Potential of Floating PV Power Plant Deployed on lakes for Partial Electricity Supply: A Case study of NUST Lake

By

Hamza Hafeez

Reg. No. 00000319087

Session 2019-21

Supervised by

Dr. Adeel Waqas

US-Pakistan Center for Advanced Studies in Energy (USPCASE)

National University of Sciences and Technology (NUST)

H-12, Islamabad 44000, Pakistan

December 2021

Potential of Floating PV Power Plant Deployed on lakes for Partial Electricity Supply: A Case study of NUST Lake

By

Hamza Hafeez

Reg. No. 00000319087

Session 2019-21

Supervised by

Assoc. Prof. Dr. Adeel Waqas

A Thesis Submitted to the U.S.-Pakistan Center for Advanced Studies in Energy in partial fulfillment of the requirements for the degree of

MASTER of SCIENCE in

Energy Systems Engineering

US-Pakistan Center for Advanced Studies in Energy (USPCASE)

National University of Sciences and Technology (NUST)

H-12, Islamabad 44000, Pakistan

December 2021

THESIS ACCEPTANCE CERTIFICATE

Certified that final copy of MS/MPhil thesis written by **Mr. Hamza Hafeez** having Registration No. 00000319087 of USPCAS-E has been vetted by undersigned, found complete in all respects as per NUST Statues/Regulations, is free of plagiarism, errors, and mistakes and is accepted as partial fulfillment for the award of MS/MPhil degree. It is further certified that necessary amendments as pointed out by GEC members of the scholar have also been incorporated in the said thesis.

Signature: ______________________________

Name of Supervisor: Dr Adeel Waqas

Date: ______________________________

Signature (HoD): ______________________________

Date: ______________________________

Signature (Dean/Principal): ______________________________

Date: ______________________________

Certificate

This is to certify that work in this thesis has been carried out by Mr. Hamza Hafeez and completed under my supervision in Solar Energy Research Laboratory, U.S.-Pakistan Center for Advanced Studies in Energy, National University of Sciences and Technology, H-12, Islamabad, Pakistan.

Supervisor: ____________________

Dr. Adeel Waqas
USPCAS-E
NUST, Islamabad

GEC member 1: ____________________

Dr. Nadia Shahzad
USPCAS-E
NUST, Islamabad

GEC member 2: ____________________

Dr. Sehar Shakir
USPCAS-E
NUST, Islamabad

GEC member 3: ____________________

Engr. Abdul Kashif
USPCAS-E
NUST, Islamabad

HOD-ESE/TEE/EPE: ____________________

Dr. Rabia Liaquat
USPCAS-E
NUST, Islamabad

Dean/Principal: ____________________

Dr. Adeel Waqas
USPCAS-E
NUST, Islamabad

Dedication

The thesis is wholeheartedly dedicated to my beloved parents especially to my father Mr. Abdul Hafeez Zafar and my supervisor Dr. Adeel Waqas. A special thanks to Dr Nadia Shahzad and Sir Abdul Kashif Janjua for pushing me forward in times when I struggled. I am thankful for their love and measureless support. All of you have been a driving force throughout this process.

Abstract

Water bodies like small lakes, canals, and rivers in urban areas serve to be a way forward to deploy photovoltaic technology with no constraints to involve land procurement. This research aims to estimate the potential deployment of a floating photovoltaic system on an urban lake site to assess its scope and compare it with a similar specification on-ground photovoltaic system. System Advisor Model (SAM) has been used for techno-economic analysis of a site in Pakistan. The technical analysis involves observing the effect of real time temperature drop and calculation of water reduction efficiency for FPV systems. The economic parameters like net present value (NPV) and payback period are used to judge the economic feasibility of the floating photovoltaic deployment project. The floating photovoltaic deployment in an urban area is subject to soiling as the water reservoir being used exists in an area close to or within the city boundaries. The required cleaning water costs a one-time extraction rate of $1435, while for a floating photovoltaic system, the extraction cost is estimated to be $1.35. Under standard temperature conditions (STC) one-year capacity factor turns out to be 0.70% more, producing an additional energy yield of 64 kWh/kW for lake scenarios when a 10 $^{\circ}$C temperature drop is considered. The total power potential for the entire NUST Lake turns out to be 4.47 MW. A 1 MW FPV system in NUST lake would result in a water reduction efficiency of 11.6%/year. Under standard temperature conditions, the net present value for the on-ground system becomes negative while it remains optimistic for the floating photovoltaic system as no land costs are required. Similarly, once the land cost is included in the feasibility analysis, the payback period for the on-ground system goes beyond 15 years which is only 5.37 years for a floating photovoltaic system signifying the economic feasibility of the floating photovoltaic project.

Keywords: System Advisor Model (SAM); PV systems; Floating PV systems; Solar Energy; Economic Feasibility; Technoeconomic Analysis

Table of Contents

List of Figures

List of Tables

List of Papers

1. **Hamza Hafeez**, Abdul Kashif Janjua, Hamza Nisar, Sehar Shakir, Nadia Shahzad, Adeel Waqas "Techno-economic Perspective of a Floating Solar PV Deployment over urban lakes: A case study of NUST lake Islamabad"
   Journal: Solar Energy 2021.
   DOI: https://doi.org/10.1016/j.solener.2021.11.071

2. Hamza Nisar, Abdul Kashif Janjua, **Hamza Hafeez**, Sehar Shakir, Nadia Shahzad, Adeel Waqas "Thermal and Electrical Performance of Solar Floating PV System Compared to On-ground PV System-An Experimental Investigation"
   Journal: Renewable Energy, 2021 (Under Revision).

List of Abbreviation

AC	Alternating Current
DC	Direct Current
FPV	Floating Photovoltaic
GCR	Ground Coverage Ratio
IESCO	Islamabad Electric Supply Company
LCOE	Levelized Cost of Energy
NPV	Net Present Value
NREL	National Renewable Energy Laboratory
NUST	National University of Science and Technology
OPV	On-ground Photovoltaic
PV	Photovoltaic
SAM	System Advisor Model
STC	Standard Temperature Conditions

Chapter 1: Introduction

1.1 Background

Climate change is real and is happening as a fast rate. Global warming, rising temperatures, emission of greenhouse gasses has led the world to reconsider and move towards renewable resources. Despite Covid-19 the renewable sector has had a rapid growth with the most growth in the solar sector a 139 GW out of an estimated 760 GW of installed power capacity [1]. But a new problem is emerging in which population growth and urbanization are on the rise. People are moving towards the urban areas and land costs are rising rapidly. In many countries' population density is very high due to which land is expensive. The heated debate of land usage for renewables has been toned down with the emergence of floating PV systems as it requires no land cost to be deployed. FPV is a new niche in the solar PV industry which requires the installation of PV modules on a floating platform and deployed over a water reservoir [2]. Eastern China is an example where due high population and scarce land FPV systems have been adopted instead of On-ground PV system [3]. The latest installations of Floating Photovoltaic Projects that were initiated and installed during 2020 include: the largest FPV power plant of 27.4 MW in Europe that was integrated into the regional grid, was installed in a solar park in the Netherlands[4] [5], in Ghana a 5 MW FPV was connected with the transmission system of the hydropower reservoir of a dam on the Black Volta River [6], and Chile deployed its largest floating project under the net billing scheme [7]. As of early 2021, the largest floating solar plant in operation was a 181 MW plant off the west coast of Chinese Taipei [8]. A technoeconomic analysis has been adopted by using System Advisor Model in which the technoeconomic feasibility of FPV systems has been studied for Urban non utilizable water reservoirs. SAM has been used in literature to calculate and compare the technical analysis for power outputs, calculation of reduction in evaporation and comparison of FPV systems with On-ground systems [9][10]. SAM also aids in performing a techno-economic analysis [11] which is also the aim of this paper.

1.2 Emergence of Floating Photovoltaic Systems

The solar photovoltaic industry emerged with a new niche known as Floating Photovoltaic Technology. This technology requires the installation of photovoltaic panels directly on the water body with the help of a floating platform instead of installing them on land or buildings [12]. A floating photovoltaic system can be installed on the surface of natural or artificial water bodies such as lakes, rivers, dams, canals, and ponds [13]. Globally, in 2020, there were around 2.6 GW of total capacity of floating solar photovoltaic projects that are either under construction or are completely functional in more than 60 countries [14]. Floating solar photovoltaic projects are most common in Asia, but they are found all over the world [15]. The floating solar industry continued to expand rapidly because land is difficult to come by and expensive in several places and the floating solar capacity has exceeded over 3 GW in 2020 as compared to 10 MW in 2015 [16]. Floating projects tend to have higher costs than ground-mounted facilities, but they offer advantages like reducing evaporation for water reservoirs, save land where it is scarce and they can be combined with hydropower projects as well [17].

1.3 Advantages of Floating Photovoltaic Systems

Utilization of land for installation of Floating PV systems do not require land for installation and hence bear no cost. These systems can be installed over a water reservoir. [18] A major advantage of using FPV technology is the integration of Floating Photovoltaic projects with hydropower reservoirs which increased in 2020 [19]. The example of eastern China is an excellent instance of the widespread use of Floating Photovoltaic deployments due to its high population density along with its low land availability [3]. The main advantage of these hybrid systems includes decreased evaporation, lower cost of the energy infrastructure, generation complementarity due to seasonality and compensate the declining performance of the exiting hydro power plants [20]. FPV systems reduce the evaporation of water of up to 15,000 to 25,000 m3 per mega-watt, provide shade preventing algae growth and drop the temperature of overall reservoir. This is essential for water scarce countries as it is said to reduce water loss by 25 to 70%. [21], [12], [22], [23], [24] In another study at the University of Valencia the installation of FPV on irrigation waters gave positive results by reducing the rate of evaporation [25]. FPV benefit from the natural cooling of the water reservoirs bringing the temperature down in areas where temperatures are very high [23] [26]. FPV have a 12% better efficiency than the on-ground system. This is due to the increase in water surface reflection which is incoming on the PV modules increasing the power generation of the system [27]

[23]. This will enhance land incentives promoting land for other purposes like agriculture and tourism while bringing in play a non-utilized water body to generate power through renewable means. The FPV systems are cost competitive when compared to on ground systems. These systems can be cleaned easily as water can be obtained from the water reservoir directly as compared to on ground system where water needs to be extracted and stored for cleaning of PV modules [12].

1.4 Potential Challenges to Floating PV Systems

FPV corrode due to the presence of metallic parts turning them rusty lessening the time period of the entire system. The docking stations for ships and fishing is affected in the area where FPV are installed. There is a large possibility of mishaps in the electrical wiring traveling under the surface of water affecting the biodiversity of life under the water [12]. The FPV can reduce the penetration of sunlight into water reservoirs depriving the well-being aquatic life. FPV technologies are installed on water due to which they cannot withstand the high-speed wind swirls and turning the entire platform upside down. This is the reason why a lot of mooring points are used in FPV installations [18].

1.5 Photovoltaic Systems and Technologies

The PV systems are used to convert solar energy into electrical energy. For this purpose, semiconductor devices are used to create photoelectric effect. PV system in general has PV modules installed over a mounting platform along with an inverter to convert DC power generated by the modules into AC power which can be delivered to a load. Batteries are also attached in the system for the purpose of storing the DC power generated by the PV modules. PV system consists of solar module which are connected in series and parallel to obtain the desired electric power output. PV installations can be either On-ground systems, Rooftop systems, Wall Mounted Systems, Thin Film Technology or Floating PV systems. PV systems have different technologies that are monocrystalline silicon, polycrystalline silicon, and thin film as shown in Figure 1.1. In Floating PV systems can use commercially available solar panels of all types of technologies. The monocrystalline have a higher efficiency then the polycrystalline panels. [12][28].

Monocrystalline	Polycrystalline	Thin Film

Figure 1.1: Three different types of Photovoltaic Technologies [1]

1.6 Introduction and General Working of System Advisor Model

The System Advisor Model (SAM) is a software that deals with design and modelling of renewable energy systems. It also provides a detailed economic evaluation of a renewable system according to the parameters on which the systems have been modelled. It is an open source and free to use software used by engineers, policy analysts, researchers, and technology enthusiasts. Photovoltaic, battery storage, concentrating solar panels, fuel cells, geothermal, biomass combustion for power generation, high concentration PV systems, solar water heating, wind power, marine energy and industrial process heat from parabolic trough and linear Fresnel systems are the technologies for which modelling, designing and technoeconomic analysis can be performed. The financial models on the other hand include Residential and commercial projects, Power purchase agreement projects along with third party ownership projects [2]. This software deals with designing, performance analysis and financial modelling of photovoltaic projects [3]. The SAM software consists of database bearing information regarding photovoltaic panels, weather conditions, inverter technology, irradiance values along with all components of a renewable technology. The SAM software stores hourly data sets of 8760 values that shows the yearly data against a defined parameter [3]. The parametric tool in SAM software would be used for graphical representation of data. It is also used for comparison and sensitivity analysis of results as done in this research.

