Assessment of Technical Potential of Floating Solar Photovoltaic System for Electricity Generation in Zambia

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DOI: https://doi.org/10.51584/IJRIAS.2023.8502

Received: 28 October 2022; Accepted: 22 November 2022; Published: 22 May 2023

Abstract: Sustainable hydropower development provides a basis for a reliable and stable power source that is economical and environmentally friendly. Zambia is heavily dependent on hydropower whose hydrological pattern is facing serious threats from frequent droughts and severe weather conditions affecting power generation. However, Zambia's hydropower is characterized by larger water reservoirs (Mulungushi, Itezhi Tezhi, Kafue Gorge and Kariba North) receiving high solar energy exceeding 2000 kWh/m^2 per year. Hence, integration of floating solar PV systems with hydropower could help boost hydropower production during dry periods and save loss of water through vapor. The paper aims at assessing the technical potential of integrating floating solar PV systems for electricity generation on the existing larger hydropower water reservoirs. The findings indicate that larger hydropower reservoirs have a total surface area of 11,146 km^2 equivalent to an annual theoretical solar energy potential of 25,610TWh.At 10% of the total coverage of all the surface areas, the technical potential is estimated at 172.76 GW$_P$ (Monocrystalline), 141.44 GW$_P$ (CIS) and 116.10 GW$_P$ (CdTe) equivalent to an annual solar electricity generation potential of 304 TWh, 244 TWh and 211TWh respectively. In short, Zambia has huge potential for integration of floating solar with hydropower using the existing power grid infrastructure to increase on the electricity generation for the nation. Additionally, the solar energy profile fits well with the electricity demand profile for Zambia which makes it a better alternative for the energy mix of the country. These findings are vital to providing a guide to decision-makers for the inclusion of floating solar energy in the future national energy mix and conservation of land.

Keywords: Substation Reserve Utilizations, Floating Solar PV, Electricity Generation, Photovoltaic, Renewable Energy, Hydro Reservoirs

I. Introduction

Zambia's electricity mainly comes from renewable and none renewable energy. Renewable energy involves the generation of power using water as the prime mover of the turbines. while Solar energy comes from solar radiation. None renewable energy involves generation of power using fossil fuel materials that diminish and are not widely available throughout the country. Currently, reasonable fossil fuel deposits are found in Maamba district of Southern Province of Zambia [1,5,8]. The country has been using electricity since the early century and since then hydropower generation has evolved greatly such that, the total generation by 2021 generation was at 2,704.5 MW [28,36]. There are other renewable energy sources existing such as (biomass, wind, and [28]. Hydropower is an important source of energy in Zambia and it accounts for 81.5 percent of the total national energy generation of 3,318.4 MW [3,28]. Additionally, Zambia has an untapped hydropower potential of about 6000MW [1,36]. However, in recent past decades poor rainfall patterns, have been affecting the country's hydrological pattern [2,6,26,39]. In the 2016/2017 rain season, Zambia and most parts of the Southern African Development Community (SADC), experienced the worst drought and prolonged poor weather conditions [4,5]. Thus, the availability of water resources has been altered due to droughts, which have led to, reduced hydropower generation as can be seen in (figure 1.1) and an increased energy deficit in the nation [6]. This was caused by poor rainfall patterns as the result of raising temperatures experienced because of climate change [6,7,8,34]. Higher temperatures increased the loss of water through evaporation affecting the average capacity factor of hydropower. Considering the effects of climate change and its consequences on hydropower plant, other low-carbon energy technologies such as floating solar Photovoltaic systems need to be Prioritized and deployed at a large scale [10]. African countries have an exceptional solar potential with a yearly average solar energy exceeding 2000 kWh/m^2 [3]. Currently, Africa accounts for a PV installed capacity of only 5 GW of which Zambia has 96 MW translating to less than 1% of the total capacity of Africa's solar energy.

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS | Volume VIII Issue IV April 2023

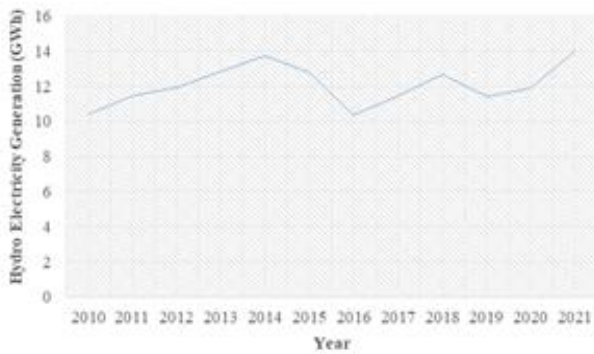

Fig1.1 Hydropower Electricity Generation in Zambia [7,28]

The International Energy Agency (2020) projected that an estimated average future deployment of almost 15 GW per year, will finally reach 320 GW globally by 2040. This would make Photovoltaic systems the largest sources of electricity to be installed in the continent, exceeding natural gas and hydropower [9]. Considering the increasing energy needs in Zambia and its vast solar resources, this study presents the feasibility of an effective energy interdependence between solar photovoltaics (PV) and hydropower through the development of Floating PV systems [32]. Furthermore, floating photovoltaic systems will compensate greatly to the reduction of hydropower output during dry seasons and reduce water loss through evaporation [2,8,9,10]. FPV Systems will offer reliable solutions to Zambia's hydropower shortages as they could rapidly cover up to the installed power capacities of the power station and use existing power system infrastructure including local expertise.

Additionally, floating photovoltaic solar system (FPV) has an additional advantage that is pertinent to Zambia's hydropower. Saving of surface land resources in Zambia will be achieved as the system will utilize much of the available water bodies and spare land for the local authority to utilize for other economic activities. It will also act as a means of saving water from considerable evaporations, as the panel will cover wider parts of some selected water bodies. The system will enhance solar efficiency because of cooling effects and will improve water quality as the growth of algae will reduce.

A lot of studies conducted so far have looked at many types of solar systems that generates electricity that is, Roof top mounted, land mounted and floating solar although, none of them have ever considered floating solar systems in relation to in fracture and local power system conditions.

