RENEWABLE ENERGY ALTERNATIVE FOR WASTEWATER TREATMENT PLANTS IN TRINIDAD - A CASE STUDY

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ABSTRACT

The feasibility of using solar photovoltaic (PV) as an alternative to power a waste water treatment plant (WWTP) in Trinidad was investigated. The site data and power consumption of the Orangefield WWTP was used to size a PV system with and without grid tied and tracking and non-tracking options. Present day costing was determined and a simple payback period for Trinidad and Tobago was calculated. The analysis indicated a minimum and maximum payback period of 27 years and 97.4 years, respectively. Therefore, in Trinidad and Tobago, even the most cost effective PV system was not financially feasible. A comparative payback period for neighbouring countries of Barbados and St. Vincent, with three times higher power cost than Trinidad and Tobago, indicated that solar power is more attractive and feasible with a minimum and maximum payback period of 9.1 and 8.6 years and 32.8 and 31.2 years, respectively.

KEYWORDS

Renewable Energy, Solar Power, Photovoltaic, Waste Water Treatment.

1. INTRODUCTION

The island of Trinidad is located 10° 40'N latitude and 61° 30' W longitude and lies very close to the equator. This location affords great potential for harvesting solar energy throughout the year as there is minimal reduction in solar intensity at any given area due to seasonal changes (Figure 1). In this study the advantages and disadvantages of using solar photovoltaic was explored as it pertains specifically to domestic wastewater treatment in Trinidad. Generally, the major advantages of using renewable energy are reduced annual energy costs, reduced environmental impacts since renewable energy technologies usually produce little to no pollutants during their operation and increased sustainability as a result of fewer pollutants [1]. Major disadvantages include site restrictions, high initial capital investment and limitations on power generation potential [2].

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Figure 1: Map showing global location of Trinidad and Tobago

2. OVERVIEW

The wastewater treatment plant (WWTP) at Orangefield, Trinidad, currently treats 309 m^3 of domestic sewage from 11,000 persons daily using a Completely Mixed Activated Sludge (CMAS) process. Domestic waste form households and schools within the vicinity flow by gravity to the intake or wet well located next to the treatment plant. Figures 2 show a plan of the treatment plant [3].

