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Life Cycle Cost Assessment Of University Campus Pumped Water Storage Solar-Hydro Power Plant

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***Abstract*— In this work, pumped water storage solar-hydro (PWSSH) power plant life cycle cost (LCC) assessment procedure is presented using the requisite technical and economic parameters associated with the plant and the installation site. Based on the specified parameters of a case study 500 KVA (or 400 KW) PWSSH power plant for the Main Campus of Akwa Ibom State University (with daily energy demand of 9,600.0 KWh/day), the LCC assessment procedure using only the discount rate of 10.5 % without inflation rate, is presented. Similarly, LCC assessment procedure using both discount rate of 10.5 % and inflation rate of 5 % is considered. The total equipment cost is N2,110,081,600 and the investment cost is N2,532,097,920. Specifically, the unit cost of energy with the first case where the LCC assessment is conducted with only discount rate is N 91.7 per KWh whereas, the unit cost of energy obtained in the second case where the LCC assessment is conducted with both discount and inflation rates is N55.4 per KWh. Further results show that the unit cost of energy increases with increase in the discount rate. On the other hand, the effective discount rate and the unit cost of energy decrease with increase in the inflation rate when the discount rate is kept constant. Summarily, the ideas presented in this research are relevant for investors and policy makers on the economic feasibility of PWSSH power plant.**

Keywords*— *Capital investment cost, discount rate, inflation rate, life cycle cost assessment, present worth, pumped water storage power plant, solar-hydro power plant

1. INTRODUCTION

Studies have shown that adequate supply of energy is essential for national development (Kovač, Paranos & Marciuš, (2021); Ali, Anufriev & Amfo, (2021); Agyekum, Amjad, Mohsin & Ansah, (2021). Accordingly, many nations across the globe have invested heavily in the generation of electricity. However, in view of the globalization of market with the resultant pressure on lowering the cost of goods and services at the local markets, great effort has been made to ensure economically viable energy options (Murphy, Breeze, Willcox, Kavanagh & Stout, 2022; Carrasco & Romi, 2022; Al-Khalidi Al-Maliki, 2021). Moreover, there is need to adopt environmentally friendly energy options to mitigate the negative impact of the fossil fuel-dominated energy industry (Udo, G., et al., 2020). Consequently, this work considers the economic assessment (Okon, B. B. and Elhag, T.S, 2011) of a solar-hydro power plant based on the life cycle cost (LCC) approach.

Specifically, this work presents some analytical expressions and procedure that can be used to explicitly determine the replacement years and the frequency of components replacements necessary within the life span of the power plant. The study also conducted the LCC assessment for a scenario where only the discount cost is considered without including the inflation rate. Furthermore, LCC study is presented using both the discount rate and the inflation rate. The study utilized a case study power plant to demonstrate the applicability of the models. In all, the ideas presented in this work is meant to serve investors and policy makers on the feasibility and affordability of the energy from the solar-hydro power plant with pumped water storage energy storage facility.

2. METHODOLOGY

2.1 The technical and economic parameters for the life cycle cost assessment

In this work, pumped water storage solar-hydro (PWSSH) power plant (Ukommi, Okon, Awaka-Ama, Umoette, and Ubom, 2024) life cycle cost assessment procedure is presented using the requisite technical and economic parameters associated with the plant and the installation site. The site parameters of the PWSSH power plant are presented in Table 1 while the parameters of the hydro power component of the power plant are presented in Table 2. The parameters that pertain to the solar photovoltaic (Festus, U., et al, 2023) component of the plant are presented in Table 3. Also, the cost of the plant components and other parameters used to determine the capital investment cost of the PWSSH power plant are presented in Table 4. Based on the listed parameters, the LCC assessment procedure using only the discount rate without inflation rate is presented. Similarly, the LCC analysis procedure using both discount and inflation rates is presented.

Specifically, the LCC assessment procedure requires computation of the following:

i. The capital investment cost of the PWSSH power plant
ii. The present worth of the annual maintenance (Jameson, F., et al, 2024) cost
iii. The replacement cost components with life span less than the project life span
iv. The salvage value present worth for the PWSSH power plant
v. The net present worth of the PWSSH power plant
vi. The annualized cost of the PWSSH power plant
vii. The total energy generated or delivered to the load per year
viii. The unit cost of energy

The LCC assessment is conducted with N, (the project life span) of 50 years. Then, as shown in Table 4 the useful life span of the hydro turbine, PV array and the water pumps are less than the project life span of 50 years. Hence, the replacement cost of the three components are computed based on their individual life span and the project life span of 50 years.

