Journal of Smart Science and Technology
2023 September Volume 3 Issue 2
PENERBIT PRESS
UNIVERSITI TEKNOLOGI MARA
eISSN: 2785-924X

Renewable Energy System Design and Evaluation: A Case Study

Vanessa Vincent[1], Donnie Boodlal[2], David Alexander[1], Parissram Jaggernath[3], Rean Maharaj[2,*]

[1]*Energy Systems Engineering Unit, University of Trinidad & Tobago, Esperanza Road, Point Lisas 540517, Trinidad &Tobago*
[2]*Process Engineering Unit, University of Trinidad & Tobago, Esperanza Road, Point Lisas 540517, Trinidad & Tobago*
[3]*Airworthiness and Aeronautical Engineering Systems and Management, Camden 550610, Trinidad & Tobago*

Received: 24-02-2023
Revised: 09-06-2023
Accepted: 23-06-2023
Published: 30-09-2023

*Correspondence
Email: rean.maharaj@utt.edu.tt
(Rean Maharaj)

DOI: https://doi.org/10.24191/jsst.v3i2.47

Abstract
Due to the Paris Agreement and efforts of the United Nations Framework Convention on Climate Change towards stabilising global Greenhouse Gas Concentrations, countries are becoming receptive to the need for an energy transition. From a holistic sustainability viewpoint, this includes a renewable energy mix in power generation sectors. For early adopters like Trinidad and Tobago (T&T), it is important that analysis be conducted to investigate how renewable energy (RE) can be optimally integrated into the current energy mix. This paper considers the University of Trinidad and Tobago's Camden Campus, located in Couva as the study site. Though the study is specific to this site, the methodology, analysis, and conclusions are transferable to other similar sites. This study uses the Homer Pro Software to design, simulate, and optimize a hybrid PV-Wind energy system (using the least cost objective function). Given the electricity rates of the country, the "as is" case was the most cost-effective, excluding renewable energy penetration and greenhouse gas emissions reduction. The base case with a subsidised electricity cost of US$ 0.05 per kWh, was found to use approximately 884,854 kWh at an annual cost of US$ 44,243 and associated CO_2 emissions of 559,226 kg. At this present subsidized cost of electricity, the RE systems were seen to be uneconomical, with the subsidised grid price being more competitive. At an estimated unsubsidized price of US$ 0.12 per kWh applicable to T&T, the optimally designed RE system at the campus would still be uneconomical and the cost at which such a system makes economic sense was US$ 0.15 per kWh (with a 10% RE penetration). Using a regional average unsubsidized cost of US$ 0.22 per kWh, the RE system became more economical, with a larger RE penetration of 36.2% and corresponding CO_2 savings of 222,328 kg per year.

Keywords
Renewable energy; Hybrid system; Cost of electricity; Subsidy; Energy audit

Citation: Vincent, V., Boodlal, D., Alexander, D., Jaggernath, P., & Maharaj, R. (2023). Renewable energy system design and evaluation: A case study. *Journal of Smart Science and Technology*, *3*(2), 83-101.

1 Introduction

With the global population projected to rise[1], energy demand and consumption increase may occur[2]. This, together with the collective global initiative to reduce greenhouse gas (GHG) emissions provides a reason to explore alternative forms of energy generation. Trinidad and Tobago (T&T), a twin-isle republic, is the southernmost island of the Caribbean, situated 130 kilometres south of Grenada and 11 kilometres southwest of Venezuela, spanning an area of 5,128 km^2. T&T, with a terrain mostly consisting of mountains and plains experiences a tropical climate. The primary economic source stems from the country's fossil fuel wealth and its heavy reliance on this non-renewable resources[3].

T&T emits a large amount of GHG per capita. As of 2016, the republic occupied the third spot with an annual CO_2 emissions figure of 5.39 tonnes per capita[4]. In 2018, T&T's energy sector contributed close to 20,000 Gg CO_2e. This accounted for 42% of the total CO_2e emissions for the country[5]. However, when viewed by total GHG emissions on a global scale, the country was ranked in the 62nd position[6] contributing less than 1% globally[7]. Despite its lower ranking on an entire GHG scale, efforts should still be pursued, evaluated, and implemented to reduce its emissions, especially due to the country being a signatory to multiple related multilateral agreements.

T&T is a party to the Paris Agreement and in 2018, under its Nationally Determined Contributions confirmed its formal commitment to reducing its GHG emissions with a target of reducing cumulative GHG by 15% from industry, power generation, and the transport sector by 2030 from a business-as-usual baseline[8]. In addition to the Sustainable Development Goals as further guiding principles, T&T also has its very own Carbon Reduction Strategy and National Climate Change Policy and Vision 2030[6]. However, despite these commitments, T&T has yet to explore renewable energy technology (RET) on a large scale. One of the main deterrents to this is the subsidized rate of electricity.

Table 1 highlights the cost of electricity (COE) in some countries throughout the Caribbean. From this, it is seen that T&T is privy to comparatively lower electricity rates than the rest of the Caribbean, whose electricity cost generally falls within a range of US$ 0.30-0.40 per kWh[3]. As an economy that is largely based on the production of oil and gas commodities due to its large natural reserves, traditional energy generation takes precedence over the creation and expansion of a renewable energy (RE) component of the energy sector.

Table 1. Cost of electricity in various Caribbean countries.

Country	Price of electricity (US$ per kwh)
Antigua & Barbuda	0.43
Bahamas	0.26
Barbados	0.32
Dominica	0.43
Jamaica	0.36
T&T	0.05

Given this, it appears as though T&T has little economic incentive to adopt RE, especially compared to the low electricity rates[9] and the forgoing of the opportunity to utilize the subsidy funds to expand or improve other aspects of the economy.

T&T's economy is centred on using a finite, non-renewable resource that is vulnerable to economic shocks, market fluctuations, and resource shortages. This, in addition to the country's high ranking in CO_2 emissions per capita[4] as well as the country's various international and local initiatives and agreements, is ample reason for RETs to be explored. This can provide an opportunity for economic diversification and preparation for an energy transition while simultaneously engaging in carbon footprint reduction (all essential ingredients for sustainable development). Both solar photovoltaic and wind technology are deemed the most suitable RET for T&T due to the abundance of sunshine hours and strong wind speeds the isle receives[10,11].

Educational buildings utilize approximately 11% of total energy consumed[12]. A campus with RE is an excellent forefront to combine RET into the country's energy mix and move towards its RE target.

The University of Trinidad and Tobago's (UTT) Camden campus is situated on Camden Base Road, Couva. It is the aviation training institution for The University of Trinidad and Tobago. Occupying 20 acres of land, it houses the largest hangar within the English-speaking Caribbean and is an aviation-relevant training institute for multiple program options within the industry.

This project aims to create and evaluate the benefits of a solar PV and wind hybrid renewable energy installation on the UTT Camden campus. The objectives of the study are:

a. Conducting and evaluating an ASHRAE Level 1 energy audit
b. Developing a system load profile
c. Modelling and simulating a renewable energy system
d. Conducting economic and CO_2 feasibility studies

The paper is divided into the following sections: literature review, methodology, results, discussion, recommendations and conclusion.

2 Literature Review

2.1 Energy Audit and Energy Efficiency

An energy audit is the inspection, survey, and analysis of the energy consumption within a building to determine energy consumption patterns and offer insight into more economical and environmentally wise improvements that can be made[13]. It is crucial in developing, managing, and making appropriate sustainable energy decisions. The main purposes of an energy audit are to quantify energy usage based on its functions and outputs, to determine an energy consumption baseline, to benchmark against standard values, and to identify energy reduction and cost-saving opportunities[14]. This allows for improved energy performance, minimization of environmental impacts, and decreased financial output[13,15]. A level one energy audit is the simplest audit that can be conducted. It entails a general overview of utility bills, operating data, and though not necessary, a building walk-through all aiming to achieve a preliminary analysis and generating low to no-cost measures to improve both the energy efficiency and performance of the building together with reducing its cost[16]. It should be noted that though, level two and three energy audits provide greater detail and afford an in-depth analysis, once done correctly, a level one audit can highlight pressing areas of energy wastage, inefficiency, and concern allowing for further analysis to be taken if necessary.