The system advisor model starts by the selection of weather files based on the location where the project needs to be installed. The next steps involve performance evaluation in the form of input set in SAM in the form of system specifications and system losses. The weather file input, system details and losses combine to result in the electricity production of the PV system. Similarly, the inputs of the economic side of the designed PV model include costs, compensation, incentives, and financing of the system. These inputs produce annual, monthly, and hourly output, capacity factor, levelized cost of energy, net present value, payback and revenue for the observed model as shown in Figure 1.2:

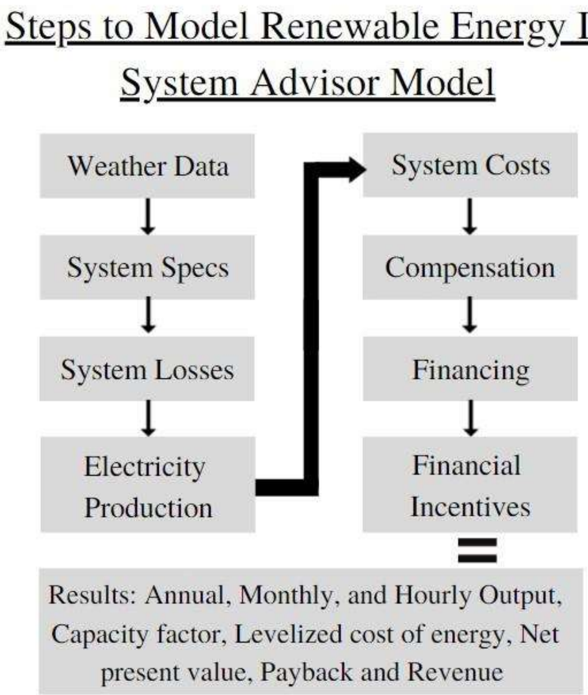

Figure 1.2: Steps to Model Renewable Energy in System Advisor Model

1.7 Problem Identification

The Floating PV system can be deployed in Urban water bodies which are non-utilizable. Due to increasing land costs, population burst and less availability of land FPV systems can be an alternate solution to all the problems. Further, deployment of renewable technology such as On-ground PV systems at the sacrifice of land incentives such as tourism, agriculture, deforestation and destruction of biodiversity is not a viable option. In this regard, an Urban Lake site has been studied for power estimation, cleaning of PV modules, and a technoeconomic analysis using SAM has been done to evaluate the feasibility of FPV systems over On-ground systems.

1.8 Justification of Research

Floating PV have a lot of potential with a world-wide estimated capacity of 2.6 GW. The selection of topic for research has the following reasons:

- FPV bears no land cost.
- Does not compromise on land incentives
- FPV growth in the international market
- No GHG emissions
- Power production using a non-utilizable water reservoir
- FPV cost effective in comparison to On-ground system
- Better Efficiency and more energy yield
- Less payback period with positive Net Present Value

1.9 Scope of Research

The experimental work has been conducted to determine the power potential of an urban non-utilizable water reservoir along with performing a technoeconomic analysis using System Advisor Model to evaluate comparison and performance of On-ground and FPV systems. A novel and cost-effective urban lake deployment of FPV has been proposed to as FPV system bears no land cost and has been performance and energy yield. The cleaning system is also observed for such FPV systems and determine if the cleaning of FPV requires less energy than On-ground PV system. Furthermore, economic analysis has been performed using sensitivity analysis in the Parametrics tool in System Advisor Model. To determine the feasibility of FPV system a comparison has been made and the effect of rising land cost in case of on ground systems and increasing DC losses for FPV system has been studied. The economic analysis is conducted in terms of the cost per watt of electricity produced by on ground and FPV systems. The Net Present Value, Payback period and Levelized Cost of Energy are the main parameters on which the economic feasibility has been determined. This study can help to analyze and compare the On-ground system with the FPV systems. Comparison of the cleaning system between On-ground and FPV can help to reduce the cleaning cost by determining the better system, the power potential gives an estimate of power which can be produced by utilizing a non-functional lake using FPV technology.

1.10 Objectives of Research

The major objective of research includes finding the potential for Floating PV system deployment in urban lakes for partial fulfilment of electricity. As a case study NUST lake has been considered which acquires an urban lake site as well as a 100 kW on-ground system.

1. To calculate the deployment potential of 100 kW FPV system.
2. To design and compare a 100 kW FPV system with a similar on-ground system in SAM software technically and economically.
3. To observe the effect of real time temperature drop and DC losses on performance and financial costs of FPV and On-ground PV systems.
4. To calculate the water reduction efficiency of 100 kW FPV system when deployed in NUST lake.
5. To propose a cleaning system for FPV system and compare the cleaning costs of 100 kW FPV and on-ground systems.

1.11 Limitations of Research

The research carried out is based on simulation results and can be practically implemented in the future. The lake location selected for the study of this research is part of an educational institution where no recreational activities are performed, and it needs no licensing, but this may not be the case for other urban water reservoirs. Conditions may be difficult and acquiring a water reservoir for other sites along with social acceptability are limitations towards the aimed project. The economic and technical assumptions taken are as close to reality as possible but may change when the selected location and time of installation is changed. The temperature drops and DC losses are proven by literature and taken in simulation conditions, but the real time out-door experiment can be performed to further solidify the results mentioned in the research. The installation and maintenance costs calculated are not final and will be changing with time. Further while actual deployment of FPV system a site study involving environmental impact assessment is required along with studying the environmental effects of deploying an FPV in NUST lake. FPV systems need to be observed in perspective of cleaning as if humidity increases the soiling losses also increase in urban deployable FPV systems. The sediments within the water of the reservoir need to be removed before cleaning of the system. The growth of algae growth around the FPV system needs to be studied in correspondence to carbon dioxide sequestration. The effect of partial shading when a cleaning system is deployed is also a constraint while deploying and studying cleaning mechanisms for FPV systems.

Thesis Flow

1. **Introduction:** Background, Emergence of FPV, Advantages, Challenges, PV Technologies, Scope, Justification and Problem Identification

2. **Literature Review:** Covid-19 & Renewables, FPV Power Estimation Factors Effecting FPV Performance, SAM Selection, Technoeconomic Analysis, Research Gap.

3. **Methodology:** Case Study Site, FPV in NUST Lake, Power Estimation, Factors Effecting FPV Performance, SAM Selection, Technoeconomic Analysis, Research Gap.

4. **Results:** Power Estimation, Cleaning Analysis, Temperature Analysis, Comparison of On-ground systems with FPV systems

5. **Conclusion and Discussion:** Conclusion and Discussion of the Proposed Results

Summary

Floating PV system potential advantages and the problems related to land have been briefly discussed in this section. A cleaning comparison to evaluate the cost of both FPV and On-ground systems have been mentioned. Several economic parameters have been considered, out of which Net present value, Payback Period and Levelized Cost of Energy are the main comparison financial factors. The solar energy potential in the urban water reservoir has been discussed from which Floating PV technology is selected due to its advantages over the on-ground system. Moreover, the advantages, scope, and limitations of the research are also stated in the end. A flow chart has also been made to show the flow of thesis.

References

1. R. E. N. Members, Renewables 2021 global status report. 2021.

2. K. Trapani and M. Redón Santafé, "A review of floating photovoltaic installations: 2007–2013," Prog. Photovoltaics Res. Appl., vol. 23, no. 4, pp. 524–532, 2015.

3. T. Kenning, "Sungrow building another record 150MW floating solar project in China," 2017. https://www.pv-tech.org/sungrow-building-another-record-150mw-floating-solar-project-in-china/ (accessed Jun. 01, 2017).

4. Z. Shahan, "Largest Floating Solar Park In Europe Connected To Grid In Netherlands," 2020. https://cleantechnica.com/2020/08/01/largest-floating-solar-park-in-europe-connected-to-grid-in-netherlands/ (accessed Aug. 01, 2020).

5. "Zonnepark Bomhofsplas gekocht," Blauwvinger Energie, 2021. https://blauwvingerenergie.nl/zonnepark-bomhofsplas-gekocht (accessed Mar. 31, 2021).

6. G. DEBOUTTE, "First unit of 250 MW floating PV project comes online in Ghana," PV Magazine, 2020. https://www.pv-magazine.com/2020/12/15/first-unit-of-250-mw-floating-pv-project-comes-online-in-ghana/ (accessed Dec. 15, 2020).

7. P. S. MOLINA, "Chile connects first floating PV plant to grid under net billing scheme," PV Magazine, 2020. https://www.pv-magazine.com/2020/09/16/chile-connects-first-floating-pv-plant-to-grid-under-net-billing-scheme/ (accessed Sep. 16, 2020).

8. J. Scully, "Chenya Energy eyes floating PV growth after completing 181MWp offshore project," PVTECH, 2021. https://www.pv-tech.org/chenya-energy-eyes-floating-pv-growth-after-completing-181mwp-offshore-project/ (accessed Feb. 05, 2021).

9. S. Gorjian, H. Sharon, H. Ebadi, K. Kant, F. B. Scavo, and G. M. Tina, "Recent technical advancements, economics and environmental impacts of floating photovoltaic solar energy conversion systems," J. Clean. Prod., p. 124285, 2020.

10. M. Padilha Campos Lopes, S. de Andrade Neto, D. Alves Castelo Branco, M. A. Vasconcelos de Freitas, and N. da Silva Fidelis, "Water-energy nexus: Floating photovoltaic systems promoting water security and energy generation in the semiarid region of Brazil," J. Clean. Prod., vol. 273, p. 122010, 2020, doi: https://doi.org/10.1016/j.jclepro.2020.122010.

11. A.P. Sukarso and K. N. Kim, "Cooling effect on the floating solar PV: Performance and economic analysis on the case of west Java province in Indonesia," Energies, vol. 13, no. 9, p. 2126, 2020.

12. Sahu, N. Yadav, and K. Sudhakar, "Floating photovoltaic power plant: A review," Renew. Sustain. Energy Rev., vol. 66, pp. 815–824, 2016, doi: 10.1016/j.rser.2016.08.051.

13. M. A. E. Galdino and M. M. de Almeida Olivieri, “Some remarks about the deployment of floating PV systems in Brazil,” J. Electr. Eng, vol. 5, no. 1, pp. 10–19, 2017.

14. F. HAUGWITZ, “Floating solar PV gains global momentum,” 2020. https://www.pv-magazine.com/2020/09/22/floating-solar-pv-gains-global-momentum/ (accessed Sep. 22, 2020).

15. N. Ford, “Floating solar design gains drive strong growth prospects,” 2020. https://www.reutersevents.com/renewables/pv-insider/floating-solar-design-gains-drive-strong-growth-prospects (accessed Jul. 22, 2020).

16. E. S. M. A. Program and S. E. R. I. of Singapore, “Where Sun Meets Water: Floating Solar Handbook for Practitioners.” World Bank, 2019.

17. M. COX, “The State of Floating Solar: Bigger Projects, Climbing Capacity, New Markets,” 2019. https://www.greentechmedia.com/articles/read/the-state-of-floating-solar-bigger-projects-and-climbing-capacity (accessed Sep. 19, 2019).

18. R. Cazzaniga, M. Cicu, M. Rosa-Clot, P. Rosa-Clot, G. M. Tina, and C. Ventura, “Floating photovoltaic plants: Performance analysis and design solutions,” Renew. Sustain. Energy Rev., vol. 81, no. September 2016, pp. 1730–1741, 2018, doi: 10.1016/j.rser.2017.05.269.

19. IEA-Pvp, “Snapshot of Global PV Markets 2020,” Www.Iea-Pvps.Org, pp. 1–16, 2020, [Online]. Available: http://www.iea-pvps.org/fileadmin/dam/public/report/technical/PVPS_report_-_A_Snapshot_of_Global_PV_-_1992-2014.pdf.

20. H. Rauf, M. S. Gull, and N. Arshad, “Complementing hydroelectric power with floating solar PV for daytime peak electricity demand,” Renew. Energy, vol. 162, pp. 1227–1242, 2020, doi: 10.1016/j.renene.2020.08.017.

21. E. M. do Sacramento, P. C. M. Carvalho, J. C. de Araújo, D. B. Riffel, R. M. da Cruz Corrêa, and J. S. P. Neto, “Scenarios for use of floating photovoltaic plants in Brazilian reservoirs,” IET Renew. Power Gener., vol. 9, no. 8, pp. 1019–1024, 2015.

22. A. M. Pringle, R. M. Handler, and J. M. Pearce, “Aquavoltaics: Synergies for dual use of water area for solar photovoltaic electricity generation and aquaculture,” Renew. Sustain. Energy Rev., vol. 80, pp. 572–584, 2017, doi: https://doi.org/10.1016/j.rser.2017.05.191.

23. M. Rosa-Clot, G. M. Tina, and S. Nizetic, “Floating photovoltaic plants and wastewater basins: an Australian project,” Energy Procedia, vol. 134, pp. 664–674, 2017.

24. D.-D. Qin, Y.-J. Zhu, F.-F. Chen, R.-L. Yang, and Z.-C. Xiong, “Self-floating aerogel composed of carbon nanotubes and ultralong hydroxyapatite nanowires for highly efficient solar energy-assisted water purification,” Carbon N. Y., vol. 150, pp. 233–243, 2019, doi: https://doi.org/10.1016/j.carbon.2019.05.010.

25. Ferrer-Gisbert, J. J. Ferrán-Gozálvez, M. Redón-Santafé, P. Ferrer-Gisbert, F. J.

Sánchez-Romero, and J. B. Torregrosa-Soler, “A new photovoltaic floating cover system for water reservoirs,” Renew. Energy, vol. 60, pp. 63–70, 2013, doi: 10.1016/j.renene.2013.04.007.

26. J. Song and Y. Choi, “Analysis of the Potential for Use of Floating Photovoltaic Systems on Mine Pit Lakes: Case Study at the Ssangyong Open-Pit Limestone Mine in Korea, Energies, Vol. 9, No. 102, 2016.” 2016.

27. P. Ranjbaran, H. Yousefi, G. B. Gharehpetian, and F. R. Astaraei, “A review on floating photovoltaic (FPV) power generation units,” Renew. Sustain. Energy Rev., vol. 110, pp. 332–347, 2019.

28. V. V Tyagi, N. A. A. Rahim, N. A. Rahim, A. Jeyraj, and L. Selvaraj, “Progress in solar PV technology: Research and achievement,” Renew. Sustain. energy Rev., vol. 20, pp. 443–461, 2013

Chapter 2: Literature Review

2.1 Covid 19 and Renewable Energy Sector

Despite COVID-19, the renewable energy sector increased by 265 gigawatts (G.W.) in power capacity, the largest ever increase. In 2020, solar photovoltaics had the best performing year of all renewable technologies, adding 139 GW to an estimated total of 760 GW. The majority of global renewables investments will go into wind and solar, with solar making up nearly half (USD 148.6 billion, 12% increase) of all renewable investments in 2020 [1].

