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Research article

Environmental Impact Assessment and Carbon Credits of Power Generation Systems at a Data Centre

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Abstract

Energy consumption of using diesel to power data centers is a contributor to global greenhouse gas (GHG) emissions. This paper presents the comparative environmental impact assessment and carbon credits of a diesel and hybrid (PV/Wind/Diesel) power systems for data center. The datacenter is located in Abuja (FCT) at a location of 9° 00' N latitude and 7° 00' E longitude with annual average solar radiation of 5.45 kWh/m²/d whereas its annual average wind is 2.4m/s. The environmental impact assessment is based on theoretical model of the power stations using National Renewable Energy Laboratory's HOMER software. The proposed Hybrid (Solar & Wind) + Diesel Generator (DG) system was simulated using the model which results in four different topologies: Hybrid (Solar & Wind) + DG, Solar only + DG, Wind only + DG, and DG. The environmental impact and reduction (% renewable penetration into the existing diesel) in the total air pollutants were calculated and monetized (carbon credits). The result shows that the configuration with highest renewable penetration (52%) has the least environmental impact (41.594 tonnes) and highest carbon credit ($8100.772) when compared to diesel only option.

Keywords: Datacenter, Diesel Generator, Renewable energy, Environmental Cost, Carbon Credits, Greenhouse Gas (GHG), Simulation, Nigeria.

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1. Introduction

An Environmental Impact Assessment (EIA) is simply a study undertaken to understand the effect of a new development on the environment. An EIA is normally undertaken when there is a perception of the possibility that the proposed development may harm the environment [1]. An EIA may therefore be defined as a process of identifying, predicting, evaluating and mitigating the biophysical, social and other relevant effects of proposed projects and physical activities before major decisions and commitments are made [2].

In the context of the Telecommunication industry, the use of diesel generation system to power a datacenter is a development that can harm the environment. A datacenter contains primarily electronic equipment used for data processing (servers, switches, routers, data storage devices and related equipment used to operate the digital economy, data storage (storage equipment), and communications (network equipment) [3]. Collectively, this equipment processes, stores, and transmits digital information which is known as "information technology" (IT) equipment. Data centers also specialized power conversion and backup equipment (as to maintain reliable, high-quality power) as well as environmental control equipment (which maintain the proper temperature and humidity for the IT equipment). Datacenters are found in nearly every sector of the economy: financial services, media, high-tech, universities, government institutions, and many others use and operate datacenters to aid business processes, information management, and communications functions [4].

With the fluctuating grid power delivery system within the nation, most of these datacenters are not connected to the national grid but rather have generating sets that fully run on diesel on a twenty-four (24) hour basis and throughout the weeks, months and years. These generators, however, are associated with many problems. These include, among other things, the high operational cost, noise pollution emanating from the generators and environmental pollution. Diesel generators exhaust harmful hydrocarbons in the atmosphere during operations. The emissions of carbon and other products that come out from the diesel generators which are used to operate the datacenters are a serious threat to health, the environment and sustainable economic growth.

Renewable energy solutions have positive environmental effects. In Asia, the three large telecommunications providers namely: China Mobile, China Unicon and China Telecom have over 10,000 sites that operate without grid power [5]. If these telecoms companies were to use renewable energy as a primary energy resource, a carbon savings of 107,000 metric tons of CO_2 per year could be achieved [5]. In 2008, the GSM Association (GSMA) gathered nearly 800 worldwide mobile operators to launch a plan for deploying renewable energy sources for 118,000 new and existing base stations in developing countries to save 2.5 billion litres of diesel and cut CO_2 emission up to 6.3 million tons per year [6]. The Mcel initiative reports an overall annual saving over 5,000 tonnes of CO_2 by turning to solar power on several of its base stations. Namibia's largest mobile operator, MTC, swapped its diesel generator for a dual solar-wind power system in one pilot BTS which provides an annual saving of 4.58 tonnes CO_2 per year [7]. Also, in September 2008, the GSMA Green Power for Mobile Programme was launched to accelerate the use of green power in the mobile industry. It plans to install new and retro-fit 118,000 off-grid BTS in developing countries by 2012 [8]. Similarly, In April 2010 the government of India initiated a programme to promote solar power in the telecom sector. Under this programme, between 30% and 50% of the cost of solar retrofits will be subsidized [5]. Each of these programmes is a huge step towards green energy and carbon emission reduction in the telecommunication industry.

