 6: Small wind turbine at the Polytechnic University of Puerto Rico

This turbine is roughly 100 m high and generates up to 0.001 kW of power (W. Lopez, personal communication, April 6, 2009).

Despite some of the negative environmental factors of wind energy, the public may still be amenable to the possibility of its implementation. In our survey of 77 Puerto Rican residents, we found that the general population was supportive of wind energy as a replacement or supplementation to the burning of fossil fuels. Figure 4-7 is a graph of the survey results.

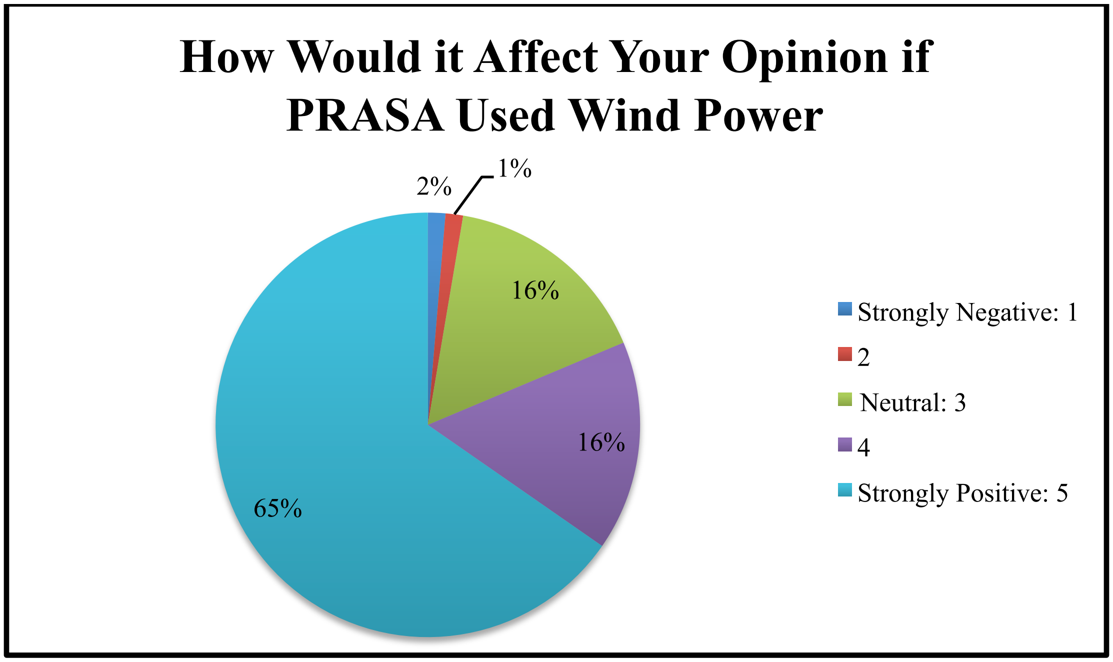

Figure 4- 7: Survey results, question 9

The majority of the people surveyed rated wind energy as a favorable alternative to fuel burning and said it would improve their opinion of PRASA if wind energy was used. 65% of the participants surveyed ranked their opinion of the conversion to wind energy as 5, the highest possible rating, with an additional 16% at 4, which is also positively in favor. In addition, 17% of the participants had neutral opinions of the conversion to wind energy, while only 2% total were opposed to the idea. The results from this survey reflect the public's general acceptance of wind energy despite some of its negative impacts.

4.3 Waste-to Energy

The island of Puerto Rico has an abundance of garbage with very few landfills. In 1994, the EPA shut down 21 of Puerto Rico's 62 landfills due to poor conditions and 9 others have been closed since then (Reuters, 2000). This means that there is an excess of waste on the island and a solution is needed to take care of this problem. The Solid Waste Management Authority (SWMA) has accepted proposals to create two waste-to-energy facilities; one would be located in the metro San Juan area and the other could possibly be built in the Arecibo area. These would each produce 50-75 MW of energy. However, Puerto Rico has a limited supply of garbage, which can only produce 150-200 MW if it is all converted to energy (J. Benitez, personal communication, March 31, 2009). If a waste-to-energy facility is built in the Arecibo area by SWMA, there will not be enough left over garbage locally to power the RO WTP. It would be very expensive to transport garbage from distant locations to run the waste-to-energy facility. In addition, there is a licensing process that takes approximately ten years and requires permission from SWMA (J. Benitez, personal communication, March 31, 2009). This means that powering the Arecibo RO WTP by waste-to-energy is not ideal.

A negative environmental impact of waste-to-energy facilities is that they release pollutants into the environment. Some of these pollutants include nitrogen oxide, mercury, and particulates. The EPA regulates the released amounts of these substances through the Clean Air Act. To comply with these regulations, waste-to-energy facilities have a number of filters and other air quality controls that have reduced emissions by 90% since 1990 (Energy Recovery Council, 2009). There are approximately 430 waste-to-energy facilities located in Europe and 90 located in the United States (ISWA, 2007). Emission controls in these plants have been thoroughly tested to ensure that any released pollutants are not harmful to the nearby population or environment.

Despite these safeguards, waste-to-energy plants have a reputation of polluting and being health hazards. Because of this, public opinion is an important factor to consider. We conducted surveys asking participants to rate the energy options on a scale from 1-5 with 1 meaning that it would have a strong negative effect if PRASA used that option and 5 that it would have a strong positive effect. We found that waste-to-energy was the least popular option receiving more “1s” than any other alternative energy. This suggests that the construction of a waste-to-energy plant will face fierce opposition, which would further complicate the long permitting process. The results from the waste-to-energy question on the survey can be found in Figure 4-8.

