e-ISSN: 2564-7954 CUSJE 20(2): 076-094 (2023) Research Article

Çankaya University

Journal of Science and Engineering

CUJSE

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Comparative Economic Viability and Sensitivity Analyses of a Hybrid PV/Battery/Diesel Generator for Water Pumping in Nigeria

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Keywords

Hybrid Power,
Net Present Cost,
PV Pumping System,
Sensitivity Analysis.

Abstract

The importance of electricity supply in agricultural processing, production and storage in any community or location cannot be over-emphasized. One critical aspect of agricultural production is the availability of water, which requires the supply of electricity. However, one of the factors affecting this sector of the economy in Nigeria is the fact that several farm facilities lack access to electricity supply from the national grid. This paper focuses on exploring and analyzing a standalone energy supply system for agricultural production, and the cost implication, in light of the global spike in fuel cost. The study presents a comparative economic feasibility analysis of a hybrid PV/Battery/Diesel Generator (DG)/Tank water pumping system (WPS) for a remote farm facility in Akinyele Local Government Area (LGA), Oyo State, Nigeria. It examines five different energy scenarios such as PV/Tank, PV/Battery, PV/Battery/Tank, DG/Tank and DG/Battery systems based on standard sizing approaches. The work also employs five different economic indices such as the Discounted Payback Period (DPBP), Net Present Value (NPV), Internal Rate of Return (IRR), Benefit-to-Cost Ratio (B/C) and Return on Investment (ROI) to determine the most economically-viable WPS configuration. The result reveals that the PV/Tank has the best economic configuration with the DPBP, NPV, IRR, B/C and ROI being 1.61, $ 12583.4, 74.9 %, 5.05 and 74.1 %, respectively, while the DG/Tank has the worst economic performance with NPV, B/C and ROI of $\$-11120.5$, 0.59 and -99.6 %. The study also presents a detailed sensitivity analysis on all the economic indices and the results showed considerable effects, which demonstrate the viability of the standalone energy supply for WPS. The analysis can also be useful for decision-making purposes.

1. Introduction

There has been an increase in the demand for water to meet the growing food production around the world, which is as a result of the issue of population growth. Based on this premise, the role of water supply in crop and animal production cannot be over-emphasized [1].

In Nigeria, several farm facilities for agricultural production are located in remote areas that lack access to good road networks and electricity supply. The lack of access to electricity has been a major hindrance to water supply in these agricultural settings. The country is blessed with huge groundwater resources but the majority of these

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Received: Jan 02, 2023, Accepted: September, 2023

farm facilities are run on diesel generators, which have both environmental and economic implications in terms of air and noise pollution and the associated high cost of diesel fuel around the globe [2]. It is against this backdrop that alternative energy means must be sought for providing water for agricultural production in remote locations in the country. A hybrid of renewable and conventional energies is one electricity supply option that can provide relatively clean energy for the mentioned locations. However, it is also important to ascertain the viability of the alternative energy supply being considered, which is the direction of this paper.

There are in existence several research studies on the aspect of alternative energy supply, renewable energy and hybrid energy systems options for residential, health, ICT, commercial, and agricultural applications. Some of these studies are mentioned in this paper as a relevant background. Girma *et al*., [3] considered the feasibility of a photovoltaic (PV)-based water pumping system (WPS) for a remote location in Ethiopia. The authors employed the PVSyst simulation tool to design PV-based WPS for up to 700 people with an average of 15 litres/day of water requirement per person. The study compared the simulation for PV with that of a diesel-based supply system and concluded that PV-based water pumping has an edge over the diesel-based option in terms of the lifecycle cost.

Also, Chaurasia *et al.,* [4] presented the techno-economic (TE) feasibility and sensitivity assessments of PV/battery systems for a location situation in Dewal, India. The authors used the HOMER simulation tool to design the proposed electricity system based on a load demand of 64.6 kWh/day and the historical solar data of the location. The paper also conducted a comparison analysis between the PV and a diesel-based system and found that the PV/battery system can avoid more than 8000 L of diesel fuel and more than 21,000 kg of emissions per year. The study results also revealed that the NPC and the cost per unit energy of the PV-based system are lower compared to the values obtained for the diesel system. Yahyaoui *et al.,* [5] discussed the sensitivity evaluation of PV/battery-based WPS in terms of the TE analysis. The paper proposed an optimal PV/battery design approach that can meet the water requirements for irrigation purposes at a farm in Northern Tunisia. Also, the authors tested the performance of the proposed design by comparing the proposed sizing algorithm with the HOMER simulation tool. The PV/battery system achieved an optimum solution in terms of cost when compared with the diesel-based option.

Soenen *et al*., [6] compared tank and battery storage systems for PV-based WPS in a rural location of Burkina Faso. The authors compared the systems by employing the TE optimization technique basically for realizing minimum lifecycle costs using users' demand and the groundwater resource as the constraints. It was reported by this study that the lifecycle cost of the proposed PV/battery-based WPS lower than when the option of a PV-based WPS with the tank (without battery) was employed. Oliveros-Cano *et al*., [7] also presented a TE and environmental analysis of a hybrid energy supply system for buildings within the Universidad del Magdalena. The authors proposed four different energy designs such as solar PV/wind/battery, solar PV/wind/gas generator, solar PV/wind/diesel gen and solar PV/wind/grid systems using the HOMER simulation tool. However, the study employed the MS Excel tool to calculate the NPV, IRR and PBT, while the HOMER tool was also used to assess the environmental performance of the proposed systems in terms of the carbon dioxide emissions generated. The study presented the first three energy configurations as viable for implementation in terms of electricity produced, emissions and the DPBP.

Meunier *et al*., [8] discussed the sensitivity analysis of PV WPS for domestic water supply in a rural area of Burkina Faso. The study demonstrated that certain parameters are key to optimal TE system sizing and performance analysis such as the PV module's peak power, the efficiency of the motor pump and the volume of the water tank, including the cost of the motor pump, water tank and the PV WPS lifetime. The paper also considered the factors that can lead to changes in the mentioned parameters and examined variations up to ± 50 % and how these affect the TE optimization results. Tsai *et al*., [9] proposed a TE and sizing evaluation of battery systems for behind-the-meter applications. The authors employed HOMER software to determine the optimal capacity of the battery bank based on the users' electricity demand. The study considered the LCOE, NPC, IRR, ROI and DPBP, including the sensitivity analysis based on the component cost and the real interest rate to ascertain how the optimal costs may be affected.

Carrelo *et al*., [10] compared the cost viability of five large electrical power solar-based irrigation systems in the Mediterranean region. The authors used the NPV, IRR, LCOE and DPBP to assess the economic feasibility of the PV-based irrigation systems design rated 40 to 360 kW. The study reported that the cost of the irrigation system is favourable Mediterranean region. Khattab *et al*., [11] discussed the cost assessments of a standalone wind/PV/diesel-powered WPS for use in Egypt. The study used PVSyst and HOMER tools to simulate and conduct TE performance evaluation for the energy system. The cost optimization was realized by the NPC and LCOE in light of the capacity shortage. The work considered different configurations such as solar PV only, solar PV + horizontal axis wind turbine (WT), solar PV + vertical axis WT, and solar PV + horizontal axis WT and DG, and DG only. The simulation results revealed the cost implication of each of the mentioned configurations.

The cost analysis of a biomass-based electrical generating system has been discussed [12]. The study presented mathematical relations and analyses for determining different economic indices such as the NPV, COE, IRR, profitability index, and DPDP, including the sensitivity analysis of some parameters and their effect on the cost of the biomass systems. Raza *et al*., [13] presented the social and economic impacts of solar electricity utilization for efficient irrigation applications. The authors analyzed the economic benefit of the solar PV system in terms of the reduction in operational costs and carbon emissions and profitability compared to when a diesel power generating system is employed for irrigation. Kurniawan *et al*., [14] presented a TE assessment of smart sluice gate systems for agricultural applications in locations. The analysis of this work was based on the NPV, IRR, B/C and DPBP, while the data was collected by employing the capital expenditure (CAPEX) and operating expenditure (OPEX) instruments. The authors discussed the economic feasibility of the system in terms of the results obtained from the mathematical relations introduced in the paper.