From the view point of cost and availability, using entirely renewable energy to power datacenters is still limited. However, hybridizing for example the diesel generator system with renewable energy sources like photovoltaic/or wind system will reduce the environmental impact and possibly cost. The purpose of this paper is to theoretically quantify the environmental impact and carbon credits of using a hybrid power system in a datacenter.

2. Materials and Method

2.1. Datacenter Power Requirement

The electric power needed for the datacenter equipment in and the energy required to remove heat from the datacenter are stated below [9].

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Table 1: Datacenter Power Requirement [9].

S/N	Datacenter Equipment Description	Rated Power Watt	BTU/Hr	QTY	Net Power in Watt/Hr	Net Power in BTU/Hr
1.	HP DL 380, G6 Servers	1000	3410	2	2000	6820
2.	CPU Servers	240	818	6	1440	4908
3.	Monitors	240	818	6	1440	4908
4.	Cisco Routers	50	171	1	50	171
5.	Cisco Switches	50	171	1	50	171
6.	PABX	240	818	1	240	818
7.	Vsat Modem	50	171	1	50	171
8.	Lighting	13	44	16	208	704
	TOTAL				5478	18671
9	Climate Equipment	3516	11989.56	1	3516	11989.56
	Grand Total				8994	30660.56

Datacenter Equipment power requirement =5, 478W/h
Climate Equipment power requirement = 3,516W/h
Therefore, the Total power requirement for Datacenter = 8.994W/h
Total power consumption for 24hrs=8,994x24
= 215,856W/d
= 216kW/d

For this work, we considered a datacenter situated at Abaji in Abuja (FCT), Nigeria being at a location of 9° 00' N latitude and 7° 00' E longitude with annual average solar radiation of 5.45 kWh/m²/d whereas its annual average wind is 2.4m/s. The data for solar resources were obtained from the NASA Surface Meteorology and Solar Energy web site [10]. Figure 1 and 2 show the solar and wind resource profile of Abuja (FCT) location tabulated in Table 2.

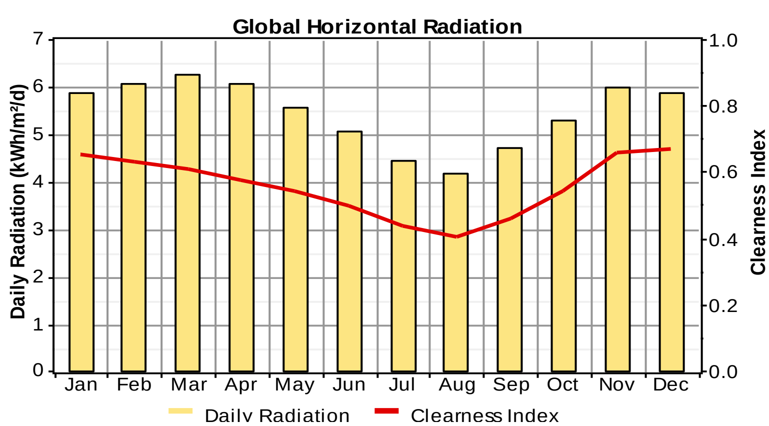

Figure 1: HOMER output graphic for solar average Radiation Profile for Abuja

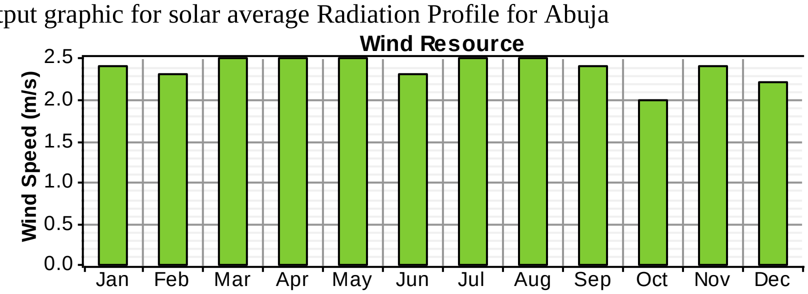

Figure 2: HOMER output graphic for Wind Speed Profile for Abuja

Table 2: Solar and wind Resources for Abuja, Nigeria [10].