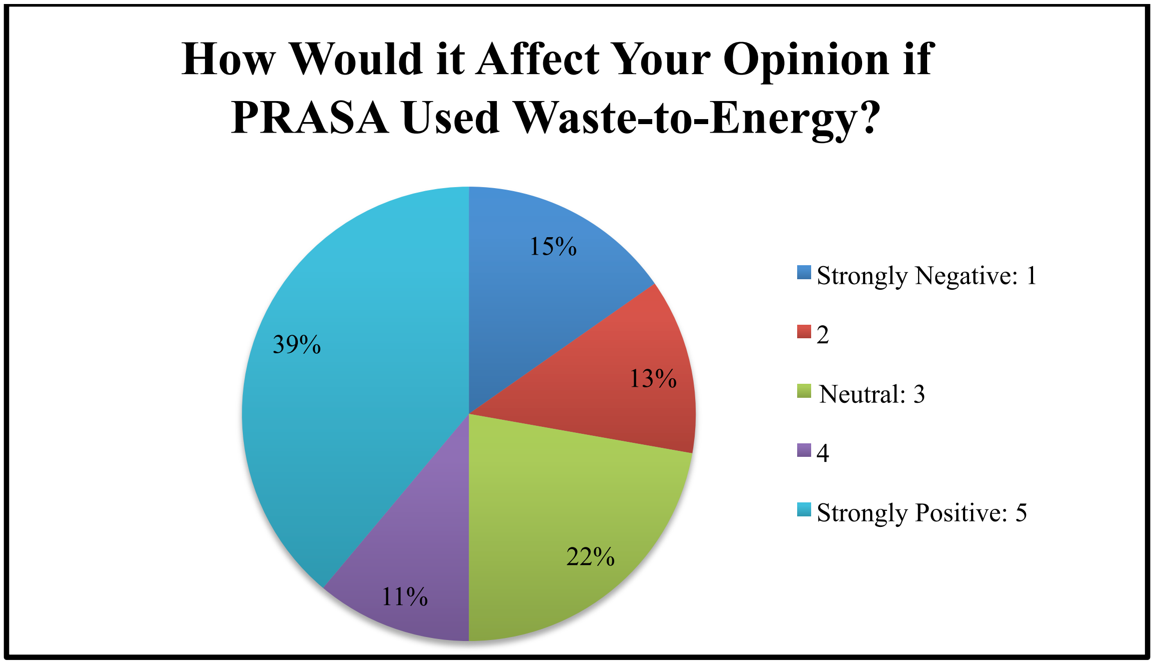

Figure 4- 8: Survey results, question 10

The facility will have methods to prevent harm to the surrounding environment thereby reducing the environmental opposition. However, the public will most likely oppose the construction of a waste-to-energy facility since it is their least favorite alternative energy option. Furthermore, there are insufficient resources in the Arecibo area to use waste-to-energy as an alternative energy source. Overall, waste-to-energy is not a feasible option to power the Arecibo RO WTP.

4.4 Waste Steam Energy

Waste steam energy is the process of converting the remaining steam produced by a simple cycle gas turbine at the nearby power plant, Cambalache, into electricity (F. Quinones, personal communication, January 28, 2009). This steam would be run through a steam turbine to produce electricity and partially power the reverse osmosis processes. The feasibility of using waste steam depends on the quality and quantity of steam produced and cooperation with PREPA. We found that the steam produced is of low quality and has already had most of its power extracted for use. The Cambalache power plant is also considering converting to the combined cycle, which would produce less waste steam than the current simple cycle (J. Benitez, personal communication, March 31, 2009). This decrease in the amount of steam, which is already lacking in power, would only further reduce the amount of usable power. With little remaining power, waste steam could only be used to pre-heat some process (J. Benitez, personal communication, March 31, 2009). The water treated at the RO WTP is filtered through reverse osmosis, which does not require heating to produce potable water, so this waste steam would not be advantageous to PRASA. In addition, cooperation with PREPA would need to be arranged, which could be difficult and possibly hinder the use of waste steam as an alternate energy source (J. Benitez, personal communication, March 31, 2009). In conclusion, waste steam is not a feasible option to power the proposed Arecibo RO WTP.

4.5 Geothermal Energy

Geothermal is a very efficient form of energy and also does not have any negative environmental impacts. In order for geothermal energy to work there must be sufficient energy density in the area, but unfortunately Arecibo has no geothermal pockets and a low energy density of only about 45 mW/m^2. See Figure 4-9.