The phases of an audit are data collection, data analysis, and results/findings and recommendations[17].

The findings of an energy audit on an airport terminal in Egypt indicated that a significant source of energy consumption came from HVAC systems and lighting[18]. This study highlighted that this could easily be decreased by reducing the difference between the interior and exterior temperatures of the environment. Another major method used in energy consumption reduction included modelling and simulation of electrical loads together with identifying various energy scenarios for optimum reduction. Similarly, an energy audit of an educational building was done and from this, it was concluded that energy wastage on the campus is highest during its operational stage through insufficient insulation, heating and air conditioning, improper use of energy installation, and poor management strategies[19].

Because energy audits identify consumption patterns and opportunities for energy savings, it is crucial that an energy audit precede system design and optimisation to ensure that the system load profile is accurately represented. This allows for the correct load profile to be built for an energy-efficient system. This avoids energy wastage and prevents an oversized or misrepresented system from being made and evaluated.

A study[20] noted the importance of conducting an energy audit prior to system design and simulation. The methodology included conducting an energy audit which revealed the amount of energy to be saved and the recommended load to be input into the HOMER software to ensure accurate system size, net present cost, cost of electricity, *etc*. The audit results were compared to the pre-audit figures, which identified that the building could save 34% of the energy it currently utilizes. Feasibility studies for the proposed solar energy system showed that the installation would reduce energy purchases from the grid and present cost-saving opportunities. The audit identifies areas where energy-saving strategies (improved energy efficiency) can be implemented allowing for less energy usage and a consequential reduction in emissions.

Energy efficiency is essentially lowering the amount of energy needed to execute a task or activity, reducing energy usage or consumption. There are various ways in which energy efficiency can be achieved. Though RE is not a form of energy efficiency, but rather a clean source of energy generation, when paired with energy efficiency measures, environmental benefits can be seen. A study conducted on RETs adduced that solar PV technology and/or wind technology, in tandem with other techniques, significantly improve energy efficiency while utilising sustainable forms of energy generation[21]. The use of more efficient lightbulbs and lighting systems, self-regulated HVAC systems, and smart devices were highlighted as some of the easiest ways of implementing energy efficient measures in a study discussing various renewable energy and energy efficiency technologies since air conditioning and lighting systems are the largest consumers of electricity in most commercial buildings[12]. Further methods include additional energy efficiency measures, daylighting, benchmarking, and using an energy efficiency or usage index.

Daylighting is the intentional management of the admission of direct sunlight or natural light into buildings to reduce the need for electrical lighting while simultaneously achieving energy savings[22]. This can save up to one-third of the total energy costs of a building[22]. This can be obtained through the controlled placement of windows, skylights, window glazes, or through daylight-responsive lighting management systems. A case study conducted in Saudi Arabia concluded that the introduction of daylighting within the three-story university's design afforded energy savings of 43.9 MW per year through a controlled lighting management system[23]. Similar to the study previously mentioned, another case study indicated the use of a sensor-based lighting management system that would turn on once illuminance fell below a specified lux level. It was concluded that over 50% of energy savings would be achieved if the system was made operational on a full-time basis[24].

Benchmarking is a tool for improvement obtained through comparison with other organizations of a similar nature that are deemed to have the best standards within the industry[25]. Its purpose is not solely for evaluation or ranking against other organizations, but rather, to learn and adopt practices to improve the performance of one's current establishment. This is done by taking a building's energy use intensity (EUI), also known as energy use index, and comparing it against buildings of the same type to determine how efficiently the building uses energy and identifies areas for improvement[26]. A EUI reflects the rate of energy use in building energy use analysis. It is calculated by dividing the amount of energy consumed in British thermal units by the building's gross area in square feet[27]. The values for external comparison can be found in databases such as the Commercial Buildings Energy Consumption Survey (CBECS) or from similar organizations with published information. For internal comparison, the benchmark values from previous years can be looked at in relation to the current year being analysed to determine whether or not the energy patterns and consumptions of the organization are deteriorating. The findings of a study in which energy usage was benchmarked across schools in the United States showed that characteristics such as occupant density, operating hours, and number of equipment can result in buildings of the same type having varying

EUIs[28]. According to the U.S. National Energy Use Intensity, educational buildings categorized as universities/colleges occupy a EUI of 84.3 kBtu ft^{-2} [29]. It should be noted that EUI values vary based on climate due to differences in cooling and heating demands.

2.2 Hybrid Renewable Energy System (HRES) and System Simulation

HRES comprises various types of energy generation/sources in a single combined system. This is more beneficial than a system relying on one lone energy source. A case study analysing a PV-wind hybrid system concluded that photovoltaic and wind hybrid energy systems are a more economically viable alternative to fulfil energy demands[30]. This result from one energy source being able to cover for the other during a period of reduced energy output. Combining RETs allows for a feasible project and increases the overall energy output. Similarly, in another case study, it was adduced that such a hybrid system is reliable and has excellent potential for electricity production based on the geographical area[30].

HRES are complex. Through the use of simulation software to design, analyse and optimize, these systems can be appropriately planned, sized and avoid unnecessary expenses. There are a number of technologies and software options available today to aid in the simulation of a RE system, each with its benefits and disadvantages based on the specific purpose for which it is being used.

2.3 Homer Pro

Homer (hybrid optimization model for electric renewable energy) is the predominantly used software for renewable energy system simulation. Its main goal is to optimise and analyse HRES which can be grid-connected or standalone. It allows for adding wind power, solar power, battery storage, generators, biomass, and other sources[31]. Homer performs economic, sensitivity, and optimization analysis.

2.4 RETScreen

RETScreen is an Excel-based software used to assess renewable energy modelling and analysis. It comprises eight technologies: wind, photovoltaic, small hydro, and solar air heating. This technology allows users to determine potential power efficacy, clean power, and combined production projects[31].

2.5 iHOGA

iHOGA (Improved Hybrid Optimization by Genetic Algorithms) is a computer program that simulates and optimizes power systems supported by renewable energy sources. Due to thorough analysis strategies, a main and secondary algorithm is considered for all systems, resulting in a slightly long analysis period.

2.6 System Advisor Model

The System Advisor Model (SAM) is a free techno-economic computer model that facilitates renewable energy decision-making. SAM contains models for photovoltaic and battery storage, solar water heating, wind, biomass, and traditional power sources among others. SAM does not create models for hybrid model systems; instead, two or more systems would have to be modelled separately and then combined to create an overall output[32].

HOMER software was the preferred application for energy simulation design. Its ability to recognize system dynamics, cost-benefit analysis, and sensitivity and optimization analysis were viewed with high importance[33]. This, in addition to its ability to quantify GHG emissions associated with each system, determines system cost at various stages (initial capital, operational, and maintenance), run sensitivity analysis to assess the effect of particular on system cost, and rank system based on Net Present Cost (NPC)[34] are all advantages to utilizing the software. It is for these reasons that HOMER was used for this study.

T&T is predominantly focused on fossil fuel use and has yet to adopt RE as a feasible option for electricity generation. As a signatory to multiple environmental agreements and as the importance of limiting greenhouse gases increases globally, RE poses a means of fulfilling these environmental obligations while simultaneously reducing the country's carbon footprint. By conducting an energy audit of the UTT Camden Campus, simulating and analysing a solar PV-wind hybrid RE system for comparison against the current grid-only system the campus currently uses, insight can be offered into the benefits of such structures allowing for alternate use across the country.

