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Development of Hybrid FPV-Hydro Energy Resources in Africa: A Review

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Abstract
The development of hybrid floating photovoltaic (FPV) and hydro energy resources present a promising avenue for addressing the energy needs and promoting sustainable development in Africa. This paper examines the potential challenges and implications of deploying hybrid FPV- Hydro systems across the continent. A structured review of high impact journal articles, technical reports and global case studies was conducted to reassess feasibility, benefits and constraints of renewable energy potentials and projects in the African continent. Africa holds over 40% of the world solar energy potentials and vast untapped hydro resources yet contribute less than 2% to global solar power output. The continent has the lowest rate of electricity access at 54%, globally, with Sub-Saharan Africa having an even lower rate of 47.7%, while the population continues to grow at the very high rate 2.7% annually. Hybrid FPV-Hydro systems offer significant advantages including reduced solar energy intermittency, minimized reservoir evaporation and improved generation efficiency. Case studies from selected countries demonstrate technical feasibility and socio-economic benefits such as enhanced energy access, job creation and better grid stability. Despite these benefits, key challenges persist ranging from financing constraints, regulatory gaps, and limited technical expertise. Overcoming these barriers requires coordinated policy support, investment in local capacity and inclusive community engagement. This study concludes that hybrid FPV- Hydro systems are practical solutions for Africa's energy transition. Their deployment can enhance electricity access, strengthen climate resilience and support long term development goals. Collaborative action among government, private investors, and development partners is essential to fully realize the potential of this integrated renewable energy solution.

Keywords: *Floating photovoltaic (FPV), hydro energy, hybrid floating photovoltaic (FPV)-hydro energy systems, energy access and reliability.*

1.0 Introduction

Energy plays a pivotal role in driving socio-economic development, modernization, and industrialization across the globe (Hosenuzzaman et al., 2015). In Africa, however, limited access to reliable and affordable energy remains a significant barrier to economic growth and improved quality of life (Casati et al., 2023). The continent's energy landscape is characterized by stark disparities: while North Africa boasts an electricity access rate of 96.5%, Sub-Saharan Africa lags behind at just 47.7%, contributing to Africa's overall lowest global electricity access rate of 54% (Manfred et al., 2018). Rapid population growth, currently at 2.7% per annum—much higher than in South Asia and Latin America—exacerbates the urgent need for expanded and sustainable energy infrastructure (Sanchez et al., 2021).

Africa's energy mix is diverse, comprising traditional biomass, fossil fuels (coal, oil, and natural gas), and an increasing share of renewables such as hydropower, solar, and wind. Fossil fuels remain dominant in North and West Africa, while hydropower is a major resource in Central and East Africa. Despite abundant solar and wind potential, these resources are unevenly distributed and often underutilized due to infrastructural, financial, and technical challenges (Blimpo et al., 2020). Traditional hydropower, while significant, faces limitations from seasonal variability, drought, and environmental impacts, while large-scale solar PV installations often compete with agriculture for land and require substantial capital investment.

Since the mid-1990s, public aid totaling just around US$600 million annually, plus an equivalent amount of private financing, has been the only external financing source for Africa's power sector. Chinese, Indian, and Arab sources have also become important energy funders in recent times (Esteban et al., 2018). However, persistent investment at significantly greater levels is predicted to be necessary to double current levels of energy access by 2030 (Igbinovia, 2016).

In this context, Floating Photovoltaic (FPV) systems combined with hydropower—referred to as hybrid FPV-hydro energy—present a promising solution tailored to Africa's unique challenges. Hybrid FPV-hydro systems leverage existing hydropower reservoirs for FPV deployment, thus maximizing land use efficiency, reducing water evaporation, and enabling more consistent power generation by complementing the intermittency of solar with the flexibility of hydropower. This synergy offers a distinct edge over standalone

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solar or hydropower systems, particularly in regions where land is scarce or water resources are under stress. Moreover, hybrid FPV-hydro projects can utilize existing grid infrastructure, reducing both costs and environmental footprints.

Therefore, the development of hybrid FPV-hydro energy resources holds significant potential to accelerate energy access, enhance grid stability, and support sustainable development across Africa. This review critically examines the current state, opportunities, and challenges of hybrid FPV-hydro energy systems in Africa, positioning them within the broader context of the continent's evolving energy landscape.

2.0 Renewable Energy Resources

Natural renewable resources are amply available in Africa. These resources are the foundational blocks for the hybrid energy systems and are important for the maintenance of a sustainable environment while being deployed to meet national energy demands on the continent.

2.1 Solar Energy Potential in Africa

Africa possesses immense solar energy potential, with 95% of daily global sunshine exceeding 6.5 kWh/m² (Uyigue & Archibong, 2010). This high solar potential is expected to persist despite climate change, with only minor decreases projected in limited areas of eastern central Africa and slight increases in northwest and southern Africa (Soares et al., 2019). Solar energy offers a viable solution to Africa's electricity challenges, climate change vulnerability, and rapid population growth (Abdelrazik et al., 2022; Soares et al., 2019). However, despite abundant renewable resources, Africa's overall energy generation from solar and wind remains insufficient (Ogunniyi & Pienaar, 2019). Obstacles include financial, technological, and human resource challenges (Abdelrazik et al., 2022). To harness Africa's renewable energy potential, increased investment in utility-scale and hybrid systems, along with energy storage development, is crucial (Ogunniyi & Pienaar, 2019). Scaling up renewable energy technologies will address energy crises, mitigate climate change, and promote socio-economic development across the continent (Casati et al., 2023). According to the International Renewable Energy Agency (IRENA)'s "Renewable Capacity Statistics," 2021, 40% of the solar energy potential in the world is in Africa. Yet, it only accounts for 1.48% of the global capacity for producing solar energy. However, solar potential tends to stand out in North and South African regions as shown in Figure 1 as research by Abdelrazik et al., (2022) reveals PV solar power potential across Africa.