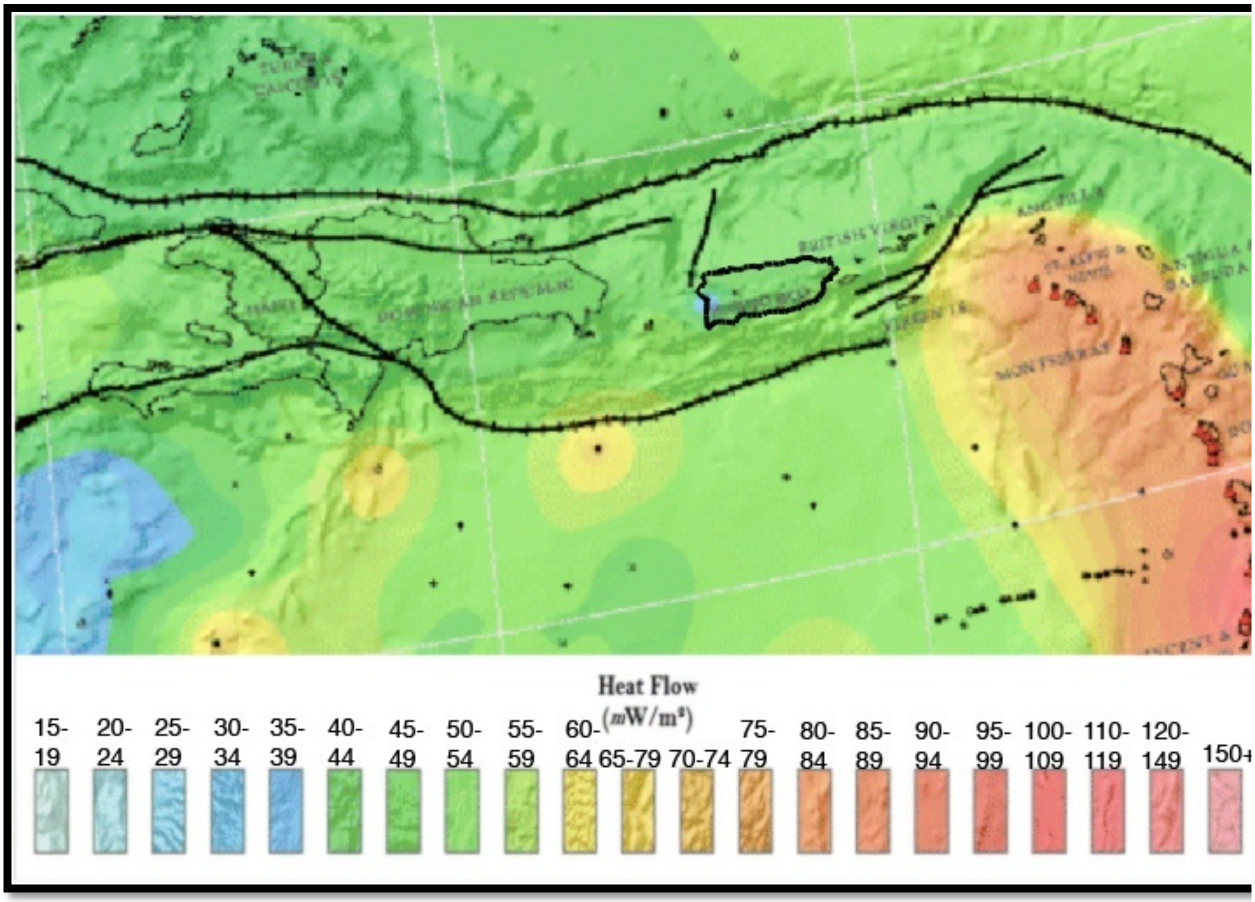

Figure 4- 9: Geothermal map of Puerto Rico
(Blackwell and Richards, 2007)

At this level geothermal energy is not feasible. Even with 100% conversion, which is not possible, geothermal power would require 2,000 acres of land to power the Arecibo plant. As this land requirement is so extreme we will no longer consider geothermal energy as an option for running the RO WTP in Arecibo.

4.6 Hydro-Kinetic Energy

Since Arecibo is located on the northern coast of Puerto Rico, harnessing some of the ocean's energy to power the plant is a logical choice. We researched the costs, energy production, and environmental factors of tidal and wave energy to determine their feasibility to provide power for the Arecibo RO WTP.

4.6.1 Tidal Energy

Tidal generators are similar to wind turbines but they are placed underwater. They have similar spacing requirements to wind turbines when multiple turbines are placed near each other. Also, after contacting several companies about their energy technologies, we found that their tidal generators require a current of at least 2-4 m/s. General tidal changes can be seen in Figure 4-10, but from the National Oceanic and Atmospheric Administration we found that Arecibo's average tidal change is 2-3 ft (NOAA, 2008). This will not create enough velocity to use tidal generators as an alternative energy source.

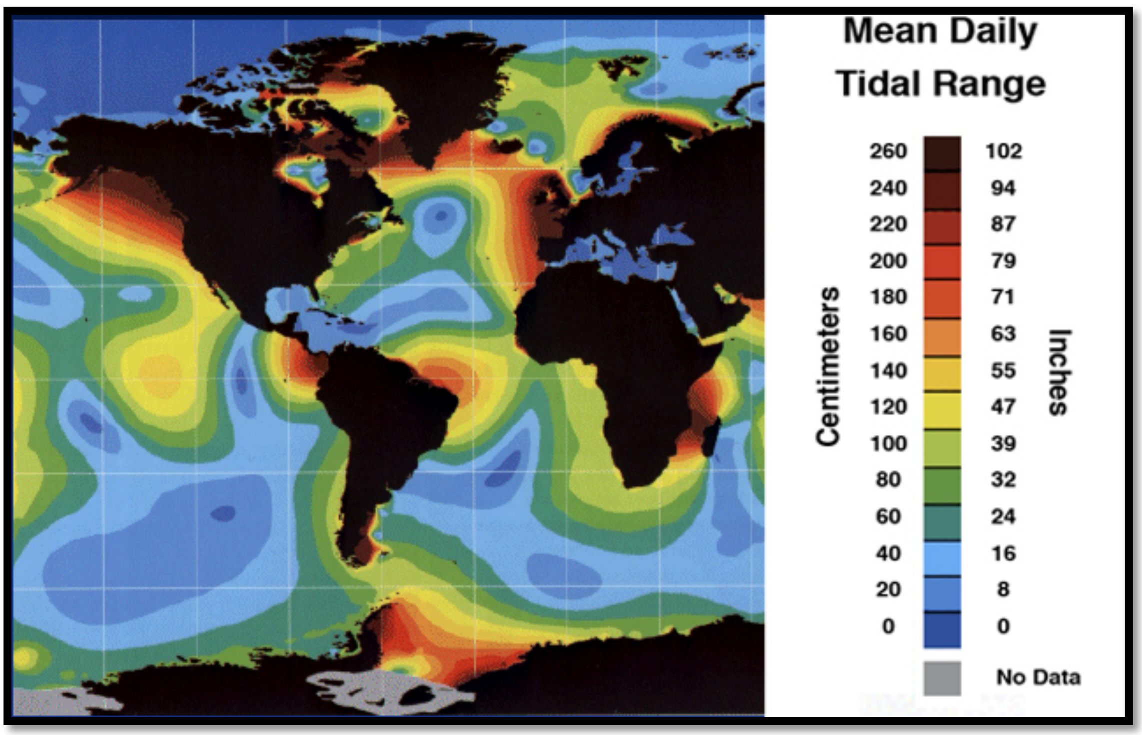

Figure 4- 10: World tidal map
(Tidal Power US)

We also learned that the cost of a tidal project called SeaGen in Strangford Lough, Ireland was $5.66 million per megawatt (S. Head, personal communication, March 24, 2009). This project was installed in April 2008 and produces 1.2 MW. The SeaGen tidal generator's dual rotor turbine can be raised out of the water for any maintenance required, such as cleaning. This makes the operation and maintenance very cheap. Unfortunately, this project only has a permit to be installed for a test period of five years (Marine Current Turbines, 2007).

Tidal generators are not an option as an alternative energy source for the Arecibo RO WTP because the conditions around the site are not appropriate, the costs are very high, and the energy produced is not enough. Also, tidal energy is an emerging field and there have not been enough permanent installations to guarantee that this technology would be suitable for commercial applications.

4.6.2 Wave Energy

Wave generators convert the changing heights of waves to electrical energy. In order to do this, the area will need to have waves that are high enough. The average wave height in Arecibo is about 5 ft as seen in Figure 4-11.

