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Grid Integration of Renewable Technology: A Techno-economic Assessment

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Abstract The present study examines the prospect of supplying renewable energy to serve the load demand of the Centre for Satellite Technology Development building (8°58'30.263" N, 7°22'34.702" E) by using the HOMER simulation tool. Meteorological data was obtained from NASA database whereas other component costs were gotten from market research and open literatures. Several configurations were considered and comparison was made based on parameters such as total net present cost (NPC), cost of energy (COE), renewable fraction (RF) and CO_2 emission. According to the optimization results, it was observed that solar and wind energies could be harnessed in the built environment and that the grid-only supply system appears the most cost effective with the least NPC and COE. Moreover, the CO_2 emitted during this process was found to be high (611,763 kg/yr). On the other hand, 70% RF was found when 350 kW PV, 320 kW converter and 10 NPS100C-21 wind turbines were integrated into the existing grid. This configuration was found to have sold 115,605 kWh per year of energy to the grid and reduced the CO_2 emission by 78%.

Keywords: *HOMER, renewable energy, net present cost, grid, Nigeria*

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1. Introduction

Sustainable energy and energy security are amongst the greatest challenges the world faces at the advent of the twenty-first century. Existing power plants and decaying infrastructures are presently incapable of meeting the global energy demands. Currently, about 1.4 billion people, an equivalent of over 20% of the world’s population do not have access to electricity [1]. With continuous growth in population; increasing rapidly than anticipated, energy consumption grows daily and poses a real threat in the near future for both developing and industrialized countries of the world. With a population of over 150 million, the Nigerian perspective is quite disturbing, with incessant power outages ranging from 1-4 hours of electricity supply per day in some rural areas, to 5-20 hours in some urban settlements. For a country that generates below 5000 MW, it is pathetic to know that the government increased electricity tariff by 40%-45% effective February 1st, 2016 with little or no corresponding increment in supply. Meanwhile, the demand gets higher unabatedly with increasing population size. According to the Energy Information Administration, the total global electricity generation stood at 8027TWh in 1980, but increased to 17,363TWh in 2005. Also, in 1980, the installed capacity of power generation was 1945GW but increased to 3878GW in 2005 [2]. The International Energy Agency (IEA) envisaged that global energy demand will grow at a rate of 1.5% annually for a 20-year period starting from 2010. Within this time frame, fossil fuel resources are expected to be the driving force with a breakdown showing 53% of coal and 22% of oil [1]. Ironically, oil prices are falling with reserves depleting worldwide resulting to multinational firms shutting down oil wells and flow stations in different locations. Consequently, based on current rate of consumption, it is estimated that existing fossil fuels such as coal, oil and gas will be consumed in approximately 60 years’ time [3]. The health implication with constant burning of these fuels are also enormous, ranging from global warming caused by emissions of greenhouse gases, toxic waste to other atmospheric pollutants. Alternatively, the energy mix indicates that renewable energy resources, which is one of the twin pillars of sustainable energy, stands a good option in mitigating the hazardous environmental impact caused by burning these fuels in electricity generation, as well as play a significant role in lightening the load on the grid network by contributing substantial amount of energy in the process. These resources- solar, tidal, wave, geothermal, biomass and wind are readily available, predominantly abundant, clean, free of pollutants, and endless energy sources. Though advantageous, concerns have been raised on the unpredictability of these resources especially solar and wind. Modeling uncertainties emanating from their intermittency as a result of seasonal variations have made some school of taught on the other side of the divide to conclude that, energy generation through renewable sources is unreliable. With that being said, advancement in technology is gradually tackling the problems of uncertainties in renewable modeling using various approaches. The objective of this study does not include ways of tackling these uncertainties; however, research have shown that several techniques such as stochastic technique using probability density function (Monte Carlo and Point Estimation), fuzzy approach using membership function, robust optimization method using range of variation of the uncertain parameter and information gap decision theory (IGDT) [26,27,28] could largely be used to handle such uncertainties.