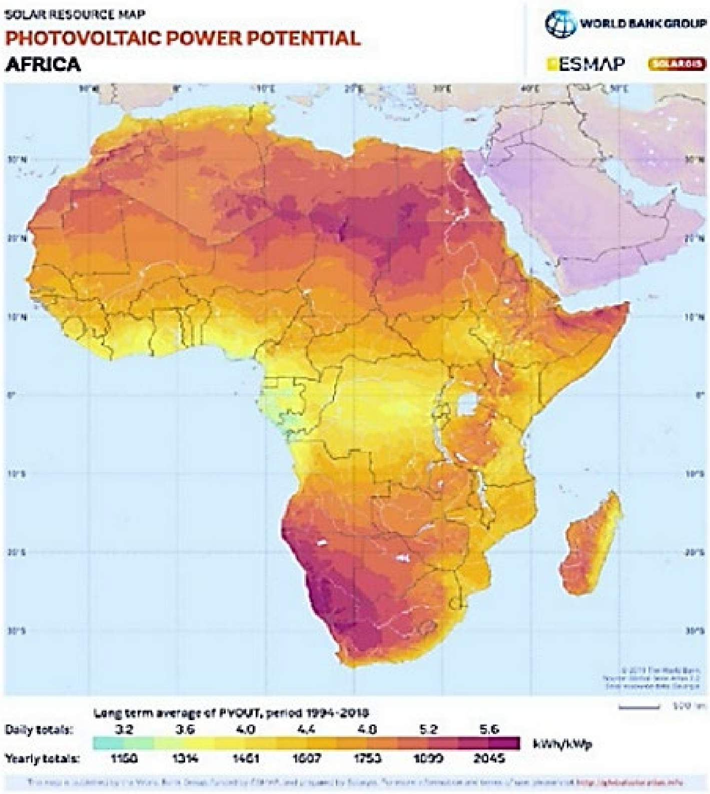

Figure 1: Photovoltaic power potential in Africa (Abdelrazik et al., 2022)

Egypt has an abundance of solar radiation. According to the solar atlas, the country receives 3,050 hours of sunlight on average per year, with direct normal irradiations ranging from 1970 to 3200 kWh/m² annually and annualized total solar irradiance ranging from 2000 to 3200 kWh/m² (Moharram et al., 2022; Seck et al.,

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2022). As a result, Egypt has exceptional solar resources that can be applied to a wide range of solar energy systems and industries, such as the establishment of photovoltaic (PV) or concentrated solar power (CSP) plant establishments. According to the Global Solar Atlas, Egypt has 74 billion MWh of solar energy potential annually. Numerous solar energy collection and generation projects have been developed or are in the process of being developed to collect solar energy and produce electrical power using a variety of solar energy technologies. Figure 2 gives details of the projects as detailed by the reports from the country's Ministry of Electricity and Renewable Energy's reaction (Moharram et al., 2022).

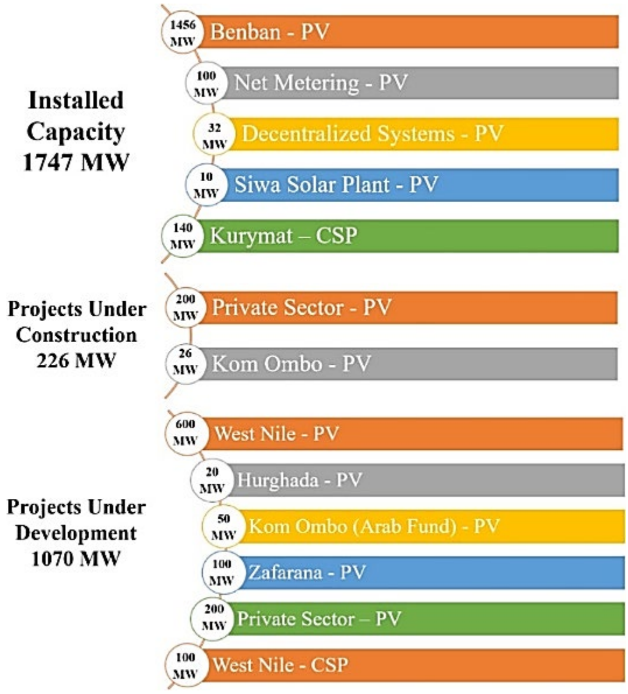

Figure 2: Solar power projects in Egypt (Moharram et al., 2022)

South Africa is among the top three countries in the world with 4.5 to 6.6 kWh/m^2 of radiation and an average of 2,500 hours of sunshine per year (Jain & Jain, 2017). Figure 3 illustrates that the region between Bloemfontein and Johannesburg, which includes Vanderbijlpark, receives between 8000 and 8500 MJ/m^2 of solar radiation annually (Hertzog & Swart, 2016)