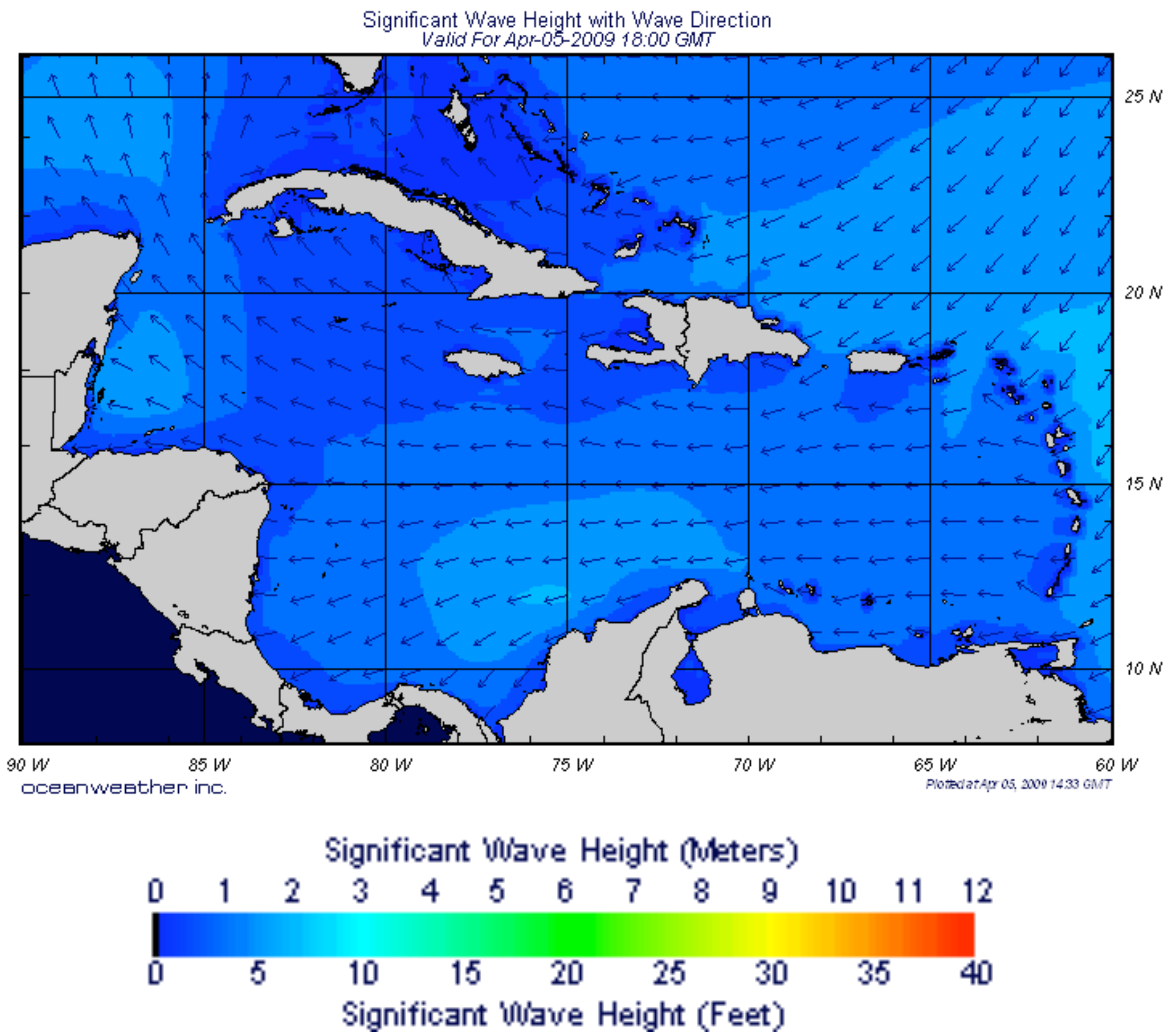

Figure 4- 11: Wave height with wave direction in Caribbean Sea
(OceanWeather Inc., 2009)

Point absorber buoys can generate up to 400 kW each, but they can be arranged in groups to produce up to 10 MW of energy. A 10 MW arrangement of Ocean Power Technology's (OPT) Power Buoys would occupy 0.125 km^2 (Ocean Power Technology, 2009). OPT has installed a 40 kW Power Buoy in New Jersey and has plans to create a 1.39 MW arrangement in Spain. To reduce the visibility from shore, Power Buoys have been located one to three miles off shore. This is a problem near Arecibo, because at that distance off shore the water is too deep due to the Puerto Rico Trench.

A wave generator that implements oscillating wave column technology would be better suited to the Arecibo area since it is typically placed near shore. The WaveGen project designed to use this technology produces 4 MW of energy and will be placed only 350 m from the shore of the Isle of Lewis in Scotland. This project was approved in January 2009 and is currently in planning stages (n-power renewables, 2009).

Arecibo has appropriate site conditions to use wave generators; however, the technology has not been thoroughly tested for an extended time, so they are not recommended for immediate use. This technology should be greatly improved within the decade at which point it would be highly recommended to use this renewable energy source.

4.6.3 Similarities of Tidal and Wave Energy

There are important environmental factors that are similar for both of the hydro-kinetic options. First, the Puerto Rico Trench is located off the northern coast of Puerto Rico. This trench has the deepest point of the Atlantic Ocean at nearly 8,400 ft (NOAA, 2003). The trench makes it difficult and incredibly expensive to install anything in that area. Any device would need to be installed between the coast and the Puerto Rico Trench, which has a gentle slope. The ocean floor surrounding Puerto Rico can be seen in the bathymetric map shown in Figure 4-12.