2.2 Potential Power Calculation for FPV Technology

The potential power calculation has been done for various countries like Korea that has been estimated to have a power production potential of 2932 GWh of FPV assuming only 10% of area coverage of all water bodies [2]. In the United States, assuming there is 27% covered surface area of water bodies, energy production would be 2116 GW, about 9.6% of the country's current generation [3]. The power potential for different coverage areas of water weirs in Brazil categorized as average area of 19.4%, 50% and 70% had different power productions of 2.3 TWh, 8.6 TWh, and 12 TWh, respectively [4]. Moreover, in a similar context the proposal of deployment of Floating Photovoltaic Technology in Pakistan is completely feasible due to sufficient water reservoirs (both natural and manmade) along with suitable climatic conditions to meet the energy demands of the country [5].

2.3 Floating Photovoltaic Technology as an Off-Grid System

Electrifying off-grid areas in the developing world is often the most cost-effective method possible due to stand-alone solar systems and renewable-based mini-grids. FPV can be used as decentralized solar power generation system reducing transmission losses and carbon emissions [6].

2.4 Factors Effecting Performance FPV System

2.4.1 Effect of Temperature

Temperature is an important factor in understanding the behaviour of FPV technology. The global average cumulative solar irradiation is 1275.6 kWh/m^2/year, and the average annual temperature is 13 $^{\circ}$C. The temperature along with weather conditions are not the same in all parts of the world due to change in climate, tropology, geography and terrain. Temperature can rise up to 50 °C in Pakistan during peak hours of the day. This is the time which can be taken advantage of and maximum energy can be harvested via solar photovoltaic technology [7]. Solar incidence is responsible for energy production from solar panels, but an increase in systems temperature above maximum limits will cause a reduction in power efficiency delivered. The operational temperature of FPV systems is 3.5 °C less than on-ground systems due to the cooling effect of water. [8] The critical part in studying temperature is the temperature difference between the On-ground and Floating photovoltaic systems. According to Choi FPV produces 11% more energy generation and is better at performing when compared with on ground photovoltaic systems [9]. The 11% better efficiency is because of the cooling effect caused by the evaporation of the water reservoir. The experiment was done by comparing 500 kW and a 100 kW FPV system located at the Hapcheon Dam Reservoir to a on ground 1 MW system located 60 km South of Hapcheon. The shading provided by the floating structure reduces the solar radiation to fall on the water reducing its temperature. Thus, temperature resistance of Floating photovoltaic systems should be ensured for tropical and hot areas. Many of the advantages gained by FPV like lessening water evaporation and algae growth and also reduces the costs of solar energy generation are because of lowering the photovoltaic operating temperature caused by the cooling effect of water [3]. Higher temperature regions lessen the life span of PV panels but can produce more energy. Conversely, high humidity, increased soiling, and less light availability due to higher altitudes lead to less solar energy production [10][11].

The rise in temperature due to climate change will lead to increased evaporation rates in water bodies. The evaporation of a water body can be because of various metrological parameters like solar irradiance, wind speed, air, water temperature, relative humidity, and atmospheric pressure. The rate of evaporation increases with the increase in solar irradiation, temperature and wind speed and low relative air humidity [12]. The loss of efficiency due to rise in temperature of the photovoltaic cell depends upon the technology being used for manufacture of the cell. Maximum power thermal coefficient expressed in %/°C is used to check the variation in efficiency with change in each °C. This parameter for commercial photovoltaic technologies is always negative reaching a maximum of 0.4

to 0.45%/°C [13]. The level of power produced by the photovoltaic cell depends on temperature and solar irradiance interacting with the photovoltaic cell. Thus, the energy yield of the photovoltaic module can increase if either the photovoltaic panels are floating on the water surface or submerged in it. The photovoltaic systems show a loss of efficiency when the temperature increases. The concentration of radiations can lead to increased temperature of up to 80 °C reducing the power efficiency [14].

2.4.2 Effect of Humidity

Cities having high relative humidity will sufficiently decreases photovoltaic cells efficiency. It reduces sunlight irradiance because of water vapor particles, which causes sunlight to refract, reflect or diffract. Size of water vapor particles also influences the sunlight irradiance, as smaller particles will scatter light at a greater angle than large particles, it directly effects the efficiency of photovoltaic system. Due to difference in water vapor particle size a non-linear relationship is observed for relative humidity with sunlight irradiance. About 15-30% of power is lost due to humidity. As humidity is a dependent variable which depends on independent variables such as temperature, dust and wind speed. A correlation between these variables exists and it determines the efficiency of solar cell [15]. Efficiency of solar cells is the amount of sunlight that can be converted into electricity. As efficiency depends on the maximum power point of the photovoltaic cells and with increase in humidity the maximum power point is deviated from optimum value. This results in decreased photovoltaic cell efficiency and amount of electricity generated as output [16]. Relative humidity is the ratio of water vapors present in the air, to the maximum capacity of air to hold water vapors at that temperature. High relative humidity not only reduce the performance but also cause corrosion of the photovoltaic cells, which reduces its life span. It can also aide the growth of microorganisms such as fungi, which further halts optimum performance of photovoltaic cells. Water will start penetrating inside the photovoltaic cells, if they are exposed in an environment with high humidity for a very long time, results in decreased efficiency of photovoltaic system. Moisture will cause interfacial adhesive bonds to become weaken, leading towards delamination and corrosion of solar cells. Penetration of moisture inside solar cells also destroys solder joints and it will aide chemical reaction between tin oxide and fluorine that produces hydrofluoric acid, which damages the interconnections of photovoltaic cells.

In areas with more than 70% relative humidity and low wind speed, overall life span of photovoltaic systems is very short because moisture penetration will cause necrosis of internal components in photovoltaic cells. Wind also influences the relative humidity in the air, with the increase in wind speed relative humidity will decrease resulting in improved photovoltaic system efficiency and vice versa. High wind speed also have a major drawback that it spreads dust particles over photovoltaic panel resulting in stratification on the edges of the solar panel, which deteriorates the performance of solar system. High relative humidity also increases the dust particle adhesion to solar panel surface, it not only decreases the efficiency of photovoltaic system but also damage its surface. Dust particles act as hygroscopic material, which attracts more water droplets especially in the early morning when relative humidity is high and photovoltaic panels are colder than the ambient air temperature. Due to micro and macro dust particles, solar panel glass surface will become rough with the passage of time, results in scattering of sunlight rather than absorbed by the solar cells, it will further decrease the overall output of photovoltaic system. The risk of solar panel corrosion by high relative humidity increases with higher temperatures in that area, it will eventually deteriorates the metal components and polymer adhesion inside the solar cells [17][18]. Humidity is an important factor that plays its role in electricity production as it reduces the amount of irradiance to be absorbed by a solar cell which decreases the total electrical current and open-circuit voltage of photovoltaic panel that ultimately reduces the efficiency of the entire installed photovoltaic system [19].

2.5 Techno-economic Feasibility of FPV Technology Using SAM

In a worldwide context, the past research related to FPV reflects upon studies that performed a techno-economic feasibility analysis along the lines of FPV deployment and its comparison with the on-ground photovoltaic systems [20] [21] [22] [23] [24] [25]. For comparison various studies have used System Advisor Model, a software that deals with the design and modelling of renewable energy systems for energy gain estimation[26]. SAM has been used to calculate and compare observed and actual electric power outputs by using FPV technology [21], for the calculation of evaporation [4], comparison of FPV with an on-ground photovoltaic system and evaluation of the technical potential for FPV technology [27]. SAM also aids in performing a techno-economic analysis [22] which is also the aim of this paper. The feasibility of an FPV system can be determined by Levelized cost of energy [28].

The objective of this research is to explore the potential of FPV deployment in the urban water reservoirs where land is hardly available. As a case study, the National University of Science and Technology (NUST) Lake (a water reservoir in an urban area) is used for finding the potential of FPV system. The 100 kW on-ground photovoltaic system already deployed in NUST is used as a reference to compare its performance with a similar floating photovoltaic project. The simulation of FPV weather conditions considering temperature as the main parameter is modelled in System Advisor Model (SAM). SAM is used for comparison and building up a sensitivity analysis focusing on temperature variation for both systems. Further, as FPV technology is being deployed in urban conditions, cleaning of FPV would be required. A cost comparison has been made between Floating photovoltaic and On-ground Photovoltaic systems. The cleaning of both systems and evaluating the cost of electricity required for attaining water from pumping systems is analysed. A financial comparison has also been made keeping in view urban land costs and water-saving costs in which the Net Present Value and Payback Period of the on-ground photovoltaic system and FPV system is analysed.

2.6 Selection of SAM Software

There are multiple software packages that can be used for the technical and financial analysis such as RETScreen developed by the Canadian Government, PVGIS developed by Joint Research Center from the European Commission's in-house science services, PVWatts, Homer, System Advisor Model all developed by The National Renewable Energy Laboratory stated in Washington, D.C., United States of America. The projects initiated by NREL have been compared briefly by Psomopoulos and Ionnidis in 2015 [29] along with Blair and Dobos in 2014 [30].

System Advisor Model is a free tool to use for evaluating the future performance of renewable based energy technologies and evaluating the financial feasibility of any renewable energy project. The availability of performing a techno economic analysis on a particular project is the reason why SAM has been chosen as the first choice of the project. The software comes with various advantages like performing a sensitivity, parametric, statistical and probability-based analysis on any renewable energy technology

[30]. SAM has also been used for design and modelling of renewable energy systems for energy gain estimation.

System advisor model has been used to evaluate all kinds of photovoltaic technologies including solar dish technology, solar thermal technologies, on-ground photovoltaic system, concentrated photovoltaic technologies and floating photovoltaic technologies. The subject of our study is floating solar photovoltaic technologies but let us have a glimpse at how these technologies can be analysed by using System Advisor Model. SAM combines time series energy modelling with financial modelling to figure out the levelized cost of energy of any project.

2.7 Utilization of SAM Software in Literature

SAM has been used in various different papers showing the scope in which it can be used. SAM has been used to do economic analysis, technical analysis, battery storage capacity, sensitivity analysis and life cycle analysis. Various different models have been adopted to run the simulations. A few examples have been listed in Table 2.1:

Table 2.1: Summary of Utilization of SAM Software for various analysis for PV module

Reference	**Name of Research Paper**	**Utilization of SAM**	**Key Finding**
Guzman et al. [31]	Simulation and Optimization of a Parabolic Trough Solar Power Plant in the City of Barranquilla by Using System Advisor Model (SAM)	Sensitivity Analysis	The levelized cost came out to be 25 cents/kWh using only the thermal power plant whereas using natural gas as a backup reduces the cost to 9.76 cents/kWh. The project installed in Colombia has an installed capacity of 50 MWe with a 10% generation from natural gas.
Gatt et el. [32]	Building Energy Renovation and Smart Integration of Renewables in a Social Housing Block Toward Nearly-Zero Energy Status	Use of Fraser Model in SAM along with technoeconomic analysis.	The results show that a 50 MW plant like this would generate 105 GWh/year of energy having a levelized cost equal to 13.38 cents/kWh.
Spencer et al. [27]	Floating Photovoltaic Systems: Assessing the Technical Potential of Photovoltaic Systems on Man-Made Water Bodies in the Continental United States	Technical Analysis	A total of 24 419 man-made water bodies, representing 27% of the number and 12% of the area of man-made water bodies in the contiguous United States, were identified as being suitable for FPV generation. FPV systems covering just 27% of the identified suitable water bodies could produce almost 10% of current national generation.

Region et al. [33]	Performance Analysis and Optimization of a Parabolic Trough Solar Power Plant in the Middle East Region	Life Cycle Cost Analysis and Modelling of a 50 MW Parabolic Trough CSP system	Its energy production is calculated to be 456,351,232 kWh with a NPV of more than $64 million. The levelized cost was calculated to be 0.16 $/kWh. The proposed model can act as a way forward for making policy and strategic planning on CSP technologies.
Lopes el al. [34]	Water-energy nexus: Floating photovoltaic systems promoting water security and energy generation in the semiarid region of Brazil	Technoeconomic analysis and Calculation of Electrical Output	The economic analysis resulted in a 3.37 cents/kWh of levelized cost of energy (LCOE) lower as compared to Ground photovoltaic systems and a 6.67% higher rate of return (IRR). Three different scenarios were adopted in which an average area was taken along with 50 and 70 percent of coverage areas resulted in different energy generations of 2.3, 8.6 and 12 TWh respectively.
Song and Choi [35]	Analysis of the potential for use of floating photovoltaic systems on mine pit lakes: Case study at the Ssangyong open-pit limestone mine in Korea	Designing of FPV system and Energy Simulations	This study uses SAM to do energy simulations on weather data and design system. 971.57 MWh/year energy could be produced by using FPV technology. The economic analysis resulted in a net present value of $897,000 USD and a payback period of 12.3 years. This result has great potential for FPV deployment in the mine pit lakes of Korea and showed an edge on

			the ground photovoltaic system that have been deployed in the abandoned mines in Korea.
Xiong el al. [36]	Techno-Economic Analysis of a Residential PV-Storage Model in a Distribution Network	Detailed PV Battery Storage Modeling and Economic Analysis	A residential photovoltaic battery model has been implemented in SAM based on two different criteria: average attainable power and number of excursions. The methodology of the study revolves around modelling of a photovoltaic battery system that has been modelled in SAM under Dubai weather conditions to efficiently optimize the photovoltaic Battery storage model considering all technical parameters. An economic study has also been done in SAM to calculate the LCOE, Payback period and NPV of the designed photovoltaic system.

