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PERFORMANCE COMPARISON BETWEEN WIND TURBINE AND DIESEL FOR OFF-GRID ELECTRICITY GENERATION IN KANO-NIGERIA

[*1]Alhassan, Y., [2]Enaburekhan, J. S., [3] Rufai I. A.

[1] Department of Mechanical Engineering, Kano University of Science and Technology Wudil
[2,3]Department of Mechanical Engineering, Bayero University Kano

Corresponding authors email: yalhassan@yahoo.com

ABSTRACT

Grid electricity supply in Nigeria is inadequate and epileptic. Households and businesses use generators for electricity provision with wide-ranging negative impacts on the economy and environment. Wind as a renewable energy is an option to the use of generators in electricity generation. This study aims to compare the performance of an improved design wind turbine against a conventional wind turbine and a diesel generator for off-grid electricity generation in Kano, Nigeria. The annual energy production, levelized cost of electricity (LCOE) and net present value (NPV) were used for making comparison over a 20-year common life span for Polaris P10-20 turbine, PLEB turbine and a 20kW rated diesel generator. Diesel generator produced highest annual energy output of 61,320kWh against 22,145kWh and 24,159kWh for Polaris and PLEB turbines respectively. The diesel generator had least LCOE of \$0.14/kWh against \$0.37/kWh and \$0.27/kWh for Polaris and PLEB turbines respectively. The NPV of diesel generator is \$91,611 negative with no internal rate of return (IRR). It had \$90,000 negative cashflow and no payback. The Polaris turbine had negative NPV of \$21,386, IRR of 5.03% and could not payback its investment. PLEB turbine had positive NPV of \$10,838, IRR of 12.08% and payback period of 12 years. The study has shown that with right investment and environmental policies, deployment of wind turbines for electricity generation in Kano is viable.

Keywords: Diesel versus wind, Electricity generation in Kano, LCOE and NPV, Wind turbine investment, Annual energy production

INTRODUCTION

About 100 million Nigerians, representing around 60% of the country's population, have no access to grid electricity (Roche, 2017). The nation's grid electricity consumption per capita is 144 kWh, well below sub-Sahara Africa average of 480 kWh (Nextier Power, 2019). Even with recent improvement in generating capacity of 7000 megawatts and distribution capacity of 4600 MW, epileptic power situation in most parts of Nigeria persists because of factors such as increase in load growth, poor maintenance of existing transmission and distribution facilities and lack of adequate physical structure (Nkalo and Agwu, 2019).

This leaves the populace in businesses resorting to the use of generators as primary or supplementary source of electricity. Estimates of the number of small gasoline generators in Nigeria range from 17-60 million (Dalberg, 2019). Installed diesel generators for manufacturing exceed 728 000 kWh and telecommunication sector had estimated 24,252 diesel generators as at 2012. The telecommunications sector is one of the largest end users of diesel generators in Nigeria. Generators in the capacity range 10-30 KVA accounts for about 80 percent of the purchases in this end-user sector (World Bank, 2014).

The prolific use of generators has wide-ranging negative impacts on the environment, public health, and government budgets. Direct impact of the continued use of the generators include illness and death due to toxic fumes released, conflict with shift towards renewable energies and preventing Nigeria from achieving 45% GHG emission reduction by 2030 target set in Paris Accord. Indirect impact include poverty through high energy expenses, unsafe work environments and environmentally unsustainable infrastructure (Dalberg, 2019).

Renewable energies are viable option for a sustainable energy growth in Nigeria. Findings by Roche (2017) show that from an investor's perspective, onshore wind, biomass, and hydropower are currently competitive with coal and gas-fired power stations, despite investment risks being higher in Nigeria than the global average.

Wind power is a viable alternative to fossil fuels for electricity generation in Nigeria that can be implemented in stand-alone or hybrid settings. Nigeria has set a goal of producing 50 MW electricity through wind technology and 200 MW wind power for water pumping etc. by the year 2030 (Sambo, 2010). Various studies by Adaramola *et al* (2011), Adaramola and Oyewola (2011), Adekoya and Adewale (1992) and others have indicated viability and potential of wind energy application in Nigeria. Findings by Zailan *et al*. (2017), Olatomiwa *et al*. (2015), Bawah *et al*. (2013) and Saheb-Koussa *et al*. (2013) have indicated economic and environmental advantages of wind hybrid systems over stand-alone diesel generators in electricity production.

This study aims to compare the performance of an improved design wind turbine against a conventional wind turbine and a diesel generator for electricity generation in Kano, Nigeria. The performance criteria would be annual energy production, levelized cost of electricity (LCOE) and net present value (NPV) of investments made.

The study would give insight to the viability of small scale wind turbine application for power generation in Nigeria.

MATERIALS AND METHOD

Kano is located on latitude 12.00°N, longitude 8.31°E and at an elevation of 488m above sea level. It has on Sudan Savannah vegetation and semi-arid climate. Average wind speed of Kano as recorded (1990-2006) is 4.38m/s at 10m height (NIMET, 2009).

Three models for electricity generation in Kano were used: Polaris P10-20 turbine, PLEB turbine and 20kW diesel generator. P10-20 is a 20 kW, three-blade commercial turbine with 10m diameter blade. It has 36.6m hub height and 10m/s rated speed. PLEB turbine is a scale model sized to P10-20, designed and modeled with protuberant leading edge blade (PLEB). It was simulated at same hub height and rated wind speed as P10-20 from which a power coefficient of 0.502 was obtained. The diesel generator is 20kW rated generator with specifications attributed as obtained in literature.

Energy generation was evaluated as the annual energy production from expressions for capacity factor and average power as given by Akpinar and Akpinar (2005). The economic analysis of wind turbines and generator were carried out with levelized cost of electricity (LCOE) and net present value (NPV) methods. LCOE represents a constant cost per unit of generation computed to compare one unit's costs with other resources over similar periods. The LCOE model considers the current net present value of current and future annual costs. The NPV method takes into consideration the current value of the total cost and benefit of energy investment during entire lifespan of energy conversion system.