A TE feasibility work has been conducted on the production of bioethanol in Nigeria from cellulose and sugar feedstock materials [15]. The economic and profitability analyses of the work are based on the NPV, DPBP and ROI, including the evaluation of changes in the price of sugarcane, tax rate, minimum wages, subsidy and the exchange on the NPV, DPBP, and ROI. Perez *et al*., [16] also presented a TE sensitivity evaluation for palm-based bio-refineries using Colombia as a case study. The authors calculated the NPV, DPBP and RPOI and then examined the effect of change in the selling price of the material, raw material costs, and operating costs on the profitability of the palm-based bio-refineries. Pardo *et al*., [17] presented a standalone PV-based direct WPS in urban networks with tank or battery storage systems. The authors considered the economic aspect in terms of the NPV, DPBP and sensitivity analysis. The analysis was based on different values of the number of solar modules, the cost of the PV array, and the discount rates. A TE and environmental impact assessment of a large-scale wind power system integration was discussed [18] with a weak transmission network. The authors based their analysis on the "mid-career repowering perspective" with the economic evaluation based on NPV, IRR and DPBP, while the environmental aspect considered the minimization of greenhouse gas (GHG) emissions. The work detailed the cost functions of the energy components.

These research studies have presented useful scholarly contributions in the area of energy supply for WPS including the economic and environmental performances and the viability analyses. This translates to the meaningful background of this current research paper. The authors used standard component sizing methods for the technical aspect, and on the economic side of the analysis, NPV was evaluated in [3-18]; COE was considered in [3,4, 9-13]; IRR was calculated in [7, 9,10, 12, 14]; DPBP was analyzed in [7, 9, 12-18]; B/C in [12-14]; ROI in [9, 15, 16], and the sensitivity analyses were considered in [4, 8-10, 12, 15-17]. However, this current work is firstly driven by the lack of energy access to several farms in Nigeria; it then considers the possibility of a standalone electricity supply system for agricultural production and the associated cost, in light of the global spike in the cost of fossil fuel such as diesel.

The paper discusses the comparative cost feasibility analysis of a hybrid PV/Battery/Diesel Generator (DG)/Tank WPS, using a remote farm facility in Akinyele Local Government Area (LGA) in Oyo State, Nigeria. It also examines five different energy scenarios such as PV/Tank, PV/Battery, PV/Battery/Tank, DG/Tank and DG/Battery systems based on standard sizing approaches. The work also considers five different economic indices which include Discounted Payback Period (DPBP), Net Present Value (NPV), Internal Rate of Return

(IRR), Benefit-to-Cost Ratio (B/C) and Return on Investment (ROI) to determine the most economically-viable WPS configuration. The analyses of these indices in the paper provide a detailed and more robust evaluation of the economic feasibility of the WPS as the works presented in [5, 6-8, 14-18] do not examine COE. Also, the IRR, DPBP, B/C, ROI indices and sensitivity analyses were not considered in [3-6, 8, 11, 13, 15-18], [3-6, 10, 11], [3-11, 15-18], and [3-8, 10-14, 17, 18], respectively. The paper also considers different energy configurations, which are then compared to understand the commonality and differences in the performances of the WPS.

The paper is expected to present relevant insights into ascertaining the economic viability and the profitability of alternative energy systems for standalone applications in remote locations. The results methods and results presented in the paper may be reproduced for other locations other than Nigeria. The remainder of the article is structured as follows: section 2 focuses on the materials and methods; section 3 is based on results and discussion, and section 4 is the conclusion.

2. Materials and Methods

2.1. Study Location and Water Requirement

The study area is a remotely located livestock farm in Akinyele Local Government Area (LGA) in Ibadan, Oyo State, Nigeria. The study location has an average daily radiation of 6.16 kWh/m^2 per year [19]. In this study, the daily water requirement was assumed to be $8.00m^3/h$ [19].

2.2. Pump System Sizing

The pump flow rate is given by Equation (1) [20]:

$$Q_f = \frac{1.2 \times Daily\ Water\ Requirement}{Daily\ Sunshine\ hour} \tag{1}$$

where 1.2 is the safety factor to account for losses or unaccounted volume.

The net hydraulic output power (P_{output}) in kW needed to deliver the daily water requirement is given by Equation (2) [20]:

$$P_{output} = \frac{Q_f \times \rho_w \times g \times H}{3.6 \times 10^6 \times \eta_{pump}} \tag{2}$$

where ρ_w is the density of water ($1000kg/m^3$); g represents the acceleration due to gravity with the value of $10\, m/s^2$; H is the pump head, which is assumed to be 10 m and η_{pump} is the pump efficiency, also assumed to be 0.65.

2.3. PV System Sizing

The required PV-array area is estimated using Equation (3) [21]:

$$PV_{array-area} = \frac{1.5 \times E_{DEL}}{G_{av} \times TCE \times \eta_{pv}} \tag{3}$$

where E_{DEL} is the total daily energy of the pump (kWh/day); G_{av} is the daily solar irradiance ($kWh/m^2/day$); η_{pv} represents the efficiency of the PV-array; TCE stands for the temperature correction factor assumed to be 0.7 [22] and 1.5 is the safety factor. The safety factor has been considered in this case to compensate for the losses and inefficiencies of the PV array system [22]. The PV panel efficiency can be estimated using Equation (4) [22]:

$$\eta_{pv} = \frac{P_{max}}{STC \times PV_{unit-area}} \tag{4}$$

where P_{max} is the maximum power at standard testing conditions, STC is the standard testing condition ($1000W/m^2$) and $PV_{unit-area}$ is the unit area of the panel. The number of PV modules can be estimated by Equation (5) [22]:

$$N_{pv} = \frac{PV_{array-area}}{PV_{unit-area}} \quad (5)$$

The total PV-array power can be calculated using Equation (6) [22]:

$$PV_{power} = N_{pv} \times P_{max} \quad (6)$$

The technical parameters of the PV module selected are outlined in Table 1 below:

Table 1. Technical Parameters of PV Panel [20, 22]

Parameters	Values
Power rating per array	250 W
System voltage	24 V
System array voltage	24 V
Short-circuit current	8.17 A
Lifetime	20 yrs
PV-module area	1.002m ×1.979m

2.4. Battery System Sizing

The use of batteries in the PV system is to mitigate the problem of intermittency of the solar power system. This will allow the use of energy at all times of the day. The size of the battery storage can be estimated using Equation (7) [22, 23, 24]:

$$B_{capacity} = \frac{1.5 \times E_{DEL} \times B_{au}}{V_{sys} \times DOD \times \eta_b \times \eta_{inv}} \quad (7)$$

where B_{au} is the days of autonomy (assumed to be 3 days); DOD is the depth of discharge (assumed to be 80%); η_b represents the battery efficiency, and η_{inv} is the efficiency of the inverter (assumed to be 90%) [20]. The values of 85 and 90 % are used in this study for η_b and η_{inv}, respectively. Suppose that a $12V, 150\ Ah$ battery is selected, then, the number of batteries wired in parallel can be determined by Equation (8) [20]:

$$B_{parallel} = \frac{B_{capacity}}{B_{unit-amp}} \quad (8)$$

where $B_{unit-amp}$is the unit ampere-hour rating of the battery.

The number of battery cells configured in series can be determined by Equation (9) [2]:

$$B_{series} = \frac{V_{sys}}{B_v} \quad (9)$$

where B_v is the unit voltage of the battery selected.

The total number of batteries required is given by [2]:

$$B_{total} = B_{series} \times B_{parallel} \quad (10)$$

2.5. Determination of Solar Charge Controller Size

The size of the charge regulator or controller can be determined by Equation (11) [20]:

$$I_{Rating} = 1.25 \times I_{sc} \times B_{parallel} \quad (11)$$

where I_{sc} is the short circuit current. Suppose that a charge controller rating of $24\ V/60\ A$ is selected, the units of charge controllers to be configured in parallel can be determined by Equation (12) [20]:

$$I_N = \frac{I_{Rating}}{Ampere\ per\ controller} \quad (12)$$

2.6. Inverter System Sizing

An inverter must be able to withstand the maximum AC load of the pump. The inverter rating can be estimated by Equation (13) [21]:

$$P_{in} = \frac{1.25 \times P_{out}}{pf} \tag{13}$$

where *pf* is the power factor assumed to be 0.8 in this study.

2.7. System Water Storage Tank Sizing

Ideally, a system water storage capacity should be able to store enough water for at least 3 days. The minimum water storage tank is given by [20]:

$$V_{tank} = 1.2 \times Daily\ water\ requirement \times 3 \tag{14}$$

2.8. Diesel Generator Sizing

The DG capacity in kVA can be estimated by Equation (15) [21]:

$$P_{DG} = \frac{1.2 \times Load\ (kW)}{pf} \tag{15}$$

The quantity of fuel consumed in L/h by the DG can be estimated by Equation (16) [22]:

$$F_c = A_g X + B_g Y \tag{16}$$

where A_g, B_g, X and Y represent the power output of the generator, the rated capacity of the generator, the fuel curve slope and the fuel curve intercept coefficient, respectively. The values of X and Y of $0.246 L/kWh$ and $0.08415 L/kWh$ are used in this work [22]:

2.9. Economic Estimation of PV-pumping System

The life cycle cost of the WPS can be determined by Equation (17) [20, 25, 26]:

$$LCC_{sys} = C_{inv} + C_m + C_r + C_f \tag{17}$$

where C_{inv} is the capital cost of the project, which includes the cost of PV modules, batteries, inverter, DG, piping/borehole drilling, etc. The C_{inv} depends on the configuration of the pumping system.