Month	Clearness Index	Average Radiation ($kWh/m^2/day$)	Wind Speed (m/s)
Jan	0.652	5.880	2.4
Feb	0.630	6.090	2.3
Mar	0.610	6.270	2.5
Apr	0.577	6.060	2.5
May	0.539	5.580	2.5
Jun	0.497	5.060	2.3
Jul	0.434	4.440	2.5
Aug	0.404	4.190	2.5
Sep	0.460	4.730	2.4
Oct	0.542	5.310	2.0
Nov	0.655	5.980	2.4
Dec	0.668	5.860	2.2
Scaled annual average		**5.450**	**2.4**

For the HPS, we use a diesel generator that is hybridized with a PV and wind system. The details of the power generating set can be found in [1] and the weather conditions of Abuja are used as input data in the simulation software used for this study.

2.2. Model for Calculating Cost of Emissions

World governments are working rapidly to place a mandatory price on the emissions of greenhouse gases, including the carbon dioxide (CO_2) which is produced by the use of diesel fuel [11 - 13]. In future, businesses will be required to reduce emissions or buy offset credits to offset CO_2 emissions. There is general agreement that the price of emissions must rise to at least \$200 /t CO_2e [14] in order to have the desired effect of reducing the GHG emissions worldwide.

Many studies on the environmental impact of systems now use National Renewable Energy Laboratory (NREL)'s, Hybrid Optimization Model for Electric Renewable (HOMER). It contains a number of energy component models and evaluates suitable technology options based on emissions. The Hybrid Optimization Model for Electric Renewables (HOMER) software was used by [15 - 17] to find optimum sizing and minimizing cost and emission for power system with specific load demand in stand-alone applications. A simulation work on contaminating emissions (CO_2, NO_x and particles) of a diesel generator was presented by [18] using Simulink and comparing the results with those obtained by means of HOMER software. The equation for the calculation of cost of generated emissions stated by [1, 11 - 13] is as follows:

$$C_{emissions} = \frac{c_{CO_2} M_{CO_2} + c_{CO} M_{CO} + c_{UHC} M_{UHC} + c_{PM} M_{PM} + c_{SO_2} M_{SO_2} + c_{NO_X} M_{NO_X}}{1000} \quad (1)$$

Where:

c_{CO_2} = cost for emissions of CO_2 [\$/t]

c_{CO} = cost for emissions of CO [\$/t]

c_{UHC} =cost for emissions of unburned hydrocarbons (UHC) [\$/t]

c_{PM} =cost for emissions of particulate matter (PM) [\$/t]

c_{SO_2} =cost for emissions of SO_2 [$/t]

c_{NO_x} =cost for emissions of NO_x [$/t]

M_{CO_2} =annual emissions of CO_2 [kg/yr]

M_{CO} =annual emissions of CO [kg/yr]

M_{UHC} =annual emissions of unburned hydrocarbons (UHC) [kg/yr]

M_{PM} =annual emissions of particulate matter (PM) [kg/yr]

M_{SO_2} =annual emissions of SO_2 [kg/yr]

M_{NO_x} =annual emissions of NO_x [kg/yr]

2.3. Simulation and Optimization

Hybrid Optimization Model for Electric Renewables (HOMER) software was used for this work. HOMER has been used to conduct several investigations of hybrid systems in many locations around the world [14 - 22]. Wies et al presented a simulation work, using Simulink, of a real hybrid PV–diesel–battery system located in Alaska [18], comparing it with a system with only a diesel generator and another diesel–battery system to supply energy for the same load. Contaminating emissions were evaluated (CO_2, NO_x and particles) for the various cases, comparing the results with those obtained by means of HOMER software [19]. Additionally, the global efficiency of the system was determined. The results obtained indicate that the system with only a diesel generator had less efficient and released more contaminating emissions than the PV–Diesel–Battery system. Shaahid and El-Amin performed a techno-economic evaluation of PV/diesel/battery systems for rural electrification in Saudi Arabia [22]. They examined the effect of the increase in PV/battery on the operational hours of diesel generators and reduction in GHG emissions. HOMER is an optimization program based on energy (Cost and Environmental) calculations. The system architecture employed in the hybrid system is AC coupled where the solar PV, wind and the diesel generator all feed into the AC side of the network as depicted in Fig. 3. This is the network arrangement used for this study.

