

Site Level Cost Benefit Analysis of Renewable Energy in the Near-shore Environment

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Abstract

This study addresses the task of comparing wind, wave, and solar renewable energy resource production at the site level in the near-shore environment. Through the design and build of a renewable energy monitoring system, the different energy sources currently shaping the renewable energy market were compared through a cost benefit analysis. The monitoring system recorded variation in intensity and consistency of wind speed and direction, multi-angular solar light, and significant wave height at a fine spatial and temporal scale. This system monitored a near-shore low energy site in Edmonds, WA on April 4th, 2015. Based on the power output calculated from the site measurements, wind energy had the highest output followed by wave and solar. Consumer costs of 7.5 cents per kWh for wave energy, 6 cents for wind, and 5.6 cents for solar energy were applied to these data and a cost analysis for each energy source calculated. The highest return per unit value was determined to be the highest for wind with an alternative selection of solar energy. Wave energy had relatively high production values, but was offset by its high cost per kWh. Solar energy had the cheapest consumer cost, but had inconsistent measurements in daily production with low output values not suited for users in the near-shore environment.

Introduction

Renewable energy resources are defined as energy harvested from natural processes that can be replenished at a higher rate than consumed. With the growing population, the energy consumption is also rapidly increasing leading to the continual depletion of the non-renewable resources and enhanced greenhouse gas production through the burning of fossil fuel. The apparent need for a global transition from fossil fuel burning to renewable resources drives the motivation for this investigation of wind, solar, and wave energy to prevent further environmental degradation.

Currently, it is projected that 25% of all energy across the globe used will be from renewable resources by 2018, with the main resources including wind, solar, wave and tidal energy (International Energy Agency, 2014). Nearly 37% of all of the world's population lives with 60 miles of a coastline, leading to increased investigation of renewable resources in near-shore environments (Jarocki 2010). The cost to transport renewable energy is expensive making the coastal and near-shore environments ideal for renewable energy production comparisons in the same area.

The Puget Sound is generally considered to be a low energy coastal environment due to the sheltering from storms and swells by a combination of offshore topography and adjacent topographical features (Otvos, 1982). The protected near-shore environment provides a low investment risk for siting of renewable energy productions. In these low energy environments, it is difficult to predict the most efficient renewable resource in daily production due to the sheltering of wind and the high average cloud cover of the Pacific Northwest.

This study is focused on solutions for the use of renewable energy to meet increased demand by addressing the most economically efficient renewable resource in low energy coastal environments. The aim is to evaluate renewable energy resources in an integrated approach through a synchronized set of site observations where the potential for wind, wave, and solar energy can be converted for a comparison on a price per unit value in a site-specific cost benefit analysis. A wave-monitoring buoy was designed, built, and deployed to measure wave height with a shore-based multi-angular light meter to measure solar energy at solar angles optimized for the study site. A commercially produced nanometer and wind direction vane were also utilized to simultaneously measure wind speed and direction. This unifying analysis of the power output of the measurements of solar, wind and wave energy can help renewable energy companies determine the most efficient way to utilize resources on a site level.

Currently, wave energy is considered to have the highest power density of all available renewable energy resources (Tom et al. 2010). Most Wave Energy Converters (WECS) are in the research and development stages with little progress in production and implementation. When companies are ready to start using their converters, it will be vital to determine the best location to maximize output while maintaining minimal environmental impacts. Wind energy is also widely used on a global scale and is considered to be the most advanced renewable energy resource (Devine-Wright, 2005). Offshore wind energy extraction has grown drastically over the last decade and supplies electricity to cities across the world. Solar energy has also developed immensely and is currently the fastest growing source of electric power in the US with its rapidly decreasing price point

(Maehlum, 2015). While the cost of privately implementing solar panels is decreasing, the consumer cost of utilizing fossil fuels is still lower resulting in its continual usage.

The implemented renewable energy resources vary greatly across the country with different types of environments. The renewable energy harvesting processes can be variable in different environments and can have different costs depending on the design choices. Wind energy (onshore and offshore) is currently generating about 3.5-4% of the United States total electricity and accounts for nearly 40% of the total new electricity capacity being built (Helman 2012). It is projected that 20% of US total energy production will be from wind by 2030 (American Wind Energy Association, 2015). Wind power, while efficient in many areas, has many issues with transmitting power to major cities and also demonstrates overall inconsistencies between daily production and daily needs. These inconsistencies and routing issues result in a higher price per kWh than anticipated. Cardwell (2014) estimates the total cost of onshore wind energy to be about 15 cents per kWh if you include the routing costs, while other estimates without subsidies estimate wind to cost approximately 6 cents per kWh (Helman 2012; Cardwell 2014). Offshore wind typically is more expensive, but has a higher production value of 3 W/m², versus 2 W/m² of onshore wind (American Wind Energy Association, 2013). The different cost per kWh prices are attributed from the cost to route electricity from the turbine to the cities electricity grid, due to most wind being higher outside a city, which is not accounted for in the planning proposals. Solar energy has been implemented widely with costs estimated to be about 5.6 cents per kWh for photovoltaic cells (Cardwell 2014). Wave energy is the newest renewable energy resource therefore it has higher production costs at about 7.5 cents per kWh, but is available at all times for energy collection with often the highest