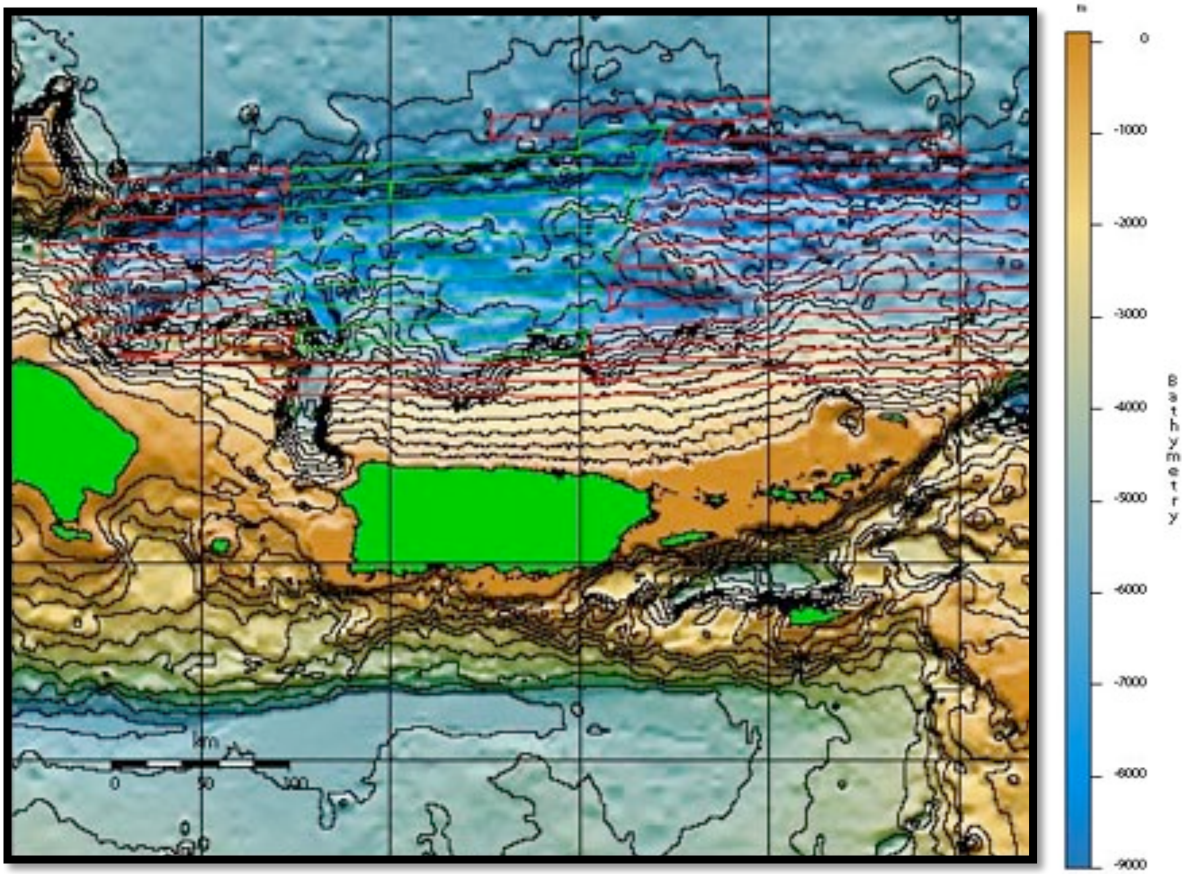

Figure 4- 12: Bathymetry map of Puerto Rico
(NOAA, 2003)

Hydro-kinetic devices could damage nearby reefs that are essential for marine ecosystems. Aquatic animals, including fish, turtles, and mammals, could also be harmed by hydro-kinetic devices. The manufacturers have tried to design the equipment to not directly harm marine life, but the moving parts of the generators may harm an occasional animal.

Arecibo has a port, which means that there is a large amount of boating traffic. Placing any device in the ocean creates obstacles for boats. The hydro-kinetic generators will need to be installed in an area that is out of the shipping lanes or there is a risk of damage to boats and to the energy device.

In our survey of public opinion, we asked the participants to rate how they feel about using hydro-kinetic energy on a scale from 1-5 with 1 meaning that it would have a strong negative effect if PRASA used that option and 5 it would have a strong positive effect. We found that the majority of people do approve of using hydro-kinetic energy. More than 50% of participants rated hydro-kinetic power as a 5. The results of this question are shown in Figure 4-13.

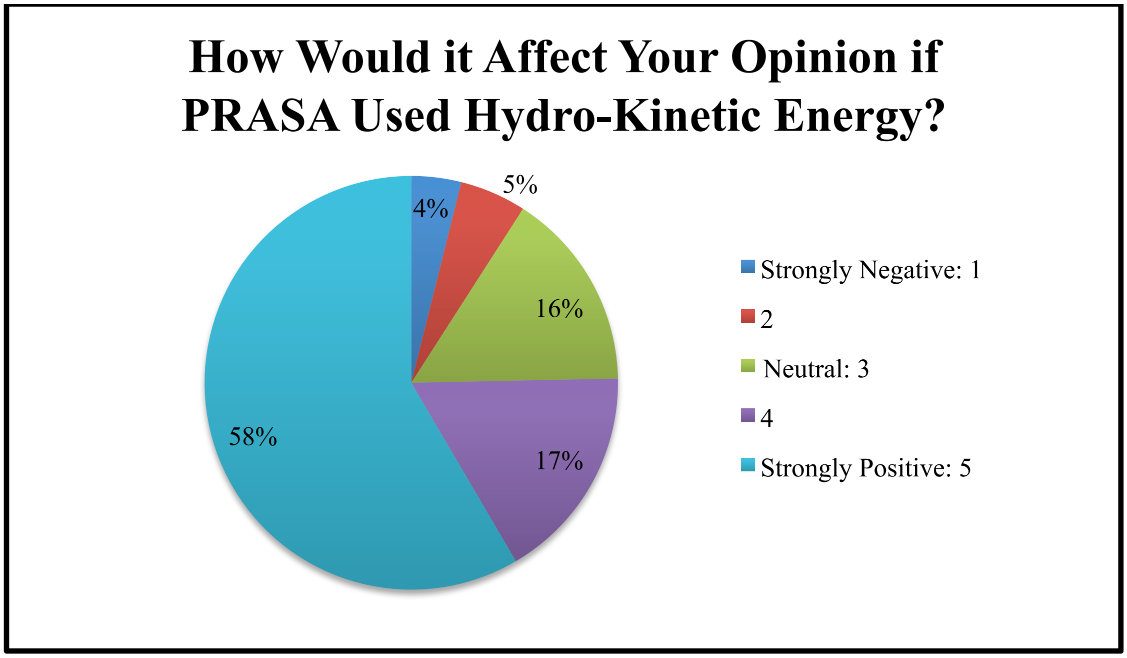

Figure 4- 13: Survey results, question 13

Another important factor for hydro-kinetic energy is cost. The federal government has several options to reduce the price of installing renewable energies in order to encourage their use. Any hydro-kinetic system that is installed is eligible to receive federal government incentives. The Renewable Energy Production Tax Credit allows corporations to receive \$0.01/kWh for the first ten years of operation. This applies to hydro-kinetic systems that are greater than 150 kW. Another available option is the Federal Business Energy Investment Credit or a grant from the U.S. Department of the Treasury which could cover up to 30% of the costs (North Carolina State University, 2009). These incentives help make hydro-kinetic energy more affordable.