The performance of the wind turbines at Kano can be evaluated by the mean power output $P_{e,ave}$ over a period of time and the capacity factor C_f (representing the fraction of the mean power output to the rated power output of the turbine P_{eR}). $P_{e,ave}$ and C_f can be calculated using the following expressions based on the Weibull distribution function (Akpinar and Akpinar, 2005):

$$P_{e,ave} = P_{eR}\left(\frac{e^{-\left(\frac{U_r}{c}\right)^k} - e^{-\left(\frac{U_c}{c}\right)^k}}{\left(\frac{U_r}{c}\right)^k - \left(\frac{U_c}{c}\right)^k} - e^{-\left(\frac{U_f}{c}\right)^k}\right) \quad (1)$$

$$C_f = \frac{P_{e,ave}}{P_{eR}} \quad (2)$$

where U_r, U_c and U_f are the rated speed, cut-in speed and cut-off speed of the turbine respectively.

The accumulated annual energy output E_o is given by:

$$E_o = P_{e,ave} \times 8760\ (kWh) \quad (3)$$

To estimate costs involved in generating electricity over life span of a wind turbine, cost of electricity per kilowatt-hour is computed by comparing LCOE with PVC to examine the economic analysis of selected turbines.

Calculation of rated power

The rated power of PLEB turbines were calculated using the expression

$$P_{eR} = \eta_t \frac{1}{2}\rho A U_r^3 \quad (4)$$

Where η_t is the overall turbine efficiency given by:

$$\eta_t = c_p \eta_{gb} \eta_{gen} \eta_{con} \quad (5)$$

η_{gb}, η_{gen}, η_{con} are nominal gearbox, generator and conversion efficiencies respectively.

The calculation of rated power is based on the following assumptions:

i) Rated wind speed taken as 10m/s (same as that of Polaris P10-20)

ii) Nominal gearbox, generator and conversion efficiencies taken as average values given by Gundtoft (2009) for wind turbines

Then for PLEB turbine, from equation (5)

$$\eta_t = 0.502 \times 0.97 \times 0.96 \times 0.97 = 0.4534$$

From equation (4),

$$P_{eR} = 0.4534 \times \frac{1}{2} \times 1.225 \times \pi \times 5^2 \times 10^3 = 21.811\ kW$$

Calculation of capacity factor:

The capacity factor was calculated from the expression

$$C_f = \left(\frac{e^{-\left(\frac{U_r}{c}\right)^k} - e^{-\left(\frac{U_c}{c}\right)^k}}{\left(\frac{U_r}{c}\right)^k - \left(\frac{U_c}{c}\right)^k} - e^{-\left(\frac{U_f}{c}\right)^k}\right) \quad (6)$$

Where the Weibull parameters c and k for Kano wind speed were estimated using Energy Pattern Factor Method defined by (Akdaq and Dinler, 2009):

$$E_{pf} = \frac{\overline{v^3}}{\bar{v}^3} \quad (7)$$

$$k = 1 + \frac{3.69}{E_{pf}^2} \quad (8)$$

$$c = \frac{\bar{v}}{\Gamma\left(1 + \frac{1}{k}\right)} \quad (9)$$

The mean monthly wind speed for Kano over a 17-year period (1990-2006) obtained from NIMET.
From equations (7) to (9),

$$E_{pf} = \frac{169.107}{147.206} = 1.149$$

$$k = 1 + \frac{3.69}{1.149^2} = 3.795$$

$$c = \frac{5.28}{\Gamma\left(1 + \frac{1}{3.795}\right)} = 5.843$$

$$C_f = \frac{e^{-\left(\frac{10}{5.843}\right)^{3.795}} - e^{-\left(\frac{2.7}{5.843}\right)^{3.795}}}{\left(\frac{10}{5.843}\right)^{3.795} - \left(\frac{2.7}{5.843}\right)^{3.795}} - e^{-\left(\frac{25}{5.843}\right)^{3.795}} = 0.1264$$

Calculation of annual energy production:

To calculate the annual power of the two turbines for comparison, equations (2) and (3) were used.
For PLEB turbine,

$$E_o = C_f \times P_{eR} \times 8760 = 0.1264 \times 21.811 \times 8760 = 24{,}150\ kWh$$

Calculation of levelized cost of electricity (LCOE):

To compare LCOE of the benchmark turbine, PLEB turbine and a diesel generator, Excel was used to evaluation using the formula:

$$LCOE = \frac{cost\ over\ lifetime}{electrical\ energy\ produced\ over\ lifetime} = \frac{\sum_{t=1}^{n}\left(\frac{I_t + M_t}{(1+r)^t}\right)}{\sum_{t=1}^{n}\left(\frac{E_t}{(1+r)^t}\right)} \qquad (10)$$

Calculation of net present value (NPV):
The following formula was used in Excel to evaluate the NPVs of PLEB turbine, Polaris turbine and the diesel generator:

$$NPV = -I_o + \frac{C_1}{(1+r)} + \frac{C_2}{(1+r)^2} + \cdots + \frac{C_t}{(1+r)^t} \qquad (3.19)$$

Following assumptions were made in evaluation of LCOE and NPV in the application of the turbines for electricity generation in Kano:

i) Lifespan *n* of the turbine considered as 20 years
ii) Interest rate *r* and inflation rate *i* taken as 20% and 15% respectively
iii) Cost of turbine taken as $2660/kW for capacity above 20 kW and $3570/kW up to 20 kW capacity (Skarstein and Uhlen, 1989)
iv) Other initial costs (land, infrastructure, etc) assumed 30-50% of total initial cost for developing world (Manwell et al.,2009)
v) Annual operation and maintenance cost taken as 7% of initial capital cost.
vi) Scrap value taken as 0% of the turbine price and civil work (Stallard, 2012).