For a component k with life span t_k years and a project life span N years, the number of replacements within the project life span is denoted as R_k and the years of replacement j (where j = 1,2, …R_k) are denoted as $Y_{k,j}$ where;

$$R_k = \begin{cases} \left\lfloor \frac{N}{t_k} \right\rfloor & for\ \frac{N}{t_k} > \left\lfloor \frac{N}{t_k} \right\rfloor \\ \max\left(0, \left\lfloor \frac{N}{t_k} \right\rfloor - 1\right) & for\ \frac{N}{t_k} = \left\lfloor \frac{N}{t_k} \right\rfloor\ or\ \left\lfloor \frac{N}{t_k} \right\rfloor = 0 \end{cases} \quad (1)$$

$$Y_{k,j} = \begin{cases} (j)(t_k) & for\ R_k > 0;\ j = 1,2, \ldots R_k \\ 0 & for\ R_k = 0 \end{cases} \quad (2)$$

Table 1: The Site Parameters of the PWSSH Power Plant and the installation site

S/N	Description of Parameter	Value and unit
1	Name of case study site	AKSU (Main Campus)
2	Geo-coordinates of the case study site	Latitude: 4.621437, Longitude: 7.763922
3	Mean daily sunshine hours	7.13 hours
4	Mean daily ambient temperature	26.74 °C
5	Annual mean of daily solar radiation	6.22 kW-hr/m^2/day
6	Power demand	500 KVA (400 KW)
7	Daily energy demand with 24 hours supply per day	9,600.0 KWh/day

Table 2: The Parameters of the Hydro Power Component of the PWSSH Power Plant

S/N	Description of parameter	Value and unit
1	Daily energy demand used to size the hydro turbine and water reservoir	9,600.0 KWh/day
2	Hydro turbine water flow rate	Per second: 1.45 m^3/s Per day: 137,832.98 m^3/day
3	Days of power autonomy	3 days
4	Water storage thank (reservoir) capacity	413,498.94 m^3 (approximated to 420,000m^3)
5	Reservoir water head	30 m
6	Daily pumping hours per day	7.13 hours
7	Total water pump flow rate	5.37 m^3/s
8	Number of parallel water pumps	40
9	Water flow rate of each of the 40 pumps	0.1342 m3/s (that is 5.37/40)
10	Power rating of each of the 40 pumps	47.638 KW.
11	Total power rating of the 40 pumps	1905.52 KW.
12	Daily energy demand of the 40 pumps with 7.13 hours water pumping operation per day	13586.3576 KWh

Table 3: The Parameters of the Solar Photovoltaic Component of the PWSSH Power Plant

S/N	**Description of parameter**	**Value and unit**
1	Daily energy demand used to size the solar power supply	13,586.430 KWh
2	Solar radiation (daily peak sun hours)	6.22 kwh/ m^2
3	Power rating of the PV array	3,437.528 KW
4	Power rating of each PV module used in the PV array	300 watts
5	Total number of PV modules in the PV array	11,458 PV modules
6	Total inverter size	10,421 KVA
7	Number of inverters used	40 units
8	Rating of each of the 40 inverters used	260.5217 KVA

Table 4: The Components of the Capital Cost (Pc) of the PWSSH Power Plant and the LCC Assessment input data

S/N	Component/Item	Quantity	Rate (₦)	Amount (₦)	Life span (years)
1	Hydro Turbine 400kW	1	8,877,600	8,877,600	30
2	PV module 12 Vdc 300 Wp	11,458	58,000	664,564,000	25
3	Reservoir 100 x 100x 21 m	2	710,000,000	1,420,000,000	100
4	Pump 120 Vdc, 47.638	40	370,000	14,800,000	15
5	Steel Pipe 0.92m diameter	40	46,000	1,840,000	70
	Sub-total (equipment cost, Pceq)			**2,110,081,600**	
6	Installation, support structure, logistics, etc.20% of the cost components. (Installation and miscellaneous cost, Pcim). It is 20% of Pceq.	lot		422,016,320	
	Total			**2,532,097,920**	

2.2 Life Cycle Cost (LCC) Assessment with only Discount rate and no Inflation rate

The LCC assessment in this section is conducted using only d (the interest rate or discount rate) of 10.5%. That means the inflation rate is not considered.

