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Small Hydropower (SHP) Development in Nigeria: An Assessment, Challenges, And Opportunities

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ABSTRACT: *This research paper presents an in-depth assessment of small hydropower (SHP) development in Nigeria, analyzing its challenges, opportunities, and implications for the country's energy landscape. With its vast water resources and growing energy demand, Nigeria stands poised to harness the potential of SHP as a clean and sustainable energy source. The paper explores the multifaceted dimensions of SHP development, encompassing technical feasibility, regulatory frameworks, environmental impact assessments, socio-economic benefits, and community engagement. Through a comprehensive analysis, the study identifies barriers such as technical complexities, regulatory ambiguities, environmental concerns, financial constraints, and the imperative of community involvement.The significance of SHP in Nigeria's energy mix is underscored by its potential to enhance energy security, reduce greenhouse gas emissions, and stimulate rural electrification. However, realizing these potential demands strategic recommendations. Strengthening the regulatory framework, embracing technological innovations, implementing environmental mitigation measures, fostering innovative financial mechanisms, and investing in capacity building emerge as key strategies. The research reveals the importance of collaboration among governmental bodies, private sector stakeholders, research institutions, local communities, and international partners. This collective effort is crucial to overcoming challenges and capitalizing on the opportunities presented by SHP development. The paper concludes by emphasizing the transformative impact that well-planned SHP projects can have on Nigeria's energy sustainability, economic growth, and environmental responsibility.*

KEYWORD: small hydropower, Nigeria, renewable energy, assessment, challenges, opportunities

INTRODUCTION

The research paper explores the development of small hydropower (SHP) in Nigeria, highlighting its potential to enhance energy security, rural electrification, and socio-economic growth (Agwu et al., 2023; Igliński et al., 2022). It highlights technical feasibility, regulatory complexities, environmental impact, and financial constraints. The paper emphasizes the need for innovative investment models, risk-sharing approaches, and capacity-building efforts. It also highlights the importance of collaboration among government bodies, private sector stakeholders, research institutions, local communities, and international partners for a sustainable energy future (Ali et al., 2023; Boroomandnia et al. 2023; Klein et al., 2023).

The World Small Hydropower Development Report (WSHPDR) estimates that the global installed solar power (SHP) capacity for plants up to 10 MW is at 78 GW (Shakirova, 2022), a 10% increase from data from the WSHPDR 2013 and 4.7% since the WSHPDR 2016. Since the WSHPDR 2013, SHP potential has increased by 30%. Asia and Europe have reported the greatest increase in installed SHP capacity, with 5.2% each (Paish, 2002). The Americas experienced a slight decrease due to updated information, while Oceania experienced a decrease due to updates and natural catastrophes. Africa experienced only a 1.5% increase. SHP represents 1.5% of the world's total electricity installed capacity, 4.5% of the total renewable energy capacity, and 7.5% of the total hydropower capacity (Ukoba, Inambao, & Njiru, 2018). Asia continues to have the largest installed capacity and potential for SHP up to 10 MW. China dominates the global SHP landscape, with 54% of the world's total installed capacity and 28% of the world's total SHP potential (Infield and Freris, 2020; Chemengich and Masara, 2022; Odunfa, 2022).

Renewable energy has a role to play for development of Africa including Nigeria (Ukoba et al., 2023). Nigeria is focusing on renewable energy (RE) sources for electrification, aiming to create a conducive environment for independent power producers to invest in RE-based power plants. This aligns with the Nigerian Energy Policy, Renewable Electricity Policy, and the Renewable Energy Master Plan and Vision 2020, which aim to generate 6,000 MW of electricity through renewable energy sources by 2020. The government has formulated numerous RE-related policies, including the National Energy Policy, Draft Renewable Energy Electricity Policy, Nigerian Biofuels Policy Incentives, Vision 2020 document, National Climate Change Policy, National Environmental Regulation, EPSRA of 2005, feed-in-tariff for electricity generated from RE sources, and the Renewable Energy Master Plan (REMP) which aims to increase RE contribution to 10% of total energy consumption in Nigeria by 2025 (Al-Shetwi, 2022; Babatunde, 2023; Adeleke, 2023; Gungah, 2023; Dasanayaka, 2020).