Following assumptions were made in evaluation of LCOE and NPV in the application of the diesel generator for electricity generation in Kano:

i) Lifespan *n* of the generator considered as 20 years
ii) Interest rate *r* and inflation rate *i* taken as 20% and 15% respectively
iii) The capital cost per kW for installed diesel generation in typical African country is taken as $600- an average of the costs given for different countries in studies by Deichmann et al. (2010), Lazard (2015), and Pauschert (2009)
iv) Capacity factor of 35% indicated for Sub-Saharan Africa (Baurzhan and Jenkins, 2017) was used.
v) Diesel consumption taken as 6.06 litres/hr and diesel cost at N240/litre
vi) Scrap value taken as 0% (Stallard, 2012).

RESULTS AND DISCUSSION

Table 1 shows comparison in annual energy production by the generating models. Diesel generator has the highest output due to higher capacity factor. The PLEB turbine has higher production than Polaris due to higher rated power derived from more optimal blade design for operating in relatively low wind speed regime in Kano.

Tables 2, 3 and 4 indicate the LCOE for diesel generator, Polaris and the PLEB turbines. The diesel generator had least LCOE of $0.14/kWh against $0.37/kWh and $0.27/kWh for Polaris and PLEB turbines respectively. The low initial capital expenditures and higher annual energy production accounted for diesel generator's advantage.

Tables 5, 6 and 7 show the breakdown of NPV for diesel generator, Polaris and PLEB turbines respectively. The NPV of diesel generator is $91,611 negative with no internal rate of return (IRR). This indicate for the life span of the generator, it would incur more costs than benefit. The cashflow as shown in Figure 1 show the costs outweighing the benefits over the life span. Figure 2 is indicating payback period would be well beyond the lifespan. At project end time, there would cumulative $90,000 negative cashflow.

The Polaris turbine indicated negative NPV of $21,386 but there IRR of 5.03%. The discounted cashflow in Figure 3 indicated negative cashflow of about $20,000 but there seemed a positive trend in payback in Figure 4. This indicated the project could pay back with a little extension of lifespan. The PLEB turbine had positive NPV of $10,838 and IRR of 12.08%. The cashflow in Figure 5 shows higher benefits compared to costs over time. The project could pay back within 12 years as shown in Figure 6.

So in terms of NPV, the PLEB turbine seems to be the best alternative.

Table 1: Energy production comparison of wind turbines and diesel generator

Electricity Source	Rated power (kW)	Capacity factor	Average power (kW)	Annual power (kWh)
Polaris Turbine	20.000	0.1264	2.528	22,145.28
PLEB Turbine	21.811	0.1264	2.757	24,150.54
Diesel Generator	20	0.35	7.00	61,320.00

Table 2: LCOE Calculation – Diesel generator

t (Years)	Discount Rate	Investment Cost ($)	Maintenance & Operations Cost ($)	Loan Interest Cost ($)	GHG Emission Cost ($)	Pollution/Health Impact Cost ($)	Sum of Costs over Lifetime ($/Lifetime)	Electricity Production (kWh)	Sum of Electrical Energy Produced over Lifetime (kWh/Lifetime)	LCOE ($/kWh)
0	0.098	13,000	-				13,000	-	-	
1		-	9,504	1,130	2,433	1,863	27,930	55,801	55,801	0.5005
2		-	8,655	1,015	2,215	1,697	41,513	55,801	111,602	0.3720
3		-	7,883	910	2,018	1,546	53,869	55,801	167,404	0.3218
4		-	7,179	814	1,838	1,408	65,108	55,801	223,205	0.2917
5		-	6,538	726	1,674	1,282	75,328	55,801	279,006	0.2700
6		-	5,955	646	1,524	1,168	84,621	55,801	334,807	0.2527
7		-	5,423	572	1,388	1,063	93,068	55,801	390,608	0.2383
8		-	4,939	505	1,264	968	100,746	55,801	446,410	0.2257
9		-	4,499	443	1,151	882	107,721	55,801	502,211	0.2145
10		-	4,097	386	1,049	803	114,056	55,801	558,012	0.2044
11		-	3,731	334	955	732	119,808	55,801	613,813	0.1952
12		-	3,398	286	870	666	125,028	55,801	669,614	0.1867
13		-	3,095	242	792	607	129,764	55,801	725,416	0.1789
14		-	2,819	201	722	553	134,058	55,801	781,217	0.1716
15		-	2,567	164	657	503	137,949	55,801	837,018	0.1648
16		-	2,338	129	598	458	141,473	55,801	892,819	0.1585
17		-	2,129	97	545	418	144,662	55,801	948,620	0.1525
18		-	1,939	67	496	380	147,544	55,801	1,004,422	0.1469
19		-	1,766	39	452	346	150,148	55,801	1,060,223	0.1416
20		-	1,609	13	412	315	152,497	55,801	1,116,024	0.1366
Total		13,000	90,065	8,719	23,053	17,660	152,497	1,116,024	1,116,024	0.1366
									In $/kW	1,196.99