Summary

The growth of renewables despite COVID 19 has been seen. Along with it the FPV power estimation for NUST lake has been observed. The main factors affecting the performance of FPV and On-ground system are temperature and humidity. System Advisor model has been selected as the main software and a technoeconomic analysis performance has been hinted by designing and comparing a 100 kW system in the upcoming chapters. Further research gap has also been discussed in the ending.

References

1. R. E. N. Members, Renewables 2021 global status report. 2021.
2. S.-M. Kim, M. Oh, and H.-D. Park, “Analysis and prioritization of the floating photovoltaic system potential for reservoirs in Korea,” Appl. Sci., vol. 9, no. 3, p. 395, 2019.
3. R. S. Spencer, J. Macknick, A. Aznar, A. Warren, and M. O. Reese, “Floating Photovoltaic Systems: Assessing the Technical Potential of Photovoltaic Systems on Man-Made Water Bodies in the Continental United States,” Environ. Sci. Technol., vol. 53, no. 3, pp. 1680–1689, 2019, doi: 10.1021/acs.est.8b04735.
4. M. Abid, Z. Abid, J. Sagin, R. Murtaza, D. Sarbassov, and M. Shabbir, “Prospects of floating photovoltaic technology and its implementation in Central and South Asian Countries,” Int. J. Environ. Sci. Technol., vol. 16, no. 3, pp. 1755–1762, 2019.
5. Muhammad, U. Muhammad, and Z. Abid, “Potential of floating photovoltaic technology in Pakistan,” Sustain. Energy Technol. Assessments, vol. 43, p. 100976, 2021.
6. P. K. S. Rathore, D. S. Chauhan, and R. P. Singh, “Decentralized solar rooftop photovoltaic in India: On the path of sustainable energy security,” Renew. energy, vol. 131, pp. 297–307, 2019.
7. H. Rauf, M. S. Gull, and N. Arshad, “Complementing hydroelectric power with floating solar PV for daytime peak electricity demand,” Renew. Energy, vol. 162, pp. 1227–1242, 2020.
8. P. Ranjbaran, H. Yousefi, G. B. Gharehpetian, and F. R. Astaraei, “A review on floating photovoltaic (FPV)power generation units,” Renew. Sustain. Energy Rev., vol. 110, no. May, pp. 332–347, 2019, doi: 10.1016/j.rser.2019.05.015.
9. Y.-K. Choi, “A study on power generation analysis of floating PV system considering environmental impact,” Int. J. Softw. Eng. its Appl., vol. 8, no. 1, pp. 75–84, 2014.
10. W. Charles Lawrence Kamuyu, J. R. Lim, C. S. Won, and H. K. Ahn, “Prediction Model of Photovoltaic Module Temperature for Power Performance of Floating PVs,” Energies , vol. 11, no. 2. 2018, doi: 10.3390/en11020447.
11. P.-A. Château, R. F. Wunderlich, T.-W. Wang, H.-T. Lai, C.-C. Chen, and F.-J. Chang, “Mathematical modeling suggests high potential for the deployment of floating photovoltaic on fish ponds,” Sci. Total Environ., vol. 687, pp. 654–666, 2019, doi: https://doi.org/10.1016/j.scitotenv.2019.05.420.
12. M. Padilha Campos Lopes, S. de Andrade Neto, D. Alves Castelo Branco, M. A. Vasconcelos de Freitas, and N. da Silva Fidelis, “Water-energy nexus:Floating photovoltaic systems promoting water security and energy generation in the semiarid region of Brazil,” J. Clean. Prod., vol. 273, 2020, doi: 10.1016/j.jclepro.2020.122010.
13. E. Skoplaki and J. A. Palyvos, “On the temperature dependence of photovoltaic module electrical performance: A review of efficiency/power correlations,” Sol. Energy, vol. 83, no. 5, pp. 614–624, 2009, doi: https://doi.org/10.1016/j.solener.2008.10.008.
14. R. Cazzaniga, M. Cicu, M. Rosa-Clot, P. Rosa-Clot, G. M. Tina, and C. Ventura,

"Floating photovoltaic plants: Performance analysis and design solutions," Renew. Sustain. Energy Rev., vol. 81, no. September 2016, pp. 1730–1741, 2018, doi: 10.1016/j.rser.2017.05.269.

15. H. A. Kazem, "Effect of Humidity on Photovoltaic Performance Based on Experimental Study," vol. 10, no. 23, pp. 43572–43577, 2015.

16. M. Kumar Panjwani and G. Bukshsh Narejo, "Effect of Humidity on the Efficiency of Solar Cell (photovoltaic)," Int. J. Eng. Res. Gen. Sci., vol. 2, no. 4, pp. 499–503, 2014, [Online]. Available: www.ijergs.org.

17. R. T. A. Hamdi, S. A. Hafad, H. A. Kazem, and M. T. Chaichan, "Humidity impact on photovoltaic cells performance : A review," vol. 03, no. 11, pp. 27–37, 2018.

18. "Humidity: A factor in the appropriate positioning of a photovoltaic power station. Gwandu, B.A.L., and Creasey, D.J.," vol. 6, no. 3, pp. 313–316, 1995.

19. A. Guechi, M. Chegaar, and et A. Merabet, "The Effect of Water Vapor on the Performance of Solar Cells," Phys. Procedia, vol. 21, pp. 108–114, 2011.

20. H. Liu, V. Krishna, J. Lun Leung, T. Reindl, and L. Zhao, "Field experience and performance analysis of floating PV technologies in the tropics," Prog. Photovoltaics Res. Appl., vol. 26, no. 12, pp. 957–967, 2018, doi: 10.1002/pip.3039.

21. S. Gorjian, H. Sharon, H. Ebadi, K. Kant, F. B. Scavo, and G. M. Tina, "Recent technical advancements, economics and environmental impacts of floating photovoltaic solar energy conversion systems," J. Clean. Prod., p. 124285, 2020.

22. P. Sukarso and K. N. Kim, "Cooling effect on the floating solar PV: Performance and economic analysis on the case of west Java province in Indonesia," Energies, vol. 13, no. 9, p. 2126, 2020.

23. El Hammoumi, A. Chalh, A. Allouhi, S. Motahhir, A. El Ghzizal, and A. Derouich, "Design and construction of a test bench to investigate the potential of floating PV systems," J. Clean. Prod., vol. 278, p. 123917, 2021, doi: 10.1016/j.jclepro.2020.123917.

24. K. Ilse et al., "Techno-economic assessment of soiling losses and mitigation strategies for solar power generation," Joule, vol. 3, no. 10, pp. 2303–2321, 2019.

25. M. Ikhennicheu, B. Danglade, R. Pascal, V. Arramounet, Q. Trébaol, and F.Gorintin, "Analytical method for loads determination on floating solar farms in three typical environments," Sol. Energy, vol. 219, no. November, pp. 34–41, 2021, doi: 10.1016/j.solener.2020.11.078.

26. Z. A. A. Majid, M. H. Ruslan, K. Sopian, M. Y. Othman, and M. S. M. Azmi, "Study on performance of 80 watt floating photovoltaic panel," J. Mech. Eng. Sci., vol. 7, no. 1, pp. 1150–1156, 2014.

27. R. S. Spencer, J. Macknick, A. Aznar, A. Warren, and M. O. Reese, "Floating photovoltaic systems: assessing the technical potential of photovoltaic systems on man-made water bodies in the continental United States," Environ. Sci. Technol., vol. 53, no. 3, pp. 1680–1689, 2018

28. H. Zou, H. Du, M. A. Brown, and G. Mao, "Large-scale PV power generation in China: A grid parity and techno-economic analysis," Energy, vol. 134, pp. 256–268, 2017,

doi: 10.1016/j.energy.2017.05.192.

29. S. Psomopoulos, G. C. Ioannidis, S. D. Kaminaris, K. D. Mardikis, and N. G. Katsikas, “A comparative evaluation of photovoltaic electricity production assessment software (PVGIS, PVWatts and RETScreen),” Environ. Process., vol. 2, no. 1, pp. 175–189, 2015.

30. N. Blair et al., “System advisor model, sam 2014.1. 14: General description,” National Renewable Energy Lab.(NREL), Golden, CO (United States), 2014.

31. L. Guzman, A. Henao, and R. Vasquez, “Simulation and Optimization of a Parabolic Trough Solar Power Plant in the City of Barranquilla by Using System Advisor Model (SAM),” Energy Procedia, vol. 57, pp. 497–506, 2014, doi: https://doi.org/10.1016/j.egypro.2014.10.203.

32. Gatt, C. Caruana, and C. Yousif, “Building Energy Renovation and Smart Integration of Renewables in a Social Housing Block Toward Nearly-Zero Energy Status,” vol. 8, no. September, 2020, doi: 10.3389/fenrg.2020.560892.

33. M. E. Region, “Performance Analysis and Optimization of a Parabolic Trough Solar Power Plant in the,” pp. 1–18, 2018, doi: 10.3390/en11040741.

34. M. Padilha Campos Lopes, S. de Andrade Neto, D. Alves Castelo Branco, M.Vasconcelos de Freitas, and N. da Silva Fidelis, “Water-energy nexus: Floating photovoltaic systems promoting water security and energy generation in the semiarid region of Brazil,” J. Clean. Prod., vol. 273, p. 122010, 2020, doi: https://doi.org/10.1016/j.jclepro.2020.122010.

35. J. Song and Y. Choi, “Analysis of the Potential for Use of Floating Photovoltaic Systems on Mine Pit Lakes: Case Study at the Ssangyong Open-Pit Limestone Mine in Korea, Energies, Vol. 9, No. 102, 2016.” 2016.

Chapter 3: Research Methodology

3.1 Case Study Site

The information on NUST lake was obtained using Google Earth Mapping Tool. The dataset provided by the mapping tool included the name, area, length, width, longitude, and latitude of the selected area. Choosing NUST lake as a choice was made to compare an Urban water body with an already installed on the ground system of 100 kW in NUST premises. It was also done willingly to promote the utilization of NUST lake to save land costs for on-ground PV system installations. NUST lake has been divided into two areas namely Area 1 and Area 2 which have a surface area of 11,575 m^2 (2.86 acres) and 11,100 m^2 (2.74 acres) respectively [1]. The surface areas of the subsections and the further lengths and widths of each subsection of respective areas where FPV deployment is proposed were calculated using Path Tool to determine the area.

3.2 FPV Plant in NUST Lake

The area of NUST lake is considered as non-utilizable land in an educational institution and bears no land cost [1]. The feasibility of the lake can be further solidified as it is not used for any ecological, economic, or tourist purposes. The lake has also been chosen to compare the 100kW on the ground system with the FPV system to save land cost by finding the potential of a non-utilizable land. The plantation of the PV system to find out the NUST Lake potential for FPV deployment starts by choosing appropriate PV panels and choosing the right inverter size. Since the FPV deployment is also based on finding out advantages and comparing both technologies. Thus, specifications for the solar panels and inverter are kept identical to that of the 100 kW on-ground system.

3.3 Potential Power Estimation for FPV Plant

The first lake area has a surface area of 11,575 m^2 (2.86 acres) as observed in Figure 3.1. The length of the lake is 463 meters while the width of the lake is 25 meters. Seven different-sized potential installations have been considered. The lake water level may vary in different seasons, so an ideal approach has been taken to cover the maximum area of the observed site.

Figure 3.1: Potential Area 1 For the deployment of FPV [10]

The second lake area has a surface area of 11,100 m^2 (2.74 acres) as shown in Figure 3.1. The length of the lake is 444 meters, and the width of the lake is 25 meters. Three different-sized potential FPV installations have been considered. A similar approach as that of area 1 has been adopted for area 2 as well as shown in Figure 3.2:

Figure 3.2: Potential Area 2 For the Deployment of FPV Project [10]

The calculation of the number of modules per string and the number of strings in a sub-array depends on the size of the solar panel. Thus, the solar panel chosen is TSM-385DE14H(II), 385-Watt polycrystalline panel as this is the same panel used in the on-ground system. The solar panel dimensions are 1.95 meters by 1 meter. The solar panels should be facing the southern side and be in orchestration with the southern line on the map, maintaining a ground coverage ratio of 1.3 times the length of the panel which is held in 90 degrees direction. The ground coverage ratio (GCR) of 1.3 times is chosen as a similar GCR is used in the on-ground system that has already been installed in NUST. The power output from PV arrays is homogenous because the azimuth and tilt angle are the same and can be united on the same inverter.

3.4 Designing of 1.0 MW FPV System in SAM

For the analysis, the PV panels used were TSM-385DE14H(II) and the Inverter used was SMA America: STP 50-US-41 [480V]. Further specifications of solar panels and inverter are mentioned in Table 3.1:

Table 3.1: Solar Module Characteristics in System Advisor Model

Module Characteristics at Reference Conditions	
Nominal Efficiency	19.66%
Maximum Power	385.36 W_{dc}
Max Power Voltage	40.10 V_{dc}
Max Power Current	9.60 A_{dc}
Open Circuit Voltage	48.50 V_{dc}
Short Circuit Current	10.00 A_{dc}

Since we are designing a 50 kW PV system for being compared with an on-ground 50 kW system. Both systems will have no major difference in terms of designing as one 50 kW inverter is used, having a total number of 128 modules and 8 strings in parallel covering an area of 250 m^2. The modules per string in subarray are 16. The actual difference observed is in the weather files of both systems. A modular approach can be adopted in which similar 50 kW systems can be combined to match the power potential of an observed site. For the FPV system, especially altered weather conditions are put in SAM as temperatures in water reservoirs are 5 to 10 $^{\circ}$C lower as compared to on-ground PV systems [2]. The power produced by the FPV system is more as compared to on-ground systems due to the cooling effect of the water bodies [3] [4] [5] [6].