output (Ocean Energy Council, 2015). Collectively, all of the renewable energy resources are striving to be less costly than fossil fuels with natural gas at about 6.1 cents per kWh and coal at 6.6 cents per kWh (Cardwell 2014; Helman 2012). With current engineering innovations and government subsidies, wind and solar energy prices are now lower than coal and natural gas prices (Cardwell 2014).

The renewable resource industry is constantly working to develop more cost efficient technology to produce no emission energy resources. Current wave energy systems include float or buoy systems that collect energy with the rise and fall of the hydraulic pump, turbine-like water devices that produce energy with kinetic motion, or a channel-like set up that generates electricity using hydropower technology with the rise and fall of the water (Ocean Energy Council, 2014). In addition, wave energy contains approximately 1000 times the kinetic energy compared to wind energy, allows for smaller energy devices, and provides much more consistency than wind and solar energy (Ocean Energy Council, 2014).

Solar energy is generally produced through photovoltaic cells on solar panels that are connected to a battery, which store energy. Some companies are also using solar energy to heat water through solar thermal systems, but can only be utilized during the day and are subjected to seasonal and daily variability (Penn State, 2015). Wind energy is typically collected through wind turbines that produce electricity via the kinetic energy produced from the movement of the turbine. The current typical tower resides at approximately 80 meters, compared to 65 meters of 10 years ago, and have maintained greater energy production, less cost, and are more consistent through developed technology practices (American Wind Energy Association, 2015).

Different WECs have varying installation costs depending on the system. In a cost analysis presented by Global Energy Partners, installation of one Oscillating Wave Converter is estimated to cost about \$3.9 to 7.2 million without federal subsidies compared to Pelamis installation capital cost, which is estimated to be about 3.3 to 5.5 million (Park 2015). Wind energy converters are seen with similar installation costs of about 3 million for commercial scale turbines (Windustry, 2015). Photovoltaic solar panels are typically the lowest installation costs with about \$1700-2500 per Kw installed depending on the capacity and number of solar panels installed (Green 2012).

The three main renewable energy resource productions can greatly vary in a give location based on environmental conditions. In the Pacific Northwest, coastal beaches at northern latitudes typically produce wind and wave energy at a higher rate than solar energy on a year round basis due to the amount of cloud cover and precipitation. The Puget Sound climate is typically known for record-breaking precipitation levels and large scale wind movement, which makes solar energy less effective and predictable in this particular environment (Puget Sound Institute, 2012).

By focusing on low energy coastal environments where future infrastructure for energy conversion is protected and near the intended user, the potential environmental impacts of construction and transmission of energy may be lessened. The intended result of this investigation is to provide a comparison of wind, solar, and wave energy at the siting scale of daily production. The information provided will show the variation of the power output (Watts) in daily production of wind, wave, and solar energy in low energy coastal environments.

Methods

Because the emphasis of this project is on the evaluation of site level potential of renewable energy, the unique characteristics of a research site must be accommodated in the experimental design. A site along the waterfront of Edmonds, Washington USA on April 4th, 2015 was chosen and all design criteria were tune to that of the field test location.

All three renewable resources measured in the near-shore environment are near the intended users with a small construction footprint and can be effectively measured on a short time scale. To compare wind, wave and solar energy, an investigative monitoring system was designed and built to be able to record simultaneous data between the different resource measurements in an easily deployable method. The design constraints were established to analyze the different energy resources over daily production. The specific constraints defined for this project allow for evaluation at a small area rather than using regional averages from stationary weather stations. The system was required to measure solar light, wind direction, wind speed, and wave height. The different resources were evaluated in the most cost efficient, accurate manner with the design constraints.

Solar light can be measured in a variety of methods, but the most efficient and low cost method was determined to be photo-resistors. Adafruit Photo-resistors were analyzed to be low cost, highly sensitive and could be utilized with an Arduino Uno Microcontroller. The data was stored using a MicroSD shield with measurements taken in half-second intervals. The photo-resistors were wired in parallel to the Arduino Uno with 10K ohm resistors to be sensitive to the cloudy, low light environment of the Pacific Northwest. In researching solar light angles, it was determined that for our particular sampling month and location, the approximate solar equinox for the Pacific Northwest (43 degrees North)

occurs at a 40 degree inclination towards the South. The solar equinox was determined to decide which direction the pathway of light would be following. The chosen light angles of 15, 45, and 90 degrees show the typical roof inclination (15 degrees), middle full light (45 degrees), and full light (90 degrees). The mount for the photo-resistors was created with a 3D printer via FreeCAD to ensure that the design could be replicated through precise angles (Appendix A & B). The solar energy values were calibrated every 10 minutes using a hand held light meter that measures the full spectrum in lux. The different solar angles were then analyzed to determine the highest solar output over time then converted lux into watts using the conversion equation (Rapid Tables, 2015; Equation 1). The economic efficiency was calculated using the estimated consumer cost of 5.6 cents per kWh (Maehlum 2015; Konrad 2014).