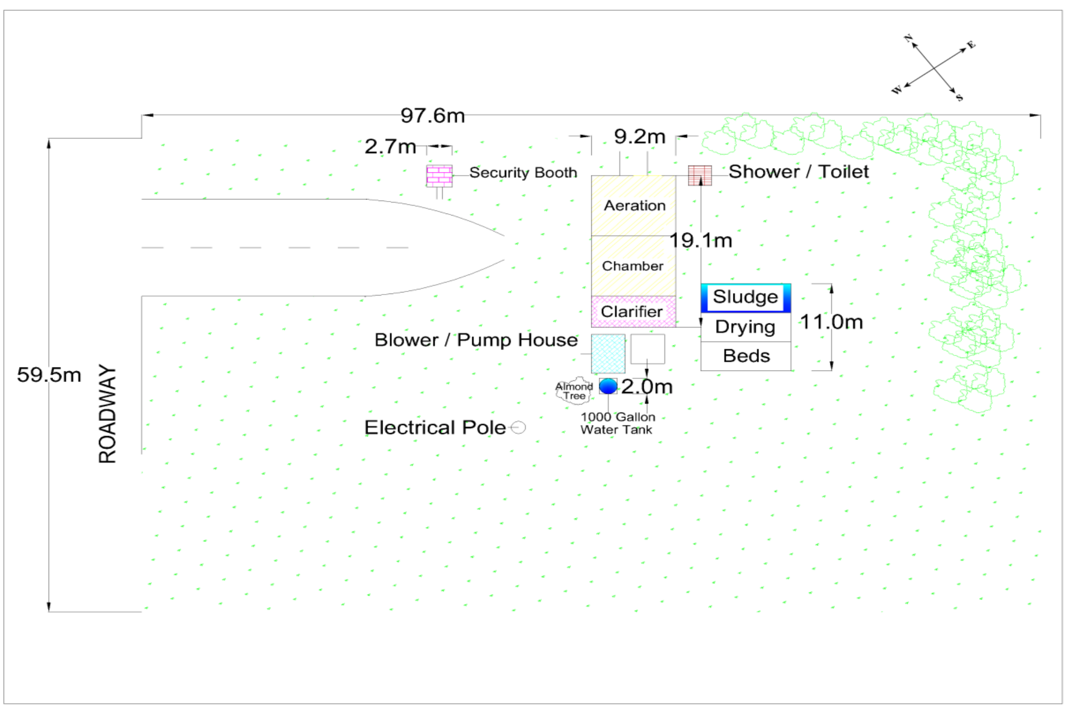

Figure 2: Plan of the Orangefield wastewater treatment plant showing the location of all integral structures

In the wet well, 2 horizontal centrifugal pumps, each powered by 1 US Electric 7.5 horsepower motor, automatically alternate when triggered by an automatic float level system to transfer wastewater to the aeration chamber. The pumps are controlled by a waterproof electrical switch installed in the water intake well which floats on top of the wastewater. When the water reaches a pre-determined height, raising the float with it, the level system automatically switches on one of the pumps which transfers the wastewater to the aeration chamber in the WWTP approximately 30m away. In the aeration chamber, oxygen is introduced into the raw sewage by means of 2 Roots Model U-RAI 56 Rotary Lobe Blowers (Figure 3), each individually powered by 1 Westinghouse 20 horsepower motor [3].

Both blowers, housed in the blower/pump house approximately 20m away from the aeration chamber, have their outlets connected to steel piping with the other end of the pipes connected to coarse bubble diffusers and submerged in the aeration chamber (Figure 4).The blowers also provide the necessary vacuum suction to transport the undigested organic settled solids (the Return Activated Sludge) from the clarifier chamber to the aeration chamber [3].

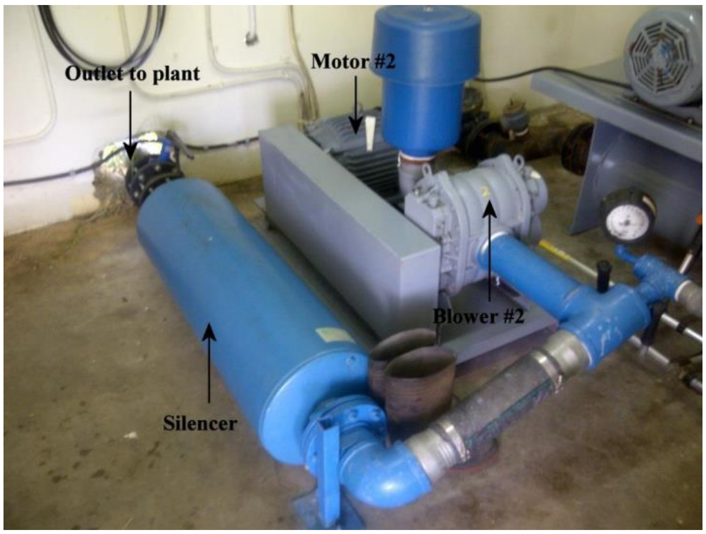

Figure 3: Inside of the blower house, showing blower #2 and the air outlet pipe leading to the treatment plant

Figure 4: Aeration chamber of the Orangefield WWTP

After 24 hours, the aerated wastewater flows by hydraulic displacement from the aeration chamber (Figure 4) to the hopper-shaped clarifier, where a minimum of 8 hours of clarification allows settleable solids to be collected at the bottom and floating solids skimmed at the top, either manually by the operator or by passively floating into troughs at the edge of the clarifier. Clarified effluent flows by gravity through a trough and down to a tablet chlorine feeder and into the chlorine contact tank where the final effluent is designed to be held for at least 45 minutes. After sufficient contact time, the disinfected effluent flows by gravity into an underground discharge pipe which eventually discharges to a surface drain at the front of the WWTP. The final aspect of treatment at the plant is the drying of waste sludge. The sludge is transported pneumatically to sludge drying beds using air lines connected to the 2 blowers in the blower house [3].

The entire system at the Orangefield WWTP is powered by electrical power from the grid and is a high consumer of much need electricity with an average bimonthly consumption of 10,500 kWh.