3 Methodology

3.1 Energy Audit

Data was requested, received, and utilized to analyse. A data list was compiled based on the necessary requirements of the study and sent to the relevant heads of the university for approval. Once approved, the requested documents were sent for research and analysis. Data gathered included electricity bills from previous years (2018, 2019, and 2020), building blueprints, electrical equipment sizes, and their demand. Combining these with a simple walk-through, an ASRAE Level 1 energy audit was conducted and analysis of the electrical load of the campus followed. A EUI value was calculated based on the energy consumed over the campus area. The Energy Usage formula is presented in Table 2 and the calculations with the formula and conversions are outlined in Table 3.

Table 2. Formula and conversions for EUI.

EUI formula	Conversions	Campus area (ft^2)
$\frac{\text{Energy consumed (kBtu)}}{\text{Area (ft}^2\text{)}}$	1 kWh = 3.412 kBtu 1 m^2 = 10.764 ft^2	46,365.61

Table 3. EUI values.

Year	kWh	kBtu	kBtu ft^{-2}
2018	487,400	1,663,008.8	35.87
2019	544,300	1,857,151.6	40.06
2020	494,000	1,685,528.0	36.35

3.2 Load Profiles

A synthetic load builder was used to produce input values into the Homer software. The load builder was an Excel-based platform that calculated the peak annual demand and kWh per day for the weekdays and weekends of all months. Inputs required for the load builder were inputs from electrical bills: monthly energy usage and monthly peak demand and user assumptions-ratio (that is, the presupposition of energy usage and relative electricity demand throughout the day including peak demand and hours). of weekends to weekdays and typical day shape. The specific day shape for a commercial building was obtained from the synthetic load builder options from Homer. The outputs were the calculated load builder load profile values which were then exported into the software.

Annual load profiles were constructed using the monthly electrical consumption values from the electrical bills provided and presented in a graphical form. Similarly, the total yearly consumption was also calculated and presented on a graph. Since 2019 was deemed the most energy intense year, the load profile per month was also generated and presented to show variation in monthly consumption.

3.3 System Simulation

The excel values from the synthetic load builder were imported into the software and used as the inputs for the load. The systems were created using generic components to produce results that were not attached to a specific brand, manufacturer, or price. Instead, general built-in prices from the software were presented as an average of what such a system would cost. Components included a grid, generic flat plate PV, generic 1 kW wind turbine, auto-sized diesel generator, generic 1 kWh lead acid battery, and a system convertor.

The base case was created by modelling the grid only system of the campus since this is the business-as-usual scenario. Two other scenarios were simulated by adding and removing components to the base case: a grid-tied system in which RE and the grid were used as energy sources and a stand-alone RE system in which only RE sources were utilized. The Homer software was used to calculate the optimised system (using a least NPC objective function) for each scenario. As such, RE fractions were exogenously found from the models. Sensitivity analysis was also conducted to see the effect that parameters such as cost of electricity and diesel price could have on the modelled results. The overall chosen system that was deemed most feasible for the campus was chosen based on considering both cost and CO_2 emission reduction.

From the results, data analysis and recommendations occurred.

3.4 HOMER Inputs

Particular inputs were needed for the software to simulate as accurate scenario as possible. This included site-specific weather data which was taken within the software and various electricity costs. The subsidized, unsubsidized and regional average of the COE, as well as diesel prices, were taken as available in the literature, while another unsubsidized calculation was done for both natural gas and diesel based on the recent prices since the unsubsidized values stated in the literature would not have reflected the current rise in fossil fuels. This was calculated by finding the percentage of the commodity which constituted the commodity itself from the full price at the particular time in which that value was used within the literature. This figure was then applied to a past six-month average.

This was done to ensure that the unsubsidized rate reflected the recent change in prices, which undoubtedly, affects the unsubsidized cost and with it the results of each scenario under that specific COE.

a. Weather data: solar and wind data site specific to the location of the university according to the NASA database available within the software.
b. Electricity cost: subsidized cost of US$ 0.05 per kWh, unsubsidized cost based on literature of US$ 0.12 per kWh[3], calculated unsubsidized cost (based on recent prices[35]) of US$ 0.22 per kWh and regional average of US$ 0.35 per kWh[3].
c. Fuel cost: subsidized cost of US $ 0.575 per L, unsubsidized cost based on the literature of US$ 0.729 per L[34], calculated unsubsidized cost (based on recent prices) of US$ 1.08 per L and global average of US$ 1.39 per L[36].
d. Sellback rates: US$ half the price of COE.

4 Results

4.1 Energy Usage Index

Table 3 showcases the EUI for the years 2018, 2019, and 2020. Based on the values calculated and the comparison to the U.S. National EUI, it is seen that all the values calculated fall more than 50% below the benchmark, indicating low energy usage and high energy efficiency. However, it must be noted that this value does not take into consideration the climate and temperature effects that the Caribbean region faces. Since the U.S. experiences an overall temperate climate compared to the tropical conditions of T&T, the demand for cooling and heating, which constitute a high percentage of energy consumption varies.

4.2 Energy Load Profiles

The typical daily load profile over a 24-hour time period is seen in Figure 1. The shape of the graph was determined by utilizing the average values from the commercial load profile within the Homer software and each figure assigned values between 1 and 6, relative to one another. This illustrates how energy consumption varies throughout the hours of the day and is consistent with a university that has both full-time and part-time students.

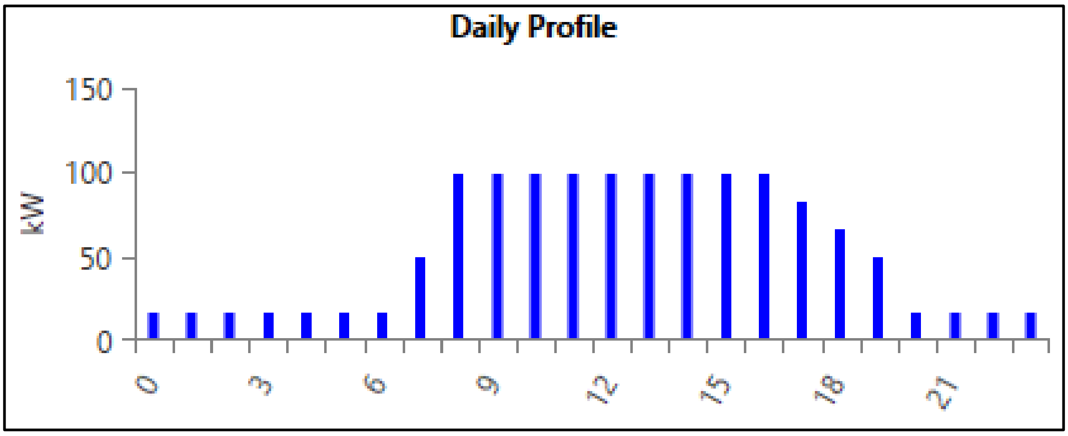

Figure 1. Relative comparison of daily energy use intensities.

The energy usage for the three years, as seen in Figure 2, was obtained from the electricity bills of the campus. This illustrates the fluctuation of energy consumption over the years and highlights peaks and dips within certain months of the year, typical with peak and off-peak activities at the University over a calendar year.

The total energy consumption for each year was determined by calculating and adding the monthly energy usage for all the months of each respective year and is illustrated in Figure 3. From this, it can be seen that 2019 utilized considerably more energy than the other years. This result is consistent with expectations as the campus was not fully utilised in 2018, and for most of 2020, online learning was adopted (due to the COVID-19 pandemic). As such, the consumption values for 2019 were used in further analysis.