Different studies have been conducted on the possibility of harnessing renewable energy to compensate for grid electricity, and vice versa. Some of these systems are at the design and evaluation stage whereas others have been implemented [4]. It offers electric utility and environmental benefits, as well as customer benefits obtained by selling excess renewable electricity to the grid [5]. However, on the economic point of view, it is important that a technical feasibility and/or economic viability assessment be carried on such system before implementation, so as to justify the investment. Subhadeep and Anindita [6] did a techno-economic performance evaluation for power generation for a rice mill in Tripura, India. During the process, they made use of HOMER software to evaluate a configuration consisting of an existing grid, in addition to photovoltaic (PV)-biomass integration. With grid electricity price of 0.08 $/kWh, they found the cost of energy to be 0.143 $/kWh with renewable contribution of 91%. Similarly, [7] carried out a comparative study of stand-alone and grid connected renewable energy supply-based systems in some selected Islands (Crete, Rhodes, Skiros and Naxos) in Greece. They applied HOMER software in the optimization procedure in terms of achieving energy efficient system and concluded that grid connection is only recommended for sale of excess electricity and not as a backup source. Gang et al. [8] simulated a grid-connected PV system to supply residential power to 11 cities with different climatic conditions in Queensland, Australia. They concluded that the optimized system did not only meet the residential load of 23 kWh per day, but also the requirement of minimizing the total cost of system investment and electricity consumption during the lifespan of the system. In the same vein, [9] carried out an economic analysis of stand-alone and grid-connected cattle farm in four different locations in Spain. With daily load consumption of 63 kWh per day in the farm, they concluded that in locations with wind speed greater than 7.39 m/s and price of electricity of 0.192 €/kWh, it is profitable to apply a stand-alone system as long as the distance to the grid is higher than 7 km. Using MATLAB with hourly meteorological data, [10] did a techno-economic study for a grid connected PV power supply in Sohar, Oman. Their methodology was based on three important parameters- capacity factor (CF), yield factor (YF) and cost of energy (COE). With daily solar radiation of 6.182 kWh/m^2/d, their result showed that CF, YF and COE were 19.46%, 1696.6 kWh/kWp, and 0.158 $/kWh respectively, and that PV technology investment is very promising in the studied site.

Although the requisite skill and technical know-how in grid-renewable integration technology still lacks in Nigeria to a certain extent, the government did not relent in its effort in encouraging public-private partnership with incentives to boost energy generation through this means. Researchers, policy makers and electricity regulators under the Nigerian Electricity Regulatory Commission (NERC) recently came up with an approved scheme to promote renewable power investments in a bid to generate 2000 MW of electricity by 2020 [16,17]. This is a welcome development as similar schemes and programs such as feed-in-tariff (FIT) in the United Kingdom, renewable energy target (RET) scheme in Australia and green pricing (GP) in the United States, are already being implemented in motivating private investors. The present study attempts to explore the possibility of supplying renewable energy to meet the load demand of the Centre for Satellite Technology Development (CSTD) building. The building's electricity supply is currently from the grid, and efforts have been made in recent past on the prospects of utilizing the available renewable resources within the facility, with a view to integrating this energy into the grid. Owing to the location of the building, this work is limited to the exploration of solar and wind energy only. Using the HOMER simulation software tool, parameters such as net present cost (NPC), cost of energy (COE), renewable fraction (RF) and CO_2 emission are considered and analyzed comparatively as criteria for comparison.

2. Description of the Building

The CSTD building is an office complex situated within the premises of the National Space Research and Development Agency, along airport road in Abuja, Nigeria. It is a 3-storey block with a pent house and located at lat. 8°58'30.263" N & long. 7°22'34.702" E. It is rectangular in shape, was built and completed in 2013 and has a total floor area of approximately 800 m^2. Energy consumption is mainly from appliances such computers, printers, air conditioners, water dispensers, fridges, and electrical bulbs. More of energy usage and profile is discussed subsequently.

3. Software and Evaluation Criteria

3.1. Software Description

The energy tool used for this work is developed by the United States National Renewable Energy Laboratory, under the Department of Energy, and referred to as HOMER. It stands for Hybrid Optimization Model for Electric Renewable and is used to assist in the design of different power generation systems to include conventional and renewable systems. Configurations such as standalone, off grid, and grid-connected systems can be modeled to determine the most cost effective. Based on the input parameters such as solar radiation data, wind speed, load profile information, economic details of components, and controls, optimized results are displayed at the end of the simulation process with the optimal configuration having the lowest NPC after satisfying the constraints of the user [23]. The tool carries out hundreds of simulations in order to get the best possible design between demand and supply. Furthermore, in determining how certain fluctuating variables such as electricity price, solar radiation and wind speed variation, etc., will react or affect the entire configuration, sensitivity analysis can be performed to that effect.

3.2. Evaluation Criteria

Net Present Cost

This encompasses all cost associated within the life span of the project. It comprises of the initial, operational & maintenance and replacement cost of system's components. All other costs involved are incorporated in the NPC. It is given by the equation [11]:

$$\frac{TAC}{CRF} = NPC(\$) \tag{1}$$

Where *TAC* is the total annualized cost ($) and represents the sum of all annualized cost of each system component. *CRF* stands for the capital recovery factor and expressed as

$$\frac{i(1+i)^N}{(1+i)^N - 1} = CFR(\$) \tag{2}$$

Where *N* is the number of years and '*i*' is the annual real interest rate (%).

Cost of Energy

This represents the average cost per kilowatt hour of useful electrical energy produced by the system and expressed as [12]:

$$\frac{Ctot}{Etot} = COE \tag{3}$$

Where *Ctot* is the total annualized cost of the system ($/year) and *Etot* s the total electricity consumption per year (kWh/year).

Renewable Fraction

Renewable fraction (RF) is defined as the amount of power produced by renewable energy sources in comparison to the total electrical energy production of the system and is expressed by [13]:

$$\frac{Ep}{Ec} = RF \tag{4}$$

Where *Ep* is the total energy produced and *Ec* is the total energy consumed.