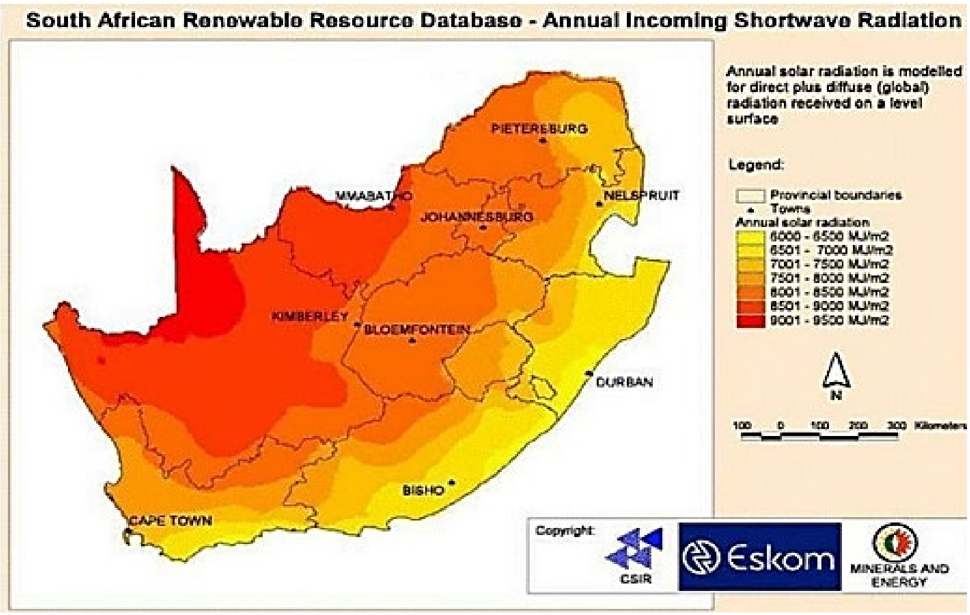

Figure 3: Annual solar radiation for South Africa (Hertzog & Swart, 2016)

2.1.1 Photovoltaic (PV) system

The fundamental component of a photovoltaic system is the PV solar cell, which consists of an interaction between two thin layers of distinct semiconductor materials, the only materials that absorb the photons'

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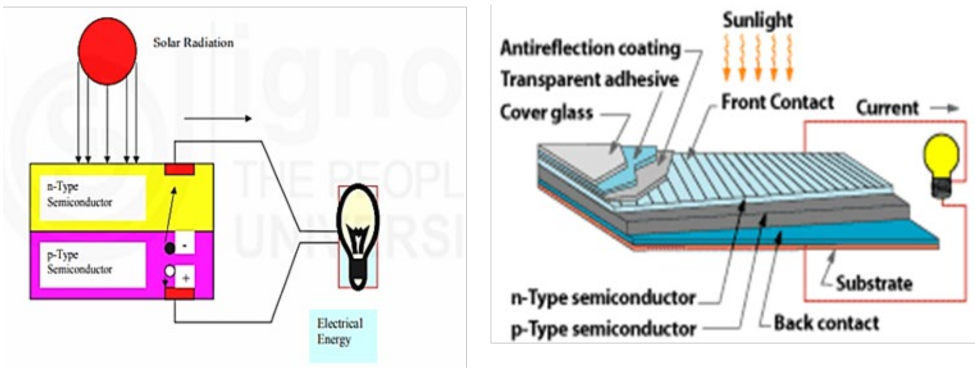
energy from sunlight (Dada & Popoola, 2023). Semiconductors can either be positive (P-type) or negative (N-type) (Minggu et al., 2010). PV solar cells are most frequently made of silicon due to its abundance in nature and efficiency especially when it is in an oxidized form as Silicon Oxide (Khan et al., 2013). The two different forms of silicon – pure silicon and amorphous silicon are used to build the cells. Initially, the use of the photovoltaic cells was limited due to high cost of processing top grade purity single crystal material used and the lack of effective mass production techniques used to produce thin silicon films (Lazaroiu et al., 2023) P-type semiconductors are made from crystalline silicon doped with a very small amount of an impurity such as boron, making the material electron deficient. N-type semiconductors also consist of crystalline silicon, but doped with small amounts of another impurity (phosphor) so these materials have an excess of free electrons (Andjela, 2021; Khan et al., 2013).

Photovoltaic (PV) technology operates on a fundamental principle known as the photovoltaic effect. The photovoltaic (PV) effect is the process of generating electromotive force (electricity) as a result of the absorption of solar radiation as shown in Figure 4 (Darwish et al., 2022). The conversion or generation of electromotive force is accomplished by absorbing sunlight and ionizing crystal atoms, thereby creating free, negatively charged electrons and positively charged ions. The primary drawback of solar power generation is its inconsistent nature, as it is contingent upon the presence of sunshine (Agresti et al., 2024; Al-Rawashdeh et al., 2023; Dambhare et al., 2021). Thus, energy storage solutions are necessary to guarantee solar power generation's stability and dependability. Energy storage technologies store excess solar energy during periods of high solar availability and release it during periods of low solar availability to ensure a steady supply of electricity (Heydari et al., 2023).