Overall, using hydro-kinetic energy near Arecibo is feasible but not recommended for immediate installation. Arecibo provides the proper site conditions to use wave energy but not tidal energy. Using wave energy would not drastically interfere with the environment, could be expanded to produce large amounts of energy, would be reasonably priced, and would have little interference from the public. Once this technology matures it will be a great option to power facilities in Arecibo.

4.7 Cost Benefit Analysis

In order to determine which option or options will work best for PRASA, we compared the costs of the different energy systems with their benefits. We considered the economic benefit of the money saved on PRASA's electricity bill and then combined that with the social benefits of using environmentally friendly technology. The Arecibo RO plant will use 45.3 million kWh of electricity every year. PREPA currently charges PRASA $0.21/kWh of electricity so this will correspond to a cost of $9.5 million per year (R. Vega, personal communication, March 26, 2009). The main benefit of using alternative energy is that it will cut the costs of this electric bill.

Although every energy we evaluated has its benefits, they do not all outweigh their costs. Geothermal energy is very clean and renewable but in Puerto Rico there is not enough energy available. The same is true for waste-to-energy and waste steam; there isn't enough trash on the island for PRASA to use and the waste steam does not have enough energy to provide significant power to the RO WTP. Furthermore, PRASA would need to obtain permission from the Solid Waste Management Authority and PREPA in order to use the garbage and waste steam respectively. Hydro-kinetic energy would be feasible but presently the technology is too new and needs time to mature before it should be implemented in such a large-scale commercial application. Solar and wind are the only viable options since both can produce a significant amount of energy at reasonable costs. All of these results are summarized in Table 4-3.

Table 4- 3: Summary of results

Energy Type	Feasibility	Lifetime Cost ($million)	Payback Period (years)	Capacity	Energy (MWh/year)
Solar	yes	125	26	12.5MW	19,700
Wind	yes	13.6	16	2.5MW	3700
Waste-to-Energy	no	not available	not available	50-75MW	not available
Waste Steam	no	not available	not available	not available	not available
Geothermal	no	not available	not available	45mW/m2	not available
Hydro-kinetic	yes	6.80	8.5	1.2MW	3,800

Any electricity produced by an alternate system can save PRASA money. By installing solar panels at the top site choice in Arecibo, PRASA can produce 19.7 million kWh of electricity a year. This means they will save $4.1 million on their electricity bill every year. Unfortunately, this savings is reduced due to annual operation and maintenance costs of $627,000 but the total gain is still $3.5 million every year. At this rate the system will pay for itself in 13 years but will require a replacement after another 13. After this replacement the savings will be purely profit for the 24 years left in the plants lifetime. These profits total $81.7 million which is almost twice the initial investment.

This same analysis applies to wind power. The 3.7 million kWh of electricity a wind turbine could produce would save PRASA $777,000 each year. After accounting for the operation and maintenance and the tax incentives for the first ten years, this annual savings becomes $810,000. With these savings, the system will be paid off after 8 years but will require replacement at the 25-year mark. After this replacement, the remaining savings will be profit. This profit totals $24.8 million which is nearly 4 times their initial investment.

Another main benefit of using these systems is the improvement in public opinion of PRASA. The people in Puerto Rico are all very concerned about the environment as can be seen in the graph of our results shown in Figure 4-14.

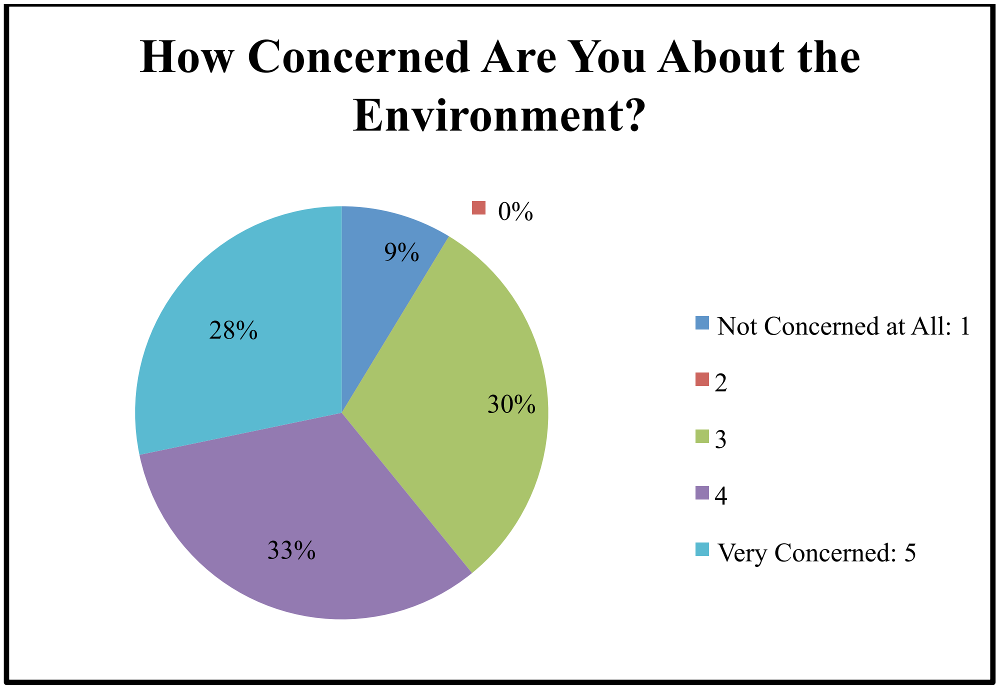

Figure 4- 14: Survey results, question 5

This concern leads to a negative opinion of fossil fuels and, most likely, companies that have large negative impacts on the environment. Only 14% of people said that they had a positive opinion of PRASA and of the 24% that voted negatively almost all of them said that it would improve their opinion if PRASA used solar or wind power. On the other hand, when respondents were asked how it would affect their opinion if PRASA used fossil fuels to power the RO plant on a scale from 1-5, 55% responded with the lowest two categories. This indicated a general negative perception towards fossil fuels and probably an improved public opinion if PRASA switched to using alternative energies.