Capacity Shortage Fraction (CSF)

The CSF is referred to as the fraction of the total load in addition to the operating reserve that the system fails to supply [14]. It is basically the number of times in percentage in which the system is unable to meet the electrical requirement of the system in addition to the operating reserve.

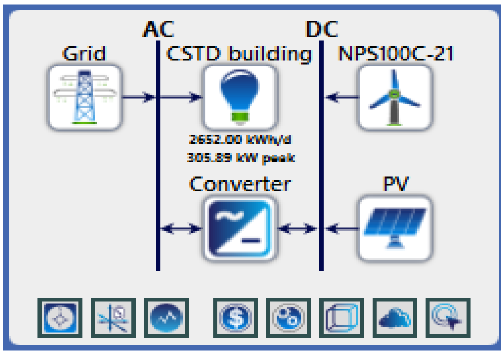


Figure 1. Schematic of the system

4. System Component and Input Data

The components of the system as seen in Figure 1 are solar PV cells to harness solar energy, wind turbines for wind energy, power converters for DC to AC conversion and the grid, which will act as a massive storage as well as supply option to meet energy demand when that generated by renewable sources is not enough.

4.1. Energy Demand and Meteorological Data

4.1.1. Load Profile

The facility's energy consumption is currently supplied from the national grid by the Abuja Electricity Distribution Company. The monthly electricity bill for previous years and 2015 were analyzed so as to estimate the daily load profile. Unfortunately, the bill does not contain energy consumption for a particular time period (hourly, monthly or yearly), rather an estimated charge to be paid monthly to include VAT and fixed charge. Furthermore, the building has no meter to determine the hourly or daily energy consumption. Therefore, ascertaining the energy consumption was done by onsite assessment of equipment with their energy ratings and estimated hours of usage. Electricity is mainly needed during daytime, except on weekends. Usage is high during working hours of 08:00-17:00 h with air conditioning taking the highest share. Minimum demand occurs between 19:00-06:00 h. Sources of electricity usage include computing, photocopying, printing, refrigeration and lighting. See Table 1 for equipment used in the office complex and their respective varying ratings.

Table 1. Electrical equipment used in the building

Equipment in use	Energy rating (W)
Desktop computer	500-820
Laptop	60-150
Split unit air conditioner	1118-1491
Floor standing air conditioner	3200
Printer/photocopying machine	400-730
Water dispenser	500-650
Refrigerator	80-160
Fluorescent light	40-1500

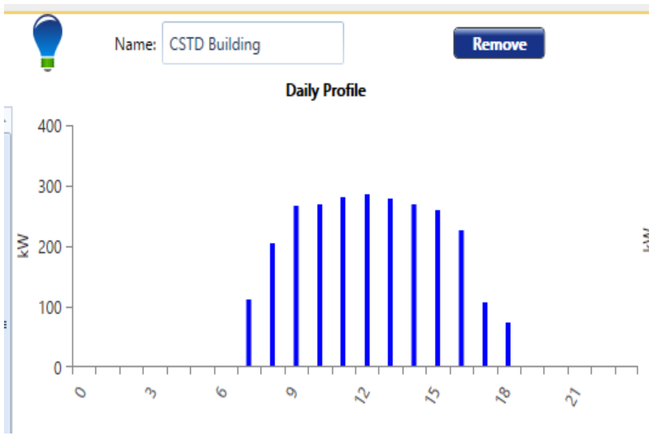


Figure 2. Daily load profile of the building

Since the hourly load profiles are not available for a complete year, HOMER synthesizes the load profiles in addition to random variables (day-to-day or time-step-to-time-step) by inserting a typical day's values. In this study, random variability factor of 2% each was respectively selected for both day-to-day and time-step-to-time-step randomness, which will carter for daily occurrence of differences in load profile over a year period. The average daily energy consumption of the facility as simulated by HOMER and seen in Figure 2 is 2652 kWh/d with peak demand of 306 kW.

4.1.2. Meteorological Data

Meteorological data for solar and wind were sourced from the NASA Surface Meteorological and Solar Energy database [18] by inputting the geographical coordinates of the data collection site; latitude 8⁰58'30.263" N and longitude 7⁰22'34.702" E. Information from this database are deemed reliable as different authors [19,20,21,22] have made use of it in their various studies. In addition to that, the same solar and wind resource information were derived when the latitude and longitude of the building coordinates were inputted into HOMER.

Solar Data

The solar data was automatically generated by inserting the building's coordinates into the NASA database. This data is depicted in Figure 3 and represents a 22-year monthly solar radiation. The solar radiation data can be seen on the left axis while the clearness index is on the right. The radiation is between 4.27 kWh/m^2/d and 6.11 kWh/m^2/d with annual average estimated at 5.36 kWh/m^2/d. Solar irradiance is high in the months of February and March, peaking at the latter, and then slightly dropped in the month of April with the least in August.