2.2.1 The Capital Investment Cost, (PIC) of the PWSSH Power Plant

The capital cost, Pic of the PWSSH power plant is obtained from Table 4 as Pic = ₦ 2,532,097,920 and it comprises of the equipment cost (denoted as Pceq) along with the installation and miscellaneous cost, (denoted as Pcim) which is taken as 20% of Pceq.

$$\text{Pcim} = \left(\frac{20}{100}\right)(\text{Pceq}) \quad (3)$$

$$\text{Pic} = \text{Pceq} + \text{Pcim} = \text{Pceq} + \left(\frac{20}{100}\right)(\text{Pceq}) \quad (4)$$

Hence, from Table 4 Pceq = ₦2,110,081,600, then;

$$\text{Pcim} = \left(\frac{20}{100}\right)(2{,}110{,}081{,}600) = ₦\,422{,}016{,}320$$

$$\text{Pic} = \text{Pceq} + \text{Pcim} = ₦2{,}110{,}081{,}600 + ₦\,422{,}016{,}320 = ₦\,2{,}532{,}097{,}920.$$

2.2.2 The Present Worth of the Annual Maintenance Cost

The present worth of the annual maintenance cost, OMc is computed based on the following assumptions:

a) Initial maintenance cost is 2% of the capital investment cost, Pic,
b) The discount rate, d = 10.5%
c) The project life span, N = 50 years.

Then (Perčić, Ančić & Vladimir, 2020; Rashedi & Khanam 2020; Frischknecht, Itten, Sinha, de Wild-Scholten, Zhang, Fthenakis and Stucki, 2020; Deele, Ozuomba and Okpura, 2019);

$$OMc = \left(\frac{2}{100}\right)(Pic)\left(\frac{(1+d)^N-1}{(d)(1+d)^N}\right) \quad (5)$$

Hence;

$$OMc = \left(\frac{2}{100}\right)(2{,}532{,}097{,}920)\left(\frac{(1+0.105)^{50}-1}{(0.105)(1+0.105)^{50}}\right) = 479{,}029{,}396.0$$

2.2.3 The Present Worth of the Replacement Cost of the Components that their Life Span is less than the Life Span of the Plant

Based on the data provided in table 4, the three components with their life spans less than the life span of the plant are the hydro turbine, the PV array and the water pumps. Hence, the present worth of the replacement cost of the three components is computed based on their individual life span and the project life span of 50 years.

a) The Present Worth of the Replacement Cost of the Hydro Turbine

The hydro turbine has life span, t_1 =30 years and with N = 50 years, then $\left\lfloor\frac{50}{30}\right\rfloor = 1$ and $\frac{50}{30} = 1.666$. Hence, from Equation 1,

$$R_1 = \left\lfloor\frac{N}{t_k}\right\rfloor = \left\lfloor\frac{50}{30}\right\rfloor = 1 \text{ since } \frac{N}{t_k} > \left\lfloor\frac{N}{t_k}\right\rfloor.$$

Furthermore, since $R_1 > 0$ for the hydro turbine, the replacement year, $Y_{1,1}$ is given from Equation 2 as;

$$Y_{1,1} = (j)(t_k) = (1)(30) = 30 \text{ years.}$$

Then, the replacement cost of the turbine after 30 years is denoted as C_{TB30} and it is given as;

$$C_{TB30} = \frac{(1.2)(C_{TB0})}{(1+d)^{30}} \quad (6)$$

Where C_{TB0} is the initial cost of the turbine which from Table 4 is ₦8,877,600, The 20% or 1. factor is to account for the installation and associated logistics for replacing the turbine. Hence,

$$C_{TB30} = \frac{(1.2)(8{,}877{,}600)}{(1+0.105)^{30}} = 532{,}854.3$$

b) The replacement cost of the PV array

The PV array has life span, t_2 =25 years and with N = 50 years, then $\left\lfloor\frac{50}{25}\right\rfloor = 2$ and $\frac{50}{25} = 2$. Since $\frac{N}{t_k} = \left\lfloor\frac{N}{t_k}\right\rfloor$, then from Equation 1,

$$R_2 = \max\left(0, \left\lfloor\frac{N}{t_k}\right\rfloor - 1\right) = \max(0, 2-1) = \max(0,1) = 1$$

Furthermore, since $R_2 > 0$ for the PV array, the replacement year, $Y_{2,1}$ is given from Equation 2 as;

$$Y_{2,1} = (j)(t_k) = (1)(25) = 25 \text{ years.}$$

Then, the replacement cost of the PV array after 25 years is denoted as C_{PV25} and it is given as;

$$C_{PV25} = \frac{(1.2)(C_{PV0})}{(1+d)^{25}} \quad (7)$$

Where C_{PV0} is the initial cost of the PV array which from Table 4 is ₦ 664,564,000. The 20% or 1.2 factor is to account for the installation and associated logistic for replacing the PV array. Hence,

$$C_{PV25} = \frac{(1.2)(664{,}564{,}000)}{(1+0.105)^{25}} = 39{,}888{,}684.8$$

c) The Replacement Cost of the Water Pump

The water pump (Ekim, C., et all, 2024 and Edet, U., et al, 2024) has life span, t_3 =15 year and with N = 50 years, then $\left\lfloor\frac{50}{15}\right\rfloor = 3$ and $\frac{50}{15} = 3.3333$. Since $\frac{N}{t_k} > \left\lfloor\frac{N}{t_k}\right\rfloor$ then from Equation 1,

$$R_3 = \left\lfloor\frac{N}{t_k}\right\rfloor = \left\lfloor\frac{50}{15}\right\rfloor = 3$$