The wind variation was recorded using a wind direction vane and anemometer commercially built by HOBO mounted onto a stand intended to be placed in a non-sheltered area. Both of the wind monitoring sensors were connected to a commercial HOBO data logger programmed to record measurements every second. The data was exported into HOBOWare and then imported into Excel to begin analysis. The wind direction and speed data was processed in MATLAB computing software to construct a wind rose plot that displays average wind speed values (m/s) and the frequency of the wind in the corresponding direction in percentages. The wind data was calibrated with a Vantage Pro weather station, measuring wind speed and wind direction every 3 minutes to ensure accuracy. The wind direction values were verified with the Port of Edmonds weather station data to remove discrepancy occurring between the sensors. The wind speed was calculated into power using an equation from the Royal Academy of Engineering

(Wind Turbine Power 2015; Equation 2). The calculation will assume maximum efficiency of 59% efficiency based on Betz limit for the purpose of this study. The Watts produced by the velocity of wind recorded were used to calculate the economic efficiency using the consumer cost of 6.0 cents per kWh.

The wave buoy recorded wave motion using a low wind resistance buoy with a 9 degrees of freedom Internal Motion Unit (IMU). The IMU is connected to an Arduino Uno microcontroller with the data stored using a MicroSD shield. The sensor was sealed in a Pelican case surrounded with small buoy floats. The sensor system was then mounted on a PVC platform connected to a PVC pipe with two pounds of lead weight to limit the range of motion. The sensor system was designed to ultimately measure the vertical motion of the wave and its gyroscope rotations. The smaller sensor system was connected on a line of buoys with positive buoyancy to a hard-hat buoy anchored on the seafloor. The data stored in the MicroSD card was then exported into Excel and processed in MATLAB computing software. For the purpose of this study, only the Z-axis data was used to demonstrate the variation in wave height. The wave buoy data was applied with a high pass filter to eliminate the sensor drift of the gyroscope inside of the IMU in the post analysis process. The significant wave height variance was converted into wave energy production in Watts (MacKay 2009; Equation 3). Once the data was converted into Watts, the economic efficiency the power value was multiplied by the estimated consumer cost of 7.5 cents per kWh to provide a comparison to the other renewable resources.

The field deployment compared wind, wave, and solar energy using separate sensor packages designed to measure wind direction, wind speed, solar radiance in multiple angles, and wave amplitude. The first deployment occurred in Portage Bay off of the

Oceanography Dock and the R/V Barnes. The light sensor was originally set with a Real Time Clock (RTC). The RTC was not consistently recording with the multi-angular light meter measurements and was removed to ensure time was recorded. With the removal of the RTC, the data was hand recorded in 3 minute increments to synchronize the data between the sensors on the day of final deployment. On the first deployment of the wave monitoring system, the hard-hat buoy system was too heavy and would not maintain an upright position. The system was altered to have the sensor no longer mounted on the hard hat buoy, but integrated on a separate buoy system connected to the stationary central hardhat buoy to have less restricted motion. The wave-monitoring buoy was also intended to communicate over a wireless XBee connection, but was not taking consistent measurements. To allow for consistent readings, the IMU measurements were alternatively programmed to store data in the MicroSD shield. The revisions were then tested in the bay for a second time to check for system accuracy.

The final system deployment occurred on April 4th at approximately 10 am at the Edmonds, Washington Marina. The specific launch locations took place north of the Edmonds Dog Park on the beachfront with the wave-monitoring buoy anchored approximately 65 meters in front of the wind sensor package. The system components ran from 10 am to approximately 1:50 pm. Once data collection was completed, each of the system sensor data were processed, plotted and analyzed for economic efficiency values in cents per kW/h.

Results

The recorded solar energy was consistent among the different solar angles with the lux values reflected by the angle of the solar ascension. The solar data were recorded in lux

measurements over time from 10:08 AM to 1:37 PM local time in Edmonds, WA at 47°48'20.29"N, 122°23'42.58"W on April 4th 2015 (Fig. 1). The day of collection occurred on a cloudless, sunny day, which allowed for high lux values in direct sunlight. The recorded lux values for 15 and 45 degree solar angles were highest at the beginning of the data collection when they were closest to direct solar ascension and then decreased as the solar elevation shifted over time. As the direct solar ascension shifted during 10 AM to 11 AM, the 45 and 90 degree photo resistor recordings increased slightly then measured consistently for the remainder of the study. Since the data collection began when the direct solar ascension was closest to 15 degrees, the greatest amount of change was seen in the 135 and 165 degree angles as the solar elevation began shifting to the West after 10:30 AM local time.