The operation and maintenance cost is given by Equation (18) [27, 28]:

$$C_m = C_{opm} \times \left[\frac{1+i}{1+d}\right]\left[\frac{1-\left(\frac{1+i}{1+d}\right)^n}{1-\left(\frac{1+i}{1+d}\right)}\right] \tag{18}$$

The present value for the replacement of a component is given by Equation (19) [27, 29]:

$$C_r = C_{ini} \times \left(\frac{1+i}{1+d}\right)^n \tag{19}$$

where C_{ini} is the cost of purchase; i represents the inflation rate; d represents the discount rate, and n is the year. The annualized life cycle cost of the WPS is given by Equation (20) [20]:

$$ALCC_{sys} = LCC_{sys}\left[\frac{1-\left(\frac{1+i}{1+r}\right)}{1-\left(\frac{1+i}{1+r}\right)^n}\right] \tag{20}$$

where r is the interest rate.

The cost of water per m^3 is given by Equation (21) [20]:

$$C_{water} = \frac{ALCC_{sys}}{Q_t \times 365} \tag{21}$$

where Q_t is the amount of water/day. The other useful economic determinants, which are going to be examined in this work to check the viability of the pumping system, include the Net Present Value (NPV), Internal Rate of Return (IRR), Discounted Payback Period (DPBP), Benefit-to-Cost Ratio (B/C) and Return on Investment (ROI).

NPV gives information about the end-of-life value of a project and is given by Equation (22) [30]:

$$NPV = \sum_{t=1}^{n} \frac{C_{net}}{(1+r)^t} - C_{inv} \tag{22}$$

where C_{net} is the net cash flow in time t.

IRR represents the discounted rate which makes the NPV equal to zero and it is given by Equation (23) [30, 31]:

$$\sum_{t=1}^{n} \frac{C_{net}}{(1+IRR)^t} - C_{inv} = 0 \tag{23}$$

DPBP depicts how long it will take for a system to return its C_{inv}; this is given by Equation (24) [30]:

$$\sum_{t=1}^{DPBP} \frac{C_{net}}{(1+r)^t} \cong C_{inv} \tag{24}$$

B/C shows the benefit of the project, which is given by Equation (25) [32]:

$$B/C = \frac{\sum_{t=1}^{n} \frac{Revenue}{(1+d)^t}}{\sum_{t=1}^{n} \frac{Expenditure}{(1+d)^t}} \tag{25}$$

ROI tells the annual profitability of the project compared to the investment and is given by Equation (26) [32]:

$$ROI = \frac{Annual\ Net\ Profit}{C_{inv}} \tag{26}$$

In this study, the values for i, d and r are assumed to be 16%, 15% and 14% respectively [20] and the tariff rate is \$ 0.78 [33]. The following assumptions are made on the prices of the components based on market survey and literature:

Table 2. Technical and Cost Parameters of Components [34]

Description of items	Unit cost (\$)
PV Module + structure	$\$1.19/W$
Converter	$\$0.182/W$
Pump	$\$1.054/W$
Battery	$\$5.00/Ah$
Storage tank	$\$2.5/m^3$
DG	$\$200/kW$
Cost of bore-hole	\$625
Charge controller	$\$5.8/A$

3. Results and Discussions

The TE parameters of the WPS are discussed in this section. Results of sensitivity analysis for the technical and the economic parameters such as investment cost, tariff rate, system head and solar irradiance are presented.

3.1. Techno-Economics of Hybrid System

The study area has an average daily solar irradiance of $6.01 kW/m^2/day$ translating to peak-sun hours of 6. The PV solar module selected is a 250 W_p mono-crystalline cell type and a Surette battery of 150 Ah. The total area of the PV module required is 8.28 m^2, while the total PV power is 1.25 kW and the battery's total storage capacity is 920 Ah. The required number of PV modules and batteries are 5 and 12 respectively. The inverter, DG and charge controller were also determined to be 1kVA, 25 A and 1kVA respectively. Also, the pump rating and tank capacities were determined to be 0.5 kW and 30 m^3 respectively.

Table 3 presents the economic feasibility analysis of the five configurations of the pumping system. It is worth noting that for a configuration to be cost-effective, the NPV must be positive; there is also the need for the DPBP to be within the project lifetime, the IRR and ROI must also be greater than the discount rate and finally, B/C should be greater than 1 [19, 21]. To decide which of the pumping configurations is best, a configuration with the highest NPV, IRR, B/C and ROI, with the least DPBP is very suitable economically. From Table 3, PV/Tank has the highest $NPV\ of$ \$12583.4, $IRR\ of$ 74.9 %, B/C of 5.05 and $ROI\ of$ 74.1 %, with the least $DPBP\ of$ 1.61. The economic indicators in Table 3 also show that PV/BAT/Tank and PV/BAT are also good configurations that are profitable in the project lifetime, with PV/BAT/Tank showing a better performance than PV/BAT. The PV/BAT/Tank depicts better economic performance than PV/BAT because two-thirds of the days of battery autonomy were compensated with the storage tank. Table 3 further reveals that the DG/BAT and DG/Tank were not economically feasible because their NPVs were negative and every other economic indicator was not encouraging. Table 3 further presents the results for the unit cost of water revealing that the PV/Tank shows the least unit cost of water, this is attributed to the extremely reduced cost of O/M and replacement cost, while, the DG/Tank has the highest unit cost of water because of the continuous usage of diesel fuel which is very expensive in the global market as at today.

Table 3. Economic Analyses of the Configurations

Configuration	C_{water} (\$/m^3)	**NPV** (\$)	**DPBP** (**Years**)	**IRR** (%)	**B/C**	**ROI** (%)
PV/Tank	0.247	12583.4	1.61	74.9	5.05	74.1
PV/BAT	0.400	7892.7	5.27	29.9	2.13	29.7
PV/BAT/Tank	0.388	10841.9	2.55	49.3	3.33	49.3
DG/BAT	0.926	−1200.3	–	10.6	0.96	11.7
DG/Tank	1.661	−11120.5	–	–	0.59	−99.6

Figure 1 below shows the graph of the NPV with lifetime (in years). This result shows that DG/Tank will never be profitable because of the continuous usage of diesel fuel. The NPV of DG/Tank was decreasing as the year progresses. The figure also shows that DG/BAT would be profitable if the project lifetime continues beyond the 20 yrs lifetime because the NPV was seen to be increasing. Again from Figure 1, PV/Tank, PV/BAT/Tank and PV/BAT as seen to be economically viable configurations for WPSs because the NPV was positive.