Furthermore, since $R_3 > 0$ for the water pump, the replacement years are, $Y_{3,1}$, $Y_{3,2}$ and $Y_{3,3}$ which are given from Equation 2 as follows;

$$Y_{3,1} = (j)(t_k) = (1)(15) = 15 \text{ years for j =1}$$

$$Y_{3,2} = (j)(t_k) = (2)(15) = 30 \text{ years for j =2}$$

$$Y_{3,3} = (j)(t_k) = (3)(15) = 45 \text{ years for j =3}$$

Then, the replacement cost of the water pump after 15 years, 30 years and 45 years are denoted as C_{wp15}, C_{wp30} and C_{wp45} respectively and they are given as:

$$C_{wp15} = \frac{(1.2)(C_{wpo})}{(1+d)^{15}} \quad (8)$$

$$C_{wp30} = \frac{(1.2)(C_{wpo})}{(1+d)^{30}} \quad (9)$$

$$C_{wp45} = \frac{(1.2)(C_{wpo})}{(1+d)^{45}} \quad (10)$$

Where C_{wp0} is the initial cost of the water pump which from Table 4 is ₦ 14,800,000. The 20% or 1.2 factor is to account for the installation and associated logistics for replacing the water pump. Hence,

$$C_{wp15} = \frac{(1.2)(14{,}800{,}000)}{(1+0.105)^{15}} = 3{,}971{,}995.9$$

$$C_{wp30} = \frac{(1.2)(14{,}800{,}000)}{(1+0.105)^{30}} = 888{,}330.6$$

$$C_{wp45} = \frac{(1.2)(14{,}800{,}000)}{(1+0.105)^{45}} = 198{,}673.7$$

2.2.4 The salvage value present worth (Pspw) for the PWSSH power pant

At the end of the project life span of 50 years, the salvage value present worth (***Pspw***) for the PWSSH power plant is given as (Perčić, Ančić and Vladimir, 2020; Rashedi and Khanam 2020; Frischknecht, Itten, Sinha, de Wild-Scholten, Zhang, Fthenakis and Stucki, 2020; Deele, Ozuomba and Okpura, 2019);

$$\text{Pspw} = \frac{Pic}{(1+d)^{50}} \quad (11)$$

Then,

$$\text{Pspw} = \frac{2{,}532{,}097{,}920}{(1+0.105)^{50}} = 17{,}193{,}591.2$$

2.2.5 The Net Present Worth of the PWSSH Power Plant

The net present worth of the PWSSH power plant is dented as $\boldsymbol{Ppwnet}$ where (Perčić, Ančić & Vladimir, 2020; Rashedi & Khanam 2020; Frischknecht, Itten, Sinha, de Wild-Scholten, Zhang, Fthenakis & Stucki, 2020; Deele, Ozuomba & Okpura, 2019):

$$\text{Ppwnet} = Pic + OMc + C_{TB30} + C_{PV25} + C_{wp15} + C_{wp30} + C_{wp45} - \text{Pspw} \quad (12)$$

$$\text{Ppwnet} = 2{,}532{,}097{,}920.0 + 479{,}029{,}396.0 + 532{,}854.3 + 39{,}888{,}684.8 + 3{,}971{,}995.9 + 888{,}330.6 + 198{,}673.7 - 17{,}193{,}591.2$$

$$\text{Ppwnet} = 3{,}056{,}607{,}855.3 - 17{,}193{,}591.2 = 3{,}039{,}414{,}264.1$$

2.2.6 The Annualized Cost of the PWSSH Power Plant

The annualized cost of the PWSSH power plant is dented as C_{PYR} where;

$$C_{PYR} = (\text{Ppwnet})\left(\frac{(1+d)^N - 1}{(d)(1+d)^N}\right) \quad (13)$$

$$\text{Hence; } C_{PYR} = \frac{(3{,}039{,}414{,}264.1)}{\left(\frac{(1+0.105)^{50}-1}{(0.105)(1+0.105)^{50}}\right)} = 321{,}320{,}344.9$$