The wind rose displays that most of the wind occurring was commonly out of the S and SW directions with limited direction and speed (Fig. 2). The wind speed recorded throughout the study was about 5 to 5.5 m/s, with variation between 4-7 m/s. According to the data collected by this study, about 30-60% of the wind direction came from the South with approximately 28% coming from the SSW direction. The wind cost per kWh was determined to be 6.0 cents per kWh, neglecting subsidy implementations. The wind energy collection was the highest output in kWh with an average of 23.15 kWh (Fig. 3). The conversion of wind speed in m/s to miles per hour shows that the average wind speed was approximately 11-12 mph. For the Pacific Northwest, these are classified as moderate wind values.

The waves recorded for this study were classified as moderately high waves in near shore, reflected by the high wind values. The linear position wave data were recorded

specifically to determine the wave height and were seen to be relatively consistent for the duration of the study in Edmonds, WA at 47°48'27.57"N, 122°23'52.51"W (Fig. 4). The wave amplitude consistently measured between -1.5 and 1.5 meters. The wave amplitude average was calculated to be approximately .5 meter with an average wave period of 1.05033 seconds. The significant wave height (Hs) and period (T) calculations were used to determine the power output of the wave in kWh (Equation 3-5; MacKay, 2009).

The three distinct energy resources utilized in this case study were converted to uniform measurement of Watts for the calculation of cents per kWh. The wind energy collection was the highest power output with an average of 23.15 kWh (Fig. 4). Wave energy output had the second highest production with an average of 20.8 kWh (Fig. 4). The highest average kWh energy collection for solar was seen in the 45 and 90 degree angles, reflected by the high lux values, but experienced the lowest power production of the three renewable energy resources. The highest cost of production was wave followed by wind and solar in its respective angles (Fig. 5).

Equation 1

$$W = L * A * SL$$

Power (W), lux measurement (L) (lumen/m²), Area of photocell (A) (m²), Approximate light produced by the sun (SL) ((W/m²)/lumen)

Equation 2

$$W = .5 (DA) (Aw) (Vw)^3 (0.59)$$

Power (W), Density of air (DA), Area of air hitting hypothetical wind turbine (Aw), velocity of wind (Vw)

Equation 3

$$kW/m = 0.57 (wh)^2 (wp)$$

Power (kW/m), Significant wave height (wh), Wave period (wp)

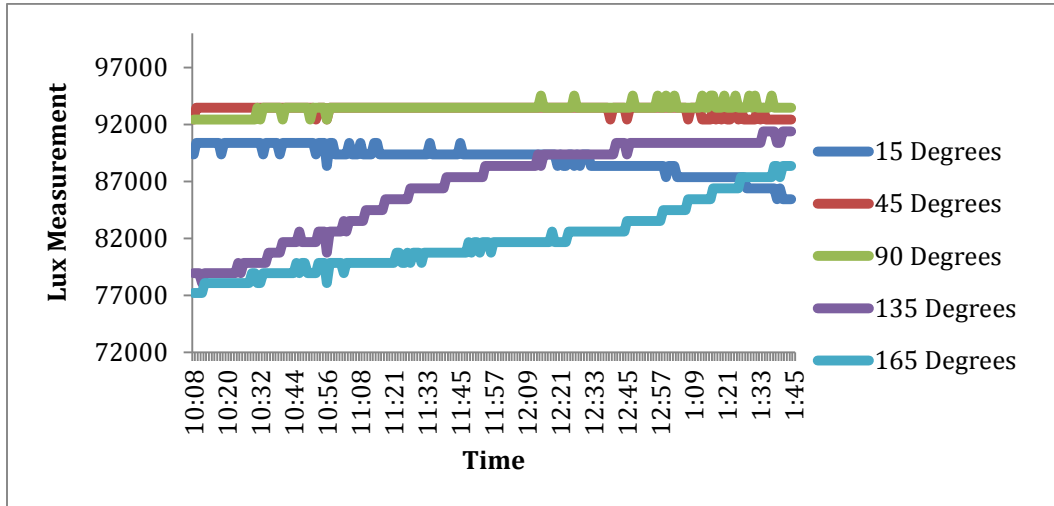


Figure 1: Lux measurement over time with the corresponding solar angles in degrees shown in color coordination taken on April 4, 2015 in Edmonds, WA (see key).