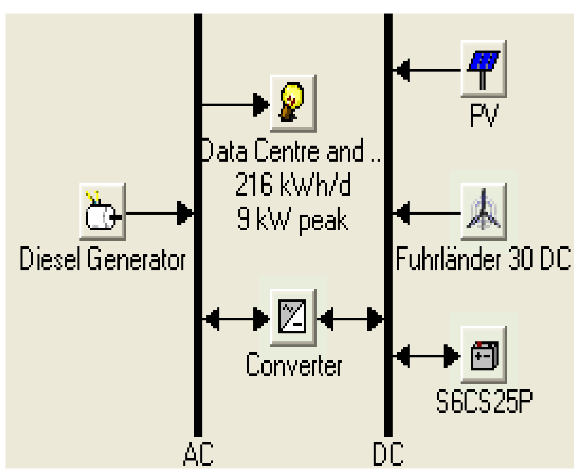

Figure 3: The network architecture for the HOMER simulator

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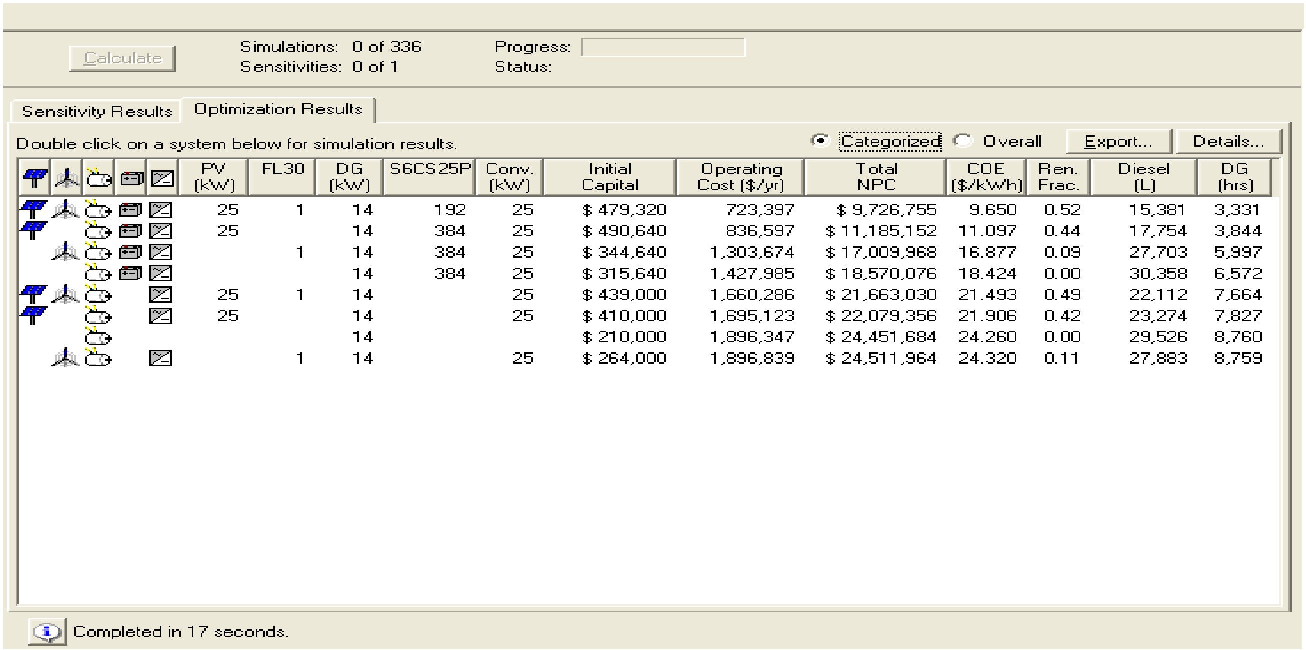
The detailed energy optimization results of Datacenter located in Abuja (FCT) is shown in Figure 4



PV (kW)	FL30	DG (kW)	S6CS25P	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
25	1	14	192	25	$ 479,320	723,397	$ 9,726,755	9.650	0.52	15,381	3,331
25		14	384	25	$ 490,640	836,597	$ 11,185,152	11.097	0.44	17,754	3,844
	1	14	384	25	$ 344,640	1,303,674	$ 17,009,968	16.877	0.09	27,703	5,997
		14	384	25	$ 315,640	1,427,985	$ 18,570,076	18.424	0.00	30,358	6,572
25	1	14		25	$ 439,000	1,660,286	$ 21,663,030	21.493	0.49	22,112	7,664
25		14		25	$ 410,000	1,695,123	$ 22,079,356	21.906	0.42	23,274	7,827
		14			$ 210,000	1,896,347	$ 24,451,684	24.260	0.00	29,526	8,760
	1	14		25	$ 264,000	1,896,839	$ 24,511,964	24.320	0.11	27,883	8,759

Figure 4: Optimization Results of Energy System for Datacenter Located in Abuja, FCT