2.2.7 The total energy generated or delivered to the load per year

The total energy generated or delivered to the load per year is indicated as $\mathbf{E}_{PYR}$ where;

$$E_{PYR} = (365)(E_{DLY}) \quad (14)$$

Where $\mathbf{E}_{DLY}$ is the daily energy supplied to the load which is the same as the energy demand of the load. Hence, given that $E_{DLY} = 9{,}600.0$ KWh/day then,

$$E_{PYR} = (365)(9{,}600.0) = 3504000 \text{ KWh per year}$$

2.2.7 The Unit Cost of Energy

The unit cost of energy, $\mathbf{U_{CE}}$ is given as (Perčić, Ančić & Vladimir, 2020; Rashedi & Khanam 2020; Frischknecht, Itten, Sinha, de Wild-Scholten, Zhang, Fthenakis & Stucki, 2020; Deele, Ozuomba & Okpura, 2019);

$$\mathrm{U}_{CE} = \frac{\mathrm{C}_{PYR}}{\mathrm{E}_{PYR}} \quad (15)$$

Hence;

$$\mathrm{U}_{CE} = \frac{321{,}320{,}344.9}{3504000} = 91.7 \text{ ₦ per KW}$$

2.3 Life Cycle Cost Assessment using both Discount rate and Inflation rate

In this case, the following discount and inflation rates are used;

i. The interest rate or discount rate, d = 10.5%
ii. The inflation rate, f = 5%

The effective discount rate is denoted as d_e, where (Agajelu, Ekwueme, Obuka & Ikwu, 2013);

$$d_e = \frac{d-f}{1+f} \quad (16)$$

Hence,

$$d_e = \frac{10.5-9.8}{1+(\frac{.8}{100})} = 5.238095\ \%$$

2.3.1 The Capital Investment Cost, (PIC) of the PWSSH Power Plant

The Pic = ₦ 2,532,097,920 and the project life span, N = 50 years.

2.3.2 The Present Worth of the Annual Maintenance Cost

The annual maintenance cost ***OMc*** is computed based on the following assumptions;

a) Initial maintenance cost is 2% of the capital investment cost, Pic,
b) The effective discount rate, de = 5.238095 %
c) The project life span, N = 50 years.

$$OMc = \left(\frac{2}{100}\right)(Pic)\left(\frac{(1+\mathrm{de})^N-1}{(\mathrm{de})(1+\mathrm{de})^N}\right) \quad (17)$$

Hence;

$$OMc = \left(\frac{2}{100}\right)(2{,}532{,}097{,}920)\left(\frac{(1+0.105)^{50}-1}{(0.052380952)(1+0.052380952)^{50}}\right) = 891{,}519{,}543.0$$

a) The Present Worth of the Replacement Cost of the Hydro Turbine

The replacement cost of the turbine after 30 years is denoted as C_{TB30} and it is given as;

$$C_{TB30} = \frac{(1.2)(C_{TB0})}{(1+de)^{30}} \quad (18)$$

Where C_{TB0} is the initial cost of the turbine which from Table 4 is ₦ 8,877,600, The 20% or 1.2 factor is to account for the installation and associated logistics for replacing the turbine. Hence,

$$C_{TB30} = \frac{(1.2)(8{,}877{,}600)}{(1+0.052380952)^{30}} = 2{,}302{,}965.6$$

b) The Replacement Cost of the PV array

The replacement cost of the PV array after 25 years is denoted as C_{PV25} and it is given as;

$$C_{PV25} = \frac{(1.2)(C_{PV0})}{(1+de)^{25}} \quad (19)$$

Where C_{PV0} is the initial cost of the PV array which from Table 4 is ₦ 664,564,000. The 20% or 1.2 factor is to account for the installation and associated logistics for replacing the PV array. Hence,

$$C_{PV25} = \frac{(1.2)(664{,}564{,}000)}{(1+0.052380952)^{25}} = 172{,}396{,}597.0$$

c) The Replacement Cost of the Water Pump

The replacement cost of the water pump after 15 years, 30 years and 45 years are indicated as C_{wp15}, C_{wp30} and C_{wp45} respectively and they are given as;

$$C_{wp15} = \frac{(1.2)(C_{wp0})}{(1+de)^{15}} \quad (20)$$

$$C_{wp30} = \frac{(1.2)(C_{wp0})}{(1+de)^{30}} \quad (21)$$

$$C_{wp45} = \frac{(1.2)(C_{wp0})}{(1+de)^{45}} \quad (22)$$

Where $\boldsymbol{C_{wp0}}$ is the initial cost of the water pump which from Table 4 is ₦ 14,800,000. The 20% or 1.2 factor is to account for the installation and associated logistics for replacing the water pump. Hence,

$$C_{wp15} = \frac{(1.2)(14{,}800{,}000)}{(1+0.052380952)^{15}} = 8{,}257{,}494.2$$

$$C_{wp30} = \frac{(1.2)(14{,}800{,}000)}{(1+0.052380952)^{30}} = 3{,}839{,}313.6$$

$$C_{wp45} = \frac{(1.2)(14{,}800{,}000)}{(1+0.052380952)^{45}} = 1{,}785{,}085.0$$