Therefore, this paper aims at assessing the technical potential of floating solar PV systems for electricity generation in Zambia from the (4) largest water reservoirs (Kafue Gorge, Kariba North Bank, Mulungushi and Itezhi -Tezhi). The evaluation in this paper was based on local conditions of some specific study sites selected from the largest hydropower reservoirs in Zambia. This paper is divided into several section: Section I provides the introduction. Section II provides a review on electricity industry in Zambia including energy demand, available water bodies and solar energy potential. Section III presents the paper findings and discussions on results of theoretical, geographical, and technical potential of floating solar Photovoltaic systems in Zambia considering the four largest hydropower reservoirs with their power systems' local conditions. Section IV summarizes the finding of the paper, outlining the importance of integrating floating solar PV system with the existing hydropower plants and using existing infrastructure to meet the current and future Zambia's energy needs.

II. An Overview of Electricity Industry in Zambia

A. Electricity Industry Players in Zambia

Electricity supply industry in Zambia mainly comprises of a vertically integrated state utility, ZESCO, and an energy service company Copperbelt Energy Corporation (CEC) that purchases power from ZESCO and supplies it to the mines [38]. In addition, other Independent Power Producers includes, Lunsemfwa Hydro Power Company

(LHCP), Maamba Collieries Ltd, Itezh Tezh Power Corporation, Dangote Industries Zambia Ltd, Ndola Energy Company Ltd, Bangweulu Power Company Ltd, Ngonye PV Power Company Ltd, and Zengamina Power Company (ZPC) and some small-scale solar based energy service companies supplying power to some rural areas are also part of the industry [1]. Additionally, other players include North-Western Energy Corporation Ltd and Rural Electrification Authority (REA). According to Ministry of Mines, Energy and Water Development of Zambia [8], ZESCO currently dominates electricity generation, transmission, distribution, and supply in Zambia.

B. Energy Demand in Zambia

Electricity consumption in Zambia has been rising steadily estimated at approximately 6% per year 150- 200MW [1]. For the past decades, the country has been experiencing energy deficit (figure 2) due to lower generation from hydropower plants caused by global warming effects. The energy peak demand varies depending on the season; the winter peak demand is about 1450MW while the summer peak demand was about 1400MW as in 2009. However, in 2014 the peak demand was forecasted to be between 2,260MW and 2,612MW [5]. The energy demand is expected to reach 21.6TWh in fiscal year 2030 respectively [4,28].

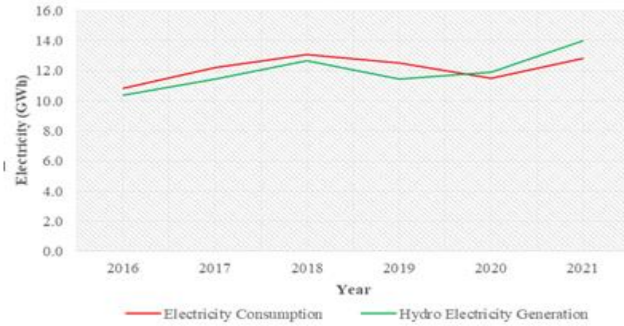

Fig. 2 Hydropower Electricity Generation vs Consumption in Zambia [7,28]

However, traditional wood fuels like charcoal and firewood have continued to be one of Zambia's main energy sources, much like in many other Sub-Saharan nations. Its share of the overall national energy mix is 70% [5,4,10,28,9]. The second most common source of energy, hydropower contributes 14% to overall energy consumption. 12% of the country's energy needs are met by petroleum products. Despite its high potential in the southern province, coal only accounts for a small 2% of the total energy supply Total energy demand in Zambia is barely 2% met by alternative energy sources like renewable energy. [7,8]

C. Water Bodies in Zambia

Zambia has adequate water bodies and reservoirs as compared to other countries in southern region with the water surface area of about 9,22 km^2 [7,31]. The country is rich in lakes such as Lake Mweru, Bangweulu, and Tanganyika and man-made lakes such as Kariba and Itezhi-Tezhi, and rivers like Zambezi, Kafue, Luapula, Chambishi, and Luangwa [31]. These existing water bodies apart from Luangwa have the potential to support floating solar photovoltaic systems. Additionally, Zambia's hydropower is characterized with large reservoirs such as Kafue Gorge, Kariba North Bank, Mulungushi and Itezh Tezh with total surface area of 11,146 km^2 receiving excellent solar radiation (Table 1) which can be integrated with floating solar PV system while using existing hydropower plants' infrastructure [20,21,1].

Table 1 Larger Hydro Reservoirs Surface Areas and Solar Radiations Parameters

Hydro Dam	Province	Installed Capacity (MW)	Solar Radiation kWh/m^2	Optimum Tilt Angle	Reservoir Surface Area (km^2)
Kariba North	Southern	1080	5.86	22^0	5580
Mulungushi	Central	31.3	5.90	15^0	4963
Kafue Gorge	Lusaka	990	5.93	22^0	805
Itezhi-Tezhi	Southern	120	5.93	15^0	392
Zambia		**2221.3**	**5.91**		**11,146**

Hydropower reservoirs constitutes the central theme of sustainable water development; however, these infrastructures are vulnerable to evaporation losses due to rise in air temperature which is estimated at 0.036^0C per year for Zambia [29,30]. If this proves to be the case then the annual evaporation loss of reservoirs is likely to continue increasing from the current evaporation losses (table 2) estimated at $1.68m^3/m^2$/year for Itezhi-Tezhi, 1.86m3/m^2/year for Kafue Gorge and $1.59m^3/m^2$/year for Kariba

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS | Volume VIII Issue IV April 2023

North (22^0). Therefore, it would be prudent to integrate floating solar with hydro power and mount solar panels on reservoirs' surface areas to mitigate against higher evaporation. Savings in evaporation from reservoir areas can be expected which will lead to increase in hydropower potential. Table 2 shows the annual open water evaporation rates for the four reservoirs under considerations.

Table 2 Annual Reservoir Evaporation Rates and Losses [29,30,43]

Hydropower Reservoir	Annual Evaporation Rate (mm)	Average Annual Rainfall (mm)	Annual Evaporation Losses (km^3)
Kafue Gorge	1840	850	1.5
Kariba North	2000	700	8.9
Mulungushi	2051	1200	5.6
Itezh Tezh	1784	700	0.66

D. Solar Energy in Zambia

Solar energy is radiant light and heat from the sun that is harnessed using a range of ever evolving technologies such as solar heating, photovoltaics, solar thermal energy, solar architecture molten salt power plants, thermal plant made out of solar concentrates, and artificial photosynthesis. It is an essential source of renewable energy, and its technologies are broadly characterized as either passive solar or active solar depending on how they capture and distribute of their energy into the power grid. The study carried out by [1,2,8] showed that Zambia has a favorable climate with an average sunshine of about six (6) to eight (8) hours per day throughout the country with solar energy of 5.5kWh/m^2/day throughout the year. Such irradiation is enough for power generation using floating solar systems [42].