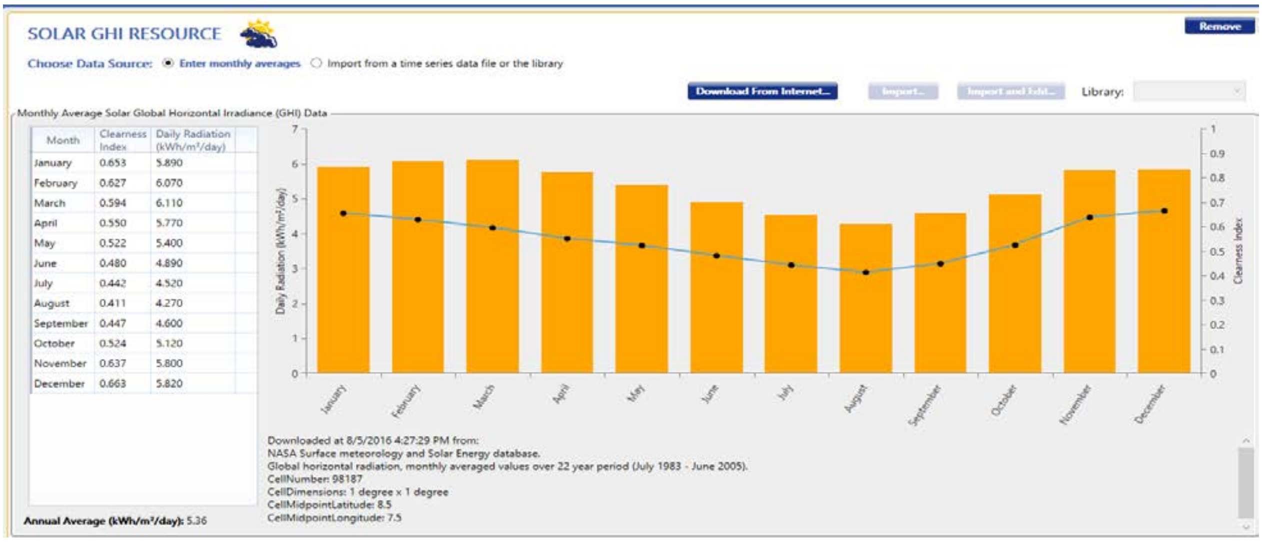


Figure 3. Solar data

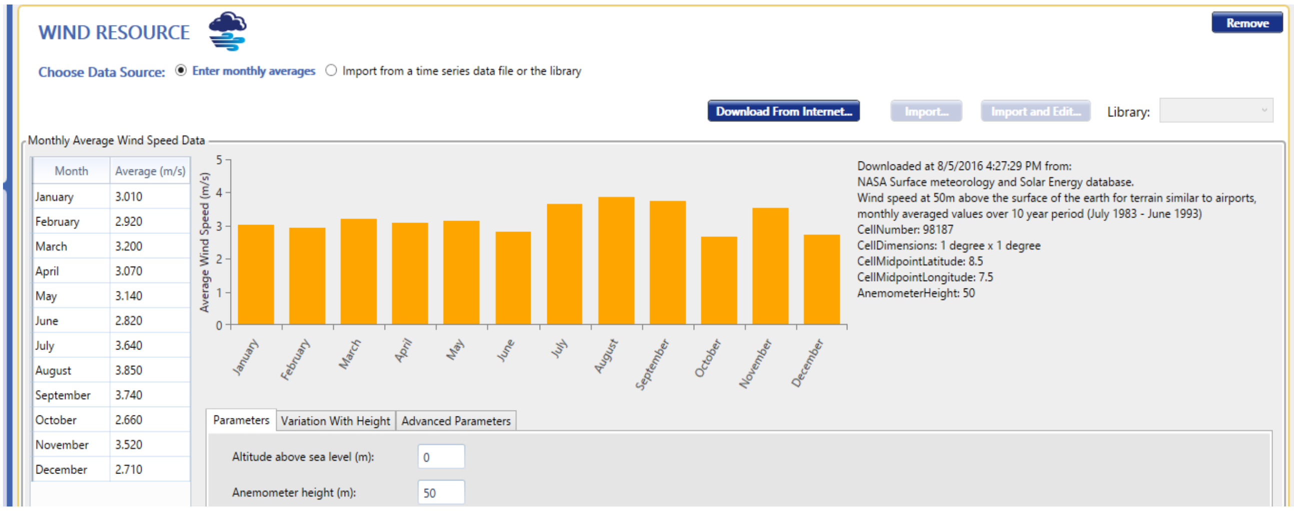


Figure 4. Wind data

Wind Data

The wind speed obtained from NASA database is a 10-year monthly average measured at an anemometer height of 50 m above the surface of the earth in the interval of 3 h as depicted in Figure 4. The wind speed ranges from 2.66 m/s to 3.85 m/s with annual average of 3.19m/s. Lowest wind speed can be found in October and December, fairly good wind in July and November and highest wind speed occurred between August and September.