2.3.3 The Salvage Value Present Worth (Pspw) for the PWSSH Power Plant

At the end of the project life span of 50 years, the salvage value present worth (Pspw) for the PWSSH power plant is given as;

$$\mathrm{Pspw} = \frac{Pic}{(1+de)^{50}} \quad (23)$$

Then,

$$\mathrm{Pspw} = \frac{2{,}532{,}097{,}920}{(1+0.052380952)^{50}} = 197{,}165{,}783.5$$

2.3.4 The Net Present Worth of the PWSSH Power Plant

The net present worth of the PWSSH power plant is indicated as Ppwnet where;

$$\mathrm{Ppwnet} = Pic + OMc + C_{TB30} + C_{PV25} + C_{wp15} + C_{wp30} + C_{wp45} - \mathrm{Pspw} \quad (24)$$

$$\mathrm{Ppwnet} = 2{,}532{,}097{,}920.0 + 479{,}029{,}396.0 + 532{,}854.3 + 39{,}888{,}684.8 + 3{,}971{,}995.9 + 888{,}330.6 + 198{,}673.7 - 17{,}193{,}591.2$$

Ppwnet = 2,532,097,920.0 + 891,519,543.0 + 2,302,965.6 + 172,396,597.0 + 8,257,494.2 + 3,839,313.6+ 1,785,085.0 - 197,165,783.5

$$\text{Ppwnet} = 3{,}612{,}198{,}918.5 - 197{,}165{,}783.5 = 3{,}415{,}033{,}135.0$$

2.3.5 The Annualized Cost of the PWSSH Power Plant

The annualized cost of the PWSSH power plant is indicated as C_{PYR} where;

$$C_{PYR} = \frac{(\text{Ppwnet})}{\left(\frac{(1+de)^{N}-1}{(de)(1+de)^{N}}\right)} \quad (25)$$

$$\text{Hence; } C_{PYR} = \frac{(3{,}415{,}033{,}135.0)}{\left(\frac{(1+0.052380952)^{50}-1}{(0.052380952)(1+0.052380952)^{50}}\right)} = 193{,}987{,}857.4$$

2.3.6 The Total Energy Generated or Delivered to the Load Per Year

The total energy generated or delivered to the load per year is denoted as E_{PYR} where;

$$E_{PYR} = (365)(E_{DLY}) \quad (26)$$

Where E_{DLY} is the daily energy supplied to the load which is the same as the daily energy demand of the load. Hence, given that E_{DLY} = 9,600.0 KWh/day, then,

$$E_{PYR} = (365)(9{,}600.0) = 3504000 \text{ KWh per year}$$

2.3.7 The Unit Cost of Energy

The unit cost of energy, U_{CE} is indicated as;

$$U_{CE} = \frac{C_{PYR}}{E_{PYR}} \quad (27)$$

Hence;

$$U_{CE} = \frac{193{,}987{,}857.4}{3504000} = 55.4 \text{ ₦ per KWh}$$

3. Results and Discussions

The results of the computations conducted for the case study PWSSH power plant at the Main Campus of Akwa Ibom State University are presented in Table 5 for the two scenarios, namely, the first case where the LCC assessment is conducted with only discount rate, d and the second case where the LCC assessment is conducted with both discount rate, d and inflation rate ,f. The results showed that with the interest rate or discount rate, d = 10.5% and inflation rate, f = 5%, the effective discount rate, $d_e = \frac{10.5-9.8}{1+(\frac{.8}{100})} = 5.238095$ % which is approximately half of the discount rate, d = 10.5% when the inflation rate is not considered. Essentially, the inflation rate reduces the operating discount rate used in the assessment and this eventually reduces the unit cost of energy obtained when both the discount and inflation rates are considered.

Specifically, the unit cost of energy with the first case where the LCC assessment is conducted with only discount rate is ₦91.7 per KWh whereas, the unit cost of energy obtained in the second case where the LCC assessment is conducted with both discount rate and inflation rate is ₦ 55.4per KWh (as shown in Table 5). Essentially, the unit cost of energy is smaller when both discount and inflation rates are considered. In the case study results shown in Table 5, with both discount rate of 10.5% and inflation rate of 5.0%, the effective discount rate, $\boldsymbol{d_e}$ obtained as 5.238095238% is smaller than the given discount rate $\boldsymbol{d}$, of 10.5 %.