(a) (b)

Figure 4: Diagram showing Photovoltaic effect (a) and photovoltaic solar cell (b) (Darwish et al., 2022)

2.1.2 Floating Photovoltaic (FPV)

The setup of floating photovoltaic (FPV) systems resembles that of land-based ones, with the exception of inverters and photovoltaic (PV) arrays placed on a floating platform (Ranjbaran et al., 2019). The electricity produced by the modules is gathered through a string combiner box and transformed into alternating current (AC) using an inverter as shown in Figure 5 (Garrod et al., 2024; Prasannalal, 2021).

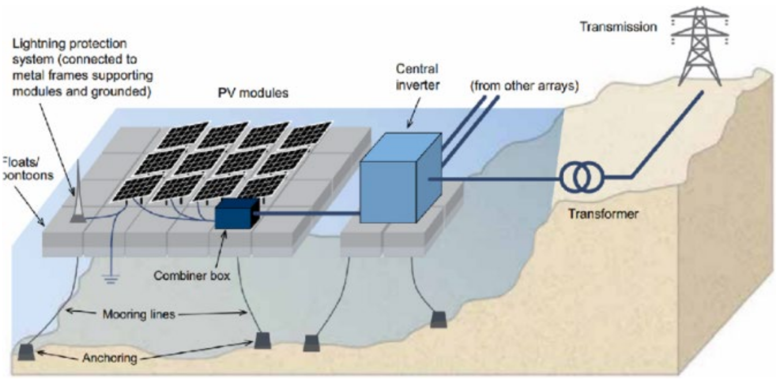


Figure 5: FPV system overview (Prasannalal, 2021)

Floating photovoltaic (FPV) systems are an emerging technology that offers several advantages over land-based solar installations. FPV systems consist of PV panels mounted on floating platforms, typically deployed on water bodies like lakes and reservoirs (Bhattacharya, 2023a; Gadzanku et al., 2021). These systems benefit from enhanced cooling effects due to water proximity, leading to improved efficiency and higher energy yields compared to conventional PV setups (Prinsloo et al., 2021; Sanchez et al., 2021). FPV installations also

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conserve land resources and can potentially reduce water evaporation (Solomin et al., 2021). Despite higher initial costs, FPV technology is rapidly expanding, with global installed capacity doubling annually as shown in Figure 6 (Ummah, 2023). However, challenges remain, including the need for more durable components and a lack of design standards for marine environments (Gadzanku et al., 2021). Ongoing research focuses on optimizing FPV system designs, including the integration of tracking systems and concentrators to further enhance performance (Refaai et al., 2022).

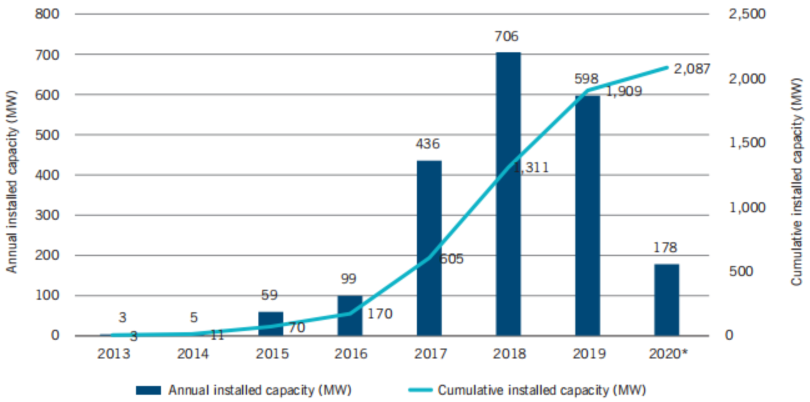

Figure 6: Global installed capacity of floating solar (Ummah, 2023)

2.1.3 Current state of PV technology in Africa

Despite certain obstacles, photovoltaic (PV) technology implementation in Africa has been gradually rising. Solar photovoltaic (PV) implementation in Africa is projected to reach an annual average of nearly 15GW, with an anticipated total capacity of 320GW by 2040. According to Tanko, (2023), this surge is poised to surpass both hydropower and natural gas, positioning solar PV as the predominant energy source for electricity generation in Africa, based on installed capacity and a number of studies have been carried out to improve the PV system's efficacy (Brunet et al., 2018).

The transition towards renewable energy (especially solar PV) is motivated by various factors. Firstly, the affordability of renewable energy sources has significantly improved, with the unsubsidized solar photovoltaic levelized cost of electricity (LCOE) dropping by approximately 90% from $400/MWh in 2011 to $41/MWh in 2022 (Diemuodeke et al., 2021). Additionally, there is a growing demand for environmentally sustainable energy options, fuelled by concerns to reduce CO_2 emissions and the finite nature of fossil fuel resources (Thadani & Go, 2021). Moreover, the necessity for energy access is a significant driving force, particularly in regions like sub-Saharan Africa, where approximately half of the population lacks access to electricity. This energy access disparity drives the market for distributed solar power generation installations, thereby facilitating broader access to electricity (Agoundedemba et al., 2023).