3. Results and Discussion

Some of the most important environmental impact indices are fuel consumption and pollutant emissions. The hazards of diesel exhaust and fumes from the use of diesel generators can cause both serious health and environmental problems according to numerous resources [23 - 24]. Simulations with HOMER provide information concerning the Fuel consumption, environmental characteristics of the power system, such as the CO_2 emissions, and the results obtained are presented in tables 3 and 4**.** In the present work, the amount of possible pollutants arising from the use of diesel fuel in powering the data center was compared with the case of hybrid systems (PV/Wind/Diesel, PV/Diesel, and Wind/Diesel) and the results are presented in table 4. The detailed analyses obtained at the end of the simulation are described below as:

Environmental Pollutions

Hybrid (PV & Wind) + Diesel Generator

In PV/wind-diesel system, the diesel generator operates for 3,331h/annum with fuel consumption of 15,381L/annum as shown in table 2. This system emits 40.502 tonnes of CO_2, 0.1 tonnes of CO, 0.0111 tonnes of UHC, 0.00754 tonnes of PM, 0.0813 tonnes of SO_2, and 0.892 tonnes of NO_x annually into the atmosphere of the location under consideration as shown in figures 5, 6, 7, 8, 9, and 10, respectively.

PV only + Diesel Generator

In hybrid PV-diesel system, the diesel generator operates for 3,844h/annum has a fuel consumption of 17,754L/annum. This system emits 46.753 tonnes of CO_2, 0.115 tonnes of CO, 0.0128 tonnes of UHC, 0.0087 tonnes of PM, 0.0939 tonnes of SO_2, and 1.03 tonnes of NO_x annually into the atmosphere of the location under consideration as shown in figures 5, 6, 7, 8, 9, and 10, respectively.

Wind only + Diesel Generator

In hybrid wind-diesel system, the diesel generator operates for 5,997h/annum and has a fuel consumption of 27,703L/annum. This system emits 72.95 tonnes of CO_2, 0.18 tonnes of CO, 0.0199 tonnes of UHC, 0.0136 tonnes of PM, 0.146 tonnes of SO_2, and 1.607 tonnes of NO_x annually into the atmosphere of the location under consideration as shown in figures 5, 6, 7, 8, 9, and 10, respectively.

Diesel Generator

Diesel only system operates for 6,572h/annum has a fuel consumption of 30,358L/annum, and generates 79.942 tonnes of CO_2, 0.197 tonnes of CO, 0.0219 tonnes of UHC, 0.0149 tonnes of PM, 0.161 tonnes of SO_2, and 1.761 tonnes of NO_x as shown in figures 5, 6, 7, 8, 9, and 10, respectively.

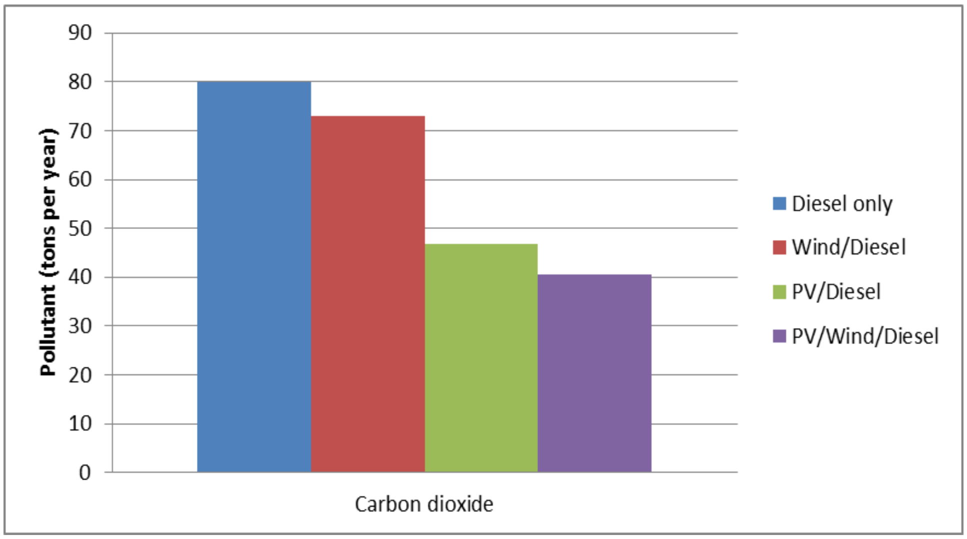


Figure 5: Carbon dioxide emitted by diesel only and diesel in hybrid Energy System