Table 3.2: Solar Inverter Characteristics in System Advisor Model

Inverter Characteristics	
Maximum AC Power	50010.00 W_{ac}
Maximum DC Power	51309.20 W_{dc}
Power use during operation	111.32 W_{dc}
Power use at night	15.00 W_{ac}
Nominal AC Voltage	480.00 V_{ac}
Maximum DC Voltage	800.00 V_{dc}
Maximum DC Current	70.77 A_{dc}
Minimum MPPT DC Voltage	500.00 V_{dc}
Nominal DC Voltage	725.00 V_{dc}
Maximum MPPT DC Voltage	800.00 V_{dc}

Thus, a comparative analysis has been done under different temperature conditions to see the effect on various financial parameters to check the feasibility of the potential that has been calculated in terms of cost-saving. The different temperature conditions include simulating weather conditions for a normal temperature data set, for a 5 °C temperature drop data set, for a 10 °C temperature drop data set, and a 20 °C temperature drop data set. Since the drop in temperature will deem a drop in financial costs the 20 ºC temperature drop tells us if the trend continues when the temperature drops at extreme weather conditions.

3.5 Cleaning of Floating Photovoltaic System and comparison with On Ground Photovoltaic System

The cleaning of FPV, when deployed in urban areas, would require the same cleaning that is required for on-ground systems. The dust deposition on PV modules (glass sheet) over time in NUST have a dust density of 3.179 g/m^2, 4.618 g/m^2, and 5.522 g/m^2 at a dust deposition rate of 0.106 g/m^2, 0.154 g/m^2, and 0.184 g/m^2 at different tilt angles of 60°, 34.5° and 15° over a span of 30 days [7]. Thus, the soiling losses would account for less power production so cleaning would be required. A per module cleaning comparison would clarify the cost difference for cleaning both PV systems. For the maximum cost efficiency and enhancing water-saving capabilities of flat fan nozzles (model VP110 015), the cleaning technique can be used for the cleaning of both systems [7]. As the flat fan nozzle technology can be effectively used for cleaning of the commercial-scale PV system, the major cost concern appears to be the extraction of water from the water reservoir for cleaning both systems and the amount of water required for cleaning in gallons. The cleaning systems for the on-ground system in NUST require water to be pumped from the under-ground bore from a depth of 106.68 meters. Meanwhile, the cleaning of the FPV system would require water to be pumped from 1.82 meters directly from the water reservoir. For 100 kW FPV system part 2 of area 2 can be considered for deployment as it has a potential (118.35 kW) exceeding the required potential (100 kW) for comparison of both PV systems.

The power required for water pumping would be different for both systems. The power required for pumping water based on a known given height can be calculated by the following equation 1 [8]

$$\text{Power Required} = \frac{Q*H*9.81*1000}{Pump\ Efficiency} \quad (1)$$

Where Q is the rate of water flow which is 0.00450 m^3/sec, H is the head height. At different head heights, the power required for an on-ground PV pump to extract water for cleaning can be calculated. Similarly, for FPV installation a lower head height would be required with a lower wattage pump. The total power required for the extraction of water would be a sum of the number of pumps required based on the number of liters of water that would be required for pump cleaning. The number of pumps required depends on the pump specifications and the area of coverage for cleaning of PV systems.

3.6 Financial Comparison of FPV with On-ground System

The financial parameters of both the FPV system and the On-ground system are compared under different weather simulation conditions to check the feasibility of the proposed FPV potential system. The analysis in SAM revolves around the Net Present Value and Payback period of the system. The payback period can be calculated as shown in equation 2: [9]

$$\text{Payback period} = \frac{\text{Total Cost of PV System to be Invested}}{\text{Estimated Annual Net Cash flow}} \quad (2)$$

Similarly, the Net Present Value of any cash flow can be calculated as shown in equation 3: [9]

$$\text{Net present Value} = \sum_{t=0}^{n} \frac{E_t - C_t}{(1+r)^t} - C_0 \quad (3)$$

Where E_t is the income generated from electricity sales per annum, C_t is the operational cost of developed systems, n is the operational period of the deployed system, r is the discount rate while C_0 is the initial deployment of the system. A flow diagram shows a better depiction of the step being taken in SAM and practical designing.

Financial analysis includes using a Parametrics tool in SAM to check the effect of varying land costs and DC losses on the Net Present Value and Pay Back Period of the FPV system. Moreover, the increase in DC losses would affect the system's financial parameters as FPV installation is being done in Urban premises. The simulation of different weather conditions having different temperatures was simulated and results were obtained using SAM. A flow diagram in Figure 3.3 shows a better depiction of steps being taken in SAM for designing, technical and financial analysis.

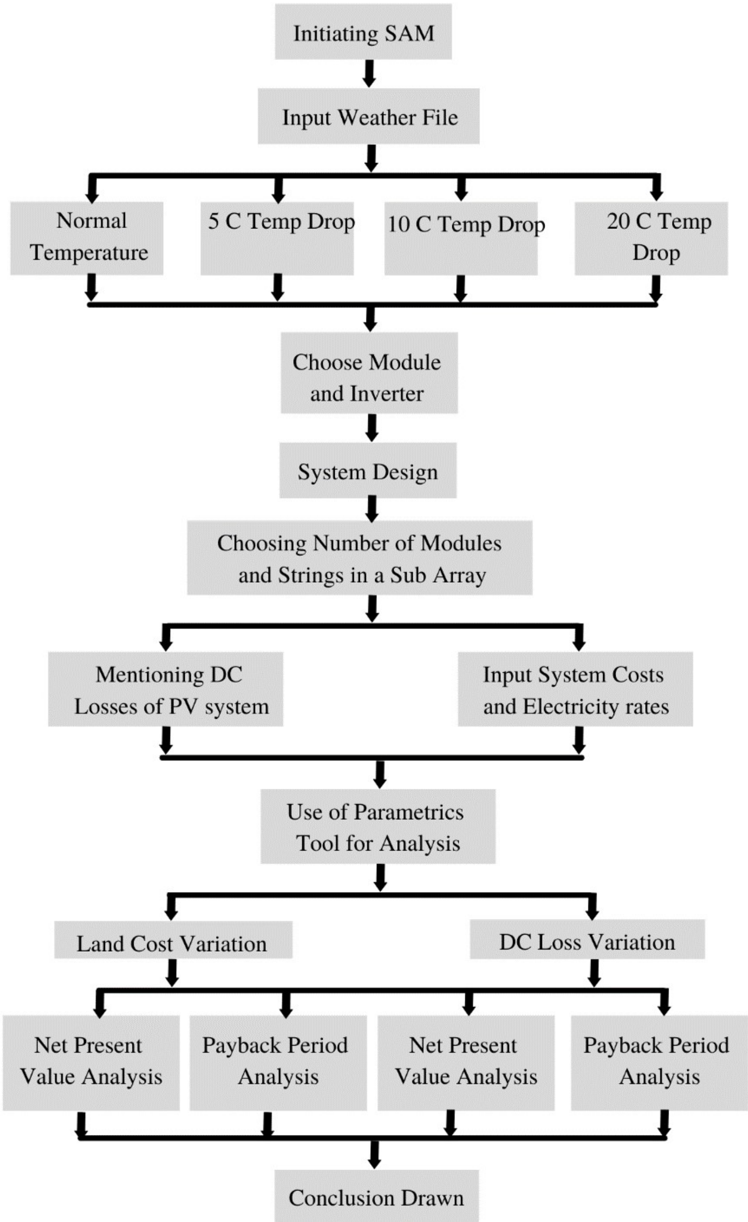

Figure 3.3: Flow Chart showing steps taken in System Advisor Model (SAM) for Technical and Economic Comparisons

3.7 PV System Design Parameters and Economic Assumptions in SAM

To calculate the LCOE of 100 kW FPV and on-ground systems, the selection of parameters has been done according to the already installed 100 kW on-ground systems. The local solar irradiance and weather datasets are combined with the technical and financial parameters and assumptions to build a PV performance model. The performance and financial models are developed by National Renewable Energy

Laboratory (NREL) to find out the location specific energy outputs against a PV systems lifetime. Following are the technical and financial assumptions:

- Module: Trina Solar TSM-385DE14H(II)
- Inverter: SMA America: STP 50-US-41 [480V]

Note: The module and the inverter have been selected from the System Advisor Model database matching the specifications of the 100 kW On-ground PV system for comparison purposes.

- System DC Design Size: 100 kW
- DC to AC Ratio: 1.02

Note: The DC to AC Ratio has been kept close to unity to match the energy production and financial efficiency. Traditionally this ratio ranges from 1.1-1.2. (Fu et al., 2015)

- PV Tracking:
    i. Fixed Tilt
    ii. Tilt Angle: 20
    iii. Ground Coverage Ratio: 0.3
- Annual Degradation Rate: 0.5%/year
- Direct Capital Cost:
    i. For Module: $0.30/W_{dc}$
    ii. For Inverter: $0.14/W_{dc}$
- Contingency: 3%
- Discount Rate:
    i. Nominal Discount Rate: 9.06%/year
    ii. Analysis period: 25 years
    iii. Real Discount Rate: 6.4%
    iv. Inflation Rate: 2.5% (Fu et al., 2015)

Note: The discount rate entered in SAM represents present value of money in dollars in project cash flows to calculate annual costs.

- Internal Rate of Return:
    i. IRR Target: 19.3%
    ii. IRR target year to achieve: 25 years
- Project Taxes:

i. Federal income tax rate: 0%/year (Hall and Greeno, 2019)
ii. Sales Tax: 0% (Hall and Greeno, 2019)
iii. Insurance Rate: 0.5%

- Depreciation Method: 5-year MACRS depreciation method as per SAM (Fu et al., 2015)
- The losses considered in SAM include following losses: (da Costa and da Silva, 2021)

i. Annual Soiling loss: 5%
ii. Module Mismatch loss: 2%
iii. Diode and connection losses: 0.5%
iv. DC wiring loss: 2%
v. AC wiring loss: 1%
vi. Nameplate loss: 5%
vii. Transformer loss: 0%

3.8 Simulation of FPV and On-ground Systems in SAM

The simulation for both the systems and their comparison has been done in System Advisor Model (SAM). The simulations are done step by step in the software. The simulation starts by selecting the renewable technology which is "Photovoltaic" and selecting a "Residential Model". A 50 kW system is designed in the SAM software which alters in the weather file conditions. The temperature and humidity conditions would differ for FPV conditions when compared to on-ground conditions.

3.8.1 Input Weather Files

A SAM weather file contains data in hourly and minutely time steps. The data perfectly describes the up-to-date solar and wind resource of a location under observation in SAM. A weather file contains typical year data for a year. The data collected is via ground weather stations, data from satellites or it can be a combination of both. The weather files used can be altered easily and the data can be changed as according to the scenario. The weather files used in this study involve two basic alterations one in temperature data and the other in humidity data. The temperature in the case of on-ground is higher while in case of FPV is cooler due to the cooling effect of the water bodies. The Solar Resource for Islamabad has been altered bringing the data as close to real time weather conditions as possible. A sample from the weather file has been shown in Table 3.3 and Table 3.4:

Table 3.3: Sample for SAM Weather File Time Series Data.

Source	Location ID	City	State	Country
NSRDB	20086	-	-	-
Year	Month	Day	Hour	Minute
2014	1	1	0	0
2014	1	1	1	0
2014	1	1	2	0
2014	1	1	3	0
2014	1	1	4	0
2014	1	1	5	0
2014	1	1	6	0

Table 3.4: Sample for SAM Weather File Solar And Wind Resource Data

Local Time Zone	Clear sky DHI Units	Clear sky DNI Units	Clear sky GHI Units	Dew Point Units
Temperature	Pressure	Relative Humidity	Wind Direction	Wind Speed
8	940	15.24	65.3	2
7	940	16.59	67.5	1.9
7	940	17.8	65.4	1.8
7	940	18.04	61.4	1.7
8	940	15.04	62.4	1.5
7	940	19.04	61.4	1.7
7	940	20.21	55.1	1.7
6	940	21.22	49.7	1.8
3	940	56.99	78	2.9

3.8.2 Location and Resource Page

In the Location and Resource Page the city under observation is selected. In this case Islamabad is selected and the relevant weather file has been downloaded. SAM has the latest meteorological data library for various locations. When a desired location is chosen SAM will take the weather data from its library. This up-to-date weather data is used to generate energy output simulations. The location and resource page is shown in Figure 3.4:

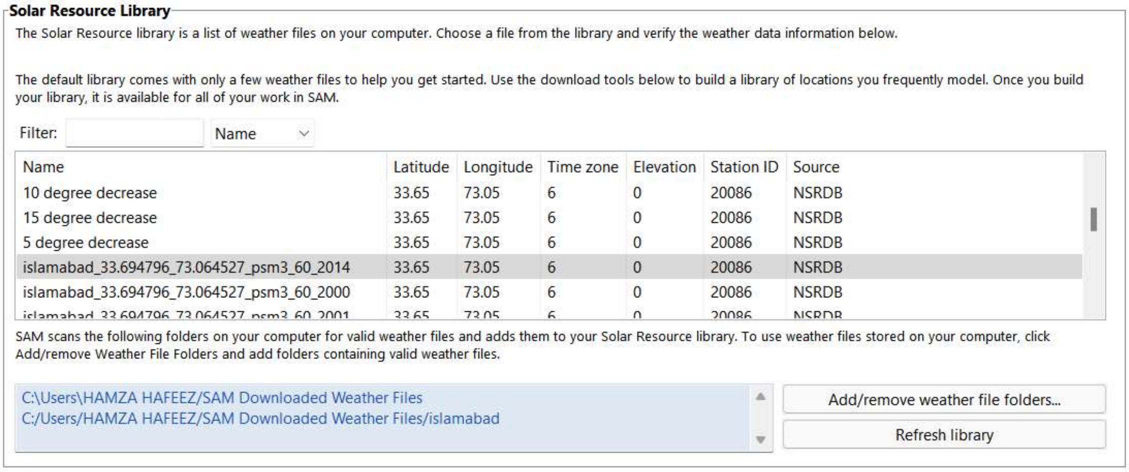

Figure 3.4: System Advisor Model (SAM) Location and Resource Interface.