Table 3: LCOE Calculation- Polaris P10-20

t (Years)	Discount Rate	Investment Cost ($)	Maintenance & Operations Cost ($)	Loan Interest Cost ($)	Sum of Costs over Lifetime ($/Lifetime)	Electricity Production (kWh)	Sum of Electrical Energy Produced over Lifetime (kWh/Lifetime)	LCOE ($/kWh)
0	0.098	71,400	-		71,400	-	-	
1		-	4,552	6,207	82,159	22,146	22,146	3.7099
2		-	4,146	5,576	91,880	22,146	44,292	2.0744
3		-	3,776	4,999	100,655	22,146	66,437	1.5150
4		-	3,439	4,472	108,565	22,146	88,583	1.2256
5		-	3,132	3,989	115,686	22,146	110,729	1.0448
6		-	2,852	3,548	122,086	22,146	132,875	0.9188
7		-	2,598	3,143	127,827	22,146	155,021	0.8246
8		-	2,366	2,773	132,966	22,146	177,166	0.7505
9		-	2,155	2,433	137,554	22,146	199,312	0.6901
10		-	1,962	2,121	141,637	22,146	221,458	0.6396
11		-	1,787	1,835	145,259	22,146	243,604	0.5963
12		-	1,628	1,571	148,458	22,146	265,750	0.5586
13		-	1,482	1,328	151,268	22,146	287,895	0.5254
14		-	1,350	1,105	153,723	22,146	310,041	0.4958
15		-	1,230	898	155,851	22,146	332,187	0.4692
16		-	1,120	707	157,678	22,146	354,333	0.4450
17		-	1,020	531	159,228	22,146	376,479	0.4229
18		-	929	367	160,524	22,146	398,625	0.4027
19		-	846	214	161,584	22,146	420,770	0.3840
20		-	770	72	162,426	22,146	442,916	0.3667
Total		**71,400**	**43,138**	**47,888**	**162,426**	**442,916**	**442,916**	**0.3667**
							In $/kW	**3,212.47**

Table 4: LCOE Calculation- PLEB wind turbine

t (Years)	Discount Rate	Investment Cost ($)	Maintenance & Operations Cost ($)	Loan Interest Cost ($)	Sum of Costs over Lifetime ($/Lifetime)	Electricity Production (kWh)	Sum of Electrical Energy Produced over Lifetime (kWh/Lifetime)	LCOE ($/kWh)
0	0.098	58,015	-		58,015	-	-	
1		-	3,699	5,043	66,756	24,146	24,146	2.7647
2		-	3,368	4,530	74,655	24,146	48,291	1.5459
3		-	3,068	4,062	81,785	24,146	72,437	1.1291
4		-	2,794	3,633	88,212	24,146	96,582	0.9133
5		-	2,545	3,241	93,998	24,146	120,728	0.7786
6		-	2,318	2,883	99,199	24,146	144,873	0.6847
7		-	2,111	2,554	103,863	24,146	169,019	0.6145
8		-	1,922	2,253	108,039	24,146	193,165	0.5593
9		-	1,751	1,977	111,766	24,146	217,310	0.5143
10		-	1,594	1,723	115,084	24,146	241,456	0.4766
11		-	1,452	1,491	118,027	24,146	265,601	0.4444
12		-	1,323	1,276	120,626	24,146	289,747	0.4163
13		-	1,204	1,079	122,910	24,146	313,892	0.3916
14		-	1,097	898	124,904	24,146	338,038	0.3695
15		-	999	730	126,633	24,146	362,184	0.3496
16		-	910	575	128,118	24,146	386,329	0.3316
17		-	829	431	129,378	24,146	410,475	0.3152
18		-	755	298	130,430	24,146	434,620	0.3001
19		-	687	174	131,292	24,146	458,766	0.2862
20		-	626	59	131,976	24,146	482,911	0.2733
Total		**58,015**	**35,051**	**38,911**	**131,976**	**482,911**	**482,911**	**0.2733**
							In $/kW	**2,394.05**

Table 5: Net Present Value for Diesel Generator

Fiscal Year	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038
Undiscounted Flows																					
Costs	-$13,000	-$16,393	-$16,376	-$16,357	-$16,335	-$16,311	-$16,284	-$16,253	-$16,219	-$16,180	-$16,136	-$16,086	-$16,030	-$15,967	-$15,896	-$15,817	-$15,727	-$15,625	-$15,511	-$15,382	-$15,237
Benefits	$0	$7,409	$7,352	$7,296	$7,240	$7,185	$7,131	$7,077	$7,023	$6,970	$6,918	$6,866	$6,815	$6,764	$6,713	$6,663	$6,614	$6,565	$6,517	$6,469	$6,421
Net Cash Flow	-$13,000	-$8,984	-$9,023	-$9,061	-$9,095	-$9,126	-$9,153	-$9,176	-$9,195	-$9,209	-$9,218	-$9,220	-$9,216	-$9,204	-$9,183	-$9,153	-$9,113	-$9,060	-$8,994	-$8,914	-$8,816
Discount Factors																					
Discount Rate	9.8%																				
Base Year	2018																				
Year Index	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Discount Factor	1.0000	0.9107	0.8295	0.7554	0.6880	0.6266	0.5707	0.5197	0.4733	0.4311	0.3926	0.3576	0.3257	0.2966	0.2701	0.2460	0.2241	0.2041	0.1858	0.1693	0.1542
Discounted Flows																					
Costs	-$13,000	-$14,930	-$13,583	-$12,356	-$11,239	-$10,221	-$9,293	-$8,447	-$7,677	-$6,975	-$6,335	-$5,752	-$5,220	-$4,736	-$4,294	-$3,891	-$3,524	-$3,189	-$2,883	-$2,604	-$2,349
Benefits	$0	$6,748	$6,098	$5,512	$4,981	$4,502	$4,069	$3,678	$3,324	$3,005	$2,716	$2,455	$2,219	$2,006	$1,813	$1,639	$1,482	$1,340	$1,211	$1,095	$990
Net	-$13,000	-$8,182	-$7,485	-$6,845	-$6,257	-$5,718	-$5,223	-$4,769	-$4,353	-$3,970	-$3,619	-$3,297	-$3,001	-$2,730	-$2,481	-$2,252	-$2,042	-$1,849	-$1,672	-$1,509	-$1,359
Cumulative	-$13,000	-$21,182	-$28,666	-$35,511	-$41,768	-$47,486	-$52,710	-$57,479	-$61,832	-$65,802	-$69,421	-$72,718	-$75,719	-$78,449	-$80,929	-$83,181	-$85,223	-$87,072	-$88,744	-$90,252	-$91,611
Net Present Value	($91,611)																				
Internal Rate of Return	#NUM!																				