Financing is crucial for realizing the federal government's policy on RE, and new investments are needed for research and development activities. The government will provide guarantees and financial frameworks to stimulate the expansion of the renewable energy market, enhancing rates of return and shortening payback periods to attract investors. The NERC has developed FITs for SHP schemes not exceeding 30 MW, as well as all biomass co-generation, solar, and wind-based power plants (Shang, 2023; Shari, 2023; Emodi and Ebele, 2016; Owusu-Manu et al., 2021; Ukoba et al., 2020).

However, the small hydropower (SHP) sector faces several challenges, including inadequate policy and regulatory frameworks, high initial investment costs, insufficient private sector participation, limited access to relevant data, lack of public awareness of RE-based electricity as a viable source, and insufficient skilled labor for developing SHP projects (Aguda, 2019; Ukoba, Eloka-Eboka and Inambao, 2017). Despite several policies and regulatory frameworks in place to promote RE-based electricity, there is no clear pathway for success (Nyarko, 2023; Falchetta, 2022; Bissiri, 2022; Adulugba, 2021). Full private sector participation in all aspects of SHP development, particularly in local turbine fabrication, is crucial for enhancing its development. The diverse geography and topography of Nigeria offer numerous opportunities for SHP projects, offering substantial benefits such as enhanced energy access, rural electrification, reduced carbon emissions, and improved energy security (Yuguda et al., 2023; Löhr, 2022; Kishore, 2021; Shaaban and Petinrin, 2014; Ogechukwu, 2011; Ukoba and Inambao, 2018).

SMALL HYDROPOWER

Definition, history, classifications/types, global capacity

Small hydropower (SHP) is a renewable energy source that utilizes flowing water's kinetic energy to generate electricity (Muteba et al., 2023). It capitalizes on the natural movement of water within rivers, streams, and other water bodies to drive turbines, converting hydraulic energy into clean and sustainable electricity (Ptak et al., 2022). SHP projects harness the kinetic energy of flowing water, converting mechanical energy into rotational energy, which drives electrical generators and producing electricity. SHP projects are characterized by their lower installed capacity, generating electricity within the range of several kilowatts to a few megawatts, making them ideal for diverse applications such as decentralized energy production, rural electrification, and community-level power generation. SHP's potential to empower communities, enhance environmental stewardship, and foster economic growth is both promising and pivotal in addressing climate change and ensuring energy security (Oliver 2002; Shamsuddeen et al., 2023; Bredenson, 2023).

Small Hydropower (SHP) has a rich history dating back to ancient civilizations, where water wheels were used for mechanical tasks. The concept gained renaissance during the 1970s global energy crisis, as the world sought alternative energy sources (Figure1).

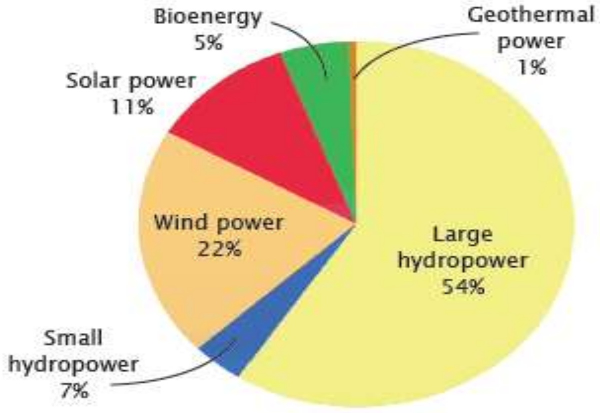

Figure 1: Global share of renewable energy (Shrestha and Shrestha, 2016)

SHP's environmental importance was fueled by concerns about environmental degradation and the finite nature of fossil fuels. Technological advancements since the 1970s have significantly bolstered SHP's capabilities, with improved turbine designs, more efficient generators, and enhanced control systems (Ukaogo et al., 2020; Singh, 2015; Holechek, 2022). SHP's global proliferation has led to countries like China, India, Brazil, and numerous European nations embracing it as a sustainable energy solution. Figure 2 shows the Global energy investment in clean energy and in fossil fuels.