Table 3 Annual Average Pan-Evaporation & Daily Solar Radiation for Provinces in Zambia [1,29,30]

Provinces	Annual Average Solar Radiation (kWh/m^2-Day)	Annual Average Pan-Evaporation (mm)
Lusaka	5,70	2,218
Luapula	5,78	1,983
Central	5,76	2,105
Copperbelt	5,75	1,865
Northern	5,83	1,907
N-Western	5,74	1,932
Western	5,89	2,300
Southern	5,80	2,015
Eastern	5,68	2,211
Zambia	**5,77**	**2,061**

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E. Solar Projects in Zambia

Solar energy resources are increasingly used across Zambia. This supports natural environmental sustainability, combat global warming and climate changes while increasing access to energy for all. Though, alternative energy resources are good, their deployment on land have got adverse effects on both the environment and the society as compared to floating solar energy harvesting systems.

In compliance with vision 2030, the Zambian government through Rural Electrification Authority (REA) project embanked on solar PV projects of installing 200 combined solar off-mini and micro grid in several villages across the country such as the 60kW in Samfya district of Luapula province, and implementation of solar PV farms such as 55MW and 35MW solar PV farms in Multi-Facility Zone (MFZ) Lusaka District, Lusaka province. Furthermore, REA has installed about 250 solar PV systems in schools and buildings of traditional authorities as well as 400 solar home systems under the Energy Service Companies (ESCO) pilot project [7,9,28]. Additionally, Zambia has more than eight (8) planned solar PV farm projects (1122MW_P) underway as shown in figure 3 below including plans to construct 200MW concentrate solar power plant (CSP) in Kalulushi to provide power to the Copperbelt Province and nearby regions [37] and wind farm in Katete District, Eastern Province. The implementation of the 1122MW_P ground solar PV projects will require approximately 2244 hacters (22.44km^2) of land representing about 0.003% of Zambia's surface area which can be used for other economic activities. If these projects are integrated on hydropower plant reservoirs only 0.20% of the largest hydro reservoirs' surface area is required thereby, saving land (22.44km^2).

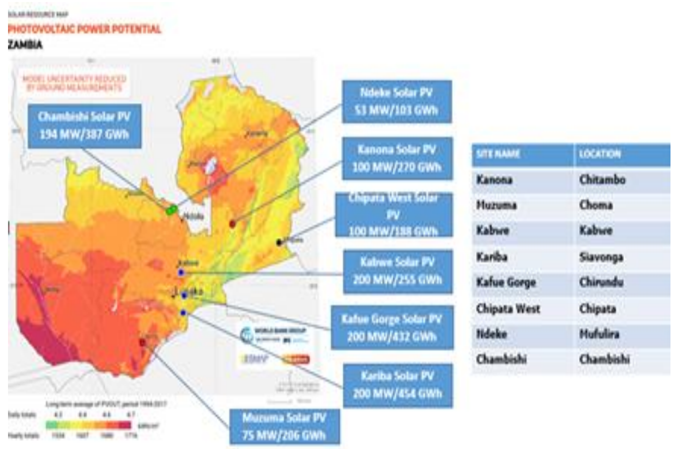

Fig.3 Solar Radiation and On-Grid planned Solar PV project in Zambia.

III. Methodology

This section provides the methods used for the assessment of theoretical, geographical and technical potential of floating solar PV system for electricity generation considering the four (4) largest hydropower reservoirs, Kariba North, Kafue Gorge, Mulungushi and Itezhi-Tezhi including water saving from evaporation while using floating solar PV systems.

F. Theoretical Potential

Theoretical solar energy potential involved the assessment of the solar energy that is received on the surface of each of the four (4) large hydropower reservoirs in Zambia. This potential involved identifying the four (4) hydropower reservoirs' boundary and the size of the reservoirs' surface area, including average daily solar radiation magnitude received on the site. Thus, the theoretical potential has been evaluated using the equation 1 below [1].

$$E_{TH} = A_{ADS} \,.\, H_R \,.\, T_{TSH} \qquad (1)$$

Where, E_{TH} is theoretical solar energy potential (TWh/year), A_{ADS} is the hydropower reservoir's surface area (km^2), H_R is the solar irradiance (TW/km^2), and T_{TSH} is annul total sunshine hours (hours/year).

G. Geographical Potential

Geographical solar energy potential involved assessing the solar energy that is received on the available and suitable land area. Thus, the process of assessing this potential involved firstly, excluding the restricted water intake areas of the power station, fishing areas, boat cruise, surface water bodies' areas, protected national parks water front, according to literatures. Therefore, the remaining water surface area was taken as the most suitable land area for floating solar energy technologies' deployment. The geographical solar energy potential has been estimated using equation 2 [1].

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$E_G = A_{ADS} .H_R$ (2)

Where E_G is geographical solar energy potential (TWh/year), A_{ADS} is available suitable area (m^2), and HR is Total average yearly solar radiation (kWh/m^2-year)

The geographical solar energy potential was evaluated considering percentage reservoir surface area coverage which was varied between 0.01% and 10%.

H. Technical Potential

The process of assessing the extractable energy potential from the sun for any surface involves firstly, by excluding areas not suitable for this technology within the defined hydropower reservoir boundaries considering the estimated geographical potential and technical characteristics of PV generation systems to convert the solar energy to electrical energy considering local conditions. The technical potential was evaluated considering reservoir surface area coverage which was varied between 0.01% and 10% considering three (3) solar PV technologies; Monocrystalline, CIS, and CdTe. Thus, the technical solar energy potential for the existing available suitable reservoir surface area was estimated using the equation 3.

$E_T = A_{ADS} . P_{PD} .CF.T_{TSH}$ (3)

Where E_T is solar electricity generation potential (TWh/year), A_{ADS} is hydropower reservoirs' available suitable area (km^2) considering reservoir coverage percentage (between 0.01% and 10%), P_{PD} is reservoir site power density (TW/km^2), CF is site solar PV capacity factor (%) considering the local condition (local air temperature, wind speed, cloud cover, etc), and T_{TSH} is total hours in a year (8760).