Overall, participants responded very positively to most of the alternative energies and, in general, seemed very excited and optimistic about the idea of PRASA implementing these technologies. One respondent mentioned, "Any technology that can reduce our dependence on oil is great in my book." If PRASA were to convert to some of these renewable technologies, not only would it save them money, it would greatly boost their public image throughout Puerto Rico. This is something that can be very beneficial to a company, especially one that works as closely with the public as PRASA does.

5. RECOMMENDATIONS AND CONCLUSIONS

We have produced information about the costs, energy production and feasibility of various energy alternatives. From these data we concluded that waste-to-energy, waste steam and geothermal energy are not options due to limited energy resources. Solar energy, wind energy and hydro-kinetic are the only viable options. Despite the feasibility of wave energy, the technology is very new and needs time to mature before it can be recommended for commercial use. We recommend that PRASA implement a combination of solar and wind power to meet a portion of the Arecibo RO WTP's energy demands.

For solar power, we recommend that PRASA use solar panels at one of the proposed choices for the RO plant. In this study we used 205 Watt Kyocera solar panels as an example, but PRASA should solicit proposals from all manufacturers on Puerto Rico's web site for acceptable solar panels (Administración de Asuntos Energéticos de Puerto Rico, 2009). Once a location for the RO plant is selected, PRASA should conduct an extensive shading analysis of the area to determine which parts of the site will still be acceptable for solar power. PRASA should also record solar radiation data in the area for at least one year to ensure the accuracy of measurements obtained from solar energy maps.

For wind energy, we recommend that one onshore turbine be constructed on either the primary or secondary site choice. The wind velocities are most likely strong enough to power turbines on any of the proposed sites, but the top two site choices would be ideal. They are both situated within one mile from the northern coast and experience high wind speeds capable of generating significant electricity. Due to land restrictions, only one turbine on each site is feasible. Any turbines purchased should also be hurricane proofed with cut-out speeds to prevent damages incurred at the high wind velocities typical of hurricanes. We also advise that more detailed and site specific measurements of wind speed and direction are taken in order to verify our results and account for any other considerations, such as diurnal and seasonal wind variations. In addition, we recommend that PRASA install turbines at the Arecibo Waste Water Treatment Plant or invest in purchasing additional land to support more wind turbines.

We have chosen to recommend solar and wind power because they can each provide a significant amount of clean and renewable energy at a price that is competitive with that of traditional energy. This system should be connected directly to the RO WTP in order to avoid transmission charges from PREPA, but the WTP would require supplemental energy supplied by the local power grid. If PRASA decides to move forward with this project, more specific data must be collected in Arecibo for at least one year. The solar radiation in the area must be measured as well as the wind speed and direction.

A solar and wind power system would be a solid investment for PRASA, helping to reduce their annual energy bill while at the same time reducing their environmental impact. All corporations should be conscious about their environmental impacts because global climate change is a serious problem and will have severe implications for the planet. PRASA is attempting to make positive changes in this respect and is leading the way for Puerto Rico to become environmentally friendly. It will also be beneficial for PRASA to produce an educational ad campaign to raise awareness about the steps that they are taking towards corporate responsibility.

Since economic considerations are paramount to PRASA, we have shown that both solar and wind power can produce a significant return on investment. Furthermore, this initiative will have valuable results for PRASA's public image in Puerto Rico, and will also be beneficial for the overall sustainability of their future projects. The implementation of solar and wind power would prove very advantageous to PRASA. We are proud to have assisted in these progressive endeavors that will help set the global trend in environmental responsibility.

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APPENDICES

Appendix A: PRASA Mission

What we do

The Puerto Rico Aqueduct and Sewer Authority (PRASA) is the largest user of water resources (freshwater) in Puerto Rico. PRASA supplies nearly 617 million gallons per day (MGD) of potable water to 98% of residents on the island (approximately 3.8 million inhabitants) through a network of 130 filtration plants, 328 deep wells, 12,400 kilometers of pipeline, 1,679 drinking water storage tanks, and thousands of pumping stations and valves. The network of purification plants and water distribution systems that PRASA operates is considered among the most complex in the world.

PRASA operates 60 water treatment plants used throughout Puerto Rico, Vieques and Culebra. These treatment plants serve 55% of the population of the island, and process a daily average of close to 308 MGD. Most urban centers in the 78 municipalities of our island have water service provided by PRASA. In most rural areas of the island they utilize individual, commercial and industrial septic tanks that discharge to the subsoil.

Vision

To ensure that Puerto Rico has a system of water supply and sewerage to promote a healthy quality of life and a strong economy in the present and future generations.

Three Major Challenges to Transformation

I Restore confidence by providing a service of aqueducts consistent with the highest standards of industry, for all the people of Puerto Rico

II Transforming the culture of the PRASA and modernizing the organizational structure

III Facilitate a positive financial performance in the PRASA

Appendix B: Timeline

<table>
<tr><th rowspan="2">TASK</th><th colspan="8">Week</th></tr>
<tr><th>3/16-3/20</th><th>3/23-3/27</th><th>3/30-4/3</th><th>4/6-4/10</th><th>4/13-4/17</th><th>4/20-4/24</th><th>4/27-5/1</th><th>5/4-5/8</th></tr>
<tr><td>Archival and General Research</td><td colspan="2">Archival and General Research</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Expert Consultation</td><td colspan="2">Expert Consultation</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Site Analyses</td><td></td><td colspan="3">Site Analyses</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Surveys</td><td></td><td></td><td></td><td colspan="2">Surveys</td><td></td><td></td><td></td></tr>
<tr><td>Conduct Cost benefit Analysis</td><td></td><td></td><td></td><td></td><td colspan="3">Conduct Cost benefit Analysis</td><td></td></tr>
<tr><td>Finalize Product</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>Finalize Product</td></tr>
<tr><td colspan="9">Projected Timeline</td></tr>
</table>

Appendix C: English Survey

We are a student group from Worcester Polytechnic Institute in the United States. A new water treatment plant has been proposed to the Puerto Rico Aqueduct and Sewer Authority (PRASA) and we will be assessing the feasibility of using various alternative energy sources to power this plant. We are conducting this survey to study the public opinion of PRASA and the various energy alternatives. All information collected will only be used for this project and kept anonymous and confidential.