Table 5: The Summary of the LCC Assessment Results using only the Discount and using both Discount and Inflation Rates:

Parameters	Results of the LCC assessment with only discount rate, ***d*** (where d = 10.500000%)	Results of the LCC assessment with both discount rate, d and inflation rate, f (d = 10.50% and f = 5% which gave effective discount rate, de = 5.238095%)
Pic	₦2,532,097,920.0	₦2,532,097,920.0
C_{TB0}	₦8,877,600.0	₦8,877,600.0
C_{PV0}	₦664,564,000.0	₦664,564,000.0
C_{wp0}	₦14,800,000.0	₦14,800,000.0
OMc	₦479,029,396.0	₦891,519,543.0
C_{TB30}	₦532,854.3	₦2,302,965.6
C_{PV25}	₦39,888,684.8	₦172,396,597.0
C_{wp15}	₦3,971,995.9	₦8,257,494.2
C_{wp30}	₦888,330.6	₦3,839,313.6
C_{wp45}	₦198,673.7	1,785,085.0
Pspw	₦17,193,591.2	₦197,165,783.5
Ppwnet	₦3,039,414,264.1	₦3,415,033,135.0
$\mathbf{C_{PYR}}$	₦321,320,344.9	₦193,987,857.4
E_{DLY}	9,600.00 KWh/day	9,600.00 KWh/day
E_{PYR}	3504000 KWh per year	3504000 KWh per year
$\mathbf{U_{CE}}$	₦ 91.7 per KWh	₦ 55.4 per KWh

Further results of the effect of discount rate on some key economic performance parameters for the case of LCC assessment based only on the discount rate are shown in Table 6 and Figure 1. Similarly, the results on the effect of inflation rate, f on the same key economic performance parameters for the case of LCC assessment based on both the discount and the inflation rates (where d = 10.5%) are shown in Table 6 and Figure 2. The results in Table 6 and Figure 1 show that the unit cost of energy increases with increase in the discount rate. On the other hand, the results in Table 7 and Figure 2 show that the effective discount rate, d_e and the unit cost of energy decreases with increase in the inflation rate when the discount rate is kept constant.

Table 6: Results on the Effect of Discount rate on some key Economic Performance Parameters for the case of LCC Assessment based only on the Discount rate

d(%)	Ppwnet (₦)	C_{PYR} (₦)	U_{CE} (₦ per KWh)
0.001	3,393,869,610.6	67,894,702.4	19.40
1.00	3,616,846,071.4	92,275,620.6	26.30
2.00	3,659,136,704.0	116,445,474.7	33.20
4.00	3,531,238,960.5	164,379,881.4	46.90
6.00	3,345,342,657.5	212,242,877.6	60.60
8.00	3,185,867,915.0	260,421,949.1	74.30
10.00	3,064,459,549.3	309,078,859.0	88.20
10.50	3,039,414,264.1	321,320,344.9	91.70
12.00	2,974,811,946.2	358,216,929.1	102.20
14.00	2,908,440,241.7	407,763,960.0	116.40

Table 7: Results on the Effect of Inflation rate, ***f*** on some key Economic Performance Parameters for the case of LCC Assessment based on both the Discount rate and the Inflation rate (where d = 10.5%)

f (%)	d (%)	Ppwnet (₦)	C_{PYR} (₦)	U_{CE} (₦ per KWh)
0.00	10.500000	3,039,414,264.10	321,320,344.90	91.70
2.00	8.333333	3,163,073,853.40	268,496,686.20	76.60
4.00	6.250000	3,323,377,392.80	218,242,646.50	62.30
5.00	5.238095	3,415,033,135.00	193,987,857.40	55.40
6.00	4.245283	3,508,600,499.50	170,243,683.90	48.60
8.00	2.314815	3,651,316,237.60	124,017,571.20	35.40
10.00	0.454545	3,526,034,959.20	78,997,171.00	22.50