IV. Economical Potential

The process of assessing the economical energy potential from the sun involved considering the electrical grid infrastructure availability for each of selected largest four (4) hydropower plant sites suitable for the integration of floating solar PV technology within the defined hydropower reservoir boundaries considering the estimated geographical surface area and technical characteristics of PV generation systems to convert solar energy to electrical energy while taking into consideration of the local conditions. The economic potential was evaluated considering Hydropower plants' installed capacity and generation deficit.

The evaluation included substation reserve margins while taking into account the installed and available power plant capacity. According to data collected from the power plants, the substation reserve margin was found to be 360 MW for Kafue Gorge, 180 MW for Kariba North, 6.67 MW for Mulungushi, and 8 MW for Itezhi-Tezhi at best power plant operation period. However, during dry seasons, it was noted that some of the generators at the power plants are usually removed from operation or operated at reduced capacity thereby, reducing available power plant capacity, thus increasing substation reserve margins.

Therefore, for optimal case and worst case the substation reserve margin was found to be; Optimal Case (420 MW for KG, 331MW for KN, and 17.3MW for IT) and Worst Case (909 MW for KG, 780MW for KN, 37.3MW for M, and 73.3MW for IT). Thus, for each of the scenarios (best, optimal and waste cases), the substation reserve margin utilization was varied between 10% and 75% considering three (3) solar PV technologies; Monocrystalline, CIS, and CdTe. Hence, 48 scenarios were conducted as shown in table 4 below 12 scenarios per hydropower plant;

Table 4 Economical Potential Scenarios

Scenario	**Substation Reserve Utilization (%)**	**KG**	**KN**	**MU**	**IT**	**Total Capacity (MW)**
		(MW)				
Best	10	36	18	1	1	**56**
	25	90	45	2	2	**139**
	50	180	90	3	4	**277**
	75	270	135	5	6	**416**
Optimal	10	42	33	-	2	**77**
	25	105	83	-	4	**192**
	50	210	165	-	9	**384**

	75	315	248	**-**	13	**576**
Worst	10	91	78	4	7	**180**
	25	227	195	9	18	**449**
	50	455	390	19	36	**900**
	75	682	585	28	55	**1350**

Thus, the economical solar energy potential for the existing available suitable reservoir surface area was estimated considering the substation reserves during normal and abnormal (dry or droughts seasons) operation of hydropower plants.

V. Evaporation Loss Savings

Evaporation of water from hydropower plant reservoirs' surfaces is sensitive to air temperature and can lead to significant amount of water loss. The amount of water lost from the surface of a reservoir due to evaporation is mainly influenced by the reservoir water surface area, shape, depth, air temperature, sun shine hours, wind speed, humidity, surrounding topography, vegetation, and its location (KNB-16.522^{0}N and 28.762^{0}E), (KUG -15.807 and 28.421), (MU-14.700 and 28.821), (II -15.760 and 26.021).

The estimation of reservoir water evaporation loss saving is often a critical issue as the opportunity rises for hydropower generation. The estimation of Water evaporation loss saving for the four selected largest hydropower reservoirs in Zambia has been estimated considering the net evaporation loss and the surface area of reservoir to be covered by floating solar PV system. The evaporation gross loss from a reservoir water surface area due to evaporation was estimated using equation (4). [29,30]

$$E_{GROSS}\,(mm) = 0.67E_{PAN} \tag{4}$$

Where E_{GROSS} (mm) is loss from a reservoir surface area due evaporation, E_{PAN} (mm) is evaporation from a Class A Open pan for the period of interest, and 0.67 is a conversion factor.

The net evaporation loss from surface of hydropower reservoir evaluation takes into consideration the amount of water gained from annual rainfall direct onto the reservoir surface and gross evaporation loss due to evaporation. Thus, the net evaporation loss was estimated using equation 5.

[29,30]

$$E_{NET}\,(mm)=E_{GROSS} - R_{RAINFALL} \tag{5}$$

Where E_{net}(mm) is the net losses from the surface of hydropower reservoir and R(mm) is annual rainfall over the period of interest. The total evaporation saving from the reservoir was calculated by multiplying the surface area covered by floating solar PV system in kilometer square and the net evaporation loss. Thus, the net evaporation loss was estimated using equation 6. [29,30]

$$E_{RESERVOIR}\,(km^3) = \frac{E_{NET}\,.\,A_{TOP}}{1000000} \tag{6}$$

Where $E_{reservoir}$(km^3) is the total evaporation saving from the reservoir due to evaporation and A_{top} (km^2) is the total surface of the reservoir covered by floating solar PV system.

VI. Result and Discussion

Zambia has currently more than eight (8) solar PV farm projects (1122MW_P) underway as shown in figure 2 with three (3) existing solar PV farm namely, 55MW_P Bangweulu, 35MW_P Ngoye and 1MW_P CEC. The implementation of the 1122MW_P projects will require approximately 22.44km^2 of land representing about 0.003% of Zambia's surface area which is equivalent to using only 0.20% of the total four largest hydro reservoir surface area. Solar energy resources are increasingly across Zambia to support natural environmental sustainability, combat global warming and climate changes while increasing access to energy for all. Additionally, the four (4) selected hydropower reservoirs receive abundant solar radiation enough for solar PV electricity generation as shown in figure 4 below.

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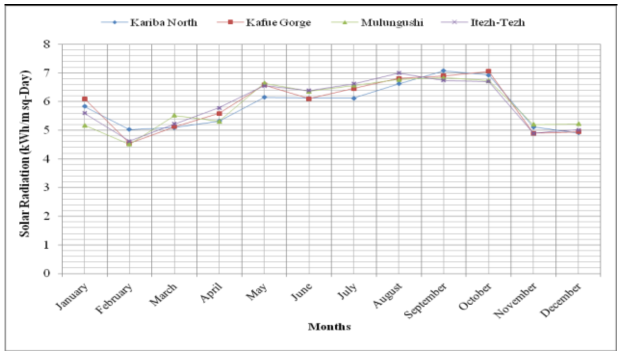


Fig.4 Monthly Average Solar Radiation Variation for the Hydropower Reservoirs Sites

However, like any alternative energy resources, utility-scale solar energy harvesting systems' deployment on land have adverse effects on both the environment and the society as compared to floating solar energy harvesting systems. Furthermore, floating solar PV systems energy potential assessments have been conducted by a number of researchers for various hydropower reservoirs in many different countries with an attempt to decrease the implementation cost, reduce evaporation on reservoirs and achieve optimal utilization of renewable energy. However, in Zambia very few to non-have been conducted to ascertain how much floating solar PV system could contribute to the future national energy mix plus contribute to evaporation water loss savings in a long term and how much available potential exist that can be tapped for integration with existing hydropower and grid infrastructures for the benefit of the nation. Thus, in this section assessment of theoretical, geographical and technical potential of floating solar PV system for electricity generation is presented.