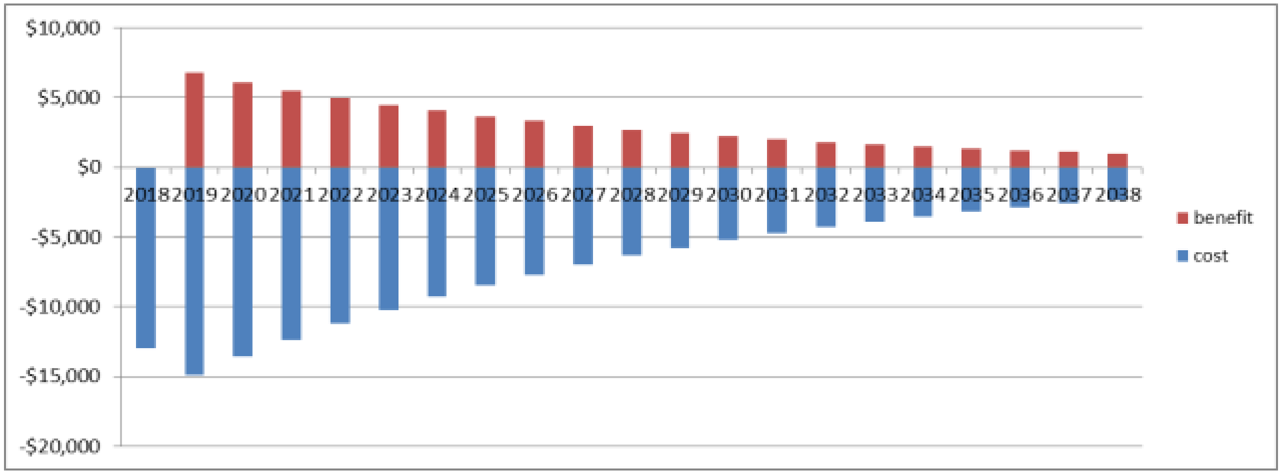

Fig. 1: Discounted cashflow for diesel generator

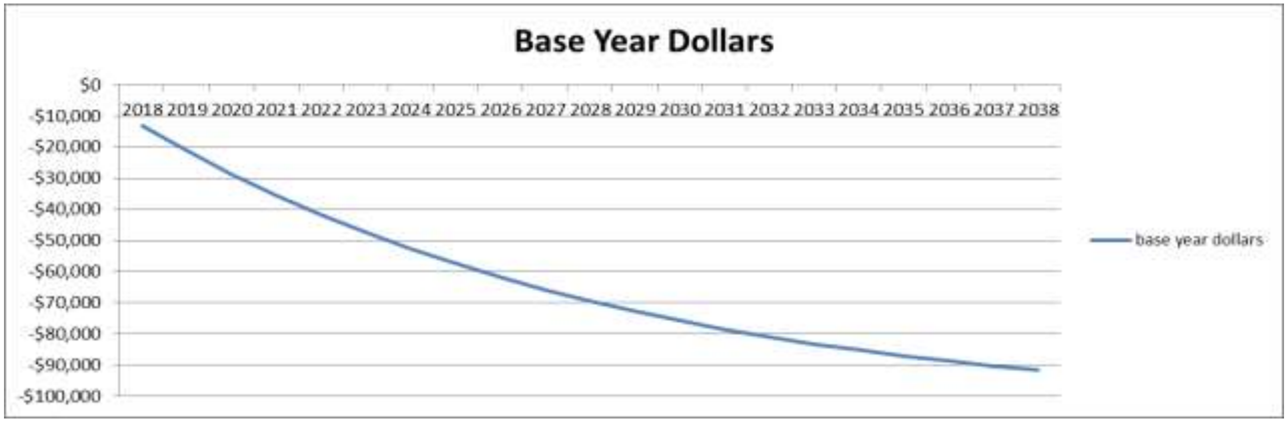

Fig. 2: Payback period for diesel generator

Table 6: Net Present Value for Polaris P10-20

	Fiscal Year																				
	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038
Undiscounted Flows																					
Costs	-$71,400	-$11,813	-$11,720	-$11,615	-$11,498	-$11,365	-$11,215	-$11,046	-$10,856	-$10,642	-$10,400	-$10,128	-$9,822	-$9,477	-$9,087	-$8,649	-$8,155	-$7,598	-$6,970	-$6,263	-$5,467
Benefits	$0	$15,738	$15,825	$15,914	$16,003	$16,093	$16,184	$16,276	$16,369	$16,463	$16,557	$16,653	$16,750	$16,847	$16,946	$17,045	$17,146	$17,247	$17,350	$17,453	$17,558
Net Cash Flow	-$71,400	$3,925	$4,105	$4,298	$4,505	$4,728	$4,969	$5,230	$5,513	$5,821	$6,157	$6,524	$6,928	$7,371	$7,858	$8,396	$8,991	$9,649	$10,379	$11,190	$12,091
Discount Factors																					
Discount Rate	9.8%																				
Base Year	2018																				
Year Index	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Discount Factor	1.0000	0.9107	0.8295	0.7554	0.6880	0.6266	0.5707	0.5197	0.4733	0.4311	0.3926	0.3576	0.3257	0.2966	0.2701	0.2460	0.2241	0.2041	0.1858	0.1693	0.1542
Discounted Flows																					
Costs	-$71,400	-$10,759	-$9,721	-$8,775	-$7,910	-$7,121	-$6,400	-$5,741	-$5,139	-$4,588	-$4,083	-$3,622	-$3,199	-$2,811	-$2,455	-$2,128	-$1,827	-$1,550	-$1,295	-$1,060	-$843
Benefits	$0	$14,333	$13,127	$12,022	$11,010	$10,084	$9,236	$8,459	$7,748	$7,097	$6,501	$5,955	$5,455	$4,997	$4,577	$4,193	$3,842	$3,519	$3,224	$2,954	$2,707
Net	-$71,400	$3,575	$3,405	$3,247	$3,100	$2,963	$2,836	$2,718	$2,609	$2,509	$2,417	$2,333	$2,256	$2,186	$2,123	$2,066	$2,015	$1,969	$1,929	$1,894	$1,864
Cumulative	-$71,400	-$67,825	-$64,420	-$61,173	-$58,073	-$55,110	-$52,275	-$49,557	-$46,947	-$44,438	-$42,020	-$39,687	-$37,431	-$35,245	-$33,122	-$31,057	-$29,042	-$27,073	-$25,144	-$23,250	-$21,386
Net Present Value	($21,386)																				
Internal Rate of Return	5.93%																				