3.8.3 Selection of Module

The selection of module depends upon the latest industry standards being followed all over the world. Availability of the selected module in the real scenario is also an important factor. The selection of module in this case is dependent upon the comparison being done with the On-ground system. Thus, the TSM-385DE14H(II), 385-Watt mono crystalline panel has been used as shown in Figure 3.5:

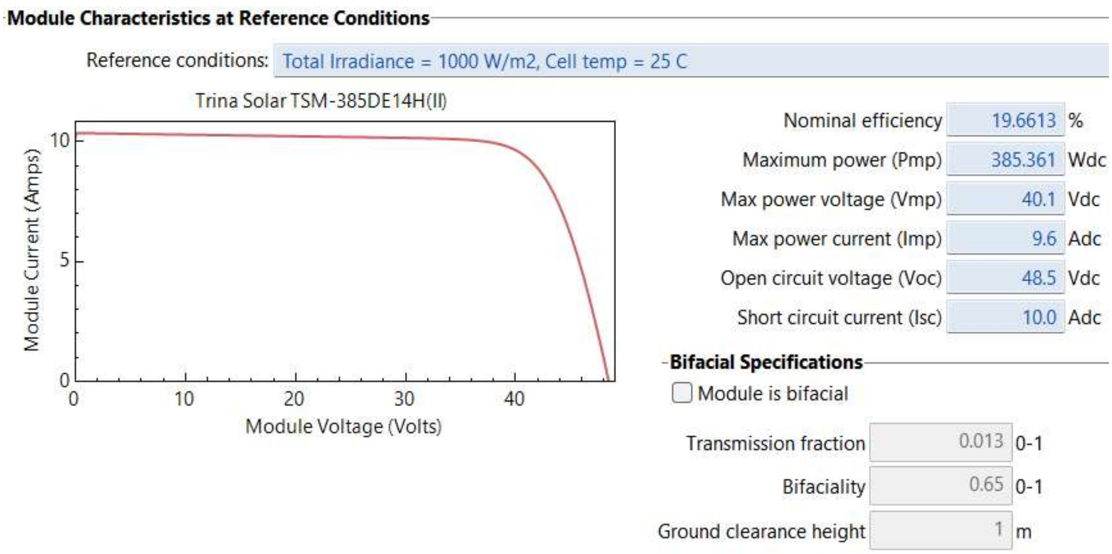

Figure 3.5: System Advisor Model (SAM) Module Characteristics.

3.8.4 Selection of Inverter

SMA America: STP 50-US-41[480V] 50 kW inverter has been selected having a Minimum MPPT DC Voltage of 500 V_{dc} and a Maximum MPPT DC Voltage of 800 V_{dc}. The inverter page in SAM is shown in Figure 3.6:

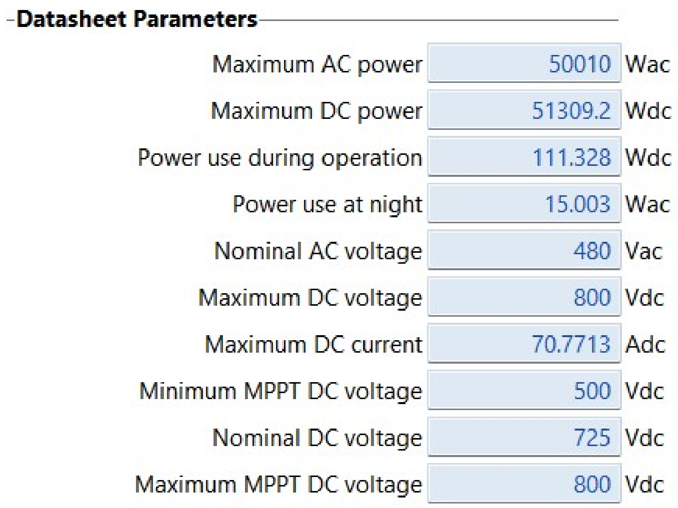

Figure 3.6: System Advisor Model (SAM) Inverter Characteristics

3.8.5 System Design Specifications

A 100-kW system has been designed for comparison of both on-ground and FPV systems. The selection of number of modules must be such which maintains the DC to AC Ratio of our system close to unity. A modular approach can be adopted to match the similar system for a larger area. The system design page in SAM has been shown in Figure 3.7:

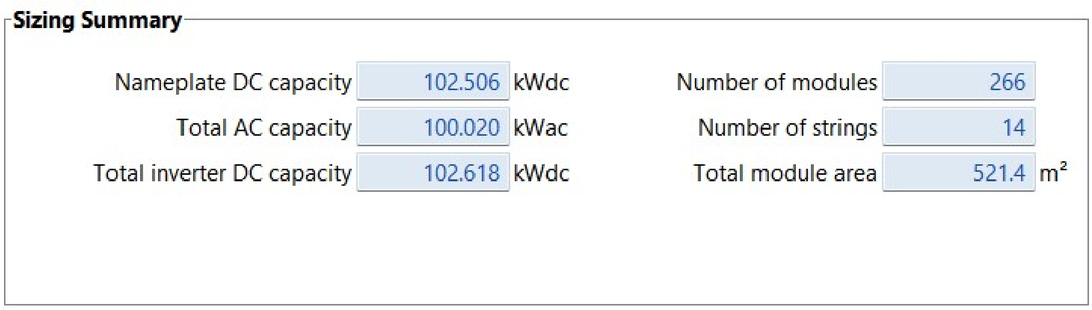

Figure 3.7: System Advisor Model (SAM) Sizing Summary.

The optimal PV tilt angle for Islamabad city is 3°. The azimuth angle is 180° and the GCR would be 0.3. The purpose of choosing these specifications is that the already installed on ground system has similar specification.

3.8.6 DC Losses Specifications

The effect of increasing Name plate DC losses of 5%, 10% and 13% respectively has been observed using parametric tool. These DC losses reflect the effect of increased water vapor quantity in the atmosphere for floating PV systems. The increase in this parameter would have effects on PV power production along with increase in the financial costs. The 5% and 10% DC losses are shown in Figure 3.8:

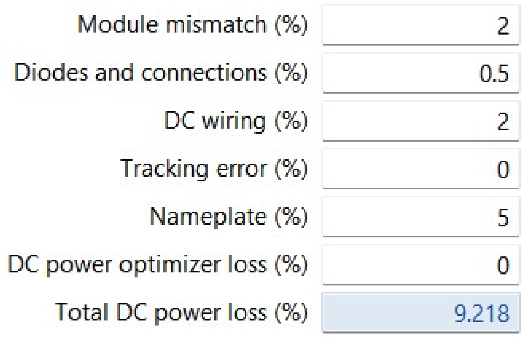

Figure 3.8: System Advisor Model (SAM) DC Loss (Name Plate DC Loss: 5%) Selection Interface.

Summary

A case study has been presented on NUST Lake being a non-utilizable water storage reservoir in NUST premises. The lake is a perfect place to install FPV system and thus a potential is calculated for NUST lake as to how much energy can be generated from the non-utilizable water reservoir. After the power estimation a 100 kW PV system has been designed in SAM software to compare both on-ground and FPV systems. Cleaning of both systems have been analyze. After that a technoeconomic analysis has been done in SAM software covering Net present value, Payback Period and Levelized Cost of Energy as financial parameter and capacity factor, energy yield and net electric out put have been observed as technical parameters.

References

1. H. Iftikhar, A. Waqas, A. Usman, K. Mustafa, and M. A. Afzal, “Utilizing built infrastructure and otherwise non-utilizable space for solar PV power projects - A case study for an educational institution,” J. Renew. Sustain. Energy, vol. 9, no. 1, 2017, doi: 10.1063/1.4976143.

2. H. Liu, V. Krishna, J. Lun Leung, T. Reindl, and L. Zhao, “Field experience and performance analysis of floating PV technologies in the tropics,” Prog. Photovoltaics Res. Appl., vol. 26, no. 12, pp. 957–967, 2018.

3. Y.-G. Lee, H.-J. Joo, and S.-J. Yoon, “Design and installation of floating type photovoltaic energy generation system using FRP members,” Sol. Energy, vol. 108, pp. 13–27, 2014.

4. S. Mehrotra, P. Rawat, M. Debbarma, and K. Sudhakar, “Performance of a solar panel with water immersion cooling technique,” Int J Sci Env. Technol, vol. 3, no. 3, pp. 1161–1172, 2014.

5. L. Liu, Q. Wang, H. Lin, H. Li, Q. Sun, and R. Wennersten, “Power Generation Efficiency and Prospects of Floating Photovoltaic Systems,” Energy Procedia, vol. 105, pp. 1136–1142, 2017, doi: 10.1016/j.egypro.2017.03.483.

6. M. Rosa-Clot, G. M. Tina, and S. Nizetic, “Floating photovoltaic plants and wastewater basins: an Australian project,” Energy Procedia, vol. 134, pp. 664–674, 2017.

7. R. Majeed, A. Waqas, H. Sami, M. Ali, and N. Shahzad, “Experimental investigation of soiling losses and a novel cost-effective cleaning system for PV modules,” Sol. Energy, vol. 201, pp. 298–306, 2020.

8. D. W. Green and M. Z. Southard, Perry’s chemical engineers’ handbook. McGraw-Hill Education, 2019.

9. A. Muhammad, U. Muhammad, and Z. Abid, “Potential of floating photovoltaic technology in Pakistan,” Sustain. Energy Technol. Assessments, vol. 43, p. 100976, 2021.

10. https://earth.google.com/web/@33.64205131,72.98522888,557.95103816a,200.11286651d,35y,0h,0t,0r

Chapter 4: Results and Discussion

4.1 Power Estimation of FPV Plant

The area under consideration in NUST lake can be dissected into areas for precise estimation and potential power calculation. Area 1 and Area 2 comprise a non-utilizable area of 11,575 m^2 and 11,100 m^2. A 100 kW PV system designed in SAM turns out to be 521.4 m^2 as shown in Figure 4.1:

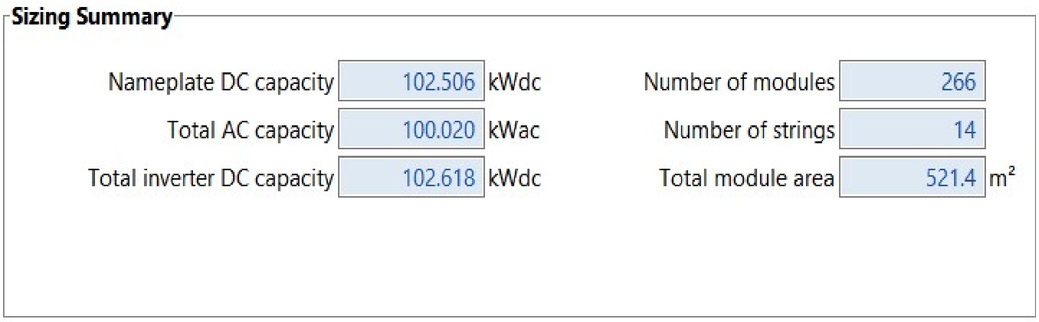

Figure 4.1: Sizing Summary for a 100 kW PV system designed in System Advisor Model

In System Advisor Model the exact power for this area is 102.5 kW_{dc}. One can use modular approach to calculate the exact power potential for the entire NUST lake. The Area 1 for NUST lake as specified has a total area of 11,575 m^2. The total FPV system that can be installed in Area 1 turns out to be 2.27 MW while for Area 2 having a total area of 11,100 m^2 turns out to have a power potential of 2.18 MW. The total power potential for the entire NUST Lake turns out to be 4.47 MW.

4.2 Cleaning of FPV systems and its comparison with On Ground system

The cleaning area required for deployment of 100 kW On-ground and FPV system is 521.40 m^2 calculated using SAM. This 521.40 m^2 area requires 938.52 litres or 248 Gallons of water for cleaning the entire area with 55% water coverage using flat fan nozzles (model VP110 015) which require 1.8 litres of water for cleaning an area of 1m^2 [1]. The water for the On-ground system needs to be extracted while for FPV system water required for cleaning of the PV panels is easily available from the reservoir itself. This advantage is contributing in the widespread acceptance of Floating PV technology [2]. The difference in cleaning both the systems come in the Cost per Watt for extraction of water. Thus, the 100 kW on-ground PV system extracts water for a boring motor which is installed at a head height of 106.68 meters having a water flow rate of 0.00450 m^3/sec. The water is than stored in water storage tanks and later utilized for PV cleaning. The power required for an on-ground PV system to pump water from a depth of 106.68 meters is 10,195 Watts or 10.195 kW for a single one-time PV cleaning cycle. The pump is turned on for 15 mins to extract water utilizing 2.54875 kWh of electricity. The FPV system has a head height of 1.82 meters. Due to the difference in head heights, the FPV system would consume less power as compared to the on-ground system each time cleaning is done.

As NUST comes under Islamabad Electric Supply Company (IESCO) as a commercial load as a sanctioned load of 5 kW and above. Thus, it is charged with the off-peak rate of $0.13/kWh. The 2.54875 kWh of electricity consumed leads to an additional $0.33/kWh which is the cost required for each time the boring pump will be used to extract water.