Theoretical Potential

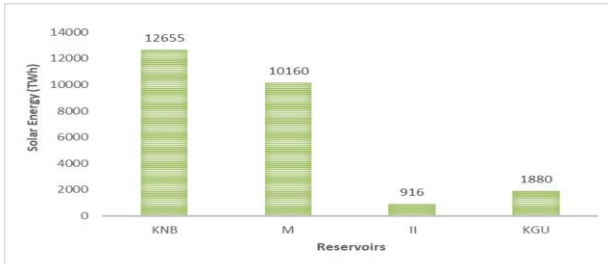
In Zambia, particularly in the rural areas were larger and suitable land areas for solar PV farms implementation are available, it is difficult and costly to implement on-grid solar due to distances to grid and if grid exist the capacity is usually not permissible to take huge solar farms due to stability issues. However, on-grid floating solar PV systems particularly in the case of Zambia is more ideal due to availability of larger hydropower reservoirs (11,146km^2) with existing grid infrastructures capable of integrating larger solar PV farms.

The results shows that Zambia has 11,146km^2 available surface of large hydropower reservoirs with a total of 25,611 TWh annual solar energy potential as shown in table 3. Kariba North Bank water reservoir receives the highest solar energy of 12,655 TWh annually due to larger surface area (5580km^2), followed by Mulungushi which receives 10,160 TWh despite having the smallest installed hydropower station with only 31.3MW whereas Kafue Gorge and Itezh Tezh have annual solar energy potential of 1,880 TWh and 916 TWh respectively. Due to available larger reservoir surface areas, Kariba North and Mulungushi have high solar energy theoretical potential as highlighted in table 5.

Table 5 Theoretical Solar Energy Potential for Four (4) Larger Hydropower Reservoirs in Zambia

Month	Theoretical Solar Energy Potential (TWh/Year)				Total Solar Energy (TWh)
	Kariba North	Kafue Gorge	Mulungushi	Itezh-Tezh	
January	1049	158	728	71	2006
February	905	131	703	65	1804
March	916	133	778	66	1893
April	958	150	774	76	1958
May	1106	171	936	83	2296
June	1102	164	926	83	2275
July	1102	168	924	84	2278
August	1190	177	954	89	2410
September	1274	185	995	88	2542

October	1247	183	949	85	2464
November	920	132	758	64	1874
December	884	129	736	63	1812
Total	**12,655**	**1,880**	**10,160**	**916**	**25,611**



[36,37]

Fig.5 Theoretical Solar Energy Potential of the Four Larger Hydro Reservoirs in Zambia

Geographical Potential

Table 6 below shows the geographical potential considering reservoir surface area coverage between 0.01% and 10%.

It can be seen that considering reservoir surface area coverage between 0.01% and 10%, Zambia has annual solar energy potential between 2.4TWh and 2393.5TWh respectively. This solar energy is enough for conversion to electricity using floating solar PV systems. Furthermore, it should be noted that only 0.20% of largest hydro reservoir surface area is required to implement all the eight (8) solar PV projects currently underway (1122MW$_P$) which will result in annual evaporation water loss saving amounting to 0.0101km^3 (10.1million m^3) representing 3.74% of total water supply consumption and 4.8% of total water used for irrigation for 2010 of Zambia. Additionally, utilization of 0.5% of the total reservoirs surface areas, the country has 119.7TWh of annual solar energy geographical potential. This potential translates to annual water saving from evaporation loss of approximately 0.0253 km^3 (25.3million m^3) (table). Figure 6, Table 6 and 7 below shows the solar energy geographical potential, reservoir surface area coverage and evaporation loss saving for the selected four (4) hydropower reservoirs.

Table 6 Solar Power Geographical Potential for all the water reservoirs

Reservoir Coverage (%)	Annual Solar Energy Geographical Potential (TWh)				Total Solar Energy (TWh)	Reservoirs Area Covered (km^2)
	KNBS	MU	KG	IT		
0.01	1.19	0.94	0.17	0.1	**2.4**	1.1
0.0125	1.49	1.18	0.22	0.1	**3.0**	1.4
0.025	2.98	2.35	0.44	0.2	**6.0**	2.8
0.05	5.97	4.70	0.87	0.4	**12.0**	5.6
0.5	59.68	47.04	8.71	4.2	**119.7**	55.7
1.0	119.35	94.09	17.42	8.5	**239.3**	111.5
2.5	298.38	235.22	43.56	21.2	**598.4**	278.7
5.0	596.75	470.43	87.12	42.4	**1196.7**	557.3
7.5	895.13	705.65	130.68	63.6	**1795.1**	836.0
10	1193.51	940.86	174.24	84.8	**2393.5**	1114.6

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS | Volume VIII Issue IV April 2023

Table 7 Hydropower Reservoir Annual Water Loss Saving

Reservoir Coverage (%)	Annual Evaporation Loss Saving (km^3)				Total Water Saving (km^3)	Reservoirs Area Covered (km^2)
	KNBS	MU	KG	IT		
0.01	0.0004	0.0001	0.00004	1.94E-5	**0.0005**	1.1
0.0125	0.0004	0.0001	0.00005	2.43E-5	**0.0006**	1.4
0.025	0.0009	0.0002	0.00011	4.85E-5	**0.0013**	2.8
0.05	0.0018	0.0004	0.00021	9.71E-5	**0.0025**	5.6
0.5	0.0179	0.0043	0.00214	0.0010	**0.0253**	55.7
1.0	0.0357	0.0086	0.00429	0.0019	**0.0506**	111.5
2.5	0.0893	0.0216	0.01072	0.0049	**0.1265**	278.7
5.0	0.1786	0.0432	0.02145	0.0097	**0.2529**	557.3
7.5	0.2678	0.0648	0.03217	0.0146	**0.3794**	836.0
10	0.3571	0.0864	0.04289	0.0194	**0.5059**	1114.6