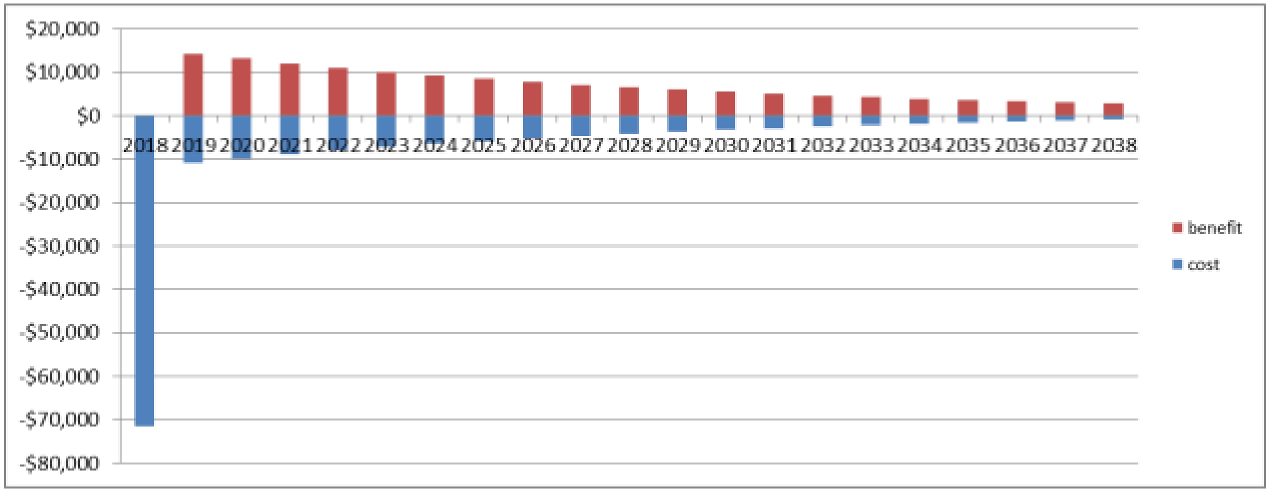

Fig. 3: Discounted cashflow for Polaris P10-20

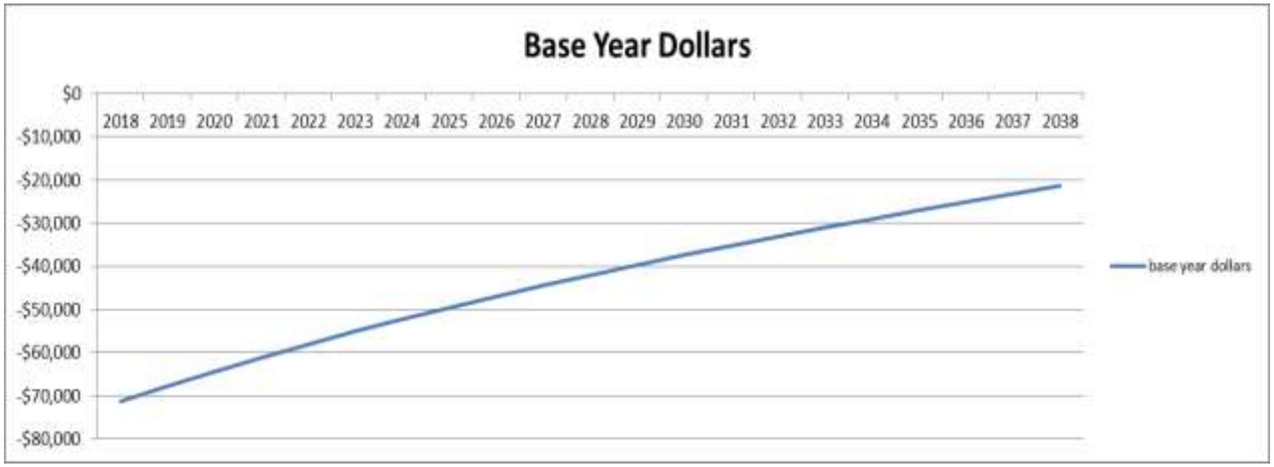

Fig. 4: Payback period for Polaris P10-20

Table 7: Net Present Value for PLEB Wind Turbine

	Fiscal Year																				
	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038
Undiscounted Flows																					
Costs	-$58,015	-$9,598	-$9,523	-$9,438	-$9,342	-$9,234	-$9,112	-$8,975	-$8,821	-$8,647	-$8,451	-$8,230	-$7,981	-$7,700	-$7,384	-$7,027	-$6,626	-$6,173	-$5,664	-$5,089	-$4,442
Benefits	$0	$15,944	$16,031	$16,119	$16,209	$16,299	$16,390	$16,482	$16,574	$16,668	$16,763	$16,858	$16,955	$17,053	$17,151	$17,251	$17,351	$17,453	$17,555	$17,659	$17,763
Net Cash Flow	-$58,015	$6,345	$6,508	$6,681	$6,866	$7,065	$7,277	$7,506	$7,753	$8,021	$8,312	$8,629	$8,974	$9,353	$9,767	$10,223	$10,725	$11,279	$11,892	$12,570	$13,322
Discount Factors																					
Discount Rate	9.8%																				
Base Year	2018																				
Year Index	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Discount Factor	1.0000	0.9107	0.8295	0.7554	0.6880	0.6266	0.5707	0.5197	0.4733	0.4311	0.3926	0.3576	0.3257	0.2966	0.2701	0.2460	0.2241	0.2041	0.1858	0.1693	0.1542
Discounted Flows																					
Costs	-$58,015	-$8,742	-$7,899	-$7,130	-$6,427	-$5,786	-$5,200	-$4,665	-$4,175	-$3,728	-$3,318	-$2,943	-$2,599	-$2,284	-$1,995	-$1,729	-$1,485	-$1,260	-$1,053	-$861	-$685
Benefits	$0	$14,521	$13,297	$12,177	$11,152	$10,213	$9,353	$8,566	$7,845	$7,186	$6,581	$6,028	$5,522	$5,058	$4,633	$4,244	$3,888	$3,561	$3,263	$2,989	$2,738
Net	-$58,015	$5,779	$5,398	$5,047	$4,724	$4,427	$4,153	$3,901	$3,670	$3,458	$3,264	$3,085	$2,923	$2,774	$2,638	$2,515	$2,403	$2,302	$2,210	$2,128	$2,054
Cumulative	-$58,015	-$52,236	-$46,838	-$41,790	-$37,066	-$32,640	-$28,487	-$24,585	-$20,915	-$17,457	-$14,194	-$11,108	-$8,186	-$5,412	-$2,773	-$258	$2,145	$4,447	$6,657	$8,784	$10,838
Net Present Value	$10,838																				
Internal Rate of Return	12.08%																				