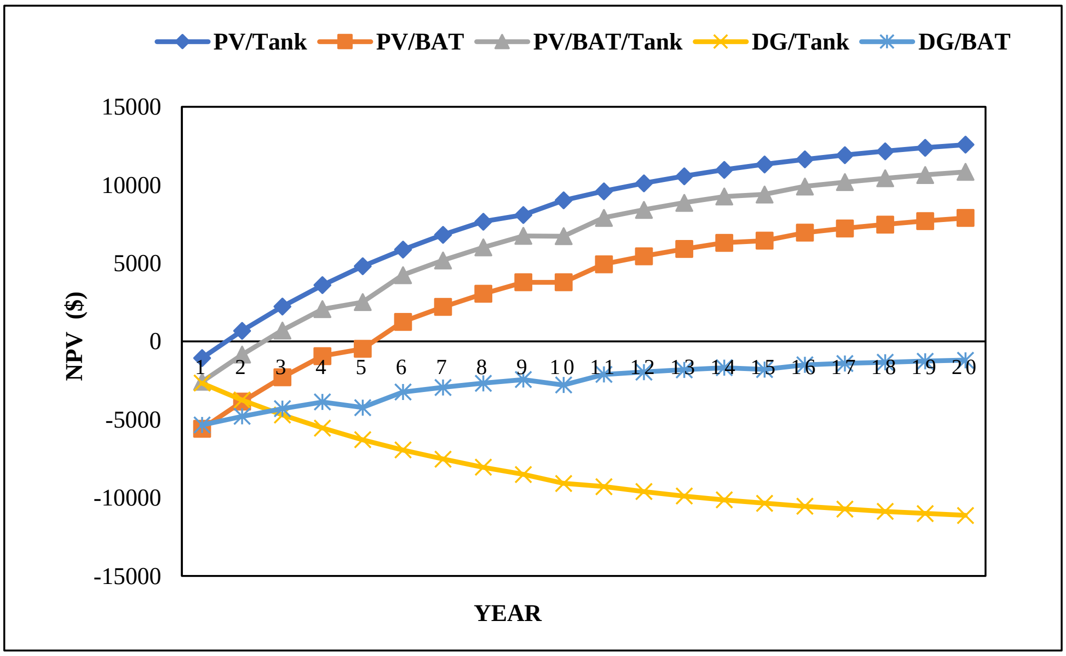

Figure 1. Graph of NPV versus Lifetime

3.2. Sensitivity Analysis

3.2.1. Change in Investment Cost on Economic Indicators

Figures 1 to 5 present the sensitivity analysis results of varying the C_{inv} by $\pm$ 30 % of the base case with a cost interval of 10 % for the five economic indicators of profitability. Figure 1 reveals that an increase in C_{inv} will be associated with an increase in DPBP slope for the three configurations; this is suggested as profitable for the WPSs. This shows that as the C_{inv} increases, the DPBP of the project will also increase, which will make the project to decrease in profitability. Figure 2 to 5 also shows that an increase in C_{inv} will automatically lead to a decrease in NPV as shown in Figure 2, IRR as in Figure 3, B/C as in Figure 4 and ROI as in Figure 5, respectively. Therefore, the results demonstrate that an increase in C_{inv} is not a good sign for profitability.