Below are descriptions of the various energy methods discussed in this survey.

Traditional Energy:

- converts fossil fuels into electricity
- non-renewable and produces large amounts of pollutants
- convenient and reliable

Solar Power:

- converts the sun's energy into electricity
- renewable and very little pollution

Wind Power:

- converts the wind's energy into electricity
- can be noisy, unsightly, and interfere with bird migration
- renewable and very little pollution

Waste-to-Energy:

- converts garbage into electricity through incineration
- releases toxins into the environment
- reduces amount of garbage in landfills

Waste Steam:

- converts left over steam from nearby power plant into electricity
- some non-renewable power may be needed to increase energy of the steam
- uses fewer fossil fuels and produces fewer pollutants than traditional power methods

Geothermal:

- converts thermal energy stored below Earth's surface into electricity
- renewable and very little pollution

Tidal Generators:

- converts tidal changes into electricity
- can be harmful to marine ecosystems
- renewable and very little pollution

Age:

18-23	24-30	31-40	41-50	51-60	61+

Gender:

Male	Female

Occupation:

Does PRASA provide your water services?

Yes	No	Unsure

How concerned are you about the environment?

Not Concerned At All				**Very Concerned**
1	2	3	4	5

What is your opinion of PRASA?

Strongly Disapprove		**Neutral**		**Strongly Approve**
1	2	3	4	5

How would it affect your opinion if PRASA used...

Traditional power?

Strong Negative Effect		**Neutral**		**Strong Positive Effect**
1	2	3	4	5

Solar power?

Strong Negative Effect		**Neutral**		**Strong Positive Effect**
1	2	3	4	5

Wind power?

Strong Negative Effect		**Neutral**		**Strong Positive Effect**
1	2	3	4	5

Waste-to-energy?

Strong Negative Effect		Neutral		Strong Positive Effect
1	2	3	4	5

Waste steam?

Strong Negative Effect		Neutral		Strong Positive Effect
1	2	3	4	5

Geothermal?

Strong Negative Effect		Neutral		Strong Positive Effect
1	2	3	4	5

Tidal generators?

Strong Negative Effect		Neutral		Strong Positive Effect
1	2	3	4	5

Appendix D: Spanish Survey

Somos un grupo de estudiantes de Worcester Polytechnic Institute en los Estado Unidos. Como parte de nuestro currículo académico estamos realizando una internado investigativo en Puerto Rico. Un nuevo proyecto para una planta de tratamiento de agua ha sido propuesto a la Autoridad de Acueductos y Alcantarillados (AAA) y nuestra investigación pretende evaluar la viabilidad de utilizar diversas fuentes de energía renovable o alterna para la planta. Estamos realizando esta encuesta para estudiar la opinión pública acerca de la AAA y energía renovable. Todos los datos recogidos en esta encuesta se utilizarán exclusivamente para este proyecto y se mantendrán anónimos y confidenciales.

A continuación se presentan una descripción de las distintas fuentes de energía evaluadas en este estudio.

Fuentes de Energía Tradicionales (petróleo, carbón, gas natural, etc):

• basados en convertir combustibles fósiles en electricidad
•fuentes no renovables que produce grandes cantidades de contaminantes
• conveniente y confiable

Energía Solar:

• convierte la energía del sol en electricidad
• fuente renovable y produce contaminación mínima

Energía Eólica (Turbinas de Viento):

• convierte la energía del viento en electricidad
• puede ser ruidoso, desagradable a la vista, e interferir con la migración de aves
• fuente renovable que produce mínima contaminación

Energía proveniente de desperdicios ("Waste-to-Energy"):

• convierte la basura en electricidad usualmente mediante incineración
• libera toxinas en el medio ambiente
• reduce la cantidad de basura en los vertederos

Vapor Residual:

• convierte el vapor residual proveniente de la operación de procesos industriales que generen vapor, por ejemplo el vapor generado en el enfriamiento de los equipos en una planta termoeléctrica
• fuentes no renovables de energía puede ser necesarias para aumentar la energía del vapor
• utiliza menos combustibles fósiles y produce menos contaminantes que las fuentes tradicionales de energía

Geotérmica:

• convierte la energía térmica almacenada debajo de la superficie de la Tierra en electricidad
• fuente renovable que produce contaminación mínima

Generadores de Energía de Mareas:

• cambios en la marea son convertidos en electricidad

• puede ser perjudicial para los ecosistemas marinos
• fuente renovable que produce contaminación mínima

ENCUESTA

1) Edad:

18-23 años	24-30	31-40	41-50	51-60	61+

2) Sexo:

Masculino Femenino

3) Ocupación:

4) ¿Es usted cliente de la AAA?

Sí No Inseguro

5) ¿Se considera usted una persona preocupada por el medio ambiente?

No Preocupado		**Neutral**		**Muy Preocupado**
1	2	3	4	5

6) ¿Cuál es su opinión de AAA?

Desapruebo Totalmente su Desempeño		**Opinión Neutral**		**Apruebo Completamente su Desempeño**
1	2	3	4	5

¿Cómo se afectaría su opinión de la AAA, si ésta utilizara alguna de las siguientes fuentes de energía renovable en alguna de sus facilidades?

7) Fuentes Tradicionales (quema de petróleo u otros combustibles fósiles)?

Efecto Negativo		**Neutral**		**Efecto Positivo**
1	2	3	4	5

8) ¿Energía Solar?

Efecto Negativo		**Neutral**		**Efecto Positivo**
1	2	3	4	5

9) ¿Energía Eólica (viento)?

Efecto Negativo		**Neutral**		**Efecto Positivo**
1	2	3	4	5

10) ¿Energía proveniente de desperdicios (incineración de basura)?

Efecto Negativo		**Neutral**		**Efecto Positivo**
1	2	3	4	5

11) ¿Vapor Residual (proveniente de planta termoeléctrica)?

Efecto Negativo		**Neutral**		**Efecto Positivo**
1	2	3	4	5

12) ¿Energía Geotérmica?

Efecto Negativo		**Neutral**		**Efecto Positivo**
1	2	3	4	5

13) ¿Generadores de Energía de Mareas?

Efecto Negativo		**Neutral**		**Efecto Positivo**
1	2	3	4	5