2.1. Site Data

Using the average readings of energy consumption from the bimonthly Trinidad and Tobago Electricity Commission (T&TEC) bill over a one year period proved to be the most accurate way to determine the overall energy consumption of the WWTP. This data was essential for predicting the energy requirements for an alternative power system before doing an upgrade.

Average daily temperature was recorded using an *Ambient Weather WS-2080* Weather Station. The thermometer of the *WS-2080* was compared to a calibrated thermometer to ensure accurate readings were obtained. Data was recorded at 1 hour intervals by a data-logger stored on site and retrieved weekly [4]. Average daily and monthly temperatures were then calculated. A pyranometer on a flat surface and voltmeter were used to record irradiance readings at 5–minute intervals over a 24-hour period for one month was (Figure 5). This was then compared to values based on readings from the USA National Aeronautics and Space Administration (NASA) satellites for central Trinidad over the same time period (the month of May). The monthly insolation values were within 3% of the average NASA readings collected from 1983 – 2005 for central Trinidad (Table 1) [5].

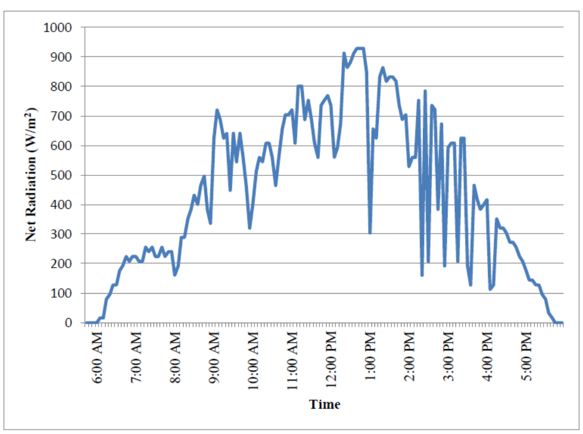

Figure 5: Graph Showing Site Irradiance Values at the Orangefield WWTP

Table 1: Summary of Monthly Insolation Values

Month	Insolation ($kWh/m^2/day$)	
	NASA	Adjusted
January	6.3	5.73
February	6.38	5.81
March	6.27	5.71
April	5.88	5.35
May	5.89	5.36
June	5.51	5.01
July	5.73	5.21
August	5.73	5.21
September	5.68	5.17
October	5.73	5.21
November	5.49	5
December	5.89	5.36

2.2. Shade Analysis

The cost-effectiveness of a PV system depends crucially on positioning its solar array to capture as much sunlight as possible [6]. Shading of a single cell connected in series in a module can cause multiple problems including dissipation of power, cracking, overheating, melting of solder or damage to the encapsulating material [6]. This problem is termed hotspot formation. The same occurs on a larger scale, that is, a single shaded module in an array can cause significant power dissipation from the entire array due to hotspot formation. It is therefore important to reduce the formation of shadows on PV modules, especially shadows caused by permanent objects such as nearby trees and buildings. As such, shade analyses were conducted at potential solar panel locations on the compound. In addition, the available area and average temperature at the site were recorded [7].

Site locations were chosen based on available area and potential for shade development by surrounding obstructions. Theodolite surveying software package which allowed measurement of azimuth, horizon angle, elevation angle and photographic capturing of the horizon were employed [7].

The site survey showed that $4606m^2$ of land space was available within the compound of the Orangefield WWTP. However, not all of the available land was suitable for placing solar modules due to shading. Figure 6 shows the sun path and potential shading obstacles present at Location A for the Orangefield WWTP. From the site survey carried out, location A, shown in Figure 7, was the most suitable location for placement of the solar PV panels. This was due to the low potential for shading by surrounding objects. The shade analysis conducted revealed a potential loss of 0.35% of insolation due to shading at this location.