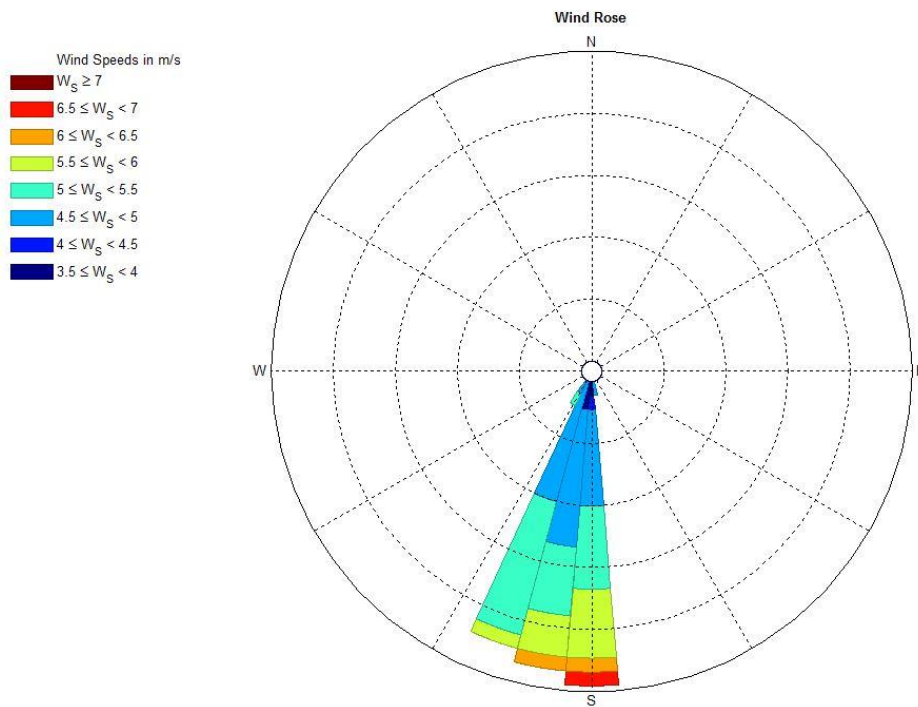


Figure 2: The wind measurement with the wind direction indicated by the bars and the corresponding wind speed in color coordination based on the data collected on April 4, 2015 in Edmonds, WA (see key). The circles from the center represent relative frequency of the wind speed/direction over time starting from 0% and moving out in 6% increments.

Warm colors represent high wind speeds (5.5 to >7 m/s), while cooler colors represent low wind speeds (3.5 to 5 m/s).

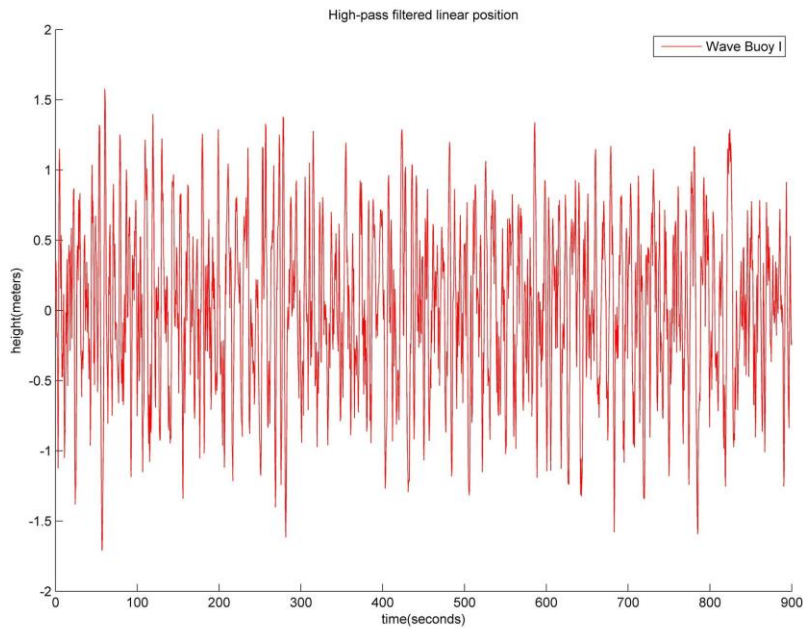


Figure 3: The linear position over time of the stationary buoy data collected on April 4, 2015 in Edmonds, WA. The position was processed in MATLAB with a high pass filter to compensate for natural sensor drift occurring in the gyroscope. When the reading is at 0, the buoy is at rest.