2.2 Hydro Energy

Hydropower is a well-established and relatively straightforward technology that generates electricity by spinning a turbine with the kinetic energy of a water supply, which is determined by its head and mass flow rate as shown in Figure 7 (Jain & Jain, 2017; Ozigis et al., 2019a; Siddig et al., 2020; Solomin et al., 2021). From a period spanning almost two thousand years ago, people ground wheat using the kinetic energy of falling water. The usage of hydropower to produce electricity dates back to the late 1800s and has followed the principle shown in figure 7 according to reports from IRENA and Energy Technology Systems Analysis Program (ETSAP) (IRENA & ETSAP, 2015). Hydropower provides some level of power generation in 159 countries (Aswathanarayana, 2010). In 2020, the installed capacity of hydropower totalled 1,330 gigawatts (GW). This indicates 1.6 percent growth year over year, which is better than 2019 but still well below the more than 2 percent required to make hydropower's crucial role in combating climate change possible. East Asia remains the world leader in respect of total hydropower installed capacity with over 14,466 MW, Europe (3,032 MW), South and Central Asia (1,609 MW), Africa (938MW), North and Central America (531 MW) and South America (476) (IEA, 2021).

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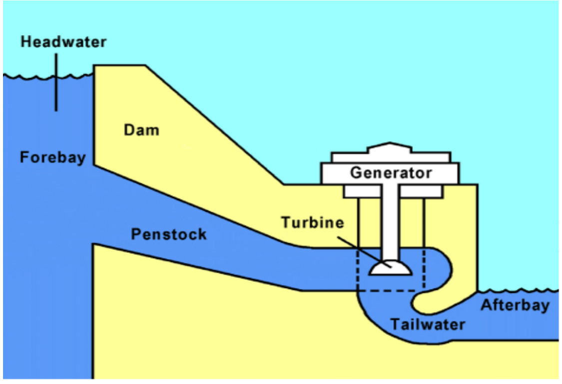

Figure 7: Hydro power plants components (Maués, 2019; Solomin et al., 2021)

2.2.1 Hydro energy potential in Africa

Africa's energy landscape would not be complete without hydroelectric power, which takes advantage of the continent's plentiful water resources to produce electricity in a sustainable manner (Agoundedemba et al., 2023). This potential is especially significant in developing and rising nations which are predominantly in Africa where the need for new energy sources is fast growing and many people still lack access to dependable energy solutions despite the fact that Hydro energy is economically viable (Trevor Criswell, 2021).

Hydropower is an important source of electricity in Africa, especially in eastern and southern Africa. For instance, 90% of the electricity generation in Ethiopia, Malawi, Mozambique, Namibia and Zambia comes from hydropower (Andjela B, 2021; Sanchez et al., 2021). Also, Africa is also the continent with the highest untapped technical hydropower potential. Despite a feasible potential of 1,750,000 GWh/year, just 4.3% have been exploited in production as of 2010 as discovered by Saxena, (2010), and only around 7% of the massive hydro potential has been utilized, according to the International hydroelectric Association (Gonz, 2019). As of 2023, Africa has utilized only about 10% of its 1,750,000 GWh/year hydropower potential, with a total installed capacity of 42 GW, including 2 GW added in 2023, led by Nigeria (740 MW), Uganda (408.2 MW), DRC (381.7 MW), and Tanzania (261.7 MW), while the AfDB is investing $1 billion to upgrade 12 existing plants (Anfom et al., 2023; Ukoba et al., 2024)

Africa has a lot of potential for producing hydroelectric electricity because it has so many rivers and other bodies of water. This type of renewable energy is essential to supplying the growing amount of electricity needed due to economic expansion and population growth (Nwagu et al., 2025; Ugwu et al., 2022). The resources of major African rivers including the Zambezi, Congo, Nile, Niger, and others can be developed for hydropower to help satisfy the region's expanding energy needs. The potential for water resources in the Zambezi and Congo River has more than 100,000 MW of hydroelectric potential, which is enough to meet the needs of the entire continent of Africa while the hydropower potential in Ethiopia and Nigeria is 30,000 MW and 20,000 MW, respectively (Dube & Nhamo, 2023; Obada et al., 2024). Currently, a few stable northern and southern African nations are home to around 82% of the world's hydropower plants (Zhao Jianda, 2017). When looking at the distribution of installed hydropower capacity, regional disparities are clear; North Africa only makes up 7.7 percent of the total, whereas Southern Africa accounts for more than 33 percent. However, the biggest geographical differences occur when the potential for hydropower generation is taken into account (Dube & Nhamo, 2023). Table 1 indicates that Central Africa has the greatest hydroelectric potential in terms of both gross theoretical and technically practical potential, especially when it comes to the development of large-scale hydropower, which is focused in the Congo basin (Obahoundje & Diedhiou, 2022). With the exception of Morocco and Egypt, North Africa is non-reliant on hydropower (Agoundedemba et al., 2023). There is around 15,000 MW of untapped hydropower potential in Ethiopia's Nile River alone. As a result, West Africa only makes up a small portion of all of Africa's hydropower technical potential with only 95 936 GWh/year (Obada et al., 2024). Making use of this potential, there is opportunity to greatly increase the availability of electricity in Ethiopia and neighbouring East African nations like Sudan, Kenya, and Djibouti that are linked to Ethiopia's power infrastructure (Basheer et al., 2020). Hydropower potential for various regions of Africa is presented in Table 1.