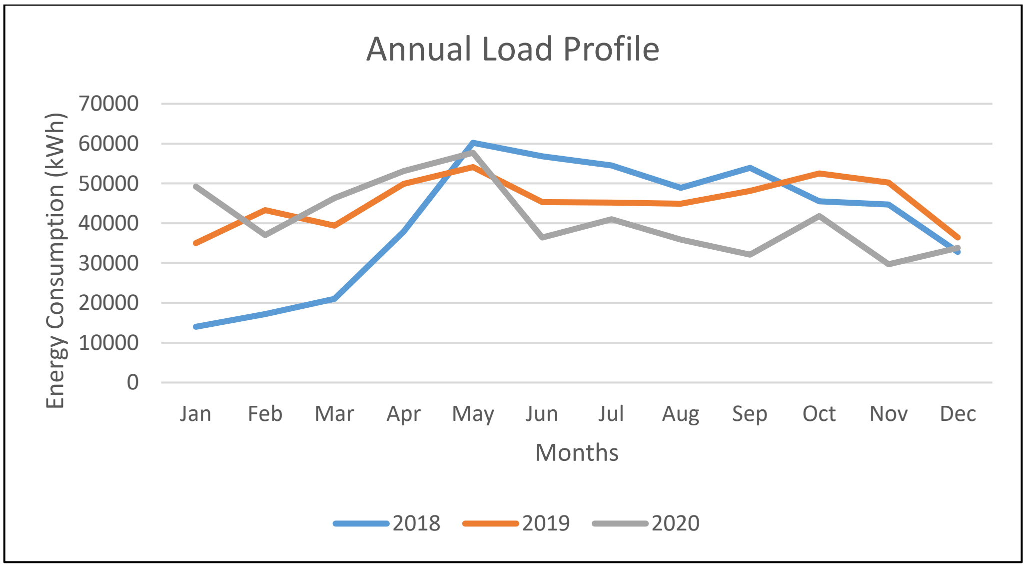

Figure 2. Comparison of annual energy usage per month for three recent years.

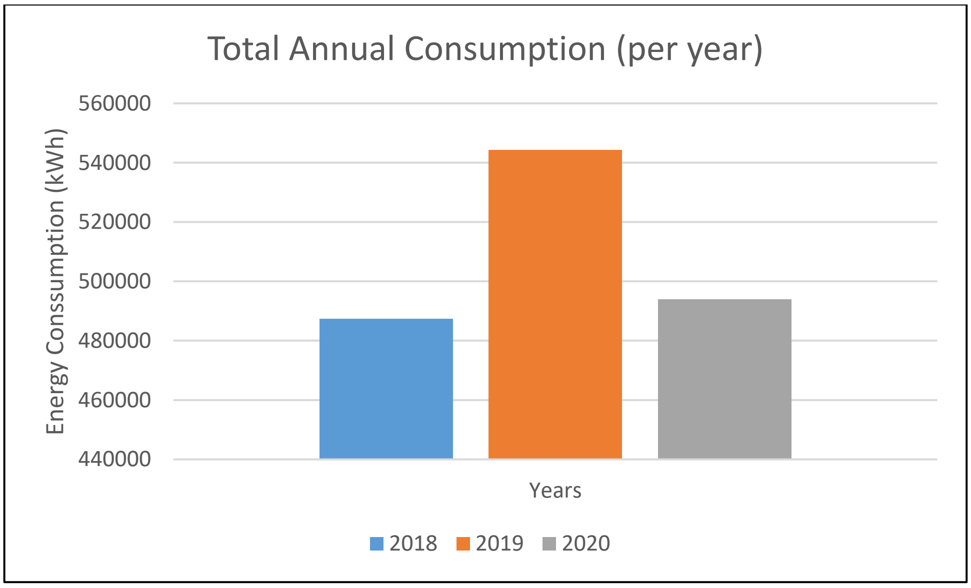

Figure 3. Comparison of energy consumption per year for three recent years.

Figure 4 shows the energy consumption per month for the year 2019. This year presented the highest energy consumption (as stated above). From this, the variation among the months of the year is seen. The flow of the graph is expected. For parts of January and December, the university is closed due to vacation. As such, the energy consumption of these months would be lower. Similarly, June, July, and August present with less consumption than other months. This is a result of summer classes which see less student attendance and occur at fewer frequencies than regular classes.

4.3 Renewable Energy System Simulation

Figure 5 illustrates the daily, seasonal, and yearly load profiles generated by Homer software. This was generated with 10% day-to-day and 20%-time step random variability to afford variation within the system. The seasonal profile portrays variation in energy use among the months, as does the yearly profile, though for the majority of the year, most consumption is seen within the 8th and 18th hours of the day.

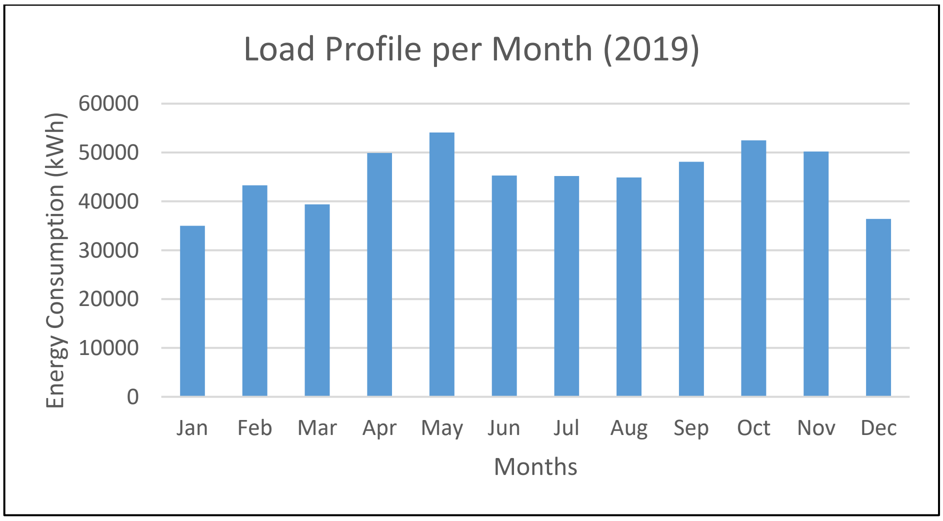

Figure 4. Energy consumption per month for 2019.

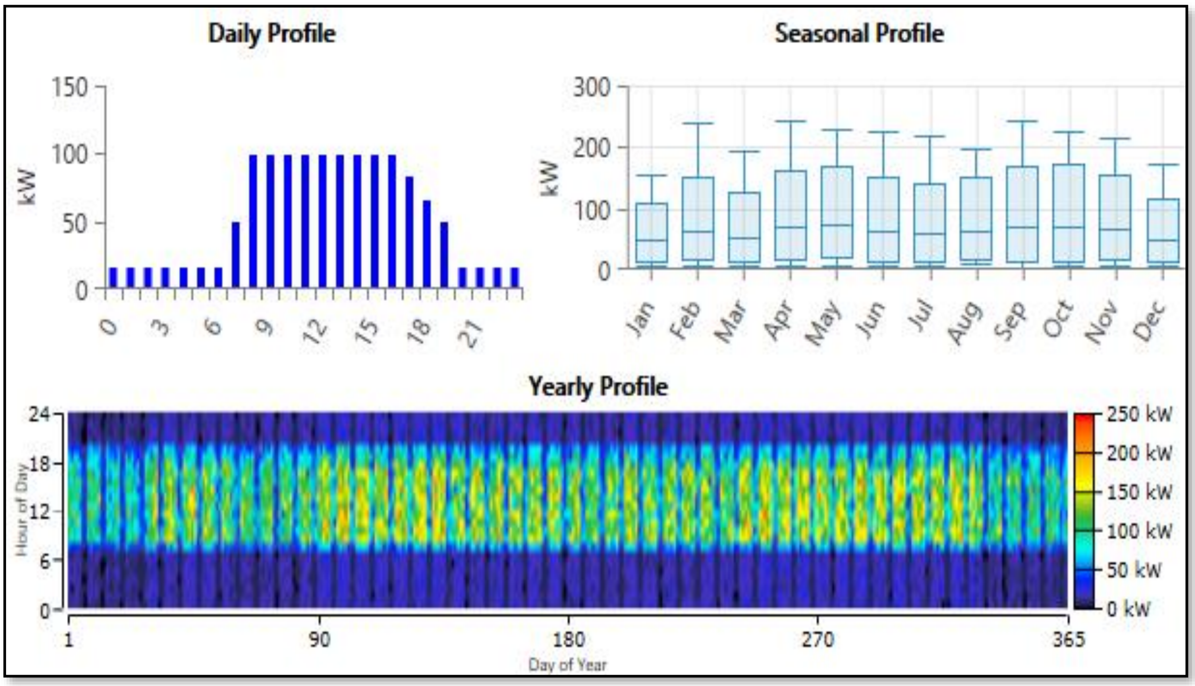

Figure 5. Energy load profile for 2019 generated by Homer software.