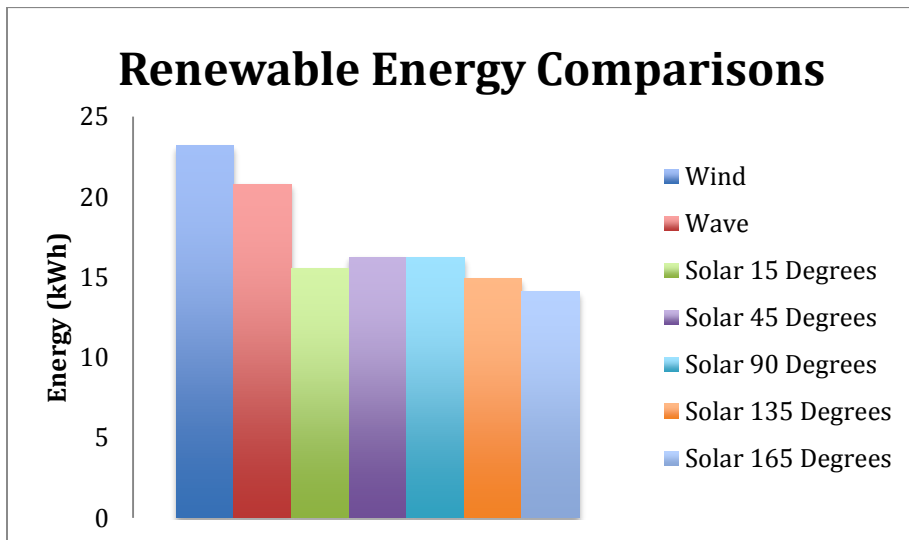


Figure 4: The average energy produced in kWh for wind, wave and solar energy in 15, 45, 90, 135 and 165 degrees calculated from the data collected on April 4, 2015 in Edmonds, WA.

<https://www.facebook.com/photo.php?fbid=10152984456936130&set=a.10150386448621130.347468.616021129&type=1>

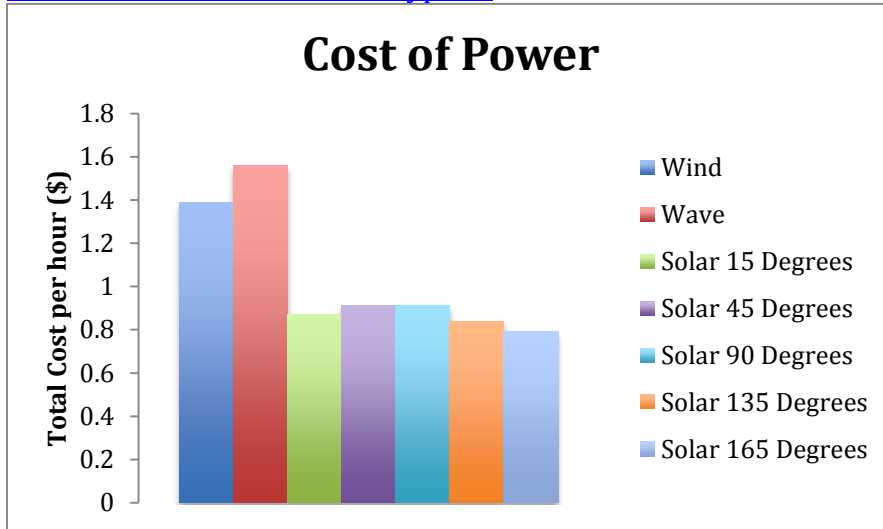


Figure 5: The total consumer cost per hour of each renewable energy resource utilizing the average kWh generated in Figure 4. The cost for each renewable resource was determined to be 6 cents per kWh for wind energy, 7.5 cents per kWh for wave energy, and 5.6 cents per kWh for solar energy.

Table 1: The cost in cents per kWh for wind, wave, solar, natural gas and coal. The coal and natural gas prices were included for comparison purposes between renewable and non-renewable resources.

Type of Energy	Consumer Price (dollars per kWh)
Solar	0.056
Wind	0.06
Wave	0.075
Coal	0.066
Natural Gas	0.061

Discussion

In comparing the renewable energy productions, the data collected in this low energy coastal environment revealed that wind energy had the highest production output and the second lowest consumer price per kWh. The wind data collected showed moderately high wind speed values with fairly consistent wind direction. The typical wind speed values for April in Washington average to be about 4.3 m/s, which is significantly lower than the average value calculated for the case study taken in Edmonds, WA (Osborn,

2015). Comparing the return per unit value, wind energy exhibited the greatest cost per unit return of the three resources. With the comparison of natural gas, a commonly used alternative to coal, wind energy costs nearly the same to produce over a kWh, but produces no fossil fuel emissions.

Wave energy experienced the second highest power output, but is also the most expensive to produce. Wave energy in most coastal environments experiences the greatest output, but is offset by its high consumer costs. Due to the fact that surface waves are affected by wind speed and fetch, the moderate wind values should have produced higher wave energy values than were calculated. The lower than anticipated values could have been a result of inaccurate sensor readings or the protected area of the low energy beachfront. Wave energy is approximately 0.9 cents higher to produce than coal and is rated as the most expensive renewable energy resource due to its development process.