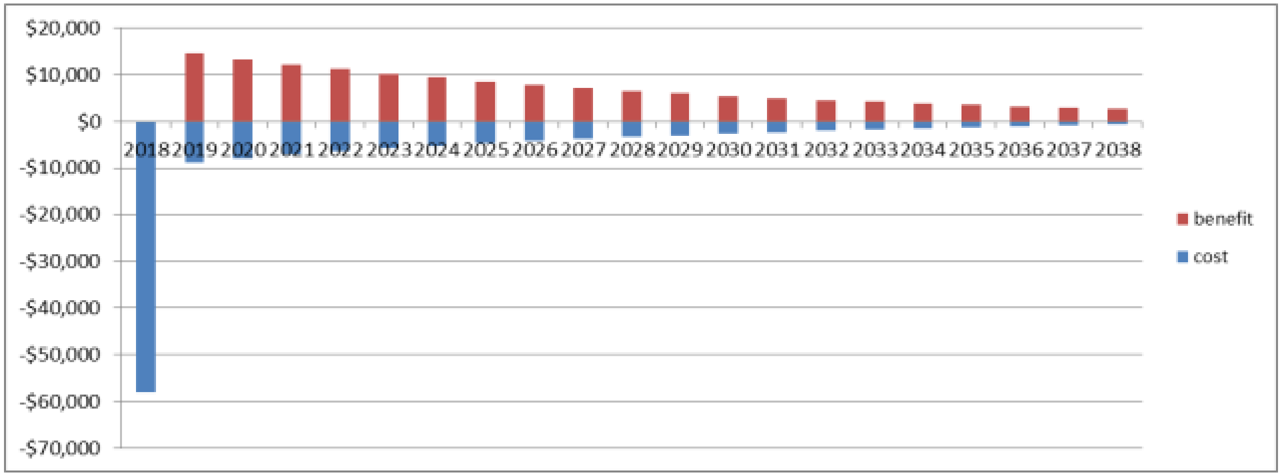

Fig. 5: Discounted cashflow for PLEB wind turbine

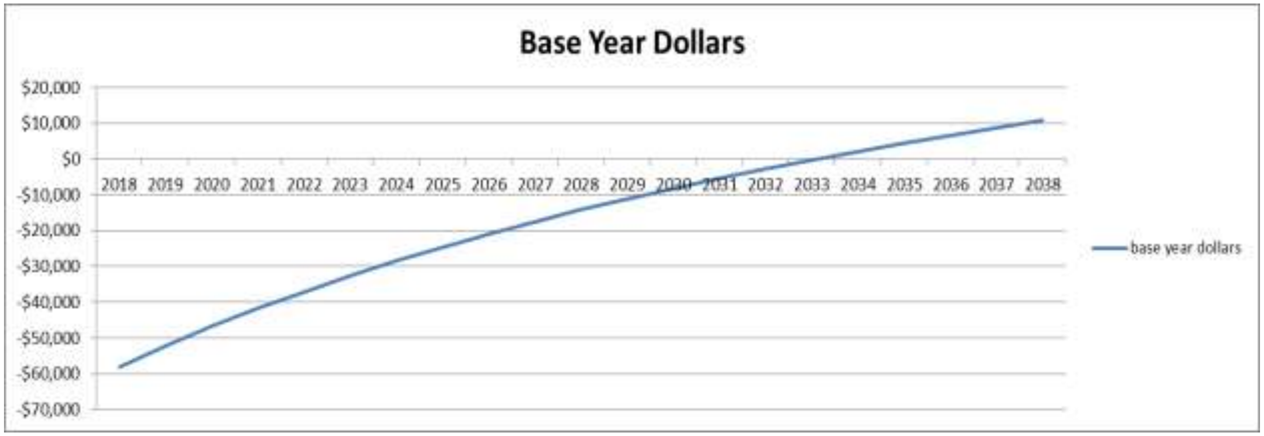

Fig. 6: Payback period for PLEB wind turbine

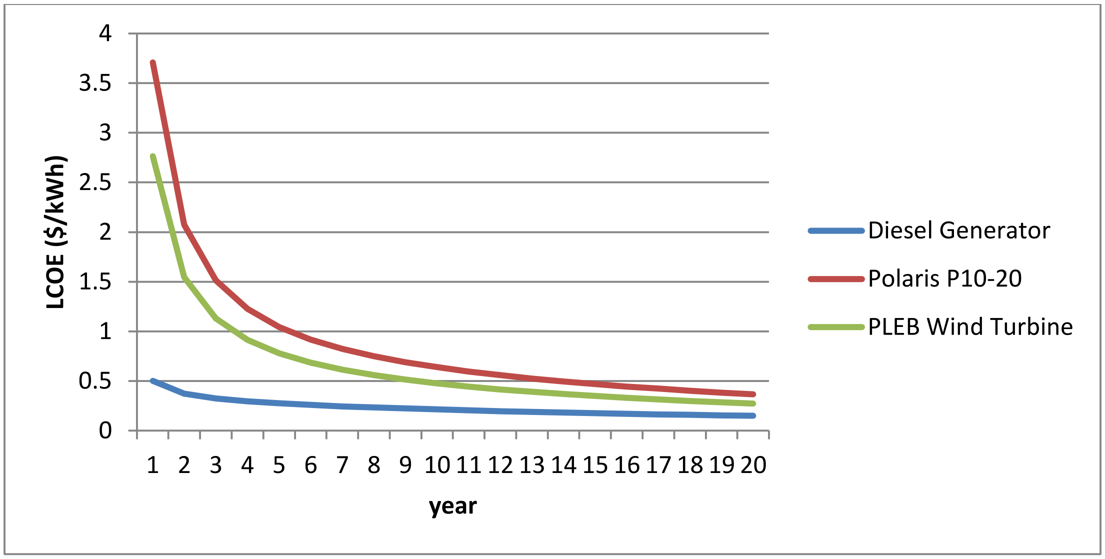

Fig. 7: Trend of LCOE of the wind turbines and DG over 20-year span

The LCOE of the systems indicate that it is cheaper to generate electricity with diesel generator in Kano at $ 0.1499/kwh compared to $0.2733 for PLEB turbine. Figure 7 shows the LCOE converging over time. This indicate for higher lifespans of say 30 years, the turbines could have be at par or lower in LCOEs compared to the diesel generator. From investment point of view, the DG may be preferred because initial capital would be much lower compared to wind turbine. Also, fuel cost in the country is still low compared to international rates. Low initial capital and fuel subsidy in Nigeria makes diesel generator electricity production cheaper compared to wind in this study.

The other reason would likely be the high initial capital cost of setting up a WEC system compared to DG. Thirdly, the maturity of diesel technology has peaked while research on WEC system is still on the learning curve.

Ironically, the comparison of WEC system to DG by Bawah *et al*. (2013) indicated a clear production advantage for WEC in rural Saudi Arabia compared to DG. Since Nigeria and Saudi Arabia have similar subsidy regimes in petroleum usage, the reason for a reverse case in their study for WEC's advantage would likely stem from higher wind regime experienced in desert environment compared to our region. The higher average wind speed in such a desert environment would most like give higher capacity factor and WEC system installed there more than in Nigeria.

Other studies like that of Zailan *et al*. (2017), Olatomiwa *et al*. (2015) showed the analysis of PLEB turbine in Kano has higher NPV and better LCOE than what they obtained for hybrid systems. This study did not consider combination of the wind turbine with DG for hybrid. Such combination would most likely raise the capacity factor of the system, but at expense of higher LCOE and lower mitigation against GHG emission.