4.4 Grid Only System

The first scenario simulated was the base case or "as is". This system relies on the grid only as seen in Figure 6. Table 4 shows the results for this base case which shows the operating cost per year as US$ 44,243 under the subsidized cost of electricity, that is, US$ 0.05 per kWh. This system produces 559,226 kg of CO_2 a year (at the generation power stations which are natural gas driven).

Various price sensitivities were applied on this base case to see how the costs of the system would differ with changes to the cost of electricity. The base case was compared to the following:

a. the unsubsidized value of electricity as available in the literature[3], that is, US$ 0.12 per kWh
b. the calculated unsubsidized value based on current fossil fuel prices[35], that is, US$ 0.22 per kWh and
c. the regional average, which is US$ 0.35 per kWh[3].

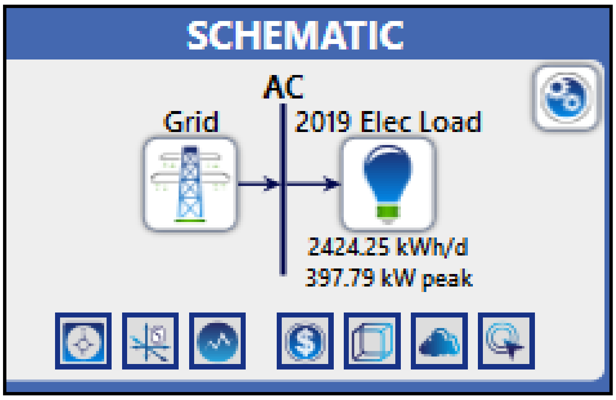

Figure 6. Schematic for grid connected system.

Table 4. Results for grid connected system.

Architecture	Cost			System		Grid
Grid (kW)	NPC ($)	COE ($)	Operating cost ($ per year)	Elec. produced	CO_2 (kg per year)	Energy purchased (kWh)
999,999	571,947	0.05	44,243	884,852	559,226	884,852

4.5 Grid-tied System

The second scenario modelled was a grid-tied system which included the grid as seen above, with the addition of renewable energy components. Figure 7 illustrates the system configuration with PV, wind turbine, and converter components. For this section, the systems were analysed in two categories: no sellback granted and sellback granted with net metering.

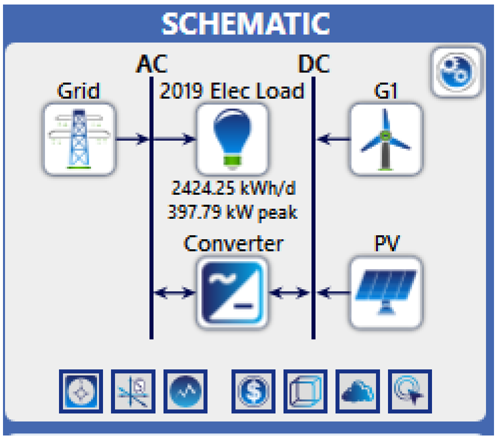

Figure 7. Schematic for grid-tied renewable energy system.

4.5 No Sellback Granted

Table 5 shows a comparison of the top optimized simulation results in each respective power price excluding sellback for all grid-tied systems. The prices seen in the table were used to illustrate the effect of rising electricity prices on the current system that T&T faces (subsidised cost of US$ 0.05 per kWh). At this current price, the operating cost is US$ 44,234 per year as discussed under the grid-only section. The unsubsidized cost found in the literature (US$ 0.12 per kWh) was used to showcase what the costs associated with such a system would be for T&T if the government were to remove the electricity subsidy that the country is currently privy to. Under the unsubsidized cost of electricity found in the literature (US$ 0.12 per kWh), the operating costs of the system move to US$ 106,182 per year. A second unsubsidized cost was calculated (US$ 0.22 per kWh) and used for the same purposes as the first unsubsidized cost. However, this cost represented a more accurate price as the prior was outdated and the calculated cost reflected current rises in natural gas figures. The regional average was included for comparison purposes as this value accounts for the cost that T&T's regional counterparts experience. At the calculated present unsubsidized cost of US$ 0.22 per kWh (since the published value was outdated to 2012), and the regional average (US$ 0.35) the operating costs move to US$ 194,667 per year and US$ 309,698 per year, respectively. This is expected as with a higher cost of electricity, the price of running such a system would increase. However, the first two price scenarios, that is, the base case (US$ 0.05 per kWh) and the unsubsidized cost of electricity found in the literature (US$ 0.12 per kWh), showed 0% RE fractions, as the lower cost of electricity under these scenarios rendered the cost of RE uncompetitive. At these lower costs of electricity, RE was not yet feasible, as seen in the other two price scenarios.

Under the estimated unsubsidized cost of electricity of US$ 0.22 (which was prorated based on present day natural gas prices), the RE components are utilised at 36.2% RE penetration. Figure 8 illustrates the direct correlation between the cost of electricity and the percentage of RE in the system. As shown in Figure 8, there is a considerable amount of RE, that being, a 10% RE fraction is feasible at approximately US$ 0.15 per kWh.

Table 5. Results for the top scenario in each power price for grid-tied renewable energy system.

	Top scenarios			
Power price ($)	0.05	0.12	0.22	0.35
Architecture: PV (kW)	-	-	240	361
Wind turbine	-	-	-	32
Cost:				
NPC ($)	571,947	1.37 M	2.35 M	3.15 M
COE ($)	0.050	0.120	0.200	0.247
Operating cost ($)	44,243	106,182	131,464	150,944
Initial capital ($)	0.00	0.00	650,225	1.2M
System:				
Renewable fraction (%)	0.00	0.00	36.2	59.2
Electricity produced (kWh per year)	884,852	884,852	932,593	1,034,154
CO_2 (kg per year)	559,226	559,226	336,898	254,036

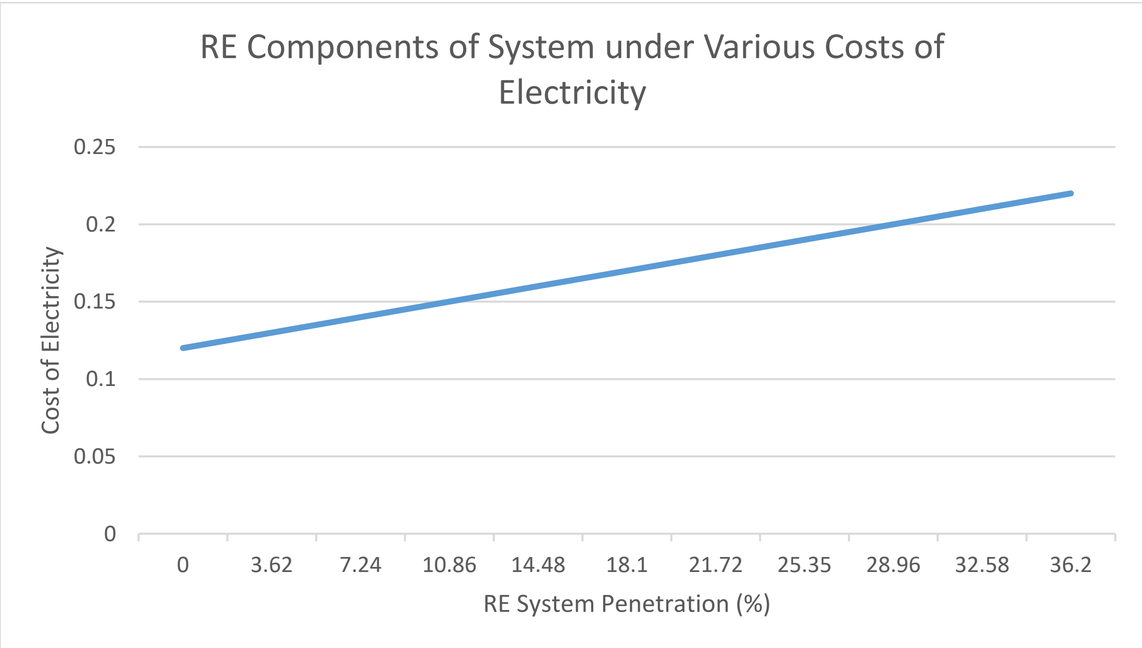

Figure 8. Line graph showing RE penetration of system under varying costs of electricity.