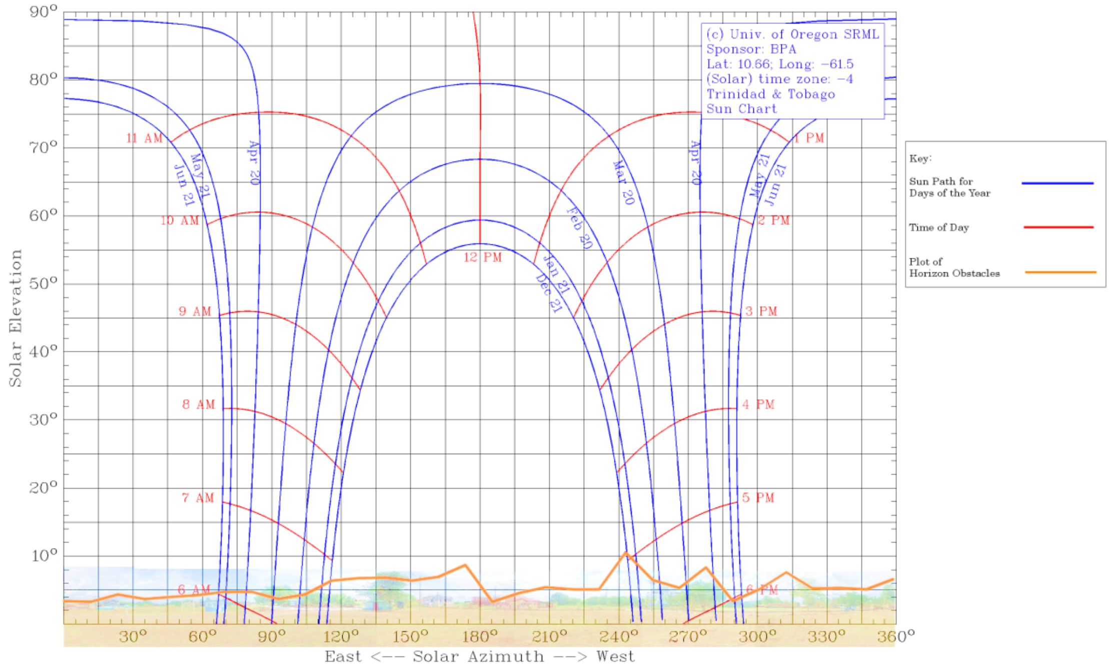

Figure 6: Sun Path and Potential Obstacles at Orangefield WWTP [7]

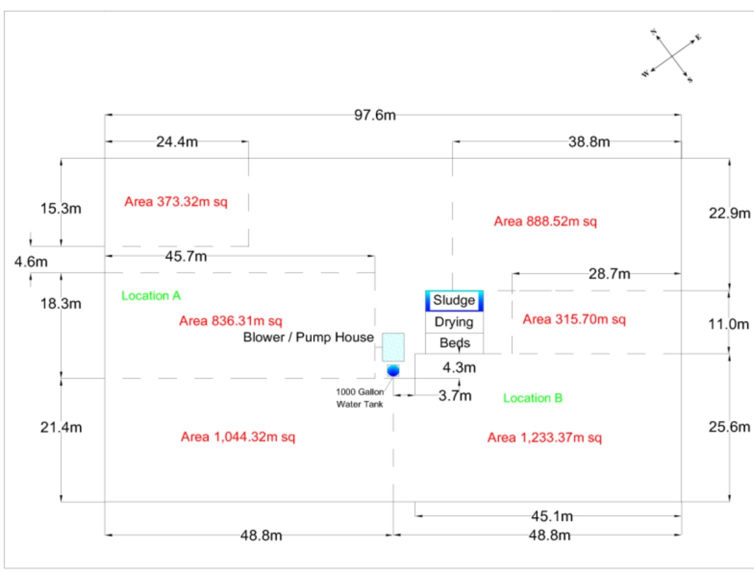

Figure 7: Plan of Orangefield WWTP Showing Dimensions and Proposed Installation Location of the Solar PV System

Ambient outdoor temperature at the site had a monthly average of 27.8 °C, with minimum and maximum monthly averages of 26.2 °C and 29.2 °C, respectively. The minimum and maximum daily temperatures recorded were 22.0 °C and 36.1 °C, respectively. Therefore, the design of the system was based on the maximum ambient temperature of 36.1°C. The ambient temperature was important to predict solar panel efficiency and operation calculations [8, 9].

3. PV SIZE DETERMINATION

Initial calculation of PV size was done using the daily energy requirement and an insolation value of 5.49 kWh/m^2/day, which was the lowest monthly insolation observed in November [10].