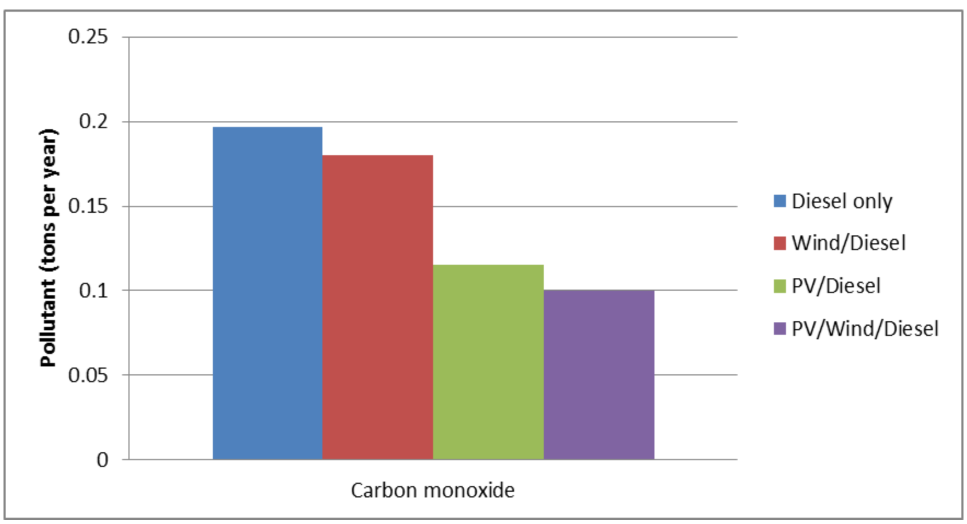


Figure 6: Carbon monoxide emitted by diesel only and diesel in hybrid Energy System

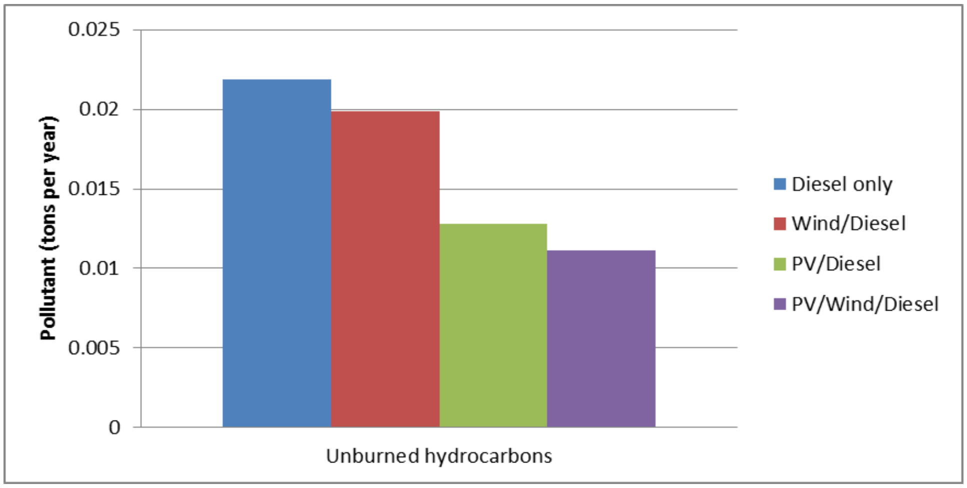


Figure 7: Unburned hydrocarbon emitted by diesel only and diesel in hybrid Energy System

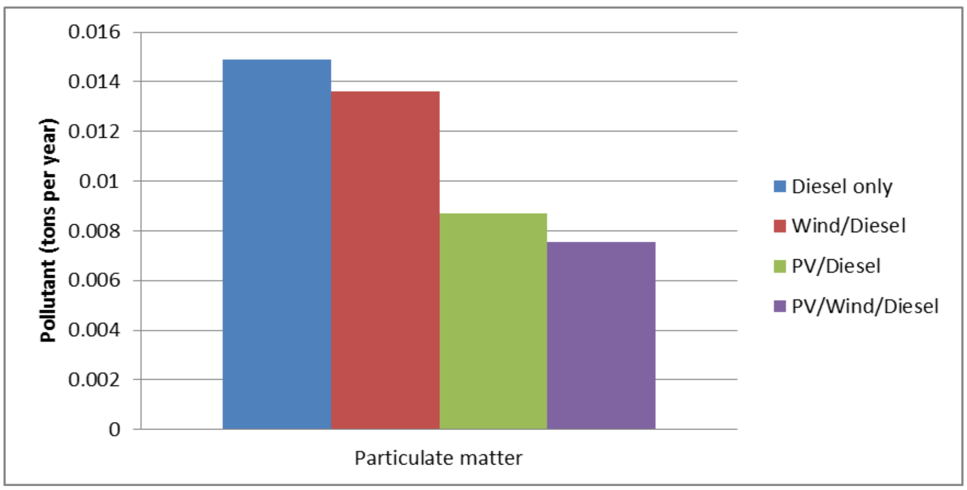


Figure 8: Particulate matter emitted by diesel only and diesel in hybrid Energy System