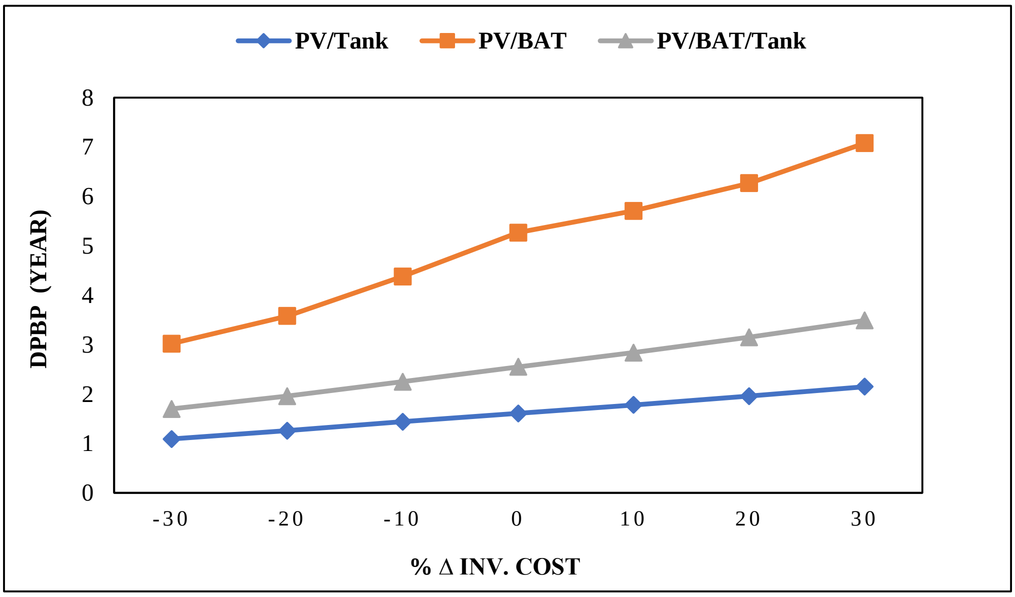

Figure 2. Effect of Variation of Investment Cost on DPBP

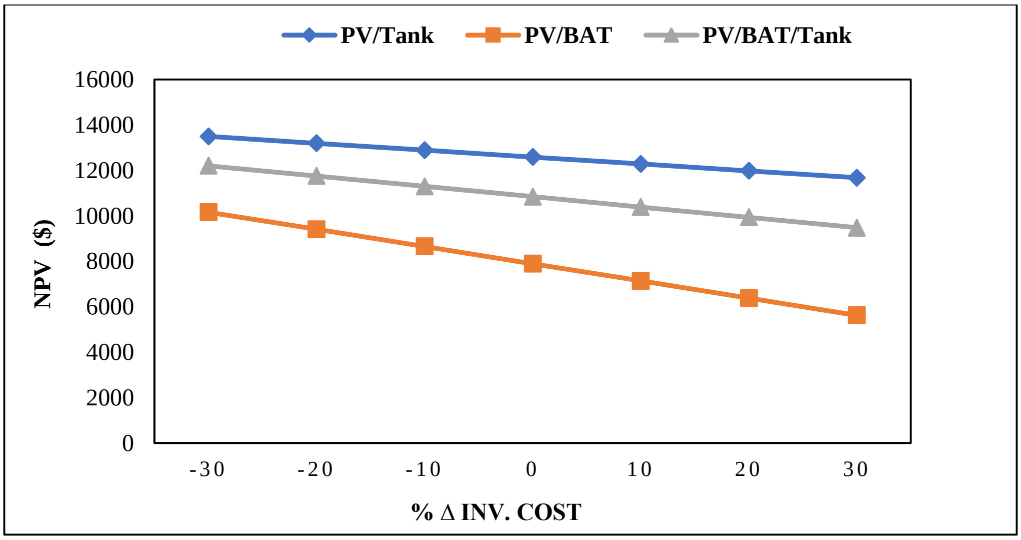

Figure 3. Effect of Variation of Investment Cost on NPV

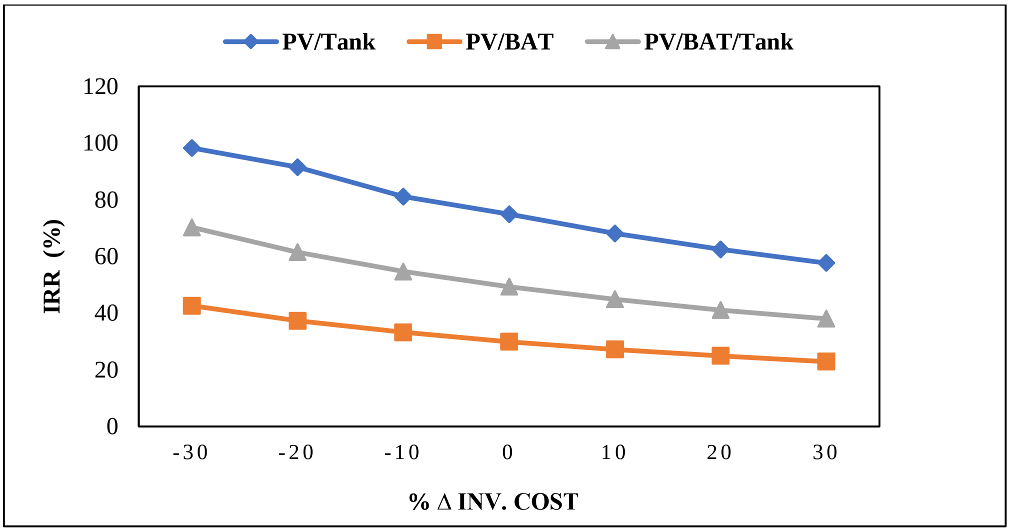

Figure 4. Effect of Variation of Investment Cost on IRR

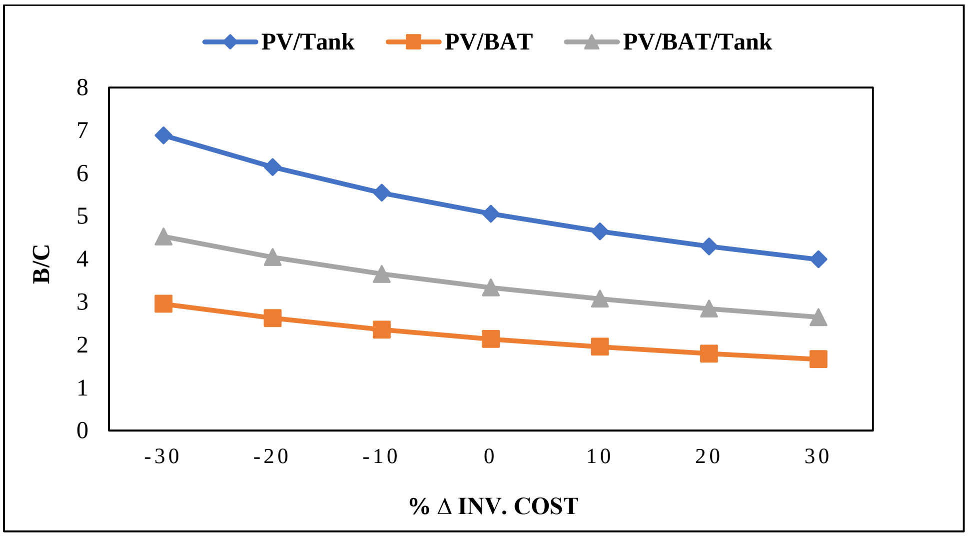

Figure 5. Effect of Variation of Investment Cost on B/C

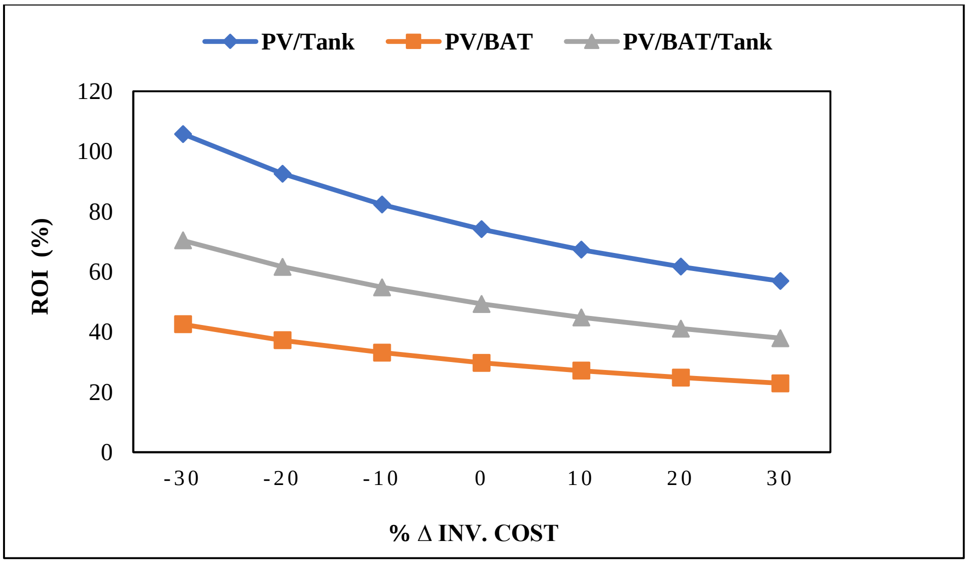

Figure 6. Effect of Variation of Investment Cost on ROI

3.2.2. Change in Tariff Rate on Economic Indicators

Figures 7 to 11 present the results of sensitivity analysis of varying the tariff rate by $\pm$ 30 % of the base case with an interval of 10 % and the five economic indicators of profitability. Figure 7 depicts that an increase in the tariff will lead to a reduction in the DPBP of the project, while Figures 8 to 11 show that an increase in tariff rate will cause an increase in NPV as in Figure 8, IRR as in Figure 9, B/C as in Figure 10, and ROI as in Figure 11, respectively. Hence, these results depict that an increase in tariff is a good parameter that will bring about more returns to the investor.