Solar energy produced the lowest amount of renewable energy power production, but is also the cheapest per kWh. The solar ascension data analysis reveals that the highest output occurs when the solar elevation is directly above the photo-resistor. Despite that the data collection occurred in optimum conditions on a cloudless, sunny day, solar energy still produced lower output values than the other tested renewable resources. Solar data can only be collected for approximately 10-12 hours per day depending on the time of year, but its cheap implementation and high cost per unit value return allow for a high ranking value among other developing resources. Although it is the cheapest energy resource for consumers, the inconsistencies for energy harvesting over daily production and low energy output determine solar energy as not the top choice in energy selection in the near-shore environment.

In reviewing the cost analysis of the three renewable energy resources, wave energy had the highest cost at \$1.56 per hour for a production of 20.8 kW (Fig. 5). Secondly, wind energy experienced the highest overall production with a lower consumer cost of \$1.39 per hour for 23.215 kW of production (Fig. 4; Fig. 5). Solar energy cost the least between \$0.79-\$0.91 with the lowest output, varying from 14.08 kW to 16.24 kW (Fig. 5). The highest cost per kWh was determined to be wave energy at 7.5 cents per kWh, which is slightly higher than coal at 6.6 cents per kWh (Tbl. 1). Alternatively, wind and natural gas are priced at similar costs with 6.0 and 6.1 cents per kWh, respectively (Fig. 6) Solar energy is the cheapest to implement at 5.6 cents per kWh, but also experienced the lowest production values in this particular study (Tbl. 1; Fig. 4).

The cost benefit analysis of the case study site showed that wind energy would have the highest cost per unit return. Because wind energy had the highest output and the second lowest cost per kWh, it would be in the best interest of the consumer to implement a wind turbine generator at this site. The alternative suggestion would be solar energy because of the moderate return value in combination with high cost per unit value. The lowest ranked renewable energy based on this data would be wave energy. The wave energy, while having a relatively high power output, is also the most expensive to implement leading to a low ranking cost per unit return. As a result of this investigation, it does not seem feasible to produce wave energy unless the cost per kWh decreases through further design development.

Conclusion

The site based cost-benefit analysis of wind, wave, and solar energy provides a selection of highest cost per unit value return based on their cost per kWh and power

production variation. On April 4th, 2015 the evaluation displayed that the highest benefits occurred with wind energy. Secondly, solar energy had significantly lower consumer costs with only slightly lower power output values. Even though solar energy was the cheapest renewable energy source for consumers, the output is not as consistent, nor productive, for users in the near-shore environment. As an alternative to wind energy, the second best selection would be solar energy. Wave energy was the least efficient with high cost per kWh and moderate output values. With these variables, wave energy had the lowest return per unit value. Due to the daily variation of production of renewable resources in near-shore environments, these results may change with alternate conditions on a site basis. To provide a more accurate evaluation of renewable energy resource production, consecutive data should be taken in different near-shore environments at varying times of year.

Works Cited

Cardwell, Diane (2014). "Solar and Wind Energy Start to Win on Price vs. Conventional Fuels." *The New York Times*. The New York Times, 23 Nov. 2014. Web. 11 Apr. 2015.

Devine-Wright, P. (2005). Beyond NIMBYism: towards an integrated framework for understanding public perceptions of wind energy. *Wind Energy*, 8(2), 125–139.

Helman, Christopher (2012) "Why It's The End Of The Line For Wind Power." *Forbes*. Forbes Magazine, 21 Dec. 2012. Web. 11 Apr. 2015.

Green, Dino (2012) "How Much Do Solar Panels Cost? – 2013 Updated Prices." *Renewable Green Energy Power*. Renewable Green Energy Power, 25 Aug. 2012. Web. 09 May 2015.

Jarocki, Dimitri (2010) Wave Energy Converter Performance Modeling and Cost of Electricity Assessment, *California Polytechnic State University*.

Konrad, Tom (2012). "Renewable Energy Stocks By Dollar Per Watt." *Renewable Energy World*, 12 May 2012. Web. 12 Apr. 2015.

MacKay, David. (2009) "Sustainable Energy Without the Hot Air" *Popular Science*. 73-75

Maehlum, Mathias (2015) "How Much Do Solar Panels Cost - Energy Informative." Energy Informative, 23 Mar. 2015. Web. 09 May 2015.

Osborn, Liz. "Seattle Weather in April." *Seattle WA Weather in April*. Current Results, n.d. Web. 10 May 2015.

Otvos, Ervin (1982) Low Energy Coast. *Beaches and Coastal Geology Encyclopedia of Earth Science*. 522

Park, Dong-hyeon (2015) The Cost Advantage of Implementing Wave Power in Hawaii. *Harvey Mudd College*. 1-11.