PV Power Capacity	= 167 kWh/5 hours
	= 33.52 kW
Adjusted PV Power	= 33.52 kW + (-0.05 x 33.52 kW)
	= 35.19 kW
Estimated Solar panel temperature	= 36.1°C x 1.2
	= 43.3°C
Power loss due to temperature	= (43.3°C – 25°C) x 0.005 x 35.19 kW
	= 3.22 kW
Power loss from DC to AC conversion	= 31.94 kW x (1 – 0.9)
	= 3.52 kW
Mismatch loss	= 35.19 kW x (1 – 0.95)
	= 1.76 kW
Dust and impurity losses	= 35.19 kW x (1 – 0.93)
	= 2.46 kW
PV System Size	= 35.19 kW + 3.22 kW + 3.52 kW + 1.76 kW + 2.46 kW
	= 46.16 kW
Increased efficiency from single axis tracking system [11]	= 13%
Required system size using tracking system	= 46.16/1.13
	= 40.85 kW

3.1. Solar Modules (panels)

The power rating of the solar panels were used in the selection criteria to determine the number required to build a 41 kW tracking system and a 46.2 kW non tracking system. Based on an increases charging efficiency by approximately 13% on a single axis tracker system [11], the lower value kWh arrangement would still meet the required daily energy production. The design life of the system was 25 years. The specifications of the selected solar panel were [12]:

3.1.1. Modules [13,14]

STC Rated Power (Factory Standard Test Conditions)(W)	300
PTC Rated Power (Photo Voltaic USA Test Conditions) (W)	280
Gross Surface Area (m^2)	1.64
Cell Type	Monocrystalline
Rated Efficiency (%)	17.1
Unit Cost (TT$)	2,058
No. of modules required (tracking)	147
No. of modules required (non tracking)	165
Total cost of modules (tracking)(TT$)	302,526
Total cost of modules (non tracking)(TT$)	339,570

3.1.2. Inverter [13,14]

Continuous Output Power (kW)	50
Continuous Output Current @ 240 VAC (A)	120
Maximum Efficiency @ 240 VAC (%)	96.7
Unit Cost (TT$)	146,737
No. of systems required	1
Total cost of inverter (TT$)	146,737

3.1.3. Installation [14]

Labour and equipment (TT$)	10,000
Foundation (20m^3 of 25 N/mm^2 concrete) (TT$)	21,800
Electrical wires and connections (TT$)	25,000

3.1.4. Battery Bank

Battery Type (design life of five years)	Wet/Flooded
Voltage (V)	12
C/20 Capacity (Ah)	420
Energy capacity (kWh)	2.52
Maximum Depth of Discharge for Bank (%)	30
Required storage capacity of bank (kWh)	283.9
No. of batteries required	113
Unit Cost (TT$)	2,122
Total cost of Battery Bank (TT$)	239,786

3.1.5. Mounting and tracking system [11]

Tracking system	Single-axis (azimuth)
No. of panels mounted per system	83
Unit Cost (TT$)	91,931
No. of systems required	2
Total cost of systems (TT$)	183,862

4. ANALYSIS

A simple payback-time analysis was conducted with an estimated life period of 25 years for the photovoltaic system. The cost-benefit assessment was compared to existing commercial rate of grid supplied power for Trinidad and Tobago, Barbados, St. Vincent, United States of America and Canada [15].

4.1. Capital cost

Photovoltaic modules – non tracking	TT$ 339570
Photovoltaic modules – tracking	TT$ 302526
Inverter	TT$ 146733
Installation	TT$ 25000
Battery – 5 sets @ 239786 per set	TT$ 1198930

4.2. Operation and maintenance [14]

The annual operation and maintenance cost was estimated as 0.2% of the photovoltaic modules cost and increased at a rate of 10% each year for 25 years with an annual discount rate of 8%.