Table 1: Hydropower potential and installed capacity by region

Region	Gross Theoretical HP Potential GWh/year	Technically Feasible HP potential GWh/year	Installed HP Capacity MW	Planned Hydro Capacity MW	References
North Africa	13 000	4 950	1 549	1 170	Agoundedemba et al., (2023)
East Africa	703 500	97 822	4 537	2 001	Baker (2023)
West Africa	117 026	95 936	3 969	6 168	Obada et al.,(2024)
Central Africa	1 771 150	921 950	3 448	43 806	Obahoundje & Diedhiou (2022)
Southern Africa	644 207	389 255	6 670	23 389	Soares et al., (2019)

3.0 Hybrid FPV-Hydro Energy Systems

Combination of floating photovoltaic (FPV) with hydro energy storage systems, or hybrid FPV-Hydro energy resource systems combines two renewable energy technologies – hydro energy storage and floating solar panels. Together, hydropower and solar energy are both dispatchable and non-dispatchable energy sources. The floating photovoltaic and hydropower hybrid system may work in perfect harmony day or night and throughout the year (Prasannalal, 2021). Of all the hybrid setups (which includes FPV + wave energy, FPV + hydro, FPV + pumped hydro converter, FPV + hydro-kinetic + water lily tree, and FPV + conventional power plant) that can be used, the hybrid configuration of a hydropower plant and floating solar photovoltaic (FPV) system is the most beneficial (Bhattacharya, 2023b; Solomin et al., 2021). The advantages of this setup include the mutual compensation for the intermittency of both Floating Photovoltaic (FPV) and hydropower plants, enhanced input to the hydropower plant by reducing evaporation losses, and simplified connection to the grid (Patil et al., 2022).

3.1 Integration of PV and Hydro Technologies

Integrating photovoltaic (PV) and hydro technologies offers numerous advantages in enhancing energy generation and system flexibility. By combining PV floating with hydroelectric power plants, it becomes possible to exploit solar energy effectively without significant challenges (Cazzaniga et al., 2019). This integration allows for creating a "virtual battery" that enhances the flexibility of both forms of generation, providing solar electricity during peak daylight hours and balancing the grid with hydropower during periods of low solar irradiation and overnight (Rodríguez, 2023). Moreover, the co-location of solar panels with hydropower plants offers benefits such as increased water availability by reducing evaporation, boosting hydroelectric generation, and improving the efficiency of PV panels due to the cooling effect of water (Rajendran Pillai et al., 2023). Countries worldwide are adopting policies to support the deployment of hybrid hydropower solar systems to increase renewable energy capacity while reducing reliance on hydropower alone (Thoresen & Skogheim, 2021).

Research also highlights the potential for integrating a Solar PV System with Pumped Hydroelectric Storage Systems (PHESs) to enhance grid connectivity and self-consumption capabilities (Zeidan et al., 2023). This integration involves designing and assessing PHESs connected to the grid alongside a PV system, showcasing the feasibility and benefits of such combined systems (Zeidan et al., 2023). Figure 8 shows the schematic diagram of a typical hybrid FPV-Hydro power plant.

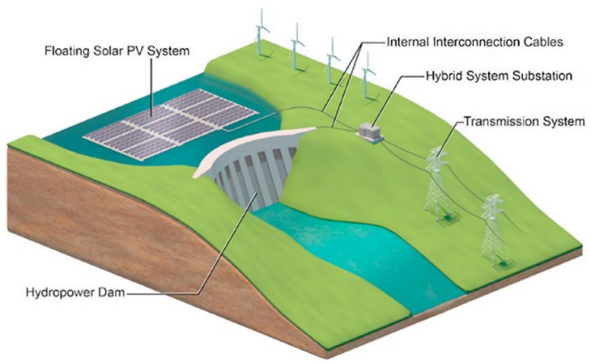

Figure 8: Hybrid FPV-hydropower system (Solomin et al., 2021)

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Hydroelectric systems consist of several key components that work together to generate electricity. The turbine converts water pressure into mechanical energy, which drives the generator to produce electrical energy (Bhattacharya, 2023b). A transformer then increases the voltage for connection to the power grid. Storage batteries are used to store excess electricity, especially in off-grid setups, while an electricity production meter tracks the amount of electricity generated for tariff benefits. Monitoring equipment plays a crucial role in overseeing turbine performance, output, and detecting any issues locally or remotely (Zhao et al., 2023). In contrast, photovoltaic (PV) systems rely on PV cells that convert sunlight into electricity by exciting electrons within semiconductor materials (Sepúlveda-Mora & Hegedus, 2021). These cells are grouped into panels or arrays to generate usable amounts of electricity. Inverters convert the direct current (DC) produced by the PV cells into alternating current (AC), which is compatible with most electrical systems. Some PV systems also incorporate tracking systems that adjust the panels to follow the sun's movement, maximizing efficiency, although this adds to the overall cost (Quaranta & Davies, 2022).

The efficiency of PV cells in converting sunlight to electricity varies based on the semiconductor material used, with state-of-the-art modules approaching 25% efficiency (Olkkonen et al., 2023). Today, most PV systems in the United States are grid-connected, providing electricity efficiently and sustainably (Gbadamosi et al., 2022).

4.0 Case Studies and Projects

4.1 Overview of Existing Projects

The pursuit of sustainable energy sources has led to the development of innovative solutions, particularly in regions like Africa where energy access remains a critical challenge (Elalfy et al., 2024). Across the globe, numerous hybrid FPV-hydro energy projects have emerged, showcasing the potential of combining solar and hydroelectric technologies (Nkambule et al., 2023). Table 2 presents the case studies of the projects around the world and Africa.