The analysis using present net value (NPV) made consideration of social cost of electricity generation, taking into account GHG emission and pollution costs. With such factors taken into consideration, the study indicates that wind turbines can produce better present values and internal rates of return. But these GHG and pollutions costs were assumed to be fully levied against DG operations and benefits shifted to wind turbines as environmental incentives to WEC operators. In reality, our government policy may and may not fully adopt such environmental strategies for the nation's energy mix. So the study assumed full cost for DG and full benefit for wind turbine as far as pollution and environmental costs are concerned. The study in Algeria by Saheb-Koussa *et al*. (2013) showed similar benefit to this study in terms of emission reduction of the CO_2, SO_2, and NOx,

Compared to similar studies on cost and benefit comparison of energy production, this study did not undertake sensitivity analysis during comparison between the WEC systems and DG. The handicap here was lack of adequate software such as HOMER that other studies like those of Saheb-Koussa *et al.* (2013), Ngan and Tan (2012) and Olatomiwa *et al.* (2015) utilised.

CONCLUSION

A comparative study on the performance of Polaris P10-20 turbine, PLEB turbine and a diesel generator for electricity production in Kano was made. Diesel generator was found to produce highest annual energy output of 61,320 kWh against

22,145 kWh and 24,159 kWh for Polaris and PLEB turbines respectively. LCOE and NPV were used for economic comparison of the models over 20-year common lifespan. The diesel generator had least LCOE of $0.14/kWh against $0.37/kWh and $0.27/kWh for Polaris and PLEB turbines respectively.

The NPV of diesel generator is $91,611 negative with no internal rate of return (IRR). At project end time, there was $90,000 negative cashflow and no payback. The Polaris turbine had negative NPV of $21,386 but with IRR of 5.03%. It could not payback its investment also. PLEB turbine had positive NPV of $10,838 and IRR of 12.08%. There was positive cashflow and the project could pay back within 12 years.

The study has indicated with right investment and environmental policies, deployment of wind turbines for electricity generation in Kano is viable.

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