4.6 Sellback Granted with Net Metering

Table 6 showcases the top scenarios of each power price with half-priced sellback rates. Similar to the case of no sellback, the RE feasibility is shown at the price of US$ 0.22 per kWh. At this point, the RE consists of approximately 53% and rises to about 95% under the regional average cost scenario. However, under this sellback scenario, more than half of the system's energy comes from RE sources (compared to the 36.2% under no sellback). This significantly improves the electricity produced while simultaneously decreasing CO_2 emissions.

The cost margin at which RE becomes practical differs from the scenario above. Though not shown in the table, under the half-priced sellback rate, 10% RE becomes feasible at a lower cost of US$ 0.14 per kWh. This is due to the third cost scenario presenting a higher RE configuration under the sellback conditions.

Table 6. Results for the top scenario in each power price with half-priced sellback rates for grid-tied renewable energy system.

	Top scenarios			
Power price	0.05	0.12	0.22	0.35
Sellback price	0.025	0.06	0.11	0.175
Architecture:				
PV (kW)	-	-	377	2,425
Wind turbine	-	-	-	36
Cost:				
NPC (US$)	571,947	1.37 M	2.28 M	2.00 M
COE (US$)	0.050	0.120	0.179	0.0425
Operating cost (US$)	44,243	106,182	96,994	-375,604
Initial capital (US$)	0.00	0.00	1.02M	6.85M
System:				
Renewable Fraction (%)	0.00	0.00	52.9	95.1
Electricity Produced (kWh per year)	884,852	884,852	1,016,643	3,851,062
CO_2 (kg per year)	559,226	559,226	292,642	111,832

4.7 Renewable Energy Stand-Alone System

The third model evaluated consisted of all the components of the second model with the addition of a generator in replacement of the grid to afford a stand-alone system, as can be seen in Figure 9. This was done for the purpose of being extensive and to analyse what 100% RE would look like for the university when compared to unsubsidized and subsidized costs.

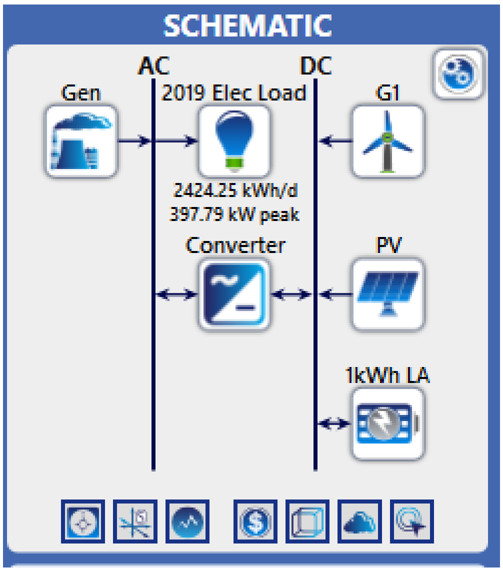

Figure 9. Schematic for stand-alone renewable energy system.

With this being a standalone system, all scenarios contain a fraction of RE, as can be seen in Table 7. There is a direct correlation between diesel price and the RE fraction of the system. As the diesel price increases, it becomes more feasible to incorporate RE, and thus the RE percentages increase as well, as does the NPC of the system. There is also an inverse relation between the RE fraction and the CO_2 emissions. As the RE increases, the CO_2 emission decrease. Unlike the other scenarios above, the first scenario in this case, that is, the subsidized diesel value of US$ 0.575 per L, sees extensive RE composition and CO_2 emissions.

Table 7. Results for the top scenario under the subsidized, unsubsidized (as available in the literature), unsubsidized (as calculated in this paper), and the regional average cost of diesel for the standalone renewable energy system.

Diesel Fuel Price (US$ per L)	0.575	0.729	1.08	1.39
Architecture:				
PV (kW)	385	409	481	501
Wind turbine	43	74	91	125
Generator (kW)	440			
1kWh LA	1,043	1,102	1,439	1,305
Cost:	4.09M	4.28M	4.65M	4.88M
NPC (US$)				
COE (US$)	0.357	0.374	0.406	0.427
Operating cost (US$)	169,495	161,216	158,394	157,174
Initial capital (US$)	1.89 M	2.19 M	2.60 M	2.85 M
System:				
Renewable Fraction (%)	59.9	68.4	77.0	85.7
CO_2 (kg per year)	255,745	199,984	141,886	98,085

5 Discussion

5.1 *Energy Audit and Load Profiles*

The level 1 energy audit of the UTT Camden campus was done and conclusions were drawn. From this, the annual EUI values were calculated and analysed. The analysis showed that EUI has increased by approximately 11% from its 2018 value of 35.87 kBtu ft^{-2} by a little over 4 kBtu ft^{-2} in 2019. This can indicate lower energy efficiency and may be an area that facilities management can focus on. Though the value for 2020 decreased to about 2018 levels, it was expected that the figure for that year would be lower due to the onset of the COVID-19 pandemic and the government regulations which saw the closure of educational facilities. It was presumed that since the campus experienced significantly less occupation, hours of operation and activity, its energy consumption values would be considerably lower. This again indicates that if social conditions were normal and the pandemic restrictions did not occur, the energy consumption of the campus could have increased as it did from 2018 to 2019. However, it should be noted that the increase from 2018 to 2019 could have occurred due to a number of factors including more registered students, an increase in classes, or class durations among others. Since the nature of this study is preliminary, these considerations were not considered for the calculations.

A typical daily load profile was constructed from the excel load builder spreadsheet and its shape was manipulated with relative figures to estimate how consumption varies throughout the day. Due to a lack of hourly data on the consumption patterns of the campus, the generic commercial profile that Homer software provides was used to form the general shape of the typical daily load. Within the hours of 9:00 am and 5:00 pm, the campus experiences its maximum amount of energy consumption for the day. This is expected as during the day the campus would encounter high occupancy from staff, students, and visitors. At these times multiple appliances such as air conditioners, lighting, computers, and other equipment will be performing at the same time. During the very late hours of the night and early hours of the morning the campus utilizes the least amount of energy as this is when occupancy is at its lowest and appliances and equipment are not being used in high volumes.

Three load profiles were generated using a created excel load builder spreadsheet for the years 2018, 2019, and 2020. The year 2019 presented with the highest electrical consumption of approximately 544,300 kWh corresponding to the highest EUI) among the three years and was chosen as the input year to act as the baseline scenario to be simulated and built upon. The year with the highest consumption was used to ensure that a system that can meet the maximum demand (based on the historical data available) was simulated. Though 2019 was chosen as the input for the simulations, general trends were able to be seen from the annual load of the years 2018 and 2019. 2020 is viewed as an anomaly and not the most accurate representation of campus consumption due to the Covid-19 pandemic. The first (January) and last month (December) are the months in which the least amount of electricity is consumed. This may be because during these months the campus experiences less staff and students due to exams and campus closure as a result of a vacation/holiday period. From around March the consumption gradually rises until it reaches its peak consumption in May. Looking at the load profile for 2019 by month confirms that May was the peak month of that year. Following close, in terms of electrical usage, it was October, November, and April respectively.