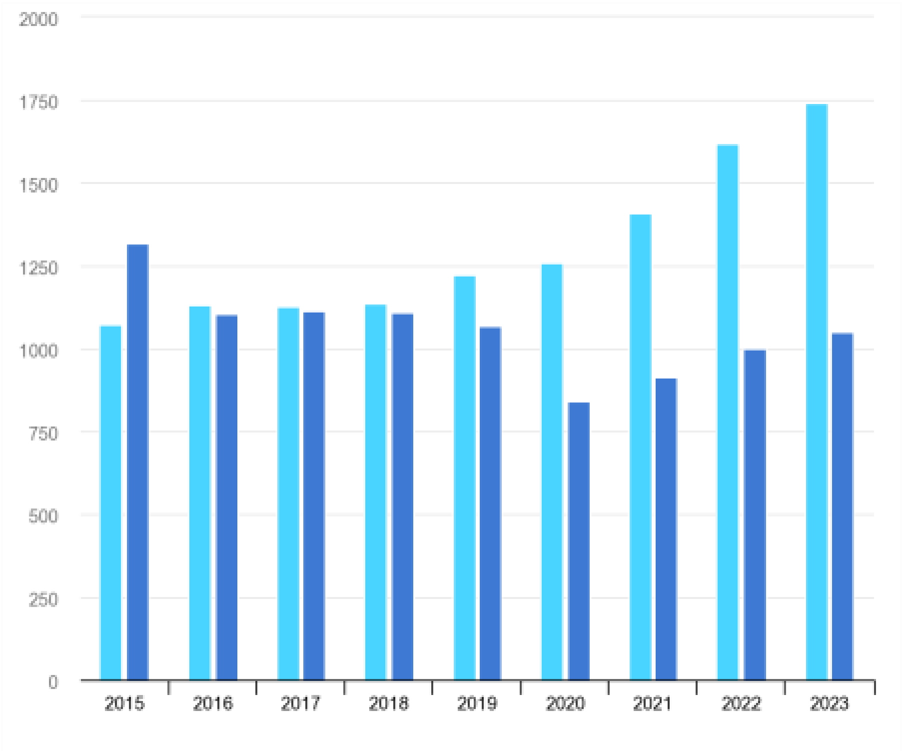

Figure 2: Global energy consumption

Source: *IEA, Global energy investment in clean energy and in fossil fuels, 2015-2023, IEA, Paris*

The growing focus on sustainability and climate change has further emphasized SHP's role as a reliable and eco-friendly option for power generation (Kuriqi and Jurasz,2022; Prasad, 2021; Im, 2022). As technological advancements continue to shape the sector, SHP will play a crucial role in shaping a sustainable and resilient energy future for generations to come.

Small Hydropower (SHP) is a diverse and adaptable renewable energy source that caters to various energy needs, water resources, and environmental considerations (Kothari, 2021; Yin, 2022; Saha, 2022; Olatunde, 2020). It offers clean and reliable electricity across various contexts, including micro, mini, pico, run-of-river, storage, and hybrid hydropower. Micro hydropower projects produce up to 100 kW of electricity, making them suitable for individual households, small rural communities, and micro-enterprises. Mini hydropower projects generate between 100 kW and 1 MW of electricity, making them suitable for powering small industries, agricultural operations, and localized grids (Shabeer, 2020). Pico hydropower projects have an installed capacity below 10 kW, catering to individual households, small-scale agricultural activities, and remote locations. Run-of-river hydropower projects utilize the natural flow of rivers and streams, minimizing their environmental footprint. Storage hydropower projects use dams to store water, allowing for controlled electricity generation. Hybrid hydropower systems combine SHP's strengths with other renewable energy sources, ensuring continuous electricity generation and addressing variability in energy generation. SHP's versatility and applicability make it a cornerstone of clean and reliable energy generation worldwide (Abdelhafeez and Ramakrishna, 2021).