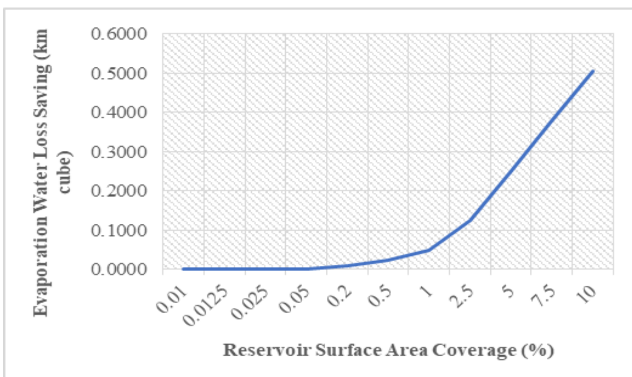


Fig.6 Solar Energy Geographical Potential of all the reservoir

The amount of water loss from the hydropower reservoirs can be significantly proportional to the total amount of water stored in the reservoirs and reservoirs' surface area. Thus, reducing the total reservoir water surface area exposure to daily air temperature through integration of floating solar PV system on the surface of these reservoirs can significantly reduce the evaporation losses and help increase hydropower generation potential. As seen from the findings that if 10% of the total surface area of the reservoirs are covered by floating solar PV systems not only enough solar energy (2393.5TWh/year) can be captured for conversion into electricity but a total of 505.9million m^3 per year of water can be saved too which is 1.04 times more than the 2010 water used for both irrigation and water supply for consumption in Zambia.

Technical Potential

Table 8, figure 7 and 8 shows the solar energy technical potential. It can be noted that of the three (3) solar PV technologies considered in this paper, for the reservoir surface area coverage varied between 0.01% and 10%, monocrystalline PV technology has the highest solar technical potential for instance at 0.01% surface area coverage, monocrystalline technology has potential to generate electricity of 0.30TWh as compared to 0.26TWh by CIS and 0.12TWh for CdTe. Furthermore, with monocrystalline PV technologies 172.764GW can be implemented for surface area coverage of 10% as compared to 141.447GW for CIS and 116.103 for CdTe. It should also be noted that using 1% of total hydropower reservoirs' surface area for implementation of floating solar PV systems, the country would be able to generate 1.34, 1.15, and 1.02 times more electricity using monocrystalline, Copper Induction Selenium (CIS) and Cadmium Telluride (CdTe) solar PV technology respectively. This 1% of the total reservoir surface area coverage translate to annual evaporation loss water saving equivalent to 50.5million m^3.

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Table 8 Solar Energy Technical Potential

Reservoir Coverage (%)	Solar Power Technical Potential (MW)			Annual Solar Electricity Generation Potential (TWh)		
	Mono	CIS	CdTe	Mono	CIS	CdTe
0.01	172	141	116	0.30	0.26	0.12
0.0125	217	177	145	0.38	0.32	0.27
0.025	431	354	290	0.77	0.61	0.53
0.05	863	707	581	1.50	1.21	1.07
0.5	8639	7073	5808	15	12.43	10.4
1.0	17277	14144	11611	29	25	22
2.5	43191	35362	29026	75	60	53
5.0	86382	70723	58053	152	123	107
7.5	129573	106085	87079	224	182	160
10	172764	141447	116103	304	244	211

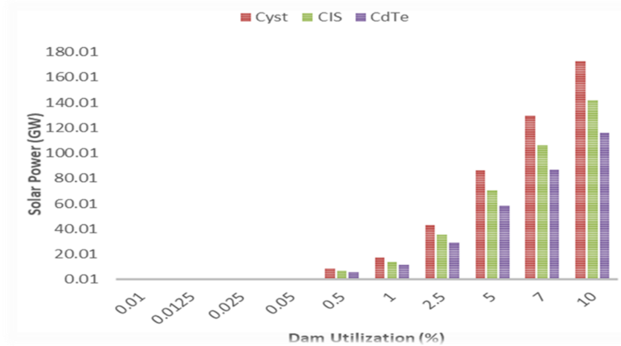

Fig.7 Solar Power Technical Potential for all the water reservoirs

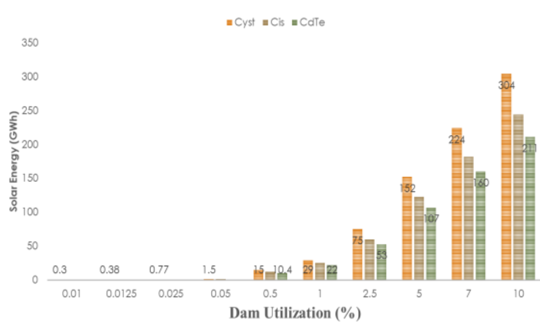

Fig.8 Solar Electricity Generation Potential of all the reservoir

Economical Potential

The economic potential was evaluated considering hydropower plant installed and available power capacity including generation deficit during dry or drought seasons. This also considered the substation installed capacity including substation reserve margins during normal and abnormal operation period of the hydropower plants. In this part 12 scenarios were considered by varying substation utilization considering power plants normal and abnormal operation period. The following were the results; at 2.28% coverage of the total surface areas of the four hydro dams with solar installation of 56MW, Mono crystalline solar

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technology generated 98.77GWh.CIS generated 96.65GWh while the CdTe solar technology generated 100.85 GWh coming out the highest with total surface area coverage of 0.0453**(km^2)**. its good performance was as a result of its good efficiency when compared with the other two solar technologies. At 15.61% coverage of the total surface areas of the floating solar system with an installation of 384MW of solar CdTe technology generated 641GWh of energy with 0.2904**(km^2)** surface area coverage while CIS and Mono crystalline generated 604GWh and 594GWh with a surface area coverage of 0.2431**(km^2)** and 0.1978**(**km^2) respectively. At 54.87% total coverage of the four dams, CdTe solar technology generated the highest energy 2922.69 GWh with the overall surface area coverage of 1.0518 (km^2**)** of the four water reservoirs while CIS and CdTe technology generated 2786.32GWh and 2699.82GWh with the total surface area coverage of 0.2143 **(**km^2 and 0.2613 **(km^2)** of the total surface areas of the four hydro dams. The results stated above shows that CdTe solar technology performed well in terms of energy generation despite occupying a relatively smaller area than these other two solar technologies mono crystalline and CIS as shown table 9 and table 10