Table 2: Case Studies of Hybrid FPV-Hydro Projects – Global and African Context

Project Name / Location	Country /Region	Project Description	Key Features / Innovations	Outcomes / Benefits	Source(s)
Yamakura Dam FPV-Hydro Project	Japan	Integrates floating photovoltaic (FPV) panels on a dam reservoir with existing hydroelectric infrastructure.	- Large-scale FPV deployment- Dual use of reservoir space- Land-use minimization	- Increased clean energy output- Preserved land for other uses- Enhanced power generation efficiency	Nkambule et al., (2023); Vourdoubas, (2023b), (2023a)
Robertville Lake Hybrid Pilot	South Africa	Integrates FPV panels on a lake used by a hydro plant, showcasing a hybrid system designed to reduce reliance on fossil fuels in a semi-urban setting.	- Pilot-scale hybrid deployment- Urban proximity- Grid feed-in capability	- Boosted clean energy supply- Decreased fossil dependence- Model for replication in other parts of Africa	Garrod et al.,(2024); Nkambule et al., (2023); Solomin et al., (2021)
Bujagali Hydroelectric Station (with FPV potential)	Uganda	While currently a hydro plant, Bujagali is being explored as a site for potential floating solar installation due to its suitable reservoir surface and solar exposure.	- Existing hydro capacity- FPV feasibility analysis underway	- Lays groundwork for hybrid expansion- Potential future site for FPV integration	Kimbowa & Mourad, (2019); Koondhar et al., (2024); Ramanan et al., (2024)

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Project Name / Location	Country /Region	Project Description	Key Features / Innovations	Outcomes / Benefits	Source(s)
Zambezi River Basin Projects	Zambia /Zimbabwe	Region under review for FPV-hydro integration to reduce drought vulnerability and improve energy access in rural areas.	- Multi-country planning- Cross-border energy collaboration- Use of river basin for joint hydro-solar ops	- Resilience against hydro variability- Opportunity for FPV scalability- Potential to reduce energy poverty	Spalding-Fecher et al., (2017)
Lake Kariba Hybrid Feasibility	Zimbabwe	Ongoing feasibility study to deploy FPV panels on Lake Kariba to complement hydroelectricity from the Kariba Dam, which is vulnerable to climate-driven water shortages.	- Climate resilience focus- Long-term hybrid potential- Grid enhancement vision	- Expected to stabilize electricity supply- Future-proof energy mix- Improved regional energy security	Garrod et al., (2024)
Volta River Authority (VRA) FPV Study	Ghana	Ghana's national energy body exploring FPV deployment on dam reservoirs like Akosombo and Kpong to enhance renewable energy integration.	- Government-backed study- Potential for regional scale-up	- Strategic diversification- Policy support for renewables- Supports Ghana's energy mix targets	Kuriakose et al., (2022)
Kainji Dam Solar-Hydro Proposal	Nigeria	Proposal stage for hybridizing Nigeria's largest dam with FPV to offset dry season energy drops and expand capacity without more land use.	- High solar potential- Idle reservoir space- Federal interest growing	- Potential for increased energy access- Minimizes deforestation and displacement	Adegbehin et al., (2016)

4.2 Assessing Their Impact on Local Communities

The impact of hybrid FPV-hydro energy projects on local communities can be multifaceted, influencing various aspects of socio-economic development, environmental sustainability, and community well-being especially in Africa as highlighted in Table 3.

Table 3: Assessment of Hybrid FPV-Hydro Projects' Impacts and Challenges in African Local Communities

Dimension	Key Impact	Key Challenge	Source(s)
Energy Access and Reliability	Improved energy access and reliability in underserved regions.	Unequal energy distribution if benefits are not inclusively managed.	Amer et al., (2023); Gamette et al., (2024); Kimbowa & Mourad, (2019)
Economic Development	Job creation and support for small businesses and entrepreneurship.	Limited local job uptake if reliant on external expertise or automation.	Asomah & Emmanuel, (2024)
Environmental Sustainability	Clean energy generation, reduced emissions, and decreased water evaporation.	Potential for habitat disruption, land use conflicts, and ecological imbalance if not properly assessed.	Briones-Hidrovo et al., (2021)