Small hydropower (SHP) is a significant contributor to the global renewable energy landscape, with an installed capacity exceeding 100 GW. SHP exemplifies the harmonious coexistence of technology and environmental stewardship, with nations like China, India, Brazil, and the United States demonstrating its diverse impact across different energy landscapes (Figure 3).

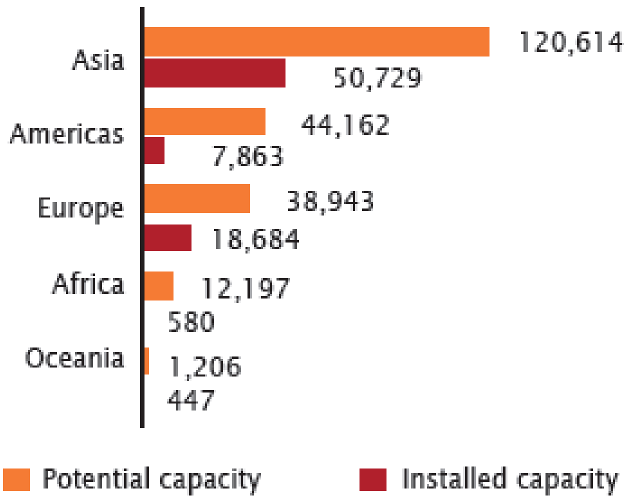

Figure 3. SHP by region (Shrestha and Shrestha, 2016)

With its extensive river networks, China's robust infrastructure, India's focus on energy access and sustainable growth (Lixiao, 2021; Kaygusuz, 2018; Harlan, 2018), Brazil's rich waterways, and the United States' gaining traction, SHP projects offer a diverse range of sustainable energy solutions. SHP's versatility extends to both grid-connected and off-grid applications, enhancing the quality of life and fostering economic growth. As countries transition away from fossil fuels, SHP plays a pivotal role in the global energy discourse, demonstrating the diverse impact of technology and environmental stewardship (Gielen et al., 2019, Dursun, 2011; Couto and Olden,2018; Shiji, 2021).

Challenges of Small Hydropower Worldwide

Small hydropower (SHP) faces numerous challenges worldwide, including technical complexities, environmental impact, land use and resettlement, regulatory and permitting challenges, financial and investment constraints, skilled workforce shortages, community engagement and acceptance, grid integration and infrastructure challenges, and global variability and contextual challenges (Kelly-Richards, 2017; Ali et al., 2023; Engen et al., 2023; Xiao et al., 2023). These challenges span geographical, technical, regulatory, environmental, and socio-economic dimensions. SHP projects face technical complexities due to unpredictable water resources, requiring careful design and innovative solutions. Environmental impact assessments and habitat restoration measures are crucial to minimize ecological disruptions and maintain aquatic ecosystems' health. Land use and resettlement are also significant challenges, with land acquisition often causing displacement of local communities and disruption of livelihoods. Securing adequate funding and reducing financial risks is essential for project viability (Vargas, 2022; Ali, 2023). A skilled workforce is essential for project success, and engaging with communities and fostering local ownership is crucial for long-term project success. Connecting SHP projects to existing electricity grids can be challenging, especially in remote areas. Global variability and contextual challenges require customized solutions that consider local realities. By addressing these challenges strategically, the global SHP sector can unlock its full potential as a sustainable and reliable energy source (Ebhota, 2019; Yadav, 2023; Hagelin 2023; Kumar et al., 2023).

2.1 State of Affair of SHP in Nigeria

The world continues to use small hydropower to meet their energy needs. Every country has their classifications and value used in defining small hydropower (SHP) as shown in table 1.