4.3 SAM Analysis for Temperature Change

The swirling of wind and natural cooling effect of water in the lake's surrounding leads to a temperature drop that increases the capacity factor of the system yielding more energy as seen from the results tabulated in Table 4.1. A decrease in temperature brings down the operation and installation cost of the PV system by lowering the Levelized Cost of Energy (LCOE). The Levelized Cost of Energy for the 100 kW FPV system turns out to be 5.64 ¢/kWh which is far less than 10 ¢/kWh the average retail electricity price of IESCO for a commercial area.This shows the economic feasibility for installing an FPV system. Moreover, the reduced temperature leads to an increase in Net present value of the system indication profitability. The reduction in Payback Period indicates reduced installation costs for the FPV system. The results of financial analysis when different weather conditions are simulated are mentioned in Table 4.1:

Table 4.1: Financial simulation results for various temperature weather files

Parameters	Normal File	5 ˚C Drop	10 ˚C Drop	20 ˚C Drop
Metric	Value	Value	Value	Value
Capacity factor (year 1)	17.80%	18.20%	18.50%	18.90%
Energy yield (year 1)	1,559 kWh/kW	1,591 kWh/kW	1,623 kWh/kW	1,654 kWh/kW

Levelized COE (nominal)	5.84 ¢/kWh	5.72 ¢/kWh	5.61 ¢/kWh	5.51 ¢/kWh
Levelized COE (real)	4.66 ¢/kWh	4.57 ¢/kWh	4.48 ¢/kWh	4.39 ¢/kWh
Net savings with system (year 1)	$14,439	$14,666	$14,893	$15,118
Net present value	$79,845	$82,462	$85,068	$87,655
Simple payback period	4.6 years	4.5 years	4.4 years	4.3 years

4.4 Calculation of Water Reduction Efficiency for FPV system

The reduction is water losses is proportional to the area occupied by the FPV system (Goswami and Sadhu, 2021). The calculation of evaporation is a complex phenomenon due to the time duration of calculation, incoming water, infiltration and precipitation (Waheeb Youssef and Khodzinskaya, 2019). Hence, the evaporation rate is constant across the NUST lake. Thus, the mathematical relation to calculate evaporation reduction efficiency for partially covered water bodies has been used (Assouline et al., 2011) in equations 4 and 5;

$$\alpha = \frac{Sc}{S}, \quad 0 \leq \alpha \leq 1 \tag{4}$$

where S_c is the partially covered surface area while S is the total are of the water reservoir.

$$\varepsilon = 1 - (1 - \alpha)^{2/3} \tag{5}$$

where ε represents the evaporation reduction efficiency while α represents the ratio of covered surface area of the water reservoir to the total surface area of the water reservoir. The evaporation reduction efficiency turns out to be only 1.17%/year. Assuming a 1 MW FPV system in NUST lake would result in a water reduction efficiency of 11.6%/year.

Finally, a 100 kW FPV system covered area would be deployed over 3ML of water. An evaporation reduction efficiency of 1.17% means about 35100 litres of water can be saved by deploying the FPV system. This FPV system would add an additional 6,167 kWh of annual energy worth $800 US dollars. An implementation of such an FPV system at a national scale would lead to additional energy production and cost savings of significant amount.

4.5 Comparison of On-ground and FPV Systems

A sensitivity analysis has been done by using Parametric tool in SAM has been used to check the effect of land cost on net present value and payback period of an On-ground PV system. In Figure 4.2 the net present value of On-ground PV installation can be observed. The NPV decreases and turns negative showing the non-feasibility of the project as time passes. Meanwhile, the payback period increases with the increase in land cost and crosses a 15-year mark. The increasing Payback period shows the increasing installation cost of On-ground PV system. High installation cost makes it difficult for investment in such a project. Thus, an FPV system should be utilized as an alternative to On-ground PV system due to having no land cost. The results are shown in Figure 4.2 and Table 4.2:

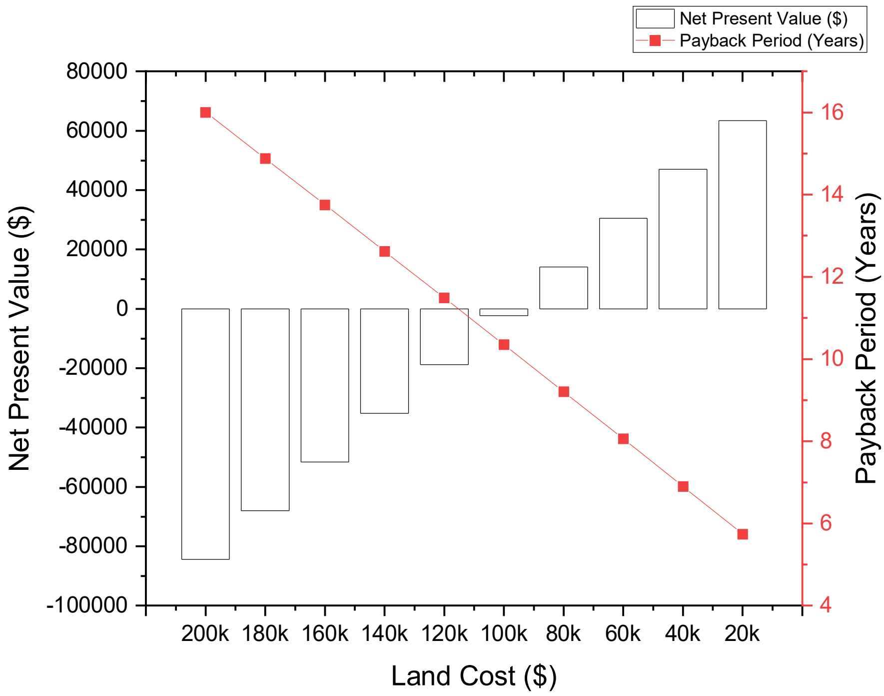

Figure 4.2: Effect of Increasing Land Cost on Net Present Value and Payback Period

Table 4.2: Sensitivity Analysis of Land Cost vs Net Present Value and Payback period

Land Cost Fixed ($)	Net Present Value ($)	Payback (years)
200000	-84485.9	16.0081
180000	-68052.8	14.8831
160000	-51619.7	13.7552
140000	-35186.6	12.6241
120000	-18753.5	11.4892
100000	-2320.37	10.3503
80000	14112.7	9.2067
60000	30545.8	8.05808
40000	46979	6.90202
20000	63412.1	5.73869

Moreover, the increasing DC losses represent the increased water vapor quantity in the atmosphere representing increased humidity for both on-ground and floating PV systems. The Net Present Value (NPV) decreases as the DC losses are increased. This decrease in Net Present Value shows an economically non-feasible PV system. When the humidity is at a rise water vapors cover the PV panels in a way that direct sunlight is blocked reducing power production from the DC side leading to losses. Similarly, the increasing payback period of our system results in high installation cost, less cash incentive and increased operation costs indicating less economic feasibility of our installed PV project. The results can be seen in Figure 4.3 and Table 4.3:

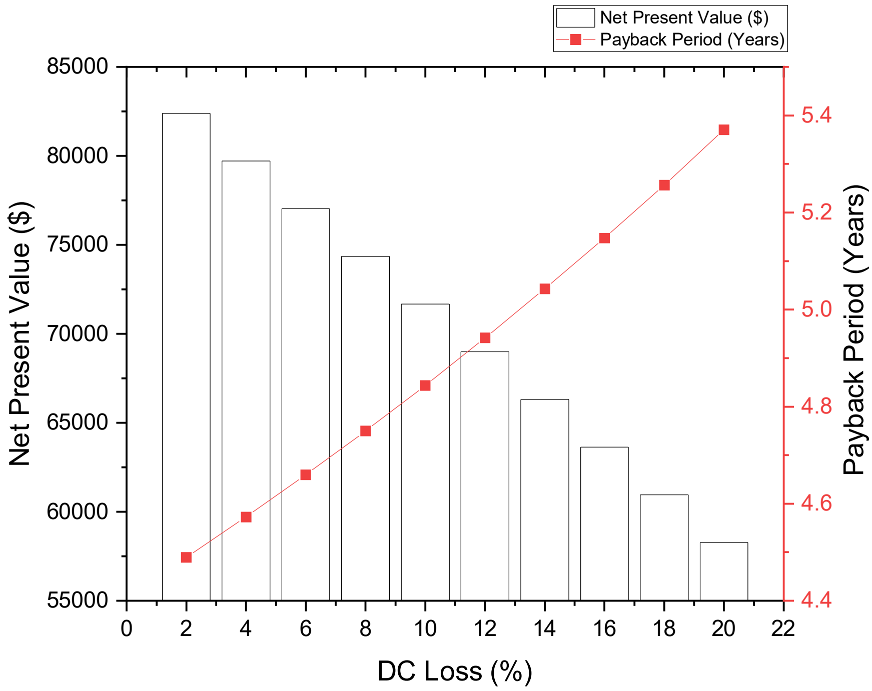

Figure 4.3: Effect of Increasing DC Loss on Net Present Value and Payback Period

Table 4.3: Sensitivity Analysis of DC Losses vs Net Present Value and Payback

DC Loss (%)	Net Present Value ($)	Payback (Years)
2	8239.1	4.48
4	79714.1	4.57
6	77237.2	4.64
8	74357.6	4.74
10	71678.2	4.84
12	68998.2	4.94
14	66317.5	5.04
16	63636.1	5.14
18	60953.9	5.25
20	58270.9	5.37

As the FPV system has no land cost, the increase in DC losses up to 20% still does not make Net Present Value to become negative. Similarly, when compared to the On-ground system the payback period for FPV is under 6 years which sky-rocketed to 16 years for the On-ground system. With the increase in DC loss the net energy produced on an annual scale is decreased. The effect of DC losses on the Annual Net Energy (kWh/year) and Annual DC Power Loss (kWh) is shown in Figure 4.4:

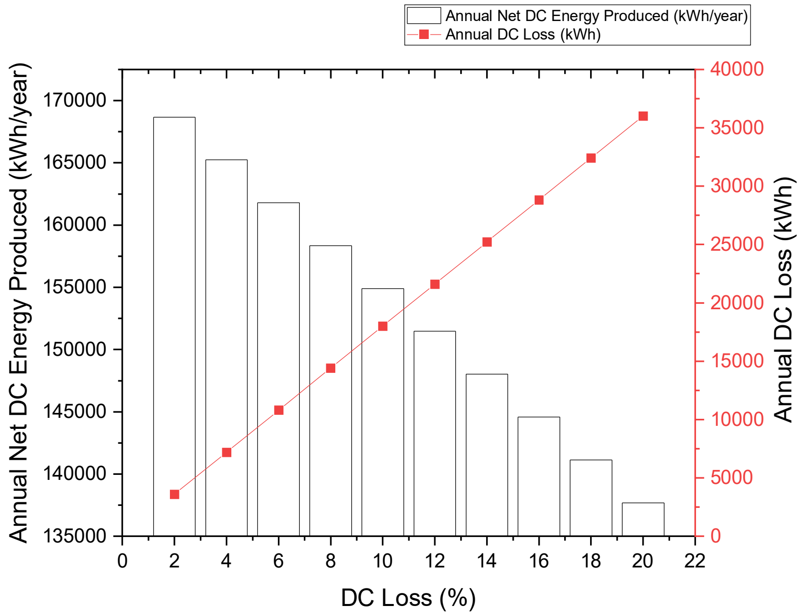

Figure 4.4: Effect of Increasing Irradiance on Annual DC Energy and DC Loss

Table 4.4: Sensitivity Analysis of DC loss vs Net DC Annual Energy Produced and Annual DC Losses

DC Loss (%)	Annual DC Net Energy (kWh/yr)	Annual DC Loss (kWh)
2	168675	3602.3
4	165233	7204.6
6	161791	10806.9
8	158348	14409.2
10	154906	18011.5
12	151464	21613.8
14	148021	25216.1
16	144579	28818.4
20	137694	36023

Summary

The power potential for non-utilizable urban lake Area 1 and Area 2 (11,575 m^2 and 11,00 m^2) turns out to be 2.27 MW and 2.18 MW. A total of 4.47 MW of renewable energy can be obtained from this non-utilizable water storage facility using Floating Photovoltaic System. In the on-ground system due to the difference in head height of the motor installed for extraction of water from the under-ground boring system for 15 mins, an addition cost of $0.33/kWh will be charged which is not applicable for Floating Photovoltaic system as water is readily available. The temperature drop increases the capacity factor yielding more energy and results in Levelized Cost of Energy for a 100 kW FPV system to be 5.64 ¢/kWh which is far less than 10 ¢/kWh the average retail electricity price of IESCO for a commercial area. In the sensitivity analysis done in SAM net present value of the on-ground PV system turns negative at $-2320.37 when land cost reaches to $100,000 showing non-feasibility of the project but remains positive at $58270.9 for the FPV system even when the DC losses are increased up to 20%. The payback period for the FPV system goes to 5.4 years when DC losses are increased up to 20% while for On-ground system the payback period crosses 15-year mark when land cost is increased up to $200,000.

References

1. R. Majeed, A. Waqas, H. Sami, M. Ali, and N. Shahzad, "Experimental investigation of soiling losses and a novel cost-effective cleaning system for PV modules," Sol. Energy, vol. 201, pp. 298–306, 2020.
2. A. Sahu, N. Yadav, and K. Sudhakar, "Floating photovoltaic power plant: A review," Renew. Sustain. Energy Rev., vol. 66, pp. 815–824, 2016, doi: 10.1016/j.rser.2016.08.051.