4.2. Design Specification, Other Technical Details and Component Cost

4.2.1. The Grid and Energy Price

The grid is the system's component which acts as storage for a grid-connected system, and stores large amount of electricity. In this configuration, batteries are not necessarily needed. During the simulation, two prices of electricity are considered; the power price (the electricity price the utility company charges for energy purchased from the grid) and the sale-back rate (the amount the utility company pays for power being sold to the grid) [8]. The Nigerian power grid is managed and regulated by NERC with a tariff scheme known as the Multi-Year Tariff Order (MYTO). Under the MYTO, the CSTD building falls within category A3 applicable to customers such as agriculture and agro-allied industries, water boards, religious houses, government research institutes and educational establishments. The electricity purchase price in Nigerian Naira for this category is ₦23 per KWh which is equal to U.S dollar of $0.09/kWh (at exchange rate of ₦315 to $1). To the best of the authors' knowledge, there is no existing sale-back rate for energy end users in the country. Moreover, [5] stipulated that the sale-back rate is always made higher than the purchase price so that it can be profitable in selling electricity to the grid. In the same regard, [19] sale-back rate was four times the purchasing price and [8] sale-back rate was over twice its buying price. The sale-back rate for this study was assumed to be 2.5 times the purchase price, i.e ₦57.5/kWh equivalent to $0.225/kWh.

4.2.2. Wind Turbine

Kinetic energy of the blowing wind is converted into electrical power with the help of a wind turbine. The wind energy is dependent upon the hub height of the turbine and the wind speed. The wind speed varies proportionately with the height of the hub [7]. The power of the wind is given by:

$$Power\left(P\right)=\frac{1}{2}\rho*A*V^{3} \qquad (5)$$

ρ is the air density, V is the wind speed and A is the swept area of the rotor blades. For this study, NPS100C-21 wind turbine which is manufactured by Northern Power systems was selected. To allow for optimum sizing during the simulation, several units of the turbine (ranging between 1 and 10 were considered). Please refer to Table 2 for the estimated cost and other specifications of the selected turbine.

Table 2. Wind turbine information

Description	Details
Model	NPS100C-21
Rated power	100 kW
Installation or capital cost ($)	350,000
Replacement cost ($)	310,000
Operating & maintenance cost ($/yr)	750
Rotor	20.7m
Hub height	20m
Life time	20 years
Number of units considered	0, 5 & 10

4.2.3. PV Modules

Solar energy is converted into electricity through the modules. The PV system design starts with the known initial load and the available solar energy per unit area. The average daily solar energy (H_{ave}) for the built environment over a year period is estimated to be 5.36 kWh/m^2/d. Furthermore, the size of the PV array can be calculated using the equation below [24]:

$$A_{PV}=\frac{L_{el}}{H_{ave}*\eta_{PV}*\eta_{B}*\eta_{I}*T_{CF}} \qquad (6)$$

where; A_{PV} is the required area of PV array in m^2, L_{el} is the required electric load in kW h/d, H_{ave} is the average irradiation available per day in kW h/m^2/d, η_{PV} is the efficiency of PV panel in %, η_{B} is the battery efficiency in %, η_{I} is inverter efficiency in % and T_{CF} is the temperature correction factor normally taken as -0.4 to -0.5% per°C for crystalline silicon. The battery and inverter efficiency is generally taken to be 80% and 90%, respectively. The PV array power is given by [23]:

$$P_{solar}=P_{STC}\,f_{PV}\,(\frac{\bar{G}_{T}}{\bar{G}_{STC}})[1+\alpha_{P}(T_{C}-T_{C,STP})] \qquad (7)$$

where; P_{STC} is the output power of the panels in standard test conditions, f_{PV} is the derating factor, $\bar{G}_{T}$ is the solar radiation incident and $\bar{G}_{STC}$ is the radiation in standard test condition (1000 W/m^2). Based on market research and open literature values, the initial capital cost (ICC) of PV may vary from $4200 to $12 000 per kilowatt depending on the manufacturer [15]. In the present study, the ICC was assumed to be $5000. Please kindly refer to Table 3 for the operation & maintenance cost, as well as other details of the PV component.

Table 3. Technical and economic specification of the PV module

Description	Details
Rated capacity	1 kW
Installation or capital cost($/kW)	5000
Replacement cost ($/kW)	5000
Operating & maintenance cost ($/kW/yr)	10
Derating factor (%)	80
Nominal operating cell temperature	47
Efficiency at standard test condition	13
Temperature coefficient	-0.5%/□C
Sizes of PV varied (kW)	0-350
Life span	20 years