Table 1: SHP definition and classification in some selected countries and organizations (Sunday and Collins, 2018)

Country / Organization	Micro (kW)	Mini (kW)	Small (kW)
Canada		<1000	1001-1500
China	<100	101-500	501-25,000
ESHA	-	-	<15,000
France	<500	501-2000	-
IN-SHP	<100	101-500	501-10,000
India	<100	<2000	-
Japan	-	-	<10,000
Philippines	-	51-500	<15,000
New Zealand	-	<10,000	<50,000
Nigeria	≤500	501-1000	1001-10,000

Sweden	-	-	101-15,000
UNIDO	<100	101-2000	2001-10,000
United Kingdom	<1000	-	-
USA	<500	501-2000	<15,000
Zimbabwe	5-500	501-5000	-

Africa's 2022-37 hydropower project pipeline stands at 60.8 gigawatts (GW), nearly double its current installed capacity of 34.3 GW, with projects listed in Ethiopia, DR Congo, Nigeria, Mozambique, Zambia, Tanzania, South Sudan, Angola, Cameroon, Uganda and Guinea, according to a new report from the International Renewable Energy Agency (IRENA). The table 2 shows the SHP in Africa

Table 2: SHP in Africa (list of SHP capacity in Africa)

Country	Subregion	Installed Capacity (MW)
Egypt	North Africa	2,810
Dem. Rep. of Congo	Central Africa	2,440
Mozambique	Southern Africa	2,180
Nigeria	West Africa	1,938
Zambia	Southern Africa	1,634
Morroco	North Africa	1,205
Ghana	West Africa	1,072
Total		**13,279**

The installed capacity of Small Hydropower (SHP) up to 10 MW in Western Africa is 44 MW (Punys et al., 2023; Ayik et al., 2023; Taele et al., 2012), accounting for 0.8% of the total installed hydropower capacity of the region and 7% of the estimated potential up to 10 MW. However, the region's installed capacity increased by 25% compared to the WSHPDR 2016. The ECOWAS data shows that in 2017, the installed capacity of SHP up to 30 MW in nine countries stood at approximately 194 MW. The region's SHP potential is estimated to exceed 2,000 MW, with almost 5% developed so far. Most rural communities in Western Africa still lack access to electricity. The ECOWAS white paper stipulates that up to 20% of new generation additions in rural and semi-urban areas should come from renewable energy sources. The ECOWAS Renewable Energy Policy aims to increase the share of decentralized rural renewable electricity services to 22% by 2020 and 25% by 2030. However, most ECOWAS member states still face difficulties in implementing these requirements (UNIDO, 2019).

There are about Ten power stations in Nigeria which are part of Nigeria's Nigerian National Integrated Power Project (NIPP) as shown in Table 3. The NIPP was developed in 2004 under the Olusegun Obasanjo presidency. The limited liability firm Niger Delta Power Holding firm Limited (NDPHC) was established as the official holding entity for the NIPP assets in 2004. The Federation Account and the Excess Crude Account are used to fund these power plants, which are managed by the NDPHC. They are listed in Table 3.

Table 3: Licensed independent Power Plants in Nigeria as of August 2023

S/N	NAME	CAPACITY	YEAR	TYPE	LOCATION
1	**Olorunsogo Power Plant**	754MW (ISO) and 676MW (Net)	2015	**Combined cycle gas turbine plant**	**Olorunsogo, Ogun State**
2	**Geregu II Power Plant**	506.1 MW (ISO) and 434MW (Net)	2017	Open-cycle gas turbine power plant	Ajaokuta, Kogi State
3	**Gbarain Power Plant**	253.8 MW (ISO) and 225MW (Net)	2017	Open cycle gas turbine power plant	Near Yenagoa, Bayelsa State
4	**Ihovbor Power Plant**	507.6 MW (ISO) and 451MW (Net)	2013	Open-cycle gas turbine power plant	Benin City, Edo State
5	**Alaoji Power Plant**	Gas Turbine: 4 x 126MW (ISO) and Steam Turbine: 2 x 286MW	2015	Open-cycle gas turbine power plant (powered by waste heat and natural gas)	Near Aba, Abia State
6	**Omoku Power Plant**	264.7MW (ISO) and 225MW (Net)	2006	Gas-fired power plant	Near Port Harcourt, Rivers State
7	**Egbema Power Plant**	380.7MW (ISO) and 338MW (Net)	2017	open-cycle gas turbine power plant	Near Owerri, Imo State
8	**Sapele Power Plant**	507.6 MW (ISO) and 451MW (Net)	2011	open-cycle gas turbine power plant	Sapele, Delta State
9	**Omotosho Power Plant**	512.8 MW (ISO) and 451MW (Net)	2006	open cycle gas turbine power plant	Okitipupa, Ondo State
10	**Calabar Power Plant**	634.5 MW (ISO) and 562MW (Net)	2015	open-cycle gas turbine power plant	Calabar, Cross River State