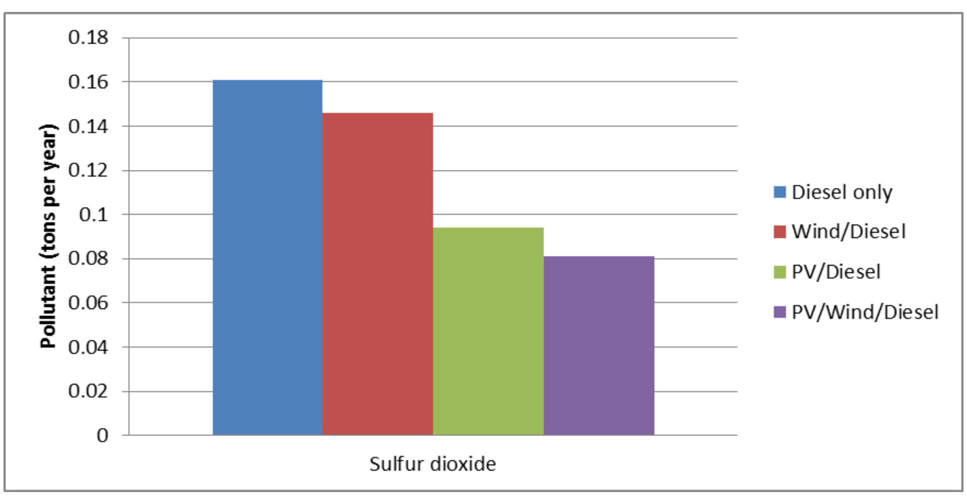


Figure 9: Sulfur dioxide emitted by diesel only and diesel in hybrid Energy System

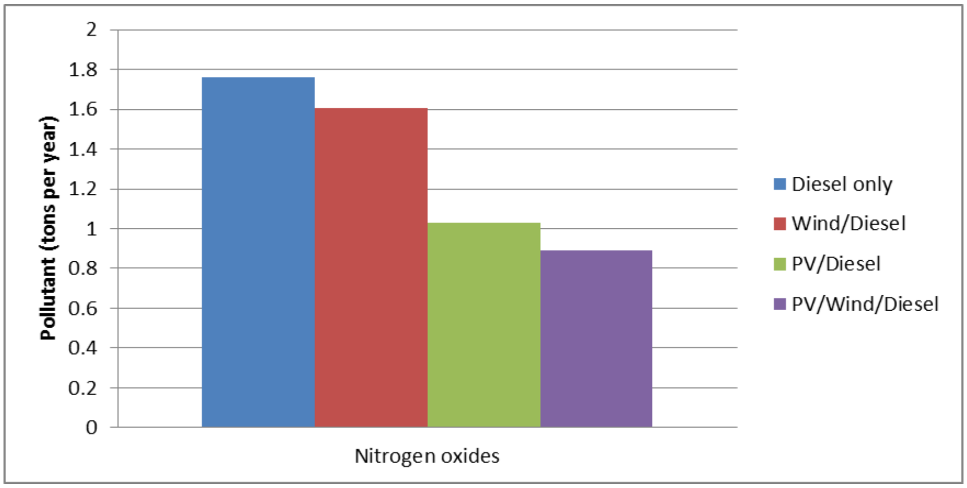


Figure 10: Nitrogen oxides emitted by diesel only and diesel in hybrid Energy System

Table 3: Comparison of simulation of Diesel in Hybrid system and Diesel only

Quantity	Units	Diesel only	Wind/Diesel	PV/Diesel	PV/Wind/Diesel
Hours of operation	hr/yr	6,572	5,997	3,844	3,331
Fuel consumption	L/yr	30,358	27,703	17,754	15,381

Environmental Costs

The $200/t price of emission giving by World governments was used in this study to cost the emissions. All costs are in USD ($) as shown in table 4. Taken the cost of emission of various pollutants to be the same and using Eq. (1), the cost of emissions were calculated and tabulated.