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Dimension	Key Impact	Key Challenge	Source(s)
Community Engagement & Empowerment	Strengthens local participation, trust, and benefit-sharing through inclusive decision-making.	Exclusion or poor consultation can lead to resistance, conflict, or project abandonment.	Adenutsi, (2023)
Resilience & Climate Adaptation	Reliable energy supply during climate variability; enhanced resilience to droughts and extreme weather.	Floods or cyclones can damage infrastructure and disrupt energy supply.	Asomah & Emmanuel,(2024); Sebestyén, (2021)
Financing & Investment	Potential for long-term returns with renewable energy focus.	High upfront costs, perceived risks, and limited investor interest.	Qadir et al., (2021); Ryenbakken & Nieuwenhout, (2023)
Regulatory & Policy Frameworks	Can stimulate energy reforms and policy innovation if well-managed.	Inconsistent regulations, unclear permitting, and bureaucratic delays.	Adenutsi, (2023); Wilkinson et al., (2021)
Infrastructure & Grid Integration	Potential to improve grid resilience and coverage with hybrid systems.	Weak or inadequate grid and transmission systems hinder effective integration.	Barman et al., (2023); Verbrugge et al., (2021)
Land Use & Environmental Conflict	Opportunity to optimize underutilized water bodies and dam areas.	Land conflicts, displacement, and environmental opposition can emerge without proper safeguards.	Sahu et al., (2016); Solomin et al., (2021)
Technological Constraints	Encourages adoption of innovative renewable energy technologies.	Inaccessibility to reliable equipment, skilled technicians, and repair capacity in remote areas.	Chanda et al., (2025)
Capacity Building	Builds local technical expertise and supports long-term sustainability.	Lack of training infrastructure and technical education limits skilled workforce development.	Seetharaman et al., (2019)
Access to Data	Better data use can enhance feasibility and optimize system performance.	Lack of reliable solar, hydro, and demand data hampers planning and risk management.	Ozigis et al., (2019); Ramos et al., (2024)
Political & Socioeconomic Stability	Projects can support local development and energy equity when politically supported.	Political instability, corruption, and social inequality discourage investment and delay implementation.	Bishoge et al., (2020)

5.0 Potential for Development in Africa

The potential for developing hybrid Floating Photovoltaic (FPV) and Hydro energy systems in Africa is substantial, driven by the continent's abundant solar and hydro resources, coupled with its growing energy demand and the imperative for sustainable development. Africa's equatorial regions receive ample sunlight year-round, making it ideal for solar energy generation, while its numerous rivers and water bodies offer significant hydroelectric potential (Sanchez et al., 2021). These complementary resources provide a strong foundation for hybrid FPV-hydro projects to enhance energy security, reliability, and resilience, particularly in remote or off-grid areas where traditional grid extension may be impractical (Lee et al., 2020).

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Table 4: Key Considerations for the Development of Hybrid Floating Photovoltaic (FPV)-Hydro Energy Systems in Africa

Category	Key Points	References
Potential for Development	- High solar irradiance in equatorial regions and vast hydro resources. - Opportunity to serve off-grid and remote areas. - Supports climate goals, reduces emissions, and creates jobs. - Requires partnerships, tech innovation, and financing strategies.	Anfom et al., (2023); Olkkonen et al., (2023)
Geographic & Climatic Factors	- Equatorial regions ideal for solar due to consistent sunlight. - Availability of rivers and water bodies essential for hydro integration. - System performance affected by irradiance, temperature, humidity, and precipitation. - Site selection and resilience planning critical to mitigate risks from extreme weather and hydrological variability.	Gür, (2018); Lima et al., (2024)
Economic Viability	- Hybrid systems provide improved efficiency and capacity utilization. - Initial costs higher but offset by long-term returns. - Revenue from energy sales, savings, and environmental benefits. - Financing through PPPs, concessional loans, carbon credits, and development banks. - Scalability influenced by resource availability, grid access, and market demand.	Mukhtar et al., (2023); Thango & Obokoh, (2024)
Policy & Regulatory Framework	- Supportive policies include feed-in tariffs, tax incentives, and deployment targets. - AREI and SE4ALL foster regional collaboration. - Recommendations: streamline permits, improve tariffs, support grid integration, invest in skills, and ensure community benefit-sharing. - Effective policies enable private investment and accelerate project rollouts.	Dhir Anubha Gautam, (2024); Handayani et al., (2019); Nyoni et al., (2021)
Technological Advances	- **FPV**: Innovations include bifacial panels, anti-soiling coatings, and improved floating structures. - **Hydro**: Advances in variable-speed and eco-friendly turbines. - Opportunities: integrated system design, energy storage (batteries, pumped hydro), hybridization with other renewables (e.g., wind), and remote monitoring using IoT and AI.	Huebner,(2025); M.V. & Philip, (2022); Teixeira et al., (2015)
Community Engagement	- Enhances local ownership, trust, and project acceptance. - Enables culturally appropriate planning and addresses local needs. - Fosters a social license to operate, reducing conflicts. - Ensures benefits are shared through jobs, training, and revenue participation. - Critical in indigenous and culturally sensitive areas.	Dada & Popoola, (2023); Obada et al.,(2024)

6.0 Conclusion

In conclusion, the analysis of hybrid Floating Photovoltaic (FPV) and Hydro energy resources in Africa reveals a compelling opportunity to address energy challenges while fostering sustainable development. With abundant solar irradiance and vast hydroelectric potential across the continent, hybrid FPV-hydro systems offer a versatile solution for optimizing energy generation, enhancing energy access, and reducing greenhouse gas emissions. However, realizing the full potential of these systems requires concerted efforts to overcome challenges such as financing constraints, regulatory barriers, and socio-cultural considerations. Moving forward, the future development of hybrid FPV-hydro energy resources in Africa hinges on supportive policies, community engagement, and technological innovation. Governments must strengthen policy frameworks, streamline regulations, and mobilize investment to accelerate the deployment of hybrid systems. Meaningful engagement with local communities, indigenous groups, and other stakeholders is essential for securing social license, building trust, and maximizing socio-economic benefits. Additionally, continued innovation in FPV, hydro, and energy storage technologies, supported by collaboration between industry stakeholders and research institutions, will drive advancements in hybrid FPV-hydro systems and pave the way for a cleaner, more sustainable energy future in Africa.

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