Table 9 Economical Potential of floating Solar PV systems

Substation Utilization (%)	**Solar PV Capacity (MW)**	**Annual Solar Electricity Generation Potential (GWH)**		
		MONO	**CIS**	**CdTe**
2.28	56	98.77	96.65	**100.85**
3.12	77	132.55	134.5	**144.7**
5.64	139	243.32	239.95	**254.55**
7.32	180	308.86	304.0	**317.3**
7.80	192	333.0	329.0	**349**
11.26	277	480.0	473.0	**502**
15.61	384	594.0	604.0	**641**
16.91	416	695.0	686.0	**734**
18.25	449	848.09	839.75	**892.24**
23.41	576	1166.53	1152.52	**1223.4**
36.58	900	1833.79	1842.84	**1954.29**
54.87	1350	2786.32	2699.82	**2922.69**

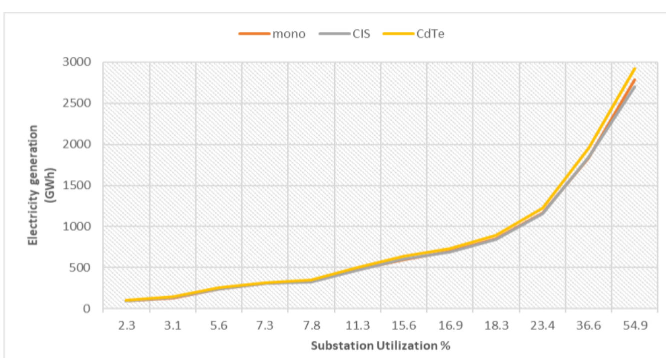

Fig9 Economical Potential of floating Solar PV systems

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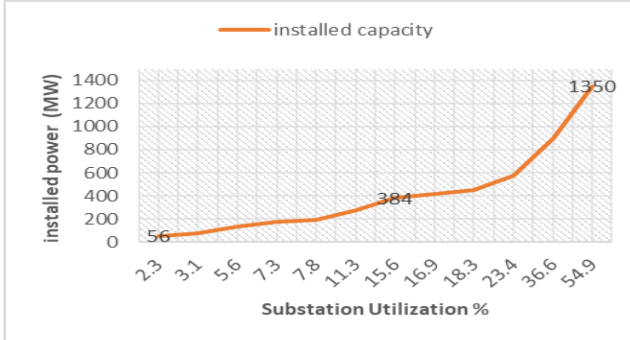

Fig10 Economical Potential of floating Solar PV systems

Table 10 Economical Potential and Reservoir Surface Area Coverage by floating Solar PV System

Substation Utilization (%)	Solar Pv Capacity (MW)	Reservoir Surface Area Coverage (km^2)		
		MONO	CIS	CdTe
2.28	56	0.0343	0.0627	**0.0453**
3.12	77	0.0372	0.0851	**0.0611**
5.64	139	0.0786	0.1369	**0.1234**
7.32	180	0.0869	0.1817	**0.2243**
7.80	192	0.1067	0.1917	**0.2443**
11.26	277	0.1705	0.2047	**0.2505**
15.61	384	0.1978	0.2431	**0.29042**
16.91	416	0.2143	0.2613	**0.3204**
18.25	449	0.2654	0.3144	**0.3866**
23.41	576	0.3202	0.3826	**0.3987**
36.58	900	0.4783	0.5805	**0.6993**
54.87	1350	0.7135	0.8687	**1.0518**

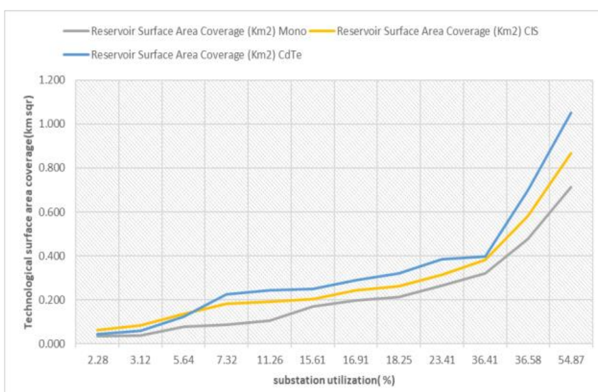

Fig 11 Economical Potential of Reservoir utilization % and solar technological surface coverage

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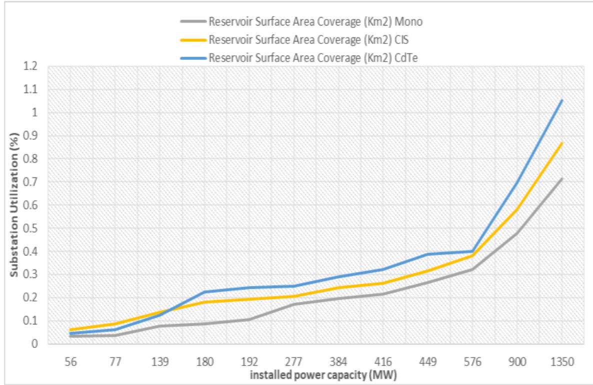

Fig12 Economical Potential of installed power and substation utilization %

Fig 9 and 10 shows electricity generated and integrated into the system using three scenarios (Best, Optimum and Waste case Scenario). The results of the three scenarios from all the (4) large water reservoirs show that at 10% of Substation reserve margins, waste case scenario generated 180TWh, Optimum 77 TWh and at best case scenario 56TWh. At 75% the highest substation reserve margin, waste case scenario energy generated was 1350TWh while at Optimum and Best-case scenarios generation were 576 TWh and 416 TWh respectively. These results shows that there is more energy generation and contribution into the grid from floating solar system during waste case scenario as it has been shown both at highest and lowest substation reserve margins followed by Optimum and Best case scenario which is in line with literature review which indicated that when there is less water for electricity generation, there is a wider reserve margin within the substation due to low energy generation making it possible for floating solar to contribute more energy .Subsequently, at Best case scenario, less energy is contributed as the system is still working normally and only requires less power contribution to raise energy profiles for the system to stabilize and operate at full capacity. From the energy generated and contributed into the system after accounting all the losses as shown in figure 9 and figure10, it is clear and possible that Zambian's energy profiles could be raised by introducing floating solar photovoltaic systems which operates mainly during the day making the country meet its national energy demand for domestic and industrial use while prolonging the life span of the dams during water savings and allow it to be used for other economic uses. Technical floating solar photovoltaic system at waste case scenario generated 1350TWh of energy enough to supply to the nation during adverse climatic conditions that might affect the energy sector. From the findings of the study floating solar photovoltaic system can manage to supply energy into the grid for both during normal and bad energy generation situations and could allow extra energy to be exported to nearby regions and improve the sectors financial base