4.2.4. Power Converter

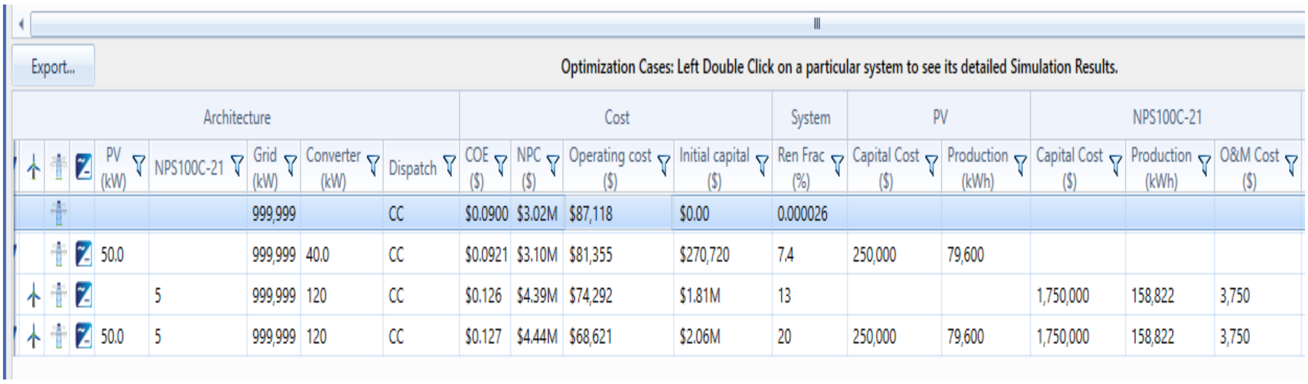
Power converter maintains energy flow between DC and AC buses. The converter selected for this study is rated 1 kW with an efficiency of 90% and estimated lifespan of 15 years. The size of converter considered was between 0 and 320 kW in an interval of 40, while the capital, replacement and operation & maintenance costs were taken as $518/kW, $ 518/kW and $ 0/kW/yr respectively [25].

5. Simulation Results and Discussion

The simulation was performed based on a project life of 20 years, inflation rate of 5% and annual capacity shortage of 4%. In addition, 10% of operating reserve was selected for the electric load, 25% and 50% were selected for solar and wind power outputs respectively. Figure 5 represents the optimization result as simulated by the software and categorized based on the NPC. It is observed in the highlighted portion (row1) that the cheapest configuration option is the use of the grid to supply electricity to meet the load demand of the building, without incorporating renewable components (referred to as grid-only). The NPC, cost of energy and operating cost of the configuration are respectively $ 3.02M, $0.09 /kWh and $ 87,118, with zero capital cost due to the absence of solar PV, converter and wind turbine. Energy yield analysis indicated that 967,980kWh per year of energy was purchased from the grid with no supply from the renewable components. The RF is practically zero percent with 611,763 kg/yr of CO_2 emitted during the process. Notwithstanding this configuration has the least NPC, harnessing the available wind and solar resources remains a vital part of the study. Still from the same figure, row 2 represents a configuration with only PV integration, row 3 represents that with only wind and row 4 has both PV and wind integration.

Grid-PV system

This system as seen in row 2 of figure 5 has a total NPC of $ 3.1M, total COE of $0.092 kWh/yr and $81,355 as operating cost. It produces 79,600 kWh/yr of solar energy with 50kW of PV panel and 40 kW converter rating, amounting to about 8.1% of the total electricity produced. The RF as a result of PV penetration is 7.4% with grid sale of 39 kWh per yr. Emission analysis during the process stood at 566,523 kg/yr of CO_2; 45,240 kg/yr less than the grid only system.



PV (kW)	NPS100C-21	Grid (kW)	Converter (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($)	Initial capital ($)	Ren Frac (%)	PV Capital Cost ($)	PV Production (kWh)	NPS100C-21 Capital Cost ($)	NPS100C-21 Production (kWh)	NPS100C-21 O&M Cost ($)
		999,999		CC	$0.0900	$3.02M	$87,118	$0.00	0.000026					
50.0		999,999	40.0	CC	$0.0921	$3.10M	$81,355	$270,720	7.4	250,000	79,600			
	5	999,999	120	CC	$0.126	$4.39M	$74,292	$1.81M	13			1,750,000	158,822	3,750
50.0	5	999,999	120	CC	$0.127	$4.44M	$68,621	$2.06M	20	250,000	79,600	1,750,000	158,822	3,750