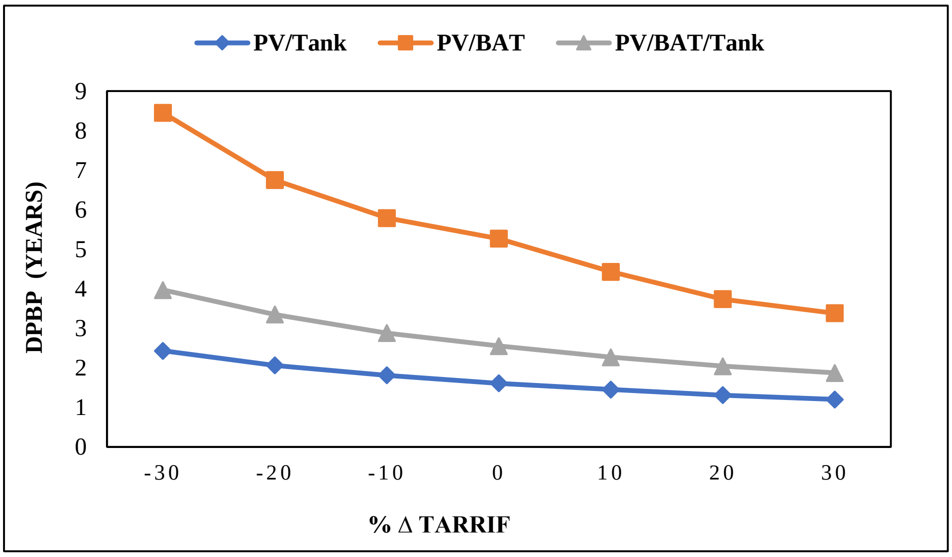

Figure 7. Effect of Variation of Tariff Rate on DPBP

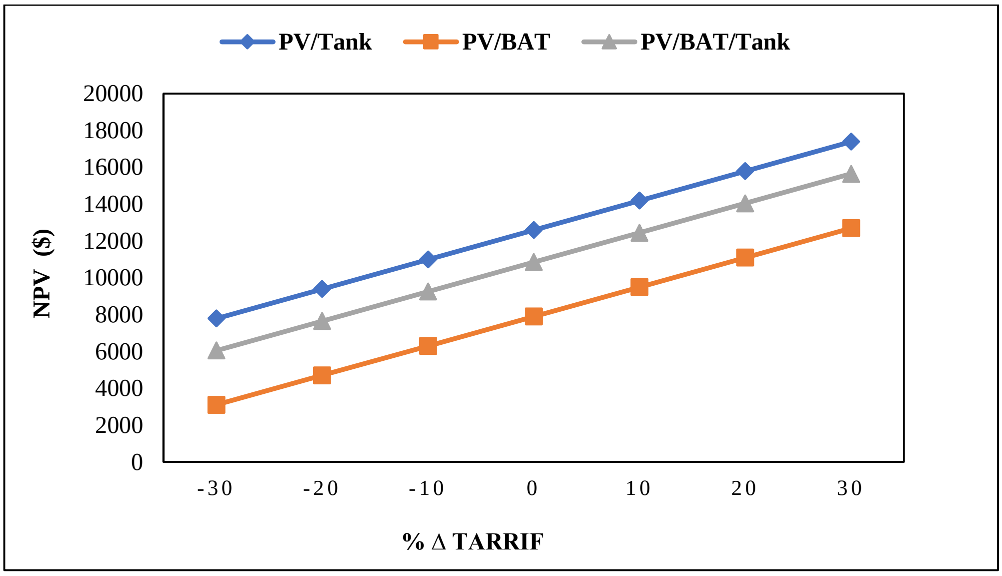

Figure 8. Effect of Variation of Tariff Rate on NPV

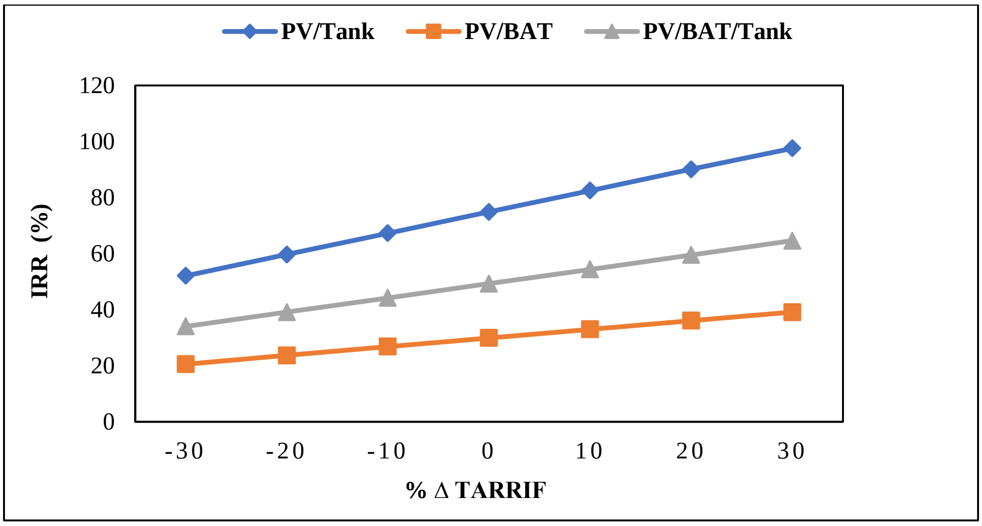

Figure 9. Effect of Variation of Tariff Rate on IRR

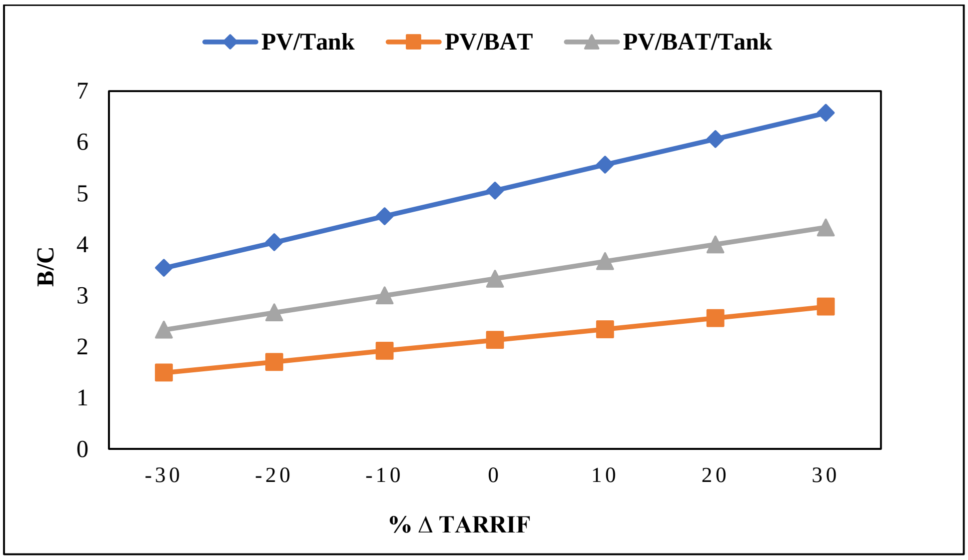

Figure10. Effect of Variation of Tariff Rate on B/C

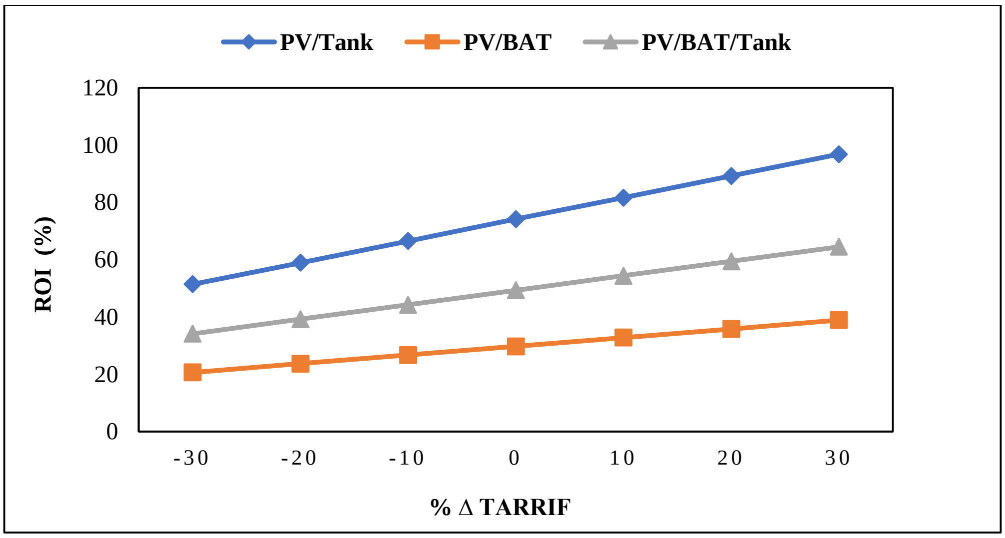

Figure 11. Effect of Changing the Tariff on ROI

3.2.3. Change in System Head on Economic Indicators

Figure 12 shows the effect of changing the system head of the WPS on DPBP. As the system head is increased, the DPBP will increase because the discharge rate of the pumping system will be reduced, hence, there will be less volume of water availability for trading. The effect of varying system head on other economic indicators like NPV as in Figure 13, IRR as presented in Figure 14, B/C as shown in Figure 15, and ROI in Figure 16 also depicts a decreasing slope, which makes it less profitable for an investor. Therefore, a reduced system head is encouraged for an increased volume of water to be harnessed.