Tom, N., R. Yeung, A. Peiffer, and T. Matlak. (2010). Design, Analysis, and Evaluation of the UCB Wave Energy Extractor. *Proceedings of the ASME 2010 29th International Conference of Ocean, Offshore and Arctic Engineering* 1-11.

"Community Wind." *Issues*. American Wind Energy Association, 2015. Web. 11 Apr. 2015.

"Puget Sound's Climate." *Encyclopedia of Puget Sound*. Puget Sound Institute, 16 Feb. 2012. Web. 11 Apr. 2015.

"Renewables." *IEA*. International Energy Agency, n.d. Web. 04 Dec. 2014

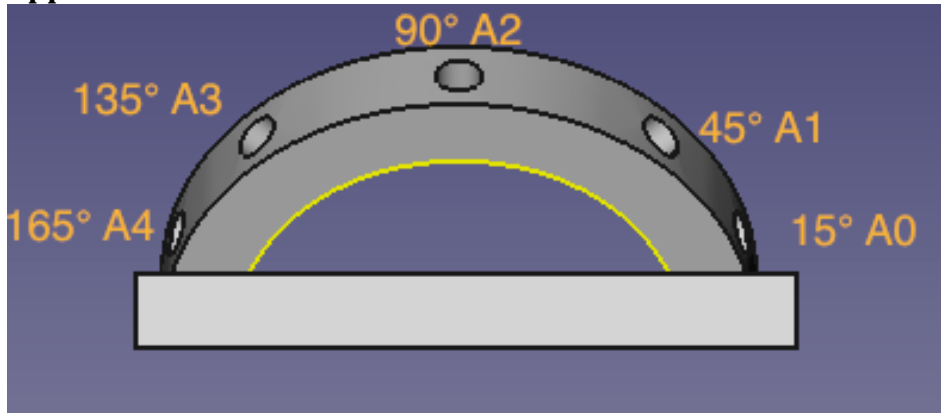
"Solar Energy - Renewable and Alternative Energy." *Renewable and Alternative Energy (Penn State Extension)*. Penn State College of Agricultural Science, n.d. Web. 11 Apr. 2015.

"Wave Energy - Ocean Energy Council." *Wave Energy*. Ocean Energy Council, n.d. Web. 11 Apr. 2015.

"Wind Turbine Power Calculations" The Royal Academy of Engineering, n.d. Web. 11 Apr. 2015.

"How Much Do Wind Turbines Cost" *FAQ*. Windustry. n.d. Web 4 Apr. 2015.

Appendix A



Free CAD diagram of the multi-angular light meter utilizing Adafruit photo-resistors in the five angles shown denoted from A0-A5.

Appendix B

```
#include <OneWire.h>
#include <SD.h>

//define a pin for Photo resistor
int p0 = 1;
int p1 = 2;
int p2 = 3;
int p3 = 4;
int p4 = 5;

int logRange = 5.0;
int rawRange = 1024;
const int chipSelect = 8;

void setup()
{
  Serial.begin(9600); //Begin serial
  communication
  Serial.print("Initializing SD card...");
  // make sure that the default chip select pin
  is set to
  // output, even if you don't use it:
  pinMode(chipSelect, OUTPUT);

  // see if the card is present and can be
  initialized:
  if (!SD.begin(chipSelect)) {
    Serial.println("Card failed, or not present");
    // don't do anything more:
    return;
  }
  Serial.println("card initialized.");
}

// Reading values
void loop()
{
  File dataFile = SD.open("dataLog.txt",
  FILE_WRITE);
  if (dataFile)
  {
    dataFile.print(lumin(analogRead(p0)));
    Serial.print(lumin(analogRead(p0)));

    dataFile.print(", ");
    Serial.print(", ");

    dataFile.print(lumin(analogRead(p1)));
    Serial.print(lumin(analogRead(p1)));

    dataFile.print(", ");
    Serial.print(", ");

    dataFile.print(lumin(analogRead(p2)));
    Serial.print(lumin(analogRead(p2)));

    dataFile.print(", ");
    Serial.print(", ");

    dataFile.print(lumin(analogRead(p3)));
    Serial.print(lumin(analogRead(p3)));

    dataFile.print(", ");
    Serial.print(", ");

    dataFile.print(lumin(analogRead(p4)));
    Serial.print(lumin(analogRead(p4)));

    dataFile.println();
    Serial.println();

    delay(500);
    dataFile.close();
  }
  else {
    Serial.println("error opening
    dataLog.txt");
    delay(10000);
  }

  // Converts raw data to lux (light sensor)
  float lumin (int raw)
  {
    float logLux = (float) raw *
    logRange/rawRange;
    return pow(10,logLux);
  }
}
```

Arduino Microcontroller code with annotations for converting light recordings from lux to lumen from the Adafruit photo-resistors