5.2 Simulated Systems

A base case was simulated as the grid-connected electricity source that the campus currently uses. The simulation calculated the operating cost at US$ 44,243, with 559,226 kg of CO_2 per year being emitted from the 884,852-kWh electricity produced. Variations among this scenario based on the cost of electricity was assessed. The unsubsidized price of electricity based on literature pushes operation costs to more than double what is paid at the subsidised price. Since the unsubsidized COE would have been based on natural gas prices of previous years, a more recent estimation was calculated to demonstrate what the unsubsidized price would be in current times due to the change in natural gas prices. This was done by using a six-month average of natural gas prices in the first half of 2022. As a result of the estimated unsubsidized cost, the operating cost quadrupled that of the base case. This is further exacerbated by the regional average, resulting in operating costs being more than five times higher than the base case. If T&T were to face either the unsubsidized prices or the prices that some of their regional counterparts pay, the country would be forced to practice and adopt energy efficiency measures and conservation methods to limit energy usage to avoid high electricity prices.

A PV, wind turbine, and grid-connected system were considered. This was viewed under two scenarios. Systems with no sellback were first analysed. Under the current COE and the unsubsidized cost based on literature, the preferred system by the software was that of the grid only. At the calculated unsubsidized COE of US$ 0.22 per kWh, the system presented with 36.2% RE, and it was deduced that at US$ 0.15 per kWh, RE started to become feasible with a relatively significant contribution of 10% penetration to the system configuration. This is the price at which RE penetration would become cost effective. At the COE margin of US$ 0.35 per kWh there is 59.2% RE. Due to the low electricity rates in the first two cost sensitivities (both lower than US$ 0.1 per kWh), RE was shown to not be economically viable. The costs and benefits of a hybrid grid connected system do not create an advantageous system for the campus nor provide long-term perks under such low COEs. However, if the COEs were to increase and the country was faced with the latter cost sensitivities, the integration of a renewable energy system for the campus would make more sense. It is at this point that the gain of such a system would be seen.

As the COE increases and the addition of renewable energy components increase, it is expected that the NPC of the system would also increase which the results indicate. Nonetheless, if the cost is examined in more detail, conclusions can be drawn. When the COE moves from US$ 0.05 per kWh to US$ 0.12 per kWh the NPC rises to almost US$ 800,000. This is due to the increase in the electricity cost solely. When moving from US$ 0.12 per kWh to US$ 0.22 per kWh the cost increase is approximately US$ 980,000 which accounts for the increase in COE and the addition of renewable energy components. This is expanding even more when moving again to US$ 0.35 per kWh which includes the COE rise and 59.2% renewable energy, for approximately US$ 800,000 more than the previous system. When moving from the first cost scenario to the second, the cost increase is slightly less than when moving to the third scenario and exactly the same when moving from the third to the fourth despite the difference between the first two scenarios only being COE. The latter scenarios include RE system components and face a higher COE, so it is expected that the cost increase would be considerable. However, it stands comparable to the systems without RE configuration. This explains how under certain cost conditions renewable energy-integrated systems become increasingly economically favorable under certain cost conditions.

When looking at CO_2 emissions avoided, the two scenarios with the lower costs, do not experience any reduction in CO_2 emitted due to them consisting of no renewable energy. With renewable energy coming into play, the other two systems see an avoidance of 222,328 kg per year and 305,190 kg per year of CO_2 respectively. It must be noted however that implementation of a carbon tax system where the government determines a price that emitters must pay for each ton of greenhouse gas emissions, they emit will result in the CO_2 reductions translating into cost savings.

The same system as above was explored but with sellback allowed under net metering. Since sellback rates vary from country to country and depend on specific regulations, the sellback rates, for the purpose of this study, were taken as half of the relative purchase price. With sell-back options being considered, the systems still follow the trend of the system above without sellback granted. However, RE becomes viable at a lower grid price of US$ 0.14 per kWh with a 10% RE fraction (compared with US$ 0.15 per kWh before without sellback).

The first two systems solely utilise the grid and, thus, do not offer any CO_2 savings. With an estimated US$ 910,000 increase in NPC from the system at the unsubsidized cost based on literature, the third costing option presents with more than half of the system being renewable energy which reduces more than half of the CO_2 emissions from the first two options at 266,584 kg per year of CO_2. The fourth costing scenario under the regional average puts forward a system with 95.1% RE with an NPC that is less costly than the system with 59%. However, it should be noted that the initial capital required for such is quite significant at US$ 6.85 M. As expected, this system reduces CO_2 by 444,394 kg per year.

The final system examined was a completely stand-alone renewable energy system. This consisted of the solar PV and wind hybrid system with a diesel generator. Four cost sensitivities were conducted on this model to gather a comprehensive view of diesel prices and their effect on the expense of the system. These were: the current subsidized diesel price within T&T, the unsubsidized cost based on literature, the calculated unsubsidized cost based on the diesel prices within the first half of 2022, and the regional average. A direct correlation between diesel price and the renewable energy fraction of the system is seen. As the diesel price increases, the more feasible it becomes to incorporate RE, and thus the RE percentages increase as does the NPC of the system. This is again similar to the systems above where the RE feasibility became more apparent and NPC increased as the COE rose. Under the current unsubsidized price, the model consists of more than half RE at 59.9%. This gradually increases until under the regional average it reaches a RE fraction of 85.7%. The NPC and the initial cost of the models also gradually increase but do not show a massive jump between one system to the next.

6 Conclusion

The implementation of a RE hybrid system for the Camden Campus can serve as a template facilitating further RE throughout the country promoting green energy and sustainability. The energy audit conducted proposed a comprehensive energy management plan offering energy savings and long-term financial benefits. The results showed that using the subsidized cost of electricity, approximately 884,854 kWh of electricity is consumed annually from the grid resulting in an annual operating cost of US$ 44,243 and associated CO_2 emissions of 559,226 kg. Using an unsubsidized cost of electricity of US$ 0.12 per kWh, an optimally designed RE system would still not be economical. The cost at which a RE system becomes feasible was found to be US$ 0.15 per kWh (with a 10% RE penetration). Using the latest natural gas prices and a present-day unsubsidized cost of US$ 0.22 per kWh, the RE system was more feasible with a larger RE penetration of 36.2% and corresponding CO_2 savings of 222,328 kg per year. Implementing a sellback rate of 50% purchase rates, the lowest cost for economical RE penetration was lowered to US$ 0.14 per kWh. When a sellback scenario was analysed using a regional average price of US $0.35 per kWh, the RE penetration was improved to 95.1% with CO_2 savings of 444,394 kg annually.

Conflict of Interest

The authors declared that there was no conflict of interest.

Acknowledgment

The authors would like to thank Ms. Jochebed Yearwood for her assistance with the preparation of the manuscript according to the required format.

Funding

There was no funding received for the research.

Author Contribution

Conceptualization: Jaggernath, P., Boodlal, D., Alexander, D., & Maharaj, R.
Data curation: Vincent. V. & Jaggernath, P.
Methodology: Boodlal, D, & Maharaj, R.
Formal analysis: Vincent, V, & Boodlal, D.
Visualisation: Not applicable
Software: Not applicable
Writing (original draft): Vincent, V.
Writing (review and editing): Jaggernath, P., Boodlal, D., Alexander, D., & Maharaj, R.
Validation: Not applicable
Supervision: Jaggernath, P., Boodlal, D., Alexander, D., & Maharaj, R.
Funding Acquisition: Not applicable
Project Administration: Not applicable