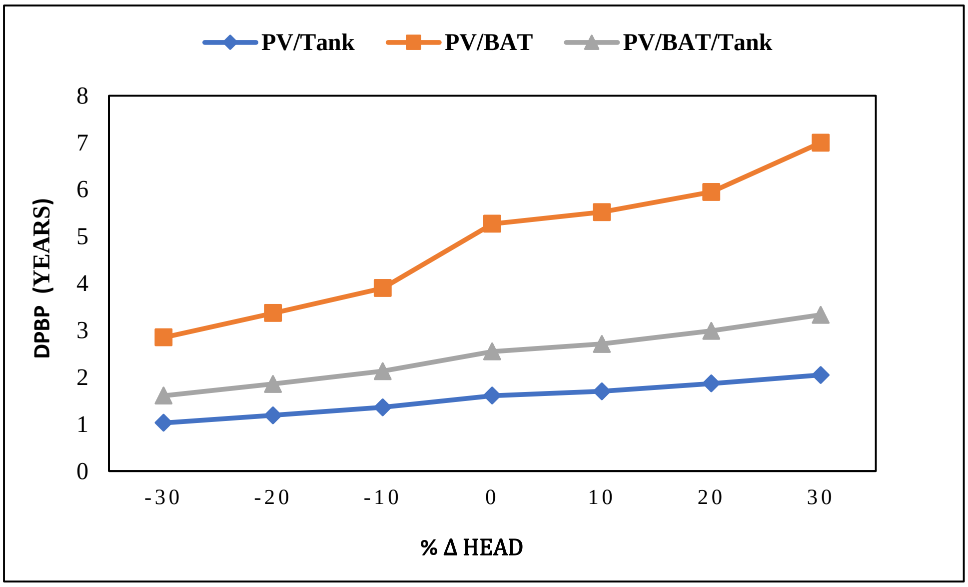

Figure 12. Effect of Variation of System Head on DPBP

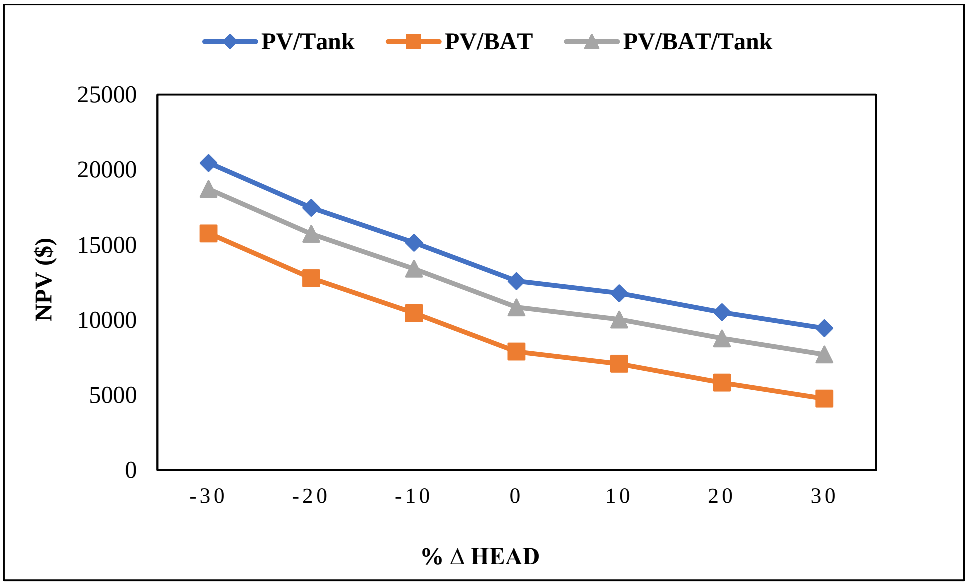

Figure 13. Effect of Variation of System Head on NPV

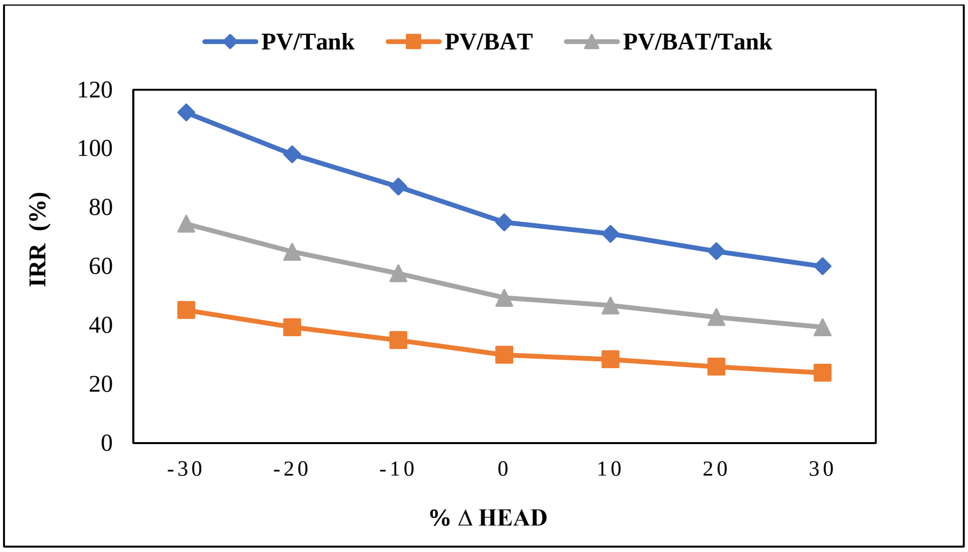

Figure 14. Effect of Variation of System Head on IRR

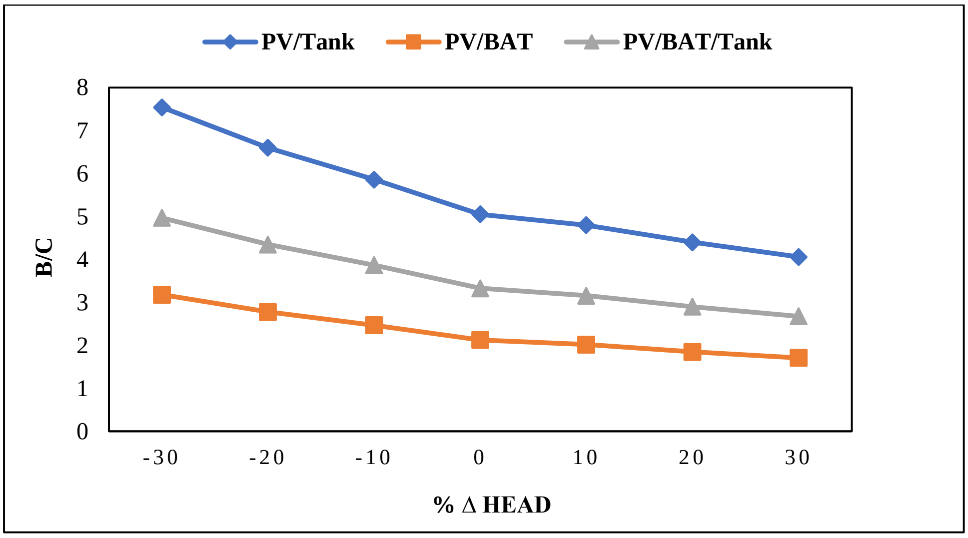

Figure 15. Effect of Variation of System Head on B/C

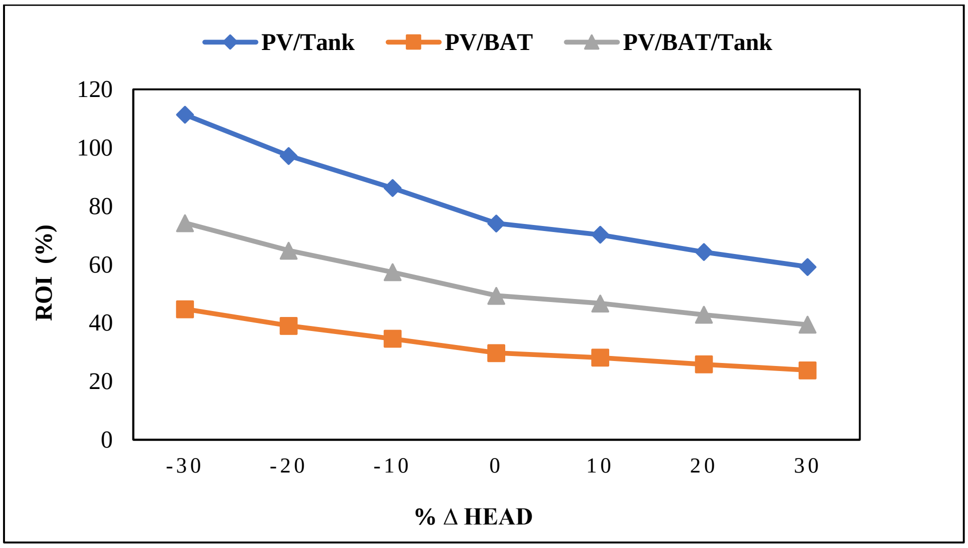

Figure 16. Effect of Variation of System Head on ROI

3.2.4. Change in Solar Irradiance on Economic Indicators

An increase in solar irradiance of a location will lead to an increase in discharge rate, which automatically will increase in sunshine hours of the location. Furthermore, an increase in solar irradiance will lead to a reduction in C_{inv}. Figure 17 shows the effect of varying solar irradiance on DPBP. An increase in solar irradiance will lead to a reduction in DPBP as more volume of water will be produced per day. The effect is also seen in NPV as presented in Figure 18, IRR as in Figure 19, B/C as shown in Figure 20, and ROI as in Figure 21, respectively, which are all increasing slopes that are favourable to an investor. Hence, an increase in solar irradiance will automatically increase the profitability of the investment.