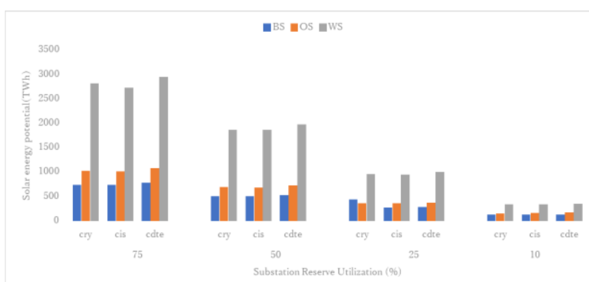

Fig.13 Solar Energy technical potential of all Scenarios

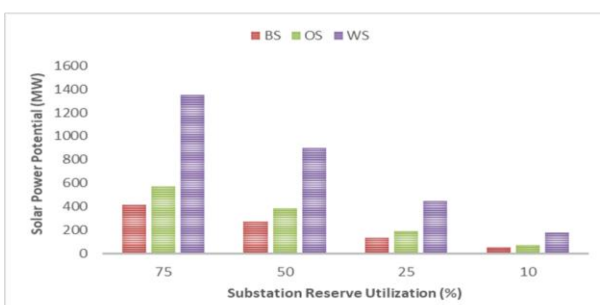

Fig.14 Power Potential for all Scenarios

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Table 11Economical Potential and Evaporation Loss Saving of floating Solar PV System

Substation Utilization (%)	Solar PV Capacity (MW)	Annual Evaporation Losss Water Saving (km^3)		
		MONO	CIS	CdTe
2.28	56	3.46E-10	6.33E-10	4.58E-10
3.12	77	3.76E-10	8.60E-10	6.17E-10
5.64	139	7.94E-10	1.38E-09	1.25E-09
7.32	180	8.78E-10	1.84E-09	2.27E-09
7.80	192	1.08E-09	1.94E-09	2.47E-09
11.26	277	1.73E-09	2.07E-09	2.53E-09
15.61	384	2.00E-09	2.46E-09	2.93E-09
16.91	416	2.16E-09	2.64E-09	3.24E-09
18.25	449	2.68E-09	3.18E-09	3.90E-09
23.41	576	3.23E-09	3.86E-09	4.03E-09
36.58	900	4.83E-09	5.86E-09	7.06E-09
54.87	1350	7.21E-09	8.77E-09	1.06E-08

VI. Environmental Responsibility

The findings of this research shows that if 10% of the total surface area of the four large reservoirs are covered by floating solar PV systems, not only enough solar energy (2393.5TWh/year) can be captured for conversion into electricity but also a total of 505.9million m^3 per year of water can be saved which is 1.04 times more than the 2010 water used for both irrigation and water supply for consumption in Zambia. Additionally, a total of 1,114.6km^2 of land could be preserved, thus, reducing environmental impact and supporting sustainable development. Promotion of renewable energy enhances clean energy which has no bad effect to the environment.

The problems associated with the implementation of floating Solar photovoltaic System in Zambia

Even though floating solar PV systems have demonstrated to be an alternative energy source in the nation, there are still certain difficulties associated with their free functioning in Zambia. These difficulties include;

i. Eenormous upfront financial requirements which requires large financial lending institutions to be involved in its execution.

ii. Other than that, operational procedures and guidelines based on high-inertia power generators that continue to support low-inertia renewable energy technologies are unable to supply the system's initial energy needs.

iii. Modifying the current legislative and grid codes, which were created to accommodate traditional power generation, in order to align them with contemporary design and constructions that could conform and accommodate future energy mix will be required

VII. Conclusion

The paper presented floating solar PV system technical potentials assessment considering four largest hydropower reservoirs in Zambia; Kafue Gorge, Kariba North, Mulungushi, and Itezhi-Tezhi with total surface area of 11,146km^2 and total installed hydropower capacity of 2221.3MW.

The findings indicates that larger hydropower reservoirs have a total surface area of 11,146 km^2 equivalent to annual solar energy potential of 25,610TWh. For 10% total water reservoir surface area coverage the technical potential is estimated at 172.76

GW_P (Monocrystalline), 141.44 GW_P (CIS) and 116.10 GW_P (CdTe) equivalent to annual solar electricity generation potential of 304 TWh, 244 TWh and 211TWh respectively.

With these results, Zambia has huge potential for integration of floating solar with hydropower using the existing power grid infrastructure to increase on the electricity generation for the nation. Additionally, solar energy profile fits well with electricity demand profile for Zambia which makes it a better alternative for energy mix for the country.

The findings are vital to provide guidance to decision makers for inclusion of floating solar energy in the future national energy mix and conservation of land. The findings shows that Zambia has untapped solar energy potential for floating Solar PV integration with hydropower systems essential to increase reliability of national power systems and increasing electricity generation.

Evaporation is the main cause of large water loss in hydropower reservoirs in Zambia and thus considering the current effect of climate change, rise in temperatures and climate variability which have potential to enhance evaporation water loss in the reservoirs. It is, therefore, necessary to incorporate floating solar PV system as an alternative measure to reduce evaporation losses and increase hydropower generation potential for these hydropower plants but also to increase energy diversity in the future national energy mix as well as avoidance of using land which could be used for other economical means.

More conclusively, it was noted that the combination of hydropower and floating solar PV power are vital to lessen strain on the land use for solar PV system implementation, conservation of water by reducing evaporation water losses and increasing hydropower electricity generation. Thus, Zambia has untapped solar energy potential which if combined with hydropower using existing electricity infrastructure would help meet the energy requirement for the country.

Based on the study findings, implementation of floating system is possible in Zambia based on the technical results which has shown that at worst case scenario when there is low power generated by hydropower, solar energy can greatly complement the energy deficit. With the combination of solar technology and hydropower, it is evident enough that electricity could be generated which can solve Zambia's energy problem. Additionally, not only will implementation of floating solar technology reduce use of land, reduce water evaporation losses, but also will increasing hydropower potential and also help reduce environmental impact and increase energy diversity mix in the national energy.

The study impact and its practical implications are that during the day, solar energy will supply power while hydropower is off and continue to save water. During the night in the absence of sun, hydropower takes over supply of power hence creating a state of power security and sustainability to the Zambian network

Acknowledgment

This study was greatly funded by University of Zambia through the School of Engineering. Much appreciation and thanks go to my supervisor for providing support and valuable input to the work and other researchers.

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