Chapter 5: Conclusion and Recommendation

5.1 Conclusion

The power potential for non-utilizable urban lake Area 1 and Area 2 (11,575 m^2 and 11,00 m^2) turns out to be 2.27 MW and 2.18 MW. A total of 4.47 MW of renewable energy can be obtained from this non-utilizable water storage facility using Floating Photovoltaic System. In the on-ground system due to the difference in head height of the motor installed for extraction of water from the under-ground boring system for 15 mins, an addition cost of \$0.33/kWh will be charged which is not applicable for Floating Photovoltaic system as water is readily available. The temperature drop increases the capacity factor yielding more energy and results in Levelized Cost of Energy for a 100 kW FPV system to be 5.64 ¢/kWh which is far less than 10 ¢/kWh the average retail electricity price of IESCO for a commercial area. In the sensitivity analysis done in SAM net present value of the on-ground PV system turns negative at \$-2320.37 when land cost reaches to \$100,000 showing non-feasibility of the project but remains positive at \$58270.9 for the FPV system even when the DC losses are increased up to 20%. The payback period for the FPV system goes to 5.4 years when DC losses are increased up to 20% while for On-ground system the payback period crosses 15-year mark when land cost is increased up to \$200,000.

SAM can be utilized before-hand to analyze the capability of any renewable technology by performing a technoeconomic analysis. The FPV system is preferable to deploy in urban areas where water bodies are available. The land cost in such areas is high due to which conventional large-scale on-ground systems must bear the land costs and become unfeasible to deploy as the payback period increases immensely. Thus, the deployment of FPV in such locations saves the land cost involved in the deployment process. Further the results suggest a recoverable payback period for the FPV system while the net present value also stays positive. On the contrary, increase in humidity leads to a reduction of solar irradiance reaching the solar panel increasing the DC losses as we install the FPV system on a water body. The net present value of the FPV system decreases with the increases in DC losses. Despite the decrease in net present value when compared to the on-ground system the FPV system performs better when only financial constraints are observed. Over time, the floating photovoltaic system serves better and requires less maintenance as it reduces the probability of dust being deployed on the panels and is independent of the effect of rising land costs in urban area.

5.2 Recommendations

A small scale 100 kW FPV project as in case of NUST lake requires no mooring lines and floating structures are comparatively cheap (Barbuscia, 2018). In addition, the wind potential is also low making the installation cost of 100 kW FPV system bearable. A $100/panel installation cost can be considered due to minimum movement of water in the water storage facility (Muhammad et al., 2021b). Thus, the installation cost for a 100 kW FPV, 266 module PV system turns out to be $26,600. The overall operation and maintenance (O&M) costs are higher for FPV but they depend on the scale of project (Barbuscia, 2018). Under the proposed cleaning system maintenance costs can be lowered as water is readily available for FPV cleaning. The O&M cost is $13/kW-year (da Costa and da Silva, 2021) which is the price of module cleaning, component replacement and land purchase agreement. While the O&M costs for FPV varies on many factors among which the main factors are water quality, its level, wear and tear of equipment and dust accumulation on the PV modules. The dust accumulation will be lesser as compared to on-ground PV as the structure would float on a reservoir. The water quality is also considerable as no residues reside in the water as it is accumulation of rainwater. The effect of algae growth on floating solar PV can be studied as a future recommendation.

Further, no water reservoir license is required for FPV deployment as it is located within the university premises and owned by the university. The Levelized Cost of Energy for the 100 kW FPV system turns out to be 5.64 ¢/kWh which is far less than 02 10 ¢/kWh, the average retail electricity price of IESCO for a commercial area. FPV system requires no land procurement, saving land costs. The increase in DC losses up to 22% still does not make Net Present Value to become negative. Similarly, when compared to the on-ground system, the payback period for FPV is under 6 years which reached 16 years for the on-ground system reflecting the economic non feasibility.

NUST is an educational institution, and its electricity resources are fulfilled by IESCO Islamabad Electric Supply Company. The additional FPV power potential of 100 kW would be a boast to the local grid contributing additional electricity by renewable means. No additional electricity infrastructure is required and the FPV system can be directly linked to the local grid. Such utility based FPV systems will contribute to the energy mix as current energy mix is dominated by hydro, gas and oil-based electricity production and such a system will introduce new method of electricity production in densely populated areas. This will be a great way to reduce the evaporation and conservation of local lakes. The utility will have no carbon emissions and will be save to the environment as it would require no land use no deforestation and no aquatic life exists in NUST lake.

Social acceptability of PV systems in general has barriers due to lack of awareness of the solar technology in rural areas. Also, the local residents lack experience and knowledge of practical solutions for solar energy problems (Irfan et al., 2019). Having said this, offshore project initiation attracts public. Similarly, the FPV system deployment is discouraged in areas of tourism and frequent recreational activities concerns (Hooper et al., 2021). Moreover, the deployment of FPV with wind energy can help lower the carbon footprint of offshore technologies. An infrastructure in terms of flatform can be used for multiple purposes like energy production and aquaculture. (Schupp et al., 2019) A potential 100 kW FPV system for NUST lake is to be installed in an educational institution which would provide a learning opportunity for students and provide employment to the locals.

FPV will have lesser environmental impacts than on-ground PV systems (Pimentel Da Silva and Branco, 2018). FPV system is bound to provide energy advantages but has some environmental concerns as it would increase the death of birds due to the attraction towards the solar panels (Grippo et al., 2015). The FPV system provide a natural shade to the water body, preventing algae growth and improving water quality (Pringle et al., 2017). This shadow also has a negative impact as it might affect the food chain of the lake instigating rivalry between marine life in search of sunlight (Burgess, 2017). Thus, lakes with water protection issues, recreational activities and fishing purposes should not be considered for FPV deployment (Choi, 2014).

Summary

This session concludes the over-all discussion by implying that the SAM can be utilized before-hand to analyze the capability of any renewable technology by performing a technoeconomic analysis. The FPV systems are better than on-ground system in all aspects may it be financially or technically. They produce more energy and have better efficiency. Further, FPV can be installed in urban water bodies to utilize a baren water reservoir. The on-ground systems are not suitable for deploying on land due to high land cost in cities while on roof tops out-door HVAC system increase the temperature of the panels. It is very difficult to achieve a perfect south due to the orientation of the building. While a true south can be achieved in water as it has no restrictions to move the floating platform on which the FPV is deployed.

References

1. Barbuscia, M., 2018. Economic viability assessment of floating photovoltaic energy. Work. Pap. 1, 1–11.
2. Burgess, G., 2017. Score review: Rameau, Jean-Philippe. “Les Indes galantes” and “Daphnis et Eglé.” Perform. Pract. Rev. 22, 1–5. https://doi.org/10.5642/perfpr.201722.01.03
3. Choi, Y.-K., 2014. A study on power generation analysis of floating PV system considering environmental impact. Int. J. Softw. Eng. its Appl. 8, 75–84.
4. da Costa, L.C.A., da Silva, G.D.P., 2021. Save water and energy: A techno-economic analysis of a floating solar photovoltaic system to power a water integration project in the Brazilian semiarid. Int. J. Energy Res. 45, 17924–17941. https://doi.org/10.1002/er.6932
5. Grippo, M., Hayse, J.W., O’Connor, B.L., 2015. Solar Energy Development and Aquatic Ecosystems in the Southwestern United States: Potential Impacts, Mitigation, and Research Needs. Environ. Manage. 55, 244–256. https://doi.org/10.1007/s00267-014-0384-x
6. Hooper, T., Armstrong, A., Vlaswinkel, B., 2021. Environmental impacts and benefits of marine floating solar. Sol. Energy 219, 11–14. https://doi.org/10.1016/j.solener.2020.10.010
7. IRENA, 2021. OFFSHORE An action agenda for deployment.
8. Irfan, M., Zhao, Z.-Y., Ahmad, M., Mukeshimana, M., 2019. Solar Energy Development in Pakistan: Barriers and Policy Recommendations. Sustainability 11, 1206. https://doi.org/10.3390/su11041206
9. Jones, L.E., Olsson, G., 2017. Solar Photovoltaic and Wind Energy Providing Water. Glob. Challenges 1, 1600022. https://doi.org/10.1002/gch2.201600022
10. Muhammad, A., Muhammad, U., Abid, Z., 2021. Potential of floating photovoltaic technology in Pakistan. Sustain. Energy Technol. Assessments 43, 100976. https://doi.org/10.1016/j.seta.2020.100976
11. Pimentel Da Silva, G.D., Branco, D.A.C., 2018. Is floating photovoltaic better than conventional photovoltaic? Assessing environmental impacts. Impact Assess. Proj. Apprais. 36, 390–400. https://doi.org/10.1080/14615517.2018.1477498
12. Pringle, A.M., Handler, R.M., Pearce, J.M., 2017. Aquavoltaics: Synergies for dual use of water area for solar photovoltaic electricity generation and aquaculture. Renew. Sustain. Energy Rev. 80, 572–584.
13. https://doi.org/https://doi.org/10.1016/j.rser.2017.05.191
14. Schupp, M.F., Bocci, M., Depellegrin, D., Kafas, A., Kyriazi, Z., Lukic, I., Schultz-Zehden, A., Krause, G., Onyango, V., Buck, B.H., 2019. Toward a common understanding of ocean multi-use. Front. Mar. Sci. 6, 1–12. https://doi.org/10.3389/fmars.2019.00165

Acknowledgment

I want to thank Allah Almighty, The Most Beneficent, The Most Merciful Who made me able to complete the research thesis. I express my sincere gratitude to **Dr. Adeel Waqas** for being such a tremendous mentor and guiding me throughout this outstanding journey. His illuminating views, constructive criticism, and consistent feedback made me sail through numerous obstacles that came in the way. I also extend my humble gratitude to all the faculty and GEC members especially Sir Abdul Kashif Janjua for his unconditional support. I pay special regards to my sister, brother, and friends for their constant encouragement and prayers that have made this endeavor easy and tireless. In the last but not least, I pay special tribute to my father who has always been by biggest supporter.

Appendix 1 – Publications

Solar Energy 231 (2022) 355–364

Contents lists available at ScienceDirect

Solar Energy

journal homepage: www.elsevier.com/locate/solener

Techno-economic perspective of a floating solar PV deployment over urban lakes: A case study of NUST lake Islamabad

Hamza Hafeez [a], Abdul Kashif Janjua [b,a], Hamza Nisar [a], Sehar Shakir [a], Nadia Shahzad [a], Adeel Waqas [a,*]

[a] US Pakistan Centre for Advanced Studies in energy, National University of Sciences and Technology, Islamabad, Pakistan
[b] School of Electrical Engineering & Computer Science, National University of Sciences and Technology, Islamabad, Pakistan

ARTICLE INFO

Keywords:
System Advisor Model (S.A.M.)
PV systems
Floating PV systems
Solar Energy
Economic Feasibility
Techno-economic Analysis

ABSTRACT

Water bodies like small lakes, canals, and rivers in urban areas serve to be a way forward to deploy photovoltaic technology with no constraints to involve land procurement. This article aims to estimate the potential deployment of a floating photovoltaic system on an urban lake site to assess its scope and compare it with a similar specification on-ground photovoltaic system. System Advisor Model (SAM) has been used for techno-economic analysis of a site in Pakistan. The technical analysis involves observing the effect of real time temperature drop and calculation of water reduction efficiency for FPV systems. The economic parameters like net present value (NPV) and payback period are used to judge the economic feasibility of the floating photovoltaic deployment project. The floating photovoltaic deployment in an urban area is subject to soiling as the water reservoir being used exists in an area close to or within the city boundaries. The required cleaning water costs a one-time extraction rate of $1435, while for a floating photovoltaic system, the extraction cost is estimated to be $1.35. Under standard temperature conditions (STC) one-year capacity factor turns out to be 0.70% more, producing an additional energy yield of 64 kWh/kW for lake scenarios when a 10 °C temperature drop is considered. The total power potential for the entire NUST Lake turns out to be 4.47 MW. A 1 MW FPV system in NUST lake would result in a water reduction efficiency of 11.6%/year. Under standard temperature conditions, the net present value for the on-ground system becomes negative while it remains optimistic for the floating photovoltaic system as no land costs are required. Similarly, once the land cost is included in the feasibility analysis, the payback period for the on-ground system goes beyond 15 years which is only 5.37 years for a floating photovoltaic system signifying the economic feasibility of the floating photovoltaic project.

1. Introduction and background:

Despite COVID-19, the gross investments in PV solar industry have risen by 12% to an investment of USD 148.6 billion. During 2020–21, solar photovoltaics (PV) was the best performing industry compared to all renewable technologies, adding 135 GW to the future estimated total of 1 TW by 2022 (Jäger et al., 2021). The solar PV industry emerged with a new niche known as Floating Photovoltaic Technology (FPV) that requires the installation of photovoltaic panels directly on the water body with the help of a floating platform instead of installing them on land or buildings (Green et al., 2012). Also, there is a heated debate about land usage among different renewable technologies, and the FPV systems can tone down this debate. It can be installed on the surface of natural or artificial water bodies such as lakes, rivers, dams, canals, and ponds (Galdino and de Almeida Olivieri, 2017). Globally, during 2020, around 2.6 GW of total capacity of floating solar PV projects were either under construction or fully functional around the globe (IRENA, 2021). Although FPV systems are desirable in Asian countries, they can be found worldwide (IRENA, 2021). The floating solar industry continued to expand rapidly due to land constraints, and the floating solar capacity exceeded over 3 GW in 2020 compared to 10 MW in 2015 (Program and Singapore, 2019). Floating projects tend to have higher costs than

Abbreviations: AC, Alternating Current; DC, Direct Current; FPV, Floating Photovoltaic; GCR, Ground Coverage Ratio; IESCO, Islamabad Electric Supply Company; LCOE, Levelized Cost of Energy; NPV, Net Present Value; NREL, National Renewable Energy Laboratory; NUST, National University of Science and Technology; OPV, On-ground Photovoltaic; PV, Photovoltaic; SAM, System Advisor Model; STC, Standard Temperature Conditions.

* Corresponding author.
E-mail address: adeel@uspcase.nust.edu.pk (A. Waqas).

https://doi.org/10.1016/j.solener.2021.11.071
Received 8 September 2021; Received in revised form 4 November 2021; Accepted 26 November 2021