Figure 5. Optimization result of the simulation

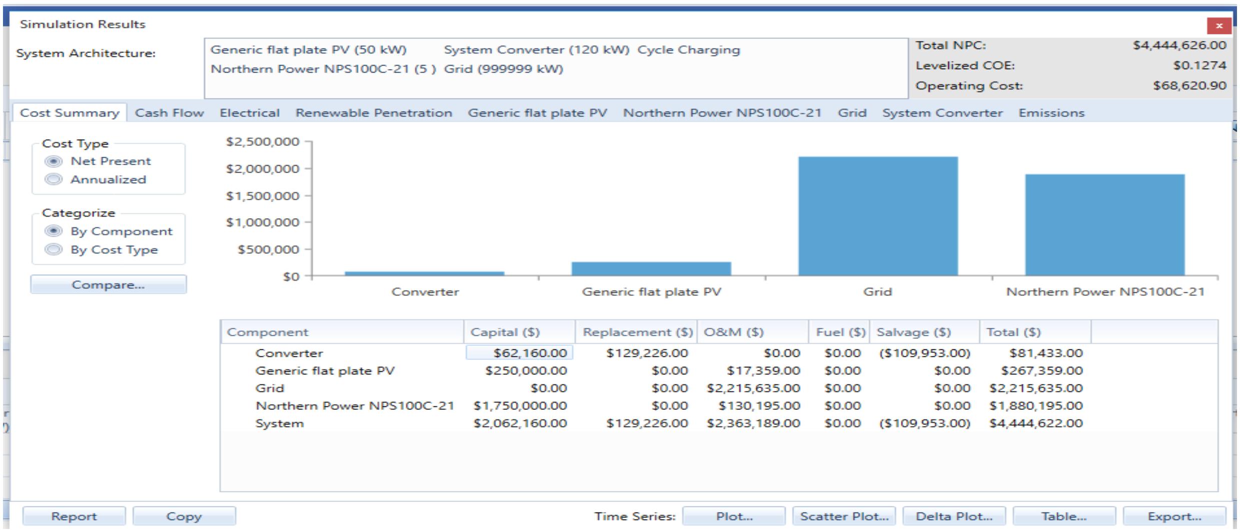


Figure 6. Cost summary of the grid-PV-wind system

Grid-wind turbine system

From row 3 in figure 5, the system required 5 NPS100C-21 wind turbines to produce 158,822 kWh/yr of electrical energy, i.e, approximately 15.5% of the total energy of 1,028,048 kWh/yr produced. Cost of energy of this configuration is $0.126 kWh/yr with operating cost of $74,292 and NPC totaling $4.39M. RF penetration from the wind turbine is 13% with 526,197 kg/yr of CO_2 emitted in the process.

Grid-PV-wind turbine system

This system comprised of 50 kW PV, 5 NPS100C-21 wind turbines, 120 kW converter and the grid as seen in row 4 of figure 5. The NPC, COE and operating cost are respectively $4.4M, 0.127 kWh/yr and $68,621. Despite the high installation cost of renewable components, one could see from the cost summary in figure 6 that the grid has the highest cost when comparing individual components, followed by wind turbines and then PV panels. Energy analysis showed that the renewable contribution is 20% with 79,600 kWh/yr of the total energy from PV and 158,822 kWh/yr; the wind turbines. Grid sale of this configuration is 36,814 kWh per year with emission resulting to 483,028 kg/yr of CO_2.

Configuration with highest renewable penetration

Figure 7 represents the configuration with the highest share of renewable energy for the grid-connected system. The highlighted portion shows that the system uses 350 kW PV, 320 kW converter and 10 NPS100C-21 wind turbines, in addition to the existing grid to produce total NPC and operating cost of $5.97M and $15,940 kWh/yr respectively. The initial capital cost is $5.42M while the cost of energy is $0.159/kWh. When one compares this configuration to that with grid supply only, it is found that this configuration has higher values of initial capital cost and NPC. This is as a result of the high initial installation cost of renewable components such as wind turbine(s), solar PV panel(s) and converter(s). Due to the high cost of these components, several governments recommended that incentives as well as subsidized rates should be given to private sector investors and energy end users so as to boost energy generation through renewable. All other components will operate throughout the lifespan of the project except the converter which needs to be replaced once in 20 years. Despite the fact that the COE per kWh of this configuration ($0.159/kWh) is almost twice as high as that of the grid only system ($0.09/kWh), the result in figure 7 shows that the operating cost in this configuration is about 5 times less than the grid only system, and that this configuration was able to supply 557,203 kWh/yr from PV and 317,643 kWh/yr from wind turbines resulting to about 70% renewable penetration to the total energy supplied as seen in figure 8. When this configuration is further compared to that with the grid only supply option which contributes one hundred percent of the energy, the result will be that this system contributes the highest share of clean energy which will typical reduce the amount of fossil fuels burnt in our power plants.

Architecture					Cost				System	PV		NPS100C-21			Converter	Grid	
PV (kW)	NPS100C-21	Grid (kW)	Converter (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($)	Initial capital ($)	Ren Frac (%)	Capital Cost ($)	Production (kWh)	Capital Cost ($)	Production (kWh)	O&M Cost ($)	Inverter Mean Output (kW)	Energy Purchased (kWh)	Energy Sold (kWh)
200	10	999,999	240	CC	$0.162	$5.92M	$37,436	$4.62M	51	1,000,000	318,401	3,500,000	317,643	7,500	61	518,077	88,005
300	10	999,999	320	CC	$0.159	$5.93M	$22,110	$5.17M	64	1,500,000	477,602	3,500,000	317,643	7,500	79	384,392	108,738
250	10	999,999	280	CC	$0.161	$5.95M	$30,291	$4.90M	58	1,250,000	398,001	3,500,000	317,643	7,500	70	446,181	94,047
350	10	999,999	320	CC	$0.159	$5.97M	$15,940	$5.42M	70	1,750,000	557,203	3,500,000	317,643	7,500	86	327,453	115,605
150	10	999,999	160	CC	$0.164	$5.97M	$47,174	$4.33M	41	750,000	238,801	3,500,000	317,643	7,500	49	613,472	79,017
	10	999,999	80.0	CC	$0.168	$5.97M	$70,071	$3.54M	18			3,500,000	317,643	7,500	22	837,442	58,530
200	10	999,999	200	CC	$0.164	$5.98M	$39,502	$4.60M	49	1,000,000	318,401	3,500,000	317,643	7,500	59	533,974	84,361
250	10	999,999	240	CC	$0.163	$5.99M	$32,244	$4.87M	57	1,250,000	398,001	3,500,000	317,643	7,500	68	457,187	88,948

Figure 7. Optimization result for the configuration with the highest share of renewable penetration

The total annual renewable energy production from this configuration is 874,846 kWh/yr with about 13% sold to the grid, and between 10-20% lost due to converter efficiency and wire losses. Monthly energy purchase and grid sale back as represented in figure 9 shows that the energy purchased is 327,453 kWh/yr with net value of 211,847 kWh/yr.