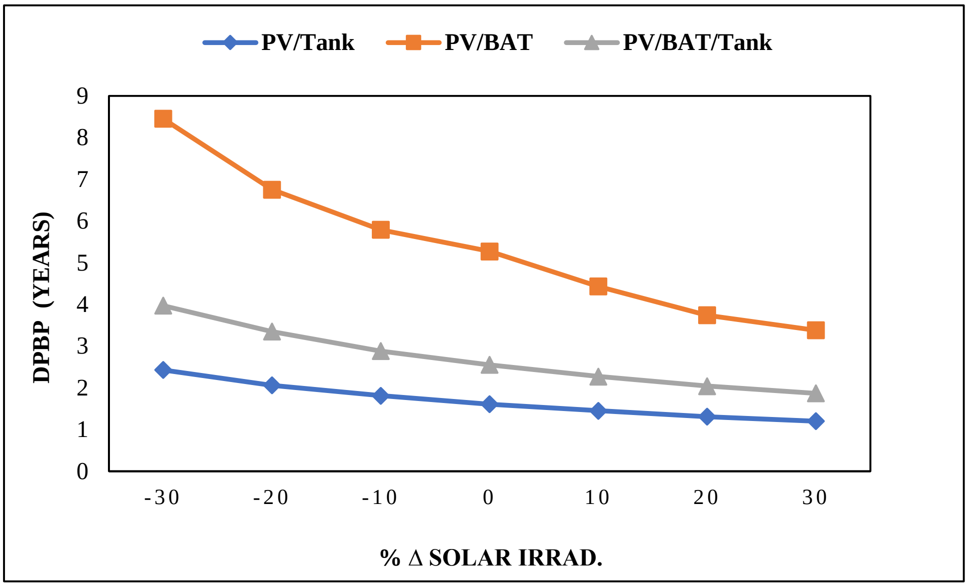

Figure 17. Effect of Variation of Solar Irradiance on DPBP

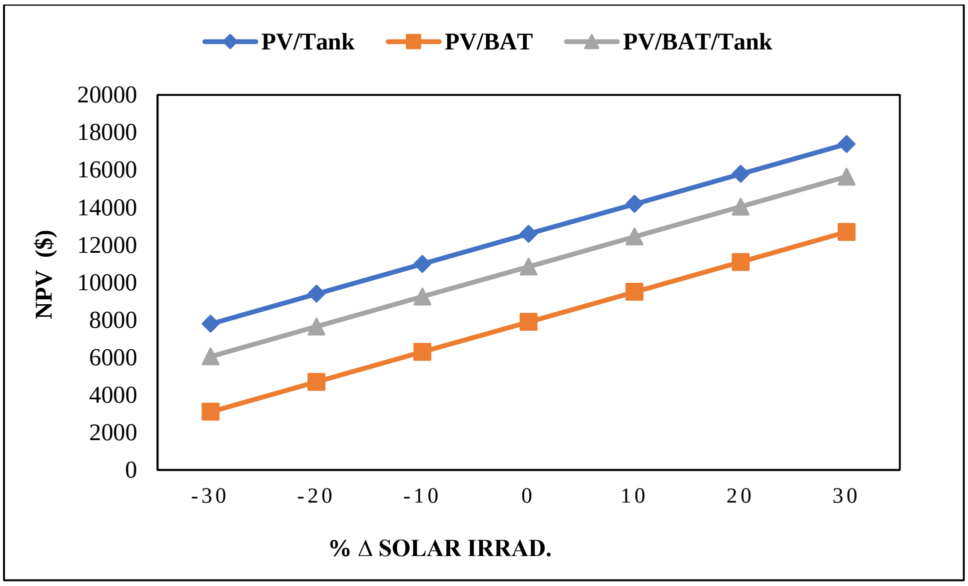

Figure 18. Effect of Variation of Solar Irradiance on NPV

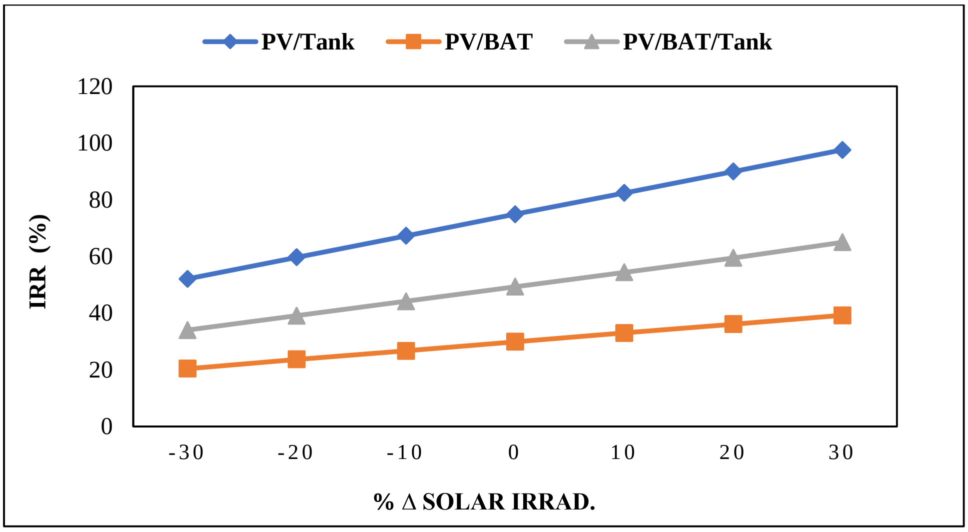

Figure 19. Effect of Variation of Solar Irradiance on IRR

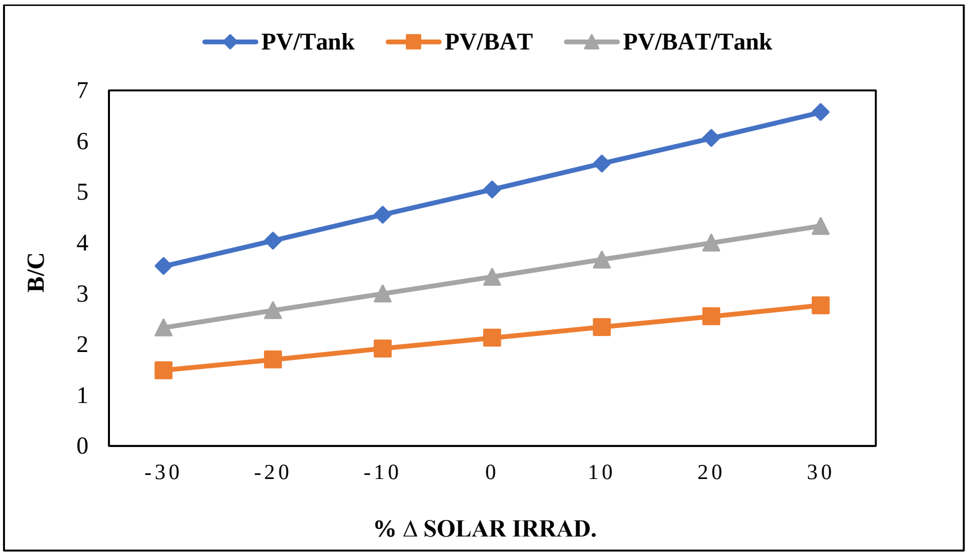

Figure 20. Effect of Variation of Solar Irradiance on B/C

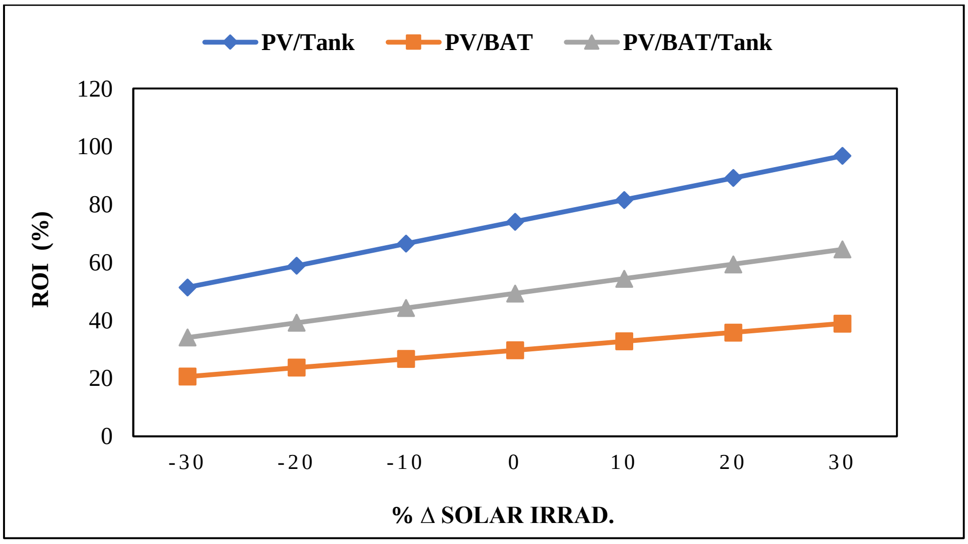

Figure 21. Effect of Variation of Solar Irradiance on ROI

4. Conclusions

This paper has presented a comparative economic viability and sensitivity study of a hybrid PV/Battery/Diesel power generation for (WPS) in Nigeria using a location in Ibadan, Nigeria as a test case. The proposed standalone energy system was designed to satisfy a daily farm water requirement of $8\,m^3$. The paper considered five different energy system configurations for pumping water, which has been configured to have at least one storage device, i.e., a battery or tank. The system configurations examined included PV/Tank, PV/BAT, PV/BAT/Tank, DG/BAT and DG/Tank options, which have been designed based on standard sizing approaches. A rigorous sensitivity analysis was conducted on the cost aspect to determine the economic viability of the WPSs. The results reveal that the total area of the PV module required is 8.28 m^2, the total PV power is 1.25 kW and the battery's total storage capacity is 920 Ah. The ratings of the inverter, charge controller and DG were also determined to be 1 kVA, 25 A and 1 kVA respectively. Also, the pump rating and tank capacities were determined to be 0.5 kW and $30\,m^3$ respectively. The results of the economic analysis based on five profitability indices include: PV/Tank has C_{water} of $\$\ 0.247/m^3,$ DPBP of 1.61, NPV of \$12583.4, IRR of 74.9 %, B/C of 5.05 and ROI of 74.1 %; PV/BAT has C_{water} of $\$0.400/m^3,$ DPBP of 5.27, NPV of \$ 7892.7, IRR of 29.9 %, B/C of 2.13 and ROI of 29.7 %; PV/BAT/Tank has C_{water} of $\$\ 0.388/m^3,$ DPBP of 2.55, NPV of \$ 10841.9, IRR of 49.3 %, B/C of 3.33 and ROI of 49.3 %; DG/BAT has C_{water} of $\$\ 0.926/m^3,$ NPV of $\$ - 1200.3$, IRR of 10.6 %, B/C of 0.96 and ROI of 11.7 %; DG/Tank has C_{water} of $\$\ 1.661/m^3,$ NPV of $\$ - 11120.5$, B/C of 0.59 and ROI of -99.6 % respectively. From the economic indices, PV/Tank was the best configuration because it has the best profitability margin, while DG/Tank was the worst configuration because of the economic indices revealed. The results for sensitivity analysis of the variation of investment cost, tariff rate, system head and solar irradiance were also revealed.

Acknowledgements

Declaration of Competing Interest

No conflict of interest was declared by the authors.

Authorship Contribution Statement

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Akintunde Samson Alayande: Methodology, Supervision

Olakunle Elijah Olabode: Methodology, Supervision

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Olasunkanmi Oriola Akinyemi: Methodology, Supervision

Ajibola Oluwafemi Oyedeji: Writing, Reviewing and Editing

Emmanuel Seun Oluwasogo: Data Preparation, Writing, Reviewing and Editing

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