Present value for operation and maintenance for 25 years $= \frac{679.14}{0.02}\left[1-\left(\frac{1.1}{1.08}\right)^{25}\right]$ = TT$ 19765

4.3. Grid power cost

Presently in Trinidad and Tobago the Trinidad and Tobago Electricity Commission (T&TEC) is the government organization responsible for the installation and maintenance of infrastructure to distribute electricity as well as customer service regarding all aspects of electricity use in Trinidad and Tobago. The current commercial rate of grid supplied electricity in Trinidad and Tobago is TT$ 0.415 or US$0.064 per kWh. This is a highly subsidise price and is one of the lowest rate in Latin America [16].

The average bi-monthly electricity bill paid to the electric company was TT$5,519. This value was calculated based on the average for an 18 month period from November 2010 to May 2012. This rate translates into a yearly cost of TT$ 33114. An annual rate of increase in commercial electricity rate was estimated at 4.5%/year based on a recommended increase by the Trinidad and Tobago Regulated Industries Commission in 2011 [16]. Therefore, the present value of grid supplied power for the next 25 years would be:

Grid power cost $= \frac{33114}{0.045}\left[1-\left(\frac{1}{1.045}\right)^{25}\right]$ = TT$ 491021

4.4. Comparative Payback Period

Based on the simple costing analysis a comparative payback period for different countries in the region was determined. The analysis was based on the total cost of a PV system with and without battery banks (grid tied) and with and without tracking. The comparative payback period for different countries was based on the current commercial rate for grid power for the respective countries and the results shown on Table 2 [17].

5. Discussion And Conclusions

Trinidad and Tobago has an oil and gas based economy and is a net exporter of the products. The power generation plants in the country are all natural gas based and the cost of power to the consumer is highly subsidised. As such Trinidad and Tobago has one of the lowest rates for electrical power in the region as can be seen from Table 2. In recent times the Trinidad and Tobago government has been encouraging investment in renewable energy and renewable energy projects. This has become necessary with the global trend to reduce carbon emissions and the grim projections of the depletion of oil and gas reserves in the not-so-distant future [20].

From the analysis, the lowest cost for powering the Orangefield WWTP by solar was US$ 83000 (TT$531072) with a non-tracking grid tied PV system. The most expensive option was US$ 299041 (TT$1913864) with an independent off grid battery bank tracking PV system. Due to the low subsidised electrical power in the country, simple payback analyses indicated a minimum and maximum payback period of 27 years and 97.4 years, respectively. The design life of most PV systems is rated as 25 years. Therefore, in Trinidad and Tobago, even the most cost effective PV system was not financially feasible [21]. However, the negative environmental concerns and global warming phenomenon has driven oil and gas rich countries to push for reducing the carbon emissions and invest in renewable energy research and technology [21, 22].

Table 2. Payback Period Comparative Analysis [8, 18, 19]

		Payback period (years)				
	Cost of PV system US$	Trinidad and Tobago Grid Power @ US$0.064 per kWh	Barbados Grid Power @ US$0.19 per kWh	St. Vincent Grid Power @ US$0.20 per kWh	Canada (average) Grid Power @ US$0.10 per kWh	United States (average) Grid Power @ US$0.12 per kWh
Grid tied PV system; non tracking. (Modules, Inverter, Installation, Maintenance)	83000	27.0 years	9.1 years	8.6 years	17.3 years	14.4 years
Grid tied PV system; tracking. (Modules, Inverter, Installation, Maintenance)	111708	36.4 years	12.2 years	11.6 years	23.3 years	19.4 years
PV system; non tracking with battery bank (5 sets for 25 year period)	270313	88.1 years	29.7 years	28.2 years	56.4 years`	47.0 years
PV system; tracking with battery bank (5 sets for 25 year period)	299041	97.4 years	32.8 years	31.2 years	62.3 years	52.0 years

A comparative payback period was analysis was done for nearby countries in the Caribbean and North America where the government power subsidy is significantly less. The consumer cost reflected on Table 2 is much closer to the actual cost of power production. For the close neighbouring countries of Barbados and St. Vincent, the prospect of solar power is more attractive and feasible due to the three times higher power cost. As indicated on Table 2 for these two countries, the least costly and most expensive PV system has a minimum and maximum payback period of 9.1 and 8.6 years and 32.8 and 31.2 years, respectively. The analysis indicated that present investment in solar power technology is a viable and feasible option when compared to the real cost of fusel fuel generated electricity.

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