Comparing this configuration to the grid supply option, it will be observed that the energy purchased value from the grid reduce from 967,980 kWh/yr (grid supply only) to 327,453 kWh/yr (the present configuration) due to renewable energy supply, and emission analysis shows that CO_2 reduced from 611,763 kg/yr for the grid only, to 133,887 kg/yr for this system.

Simulation Results

System Architecture: Generic flat plate PV (350 kW) System Converter (320 kW) Cycle Charging
Northern Power NPS100C-21 (10) Grid (999999 kW)

Total NPC:	$5,969,179.00
Levelized COE:	$0.1587
Operating Cost:	$15,939.83

Cost Summary | Cash Flow | Electrical | Renewable Penetration | Generic flat plate PV | Northern Power NPS100C-21 | Grid | System Converter | Emissions

Production	kWh/yr	%
Generic flat plate PV	557,203	46.34
Northern Power NPS100C-21	317,643	26.42
Grid Purchases	327,453	27.24
Total	1,202,299	100.00

Consumption	kWh/yr	%
AC Primary Load	967,980	89.33
DC Primary Load	0	0.00
Grid Sales	115,605	10.67
Total	1,083,585	100.00

Quantity	kWh/yr	%
Excess Electricity	34,699.0	2.9
Unmet Electric Load	0.0	0.0
Capacity Shortage	0.0	0.0

Quantity	Value
Renewable Fraction	69.8
Max. Renew. Penetration	264.6

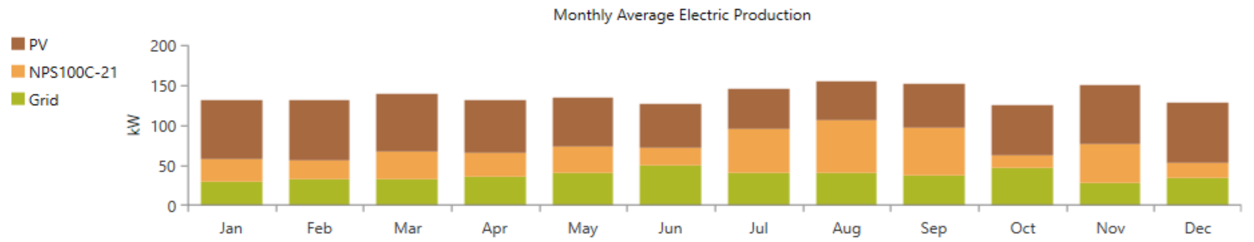


Figure 8. Electrical production for the configuration with the highest share of renewable penetration

Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Energy Purchased (kWh)	Peak Demand (kW)	Energy Charge ($)	Demand Charge ($)
May	30,428	9,324	21,104	253	$640.64	$0
June	36,561	5,364	31,197	268	$2,083.60	$0
July	30,019	14,998	15,021	265	($672.81)	$0
August	29,915	17,706	12,209	276	($1,291.50)	$0
September	26,749	15,183	11,566	271	($1,008.70)	$0
October	34,506	4,308	30,198	260	$2,136.30	$0
November	20,060	13,847	6,213	257	($1,310.30)	$0
December	26,153	5,068	21,084	257	$1,213.40	$0
Annual	327,453	115,605	211,847	278	$3,459.50	$0

Figure 9. Monthly purchased and sold enery

6. Concluding Remarks

An attempt was made in the present study to supply renewable energy to the CSTD building and integrate same into the national grid. Four parameters namely NPC, COE, RF and CO_2 emission were used for the purpose of technical and economic analysis. HOMER software tool using daily load profile and meteorological data was used for the simulation process. Different feasible configurations were obtained in the optimization result of the grid integrated system. Economic analysis indicated that the grid only supply option seemed to be the cheapest with its NPC about 1.9 times less than that with the highest share of renewable energy integration. Moreover, technical details showed that the energy purchased from the grid reduced by 61% as a result of renewable penetration and that the configuration with the highest renewable contribution (RF=70%) was able to sell back 115,605 kWh per year of energy to the grid. Furthermore, emission analysis indicated that the amount of CO_2 emitted reduced by 78% when comparison is made between the grid only system and that with the highest renewable penetration. This study has therefore shown that renewable energy (solar and wind) can be harnessed to meet the load demand of the built environment and reduce the overdependence on grid electricity supply.

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