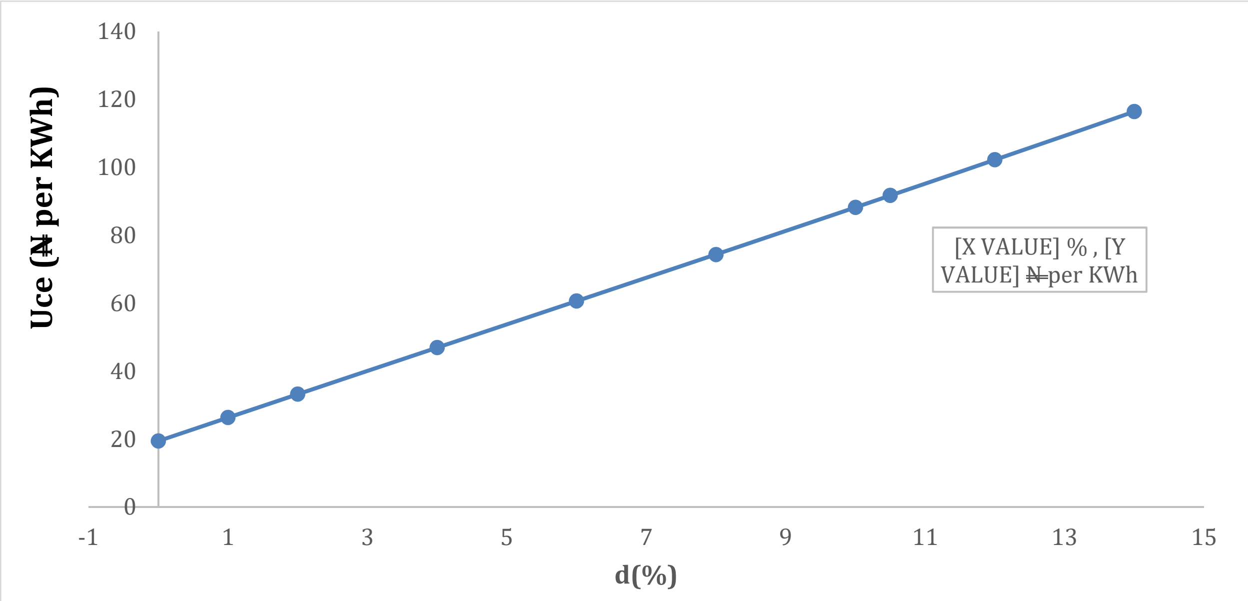

Figure 1: The Graph of Unit Cost of Energy versus the Discount rate, d

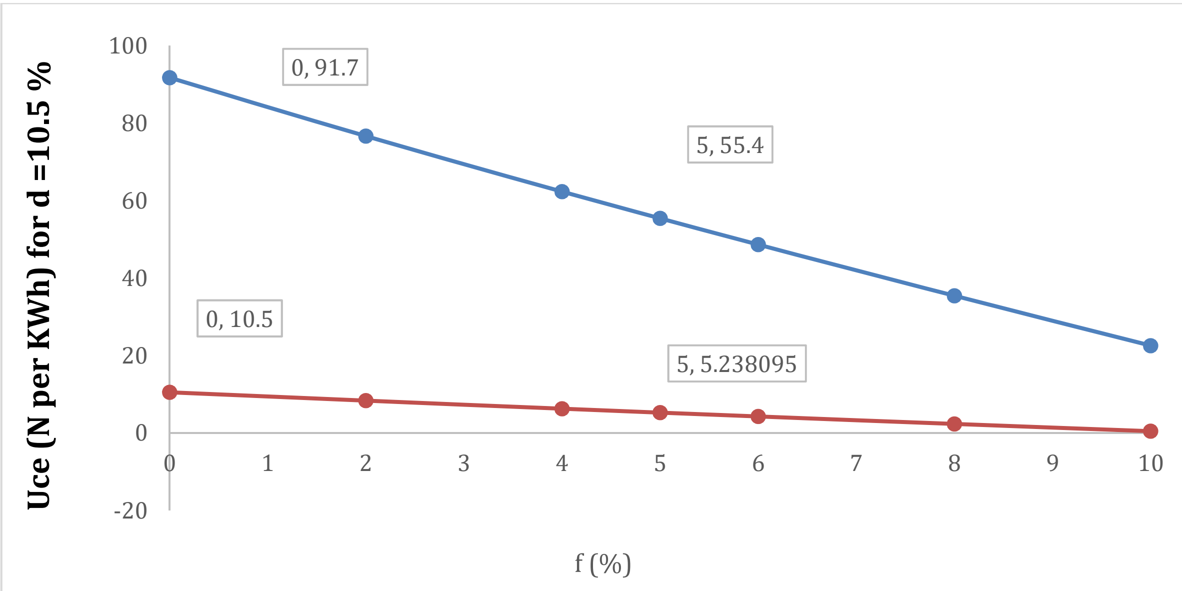

Figure 2: The Graph of Unit Cost of Energy versus the Inflation rate, ***f*** for Discount rate, d = 10.5 %

4 CONCLUSION

The economic analysis of a pumped water storage solar-hydro (PWSSH) power plant is presented using the life cycle cost assessment approach. Available technical and cost parameters pertaining to the PWSSH power plant are used to determine the unit cost of energy and the impact of discount rate and inflation rate on the unit cost of energy based on the LCC approach. In all, the results showed that when the inflation rate is considered along with the discount rate, the unit cost of energy is lower when compared with the scenario where only the discount rate is used in the LCC assessment.

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