References

1. United Nations. (2019). *World population prospects 2019: Highlights (ST/ESA/SER.A/423)*. Department of Economic and Social Affairs, Population Division. https://population.un.org/wpp/
2. Mackay, M. E. (2015). *Solar energy: An introduction* (pp. 7-12). Oxford University Press.
3. Thomas, N. (2017, May 18). *Understanding the electricity subsidy in T&T — Energy chamber of Trinidad and Tobago*. https://energynow.tt/blog/understanding-the-electricity-subsidy-in-tt
4. Worldometer. (n.d.) *Trinidad and Tobago CO_2 Emissions*. https://www.worldometers.info/co2-emissions/trinidad-and-tobago-co2-emissions/
5. Government of the Republic of Trinidad and Tobago. (2021). *First biennial update report of the republic of Trinidad and Tobago to the United Nations Framework convention on climate change*. Ministry of Planning and Development, Multilateral Environmental Agreements Unit. https://unfccc.int/documents/416010
6. The Government of Trinidad and Tobago. (2018). *Trinidad and Tobago intended Nationally Determined Contribution (iNDC) under the United Nations Framework convention on climate change*. Food and Agriculture Organization of the United Nation. https://faolex.fao.org/docs/pdf/tri190758.pdf
7. Government of the Republic of Trinidad and Tobago. (2019). *Trinidad and Tobago's NDC implementation plan: A policy blueprint to guide effective mitigation action*. Ministry of Planning and Development, Multilateral Environmental Agreements Unit. https://transparency-partnership.net/system/files/document/200114_GPD_Trinidad_and_Tobago_RZ.pdf

8. Solaun, K., Gómez, I., Larrea, I., Sopelana, A., Ares, Z., & Blyth, A. (2015). *Strategy for reduction of carbon emissions in Trinidad and Tobago, 2040*. The Government of Trinidad and Tobago. https://www.planning.gov.tt/sites/default/files/CRS%20_Strategy_Final.pdf
9. National Renewable Energy Laboratory. (2015). *Energy snapshot Trinidad and Tobago*. https://www.nrel.gov/docs/fy15osti/64117.pdf
10. Chadee, X. T., & Clarke, R. M. (2014). Large-scale wind energy potential of the Caribbean region using near-surface reanalysis data. *Renewable and Sustainable Energy Reviews, 30,* 45-58. https://doi.org/10.1016/j.rser.2013.09.018
11. Vogt, M. (2019, June 2). *The Caribbean's untapped renewable energy potential. Renewable energy world*. https://www.renewableenergyworld.com/storage/the-caribbeans-untapped-renewable-energy-potential/#gref
12. Elsadig, A. (2005). *Energy* efficiency in commercial buildings [Master's thesis, University of Strathclyde]. https://www.esru.strath.ac.uk/Documents/MSc_2004/elsadig.pdf
13. SEAI. (n.d.). *Energy audit handbook*. Sustainable energy authority of Ireland https://www.seai.ie/publications/SEAI-Energy-Audit-Handbook.pdf
14. Santalla, H. (2022). *What are the benefits of an energy audit?* Leonard Energy. https://help.leonardo-energy.org/hc/en-us/articles/203523352-What-are-the-benefits-of-doing-an-energy-audit-
15. Mbaye, A. (2022). Review on energy audit: Benefits, barriers, and opportunities. *American Journal of Energy and Natural Resources*, *1*(1), 45-58. https://doi.org/10.54536/ajenr.v1i1.1054
16. Kelsey, J., Deru, M., & Kelsey, J. (2011). *Procedures for commercial building energy audits (*2nd ed*.)*. ASHRAE. https://toaz.info/doc-view-2
17. Muhammad, H. (2017, April 24-26). *The energy audit process for universities accommodation in Malaysia: A preliminary study* [Paper presentation]. 7th International Conference on Environment and Industrial Innovation Kuala Lumpur, Malaysia. https://doi.org/10.1088/1755-1315/67/1/012027
18. Abdallah, A., Makram, A., & Abdel-Azim Nayel, M. (2021). Energy audit and evaluation of indoor environment condition inside Assiut International Airport terminal building, Egypt. *Ain Shams Engineering Journal, 12*(3), 3241-3253. https://doi.org/ 10.1016/j.asej.2021.03.003
19. Samira, A., & Nurmammad, M. (2018). Multi-disciplinary energy auditing of educational buildings in Azerbaijan: Case study at a university campus. *IFAC-Papersonline, 51*(30), 311-315. https://doi.org/10.1016/j.ifacol.2018.11.308
20. Chisale, S. W., & Mangani, P. (2021). Energy audit and feasibility of solar pv energy system: Case of a commercial building. *Journal of Energy, 2021*, 1-9. https://doi.org/10.1155/2021/5544664
21. Yüksek, I., & Karadayi, T. (2017). Energy-efficient building design in the context of building life cycle. In E. H. Yap (Ed.), *Energy efficient buildings* (pp. 93-123). IntechOpen. https://doi.org/10.5772/62592
22. Ander, G. D. (2016, 15 September). *Whole building design guide*: *Daylighting*. https://www.wbdg.org/resources/daylighting
23. Qahtan, A., Ebrahim, D., & Ahmed, H. (2020). energy-saving potential of daylighting in the Atria of Colleges in Najran University, Saudi Arabia. *International Journal of Built Environment and Sustainability*, *7*(1), 47-55. https://doi.org/10.11113/ijbes.v7.n1.421
24. Kateri, I., Vokas, G., Chondrakis, N., & Topalis, F. (2003, May). Energy savings by utilization of daylight in school buildings. In *Proceedings of Iluminat Conference 2003 2nd International Lighting Conference* (pp. 4-5), Cluj-Napoca, Romania. https://www.researchgate.net/publication/271514409_Energy_savings_by_utilization_of_daylight_in_school_buildings
25. Andersen, B., & Pettersen, P. (1996). *The benchmarking handbook*. Chapman & Hall.
26. Harvard Energy and Facilities (n.d.). *Energy benchmarking and auditing.* https://www.energyandfacilities.harvard.edu/green-building-resource/green-building-tools-resources/energy-benchmarking-and-auditing
27. Sharp, T. (1998). Benchmarking energy use in schools. In *ACEEE 1996 Summer Study of Energy Efficiency in Buildings* (pp. 305-316). American Council for an Energy Efficient Economy. https://www.aceee.org/files/proceedings/1998/data/papers/0325.PDF
28. Auvil, R. (2011, March 1). *Analyzing facility energy usage*. https://www.hpac.com/building-automation/article/20926916/analyzing-facility-energy-usage
29. Energy Star Portfolio Manager. (2018). *U.S. energy use intensity by property type*. Energy Star. https://portfoliomanager.energystar.gov/pdf/reference/US%20National%20Median%20Table.pdf
30. Sawle, Y., Gupta, S., & Kumar Bohre, A. (2016). PV-wind hybrid system: A review with case study. *Cogent Engineering*, *3*(1), 1189305. https://10.1080/23311916.2016.1189305
31. Shiroudi, A., Rashidi, R., Gharehpetian, G., Mousavifar, S., & Akbari Foroud, A. (2012). Case study: Simulation and optimization of photovoltaic-wind-battery hybrid energy system in Taleghan-Iran using HOMER software. *Journal of Renewable and Sustainable Energy, 4*(5), 053111. https://doi.org/10.1063/1.4754440
32. Ram, K., Swain, P., Vallabhaneni, R., & Kumar, A. (2021). Critical assessment on application of software for designing hybrid energy systems. *Materials Today: Proceedings, 49*(5), 425-432. https://doi.org/10.1016/j.matpr.2021.02.452

33. Freeman, J. M., DiOrio, N. A., Blair, N. J., Neises, T. W., Wagner, M. J., Gilman, P., & Janzou, S. (2018). *System Advisor Model (SAM) general description (Version 2017.9.5)*. National Renewable Energy Lab. https://doi.org/10.2172/1440404
34. Weber, J., Gao, D., & Gao, T. (2016, September 18-20). *Affordable mobile hybrid integrated renewable energy system power plant optimized using HOMER Pro*. The 2016 North American Power Symposium (NAPS), Denver, Colorado, USA. https://doi.org/10.1109/NAPS.2016.7747951
35. U.S. Energy information administration. (2022). *Natural Gas Spot Price*. https://www.eia.gov/dnav/ng/hist/rngwhhdm.htm
36. Global Petrol Prices. (2022). *Diesel prices*. https://www.globalpetrolprices.com/diesel_prices/