Table 4: Comparative Environmental Impact Assessment of a diesel and hybrid (PV/Wind/Diesel) power systems

Pollutant	**Cost of Emissions**							
	Diesel only		Wind/Diesel		PV/Diesel		PV/Wind/Diesel	
	(ton/yr)	$/t	(ton/yr)	$/t	(ton/yr)	$/t	(ton/yr)	$/t
Carbon dioxide	79.942	15988.4	72.95	14590	46.753	9350.6	40.502	8100.4
Carbon monoxide	0.197	39.4	0.18	36	0.115	23	0.1	20
Unburned hydrocarbons	0.0219	4.38	0.0199	3.98	0.0128	2.56	0.0111	2.22
Particulate matter	0.0149	2.98	0.0136	2.72	0.0087	1.74	0.00754	1.508
Sulfur dioxide	0.161	32.2	0.146	29.2	0.0939	18.78	0.0813	16.26
Nitrogen oxides	1.761	352.2	1.607	321.4	1.03	206	0.892	178.4
Total	82.0978	16419.56	74.9165	14983.3	48.0134	9602.68	41.59394	8318.788

Carbon Credit

In hybrid PV/Wind/Diesel system, the reduction (52% renewable penetration into the existing diesel) in different air pollutants were calculated and monetized (carbon credits) as the system has a total of $8100.772 carbon credits when compared to diesel only option; In hybrid PV/Diesel system, the reduction (44% renewable penetration into the existing diesel) in different air pollutants were calculated and monetized (carbon credits) as the system has a total of $6816.88

carbon credits when compared to diesel only option; In hybrid Wind/Diesel system, the reduction (9% renewable penetration into the existing diesel) in different air pollutants were calculated and monetized (carbon credits) as the system has a total of $1436.26 carbon credits when compared to diesel only option; In Diesel only system, the reduction (0% renewable penetration into the existing diesel) in different air pollutants were calculated and monetized (carbon credits) as the system has a total of $0 carbon credits when compared to diesel only option; as shown in figure 11.

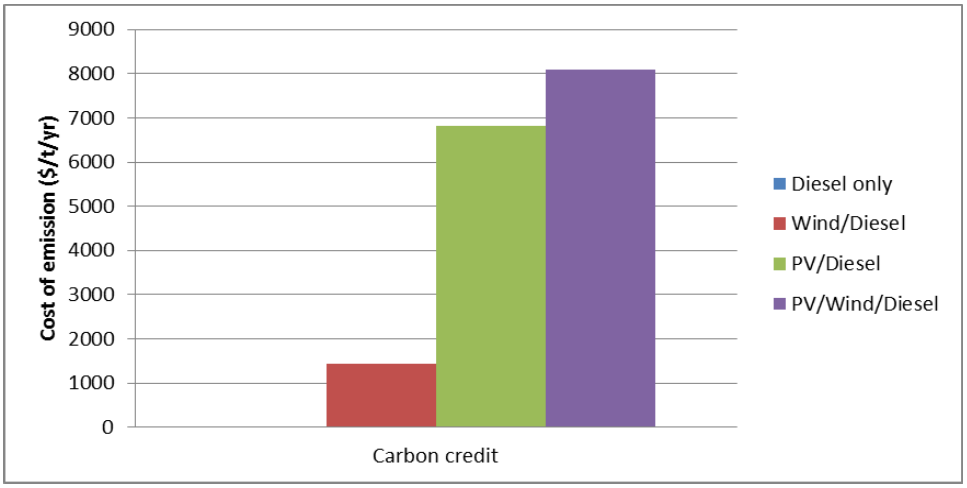


Figure 11: Carbon Credits of hybrid Energy Systems

4. Conclusions

We explored the possibility of utilizing Hybrid system (Solar PV/Wind/Diesel) to reduce the dependence on fossil fuel for power generation to meet the energy requirement of a datacenter located at Abaji (Abuja (FCT)), Nigeria. HOMER software was used to find the possible combination of the hybrid system (Solar PV/Wind/Diesel) and determine the optimum hybrid configuration.

In summary, the different configurations of power generation system PV/wind-diesel system, PV-diesel system, and Wind-diesel system have the ability for reducing the emissions emitted by diesel generator to 52%, 44% and 9%, respectively, thereby give an opportunity for carbon credits of $8100.772, $6816.88, and $1436.26, respectively.

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