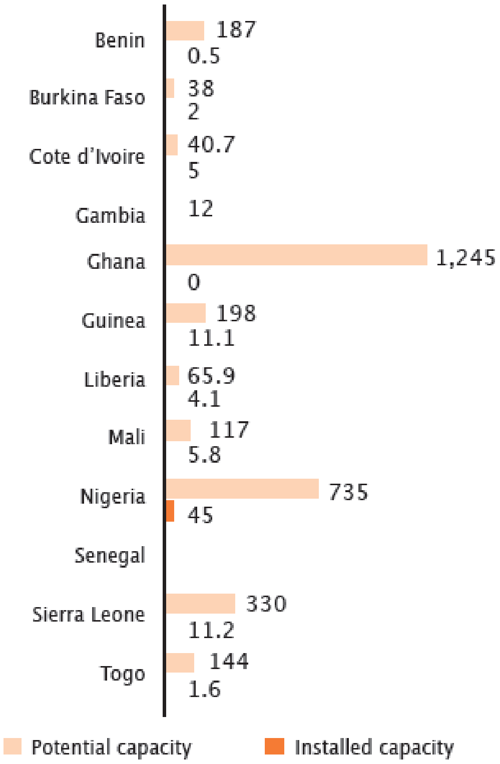

Figure 4: SHP capacities in west Africa (Shrestha and Shrestha, 2016)

Nigeria has an estimated theoretical SHP potential of 3,500 MW, with only 2% developed. However, the country has an economic SHP potential of 735 MW, with 9% developed. The United Nations Industrial Development Organization (UNIDO) has focused on raising awareness about the country's SHP potential. In 2002, the Energy Commission of Nigeria (ECN) collaborated with UNIDO and other government parastatals to organize a national stakeholder forum on renewable energy technologies for rural industrialization. The ECOWAS Centre for Renewable Energy and Energy Efficiency (ECREEE) has also developed the ECOWAS Small Scale Hydropower Program for the West Africa Region. Approximately 64.2 MW of SHP has been developed so far. The Renewable Energy Master Plan launched in 2005 aims to increase renewable energy contribution to 10% of Nigeria's total energy consumption by 2025. The EPSRA allows individuals to construct, own, or operate an off-grid power plant not exceeding 1 MW in aggregate at a site without a license, encouraging private sector participation in small, mini, and micro hydropower for rural development and off-grid generation.

Also, The National Agency for Science and Engineering Infrastructure (NASENI) has received technology transfer assistance from UNIDO for the production of small hydropower (SHP) turbines with a maximum capacity of 125 kW. Upscaling local turbine and control system production to 300 kW capacity has been envisaged under the same GEF-5 cycle (UNIDO, 2019). Table 4 shows the existing SHP in Nigeria with Ogun state having about 9 MW installed capacity.

Table 4: Existing SHP in Nigeria (Ugwu *et al*., 2022)

State	River	Capacity installed (MW)
Kano	Tiga	6
Ogun	Oyan	9
Plateau	Bage I & Bage II	3
Plateau	Kura	8
Plateau	Lere I & Lere II	8
Sokoto	Bakalor	3

Total Installed Capacity = 37.0MW

Nigeria faces significant energy challenges due to its growing economy and population. The nation has historically relied heavily on fossil fuels, particularly oil and natural gas, for electricity generation, which has exposed Nigeria to energy insecurity, price volatility, and environmental degradation. Despite being a major oil producer, Nigeria faces significant energy challenges, including frequent power outages and inadequate electricity access (Nwanze and Morales, 2020). Small hydropower (SHP) presents a promising solution to address Nigeria's energy challenges by harnessing the kinetic and potential energy of flowing water in rivers and streams to generate electricity. Nigeria's diverse topography presents a ripe environment for SHP development, as it is typically smaller in scale and can be designed to minimize adverse effects.

SHP offers a renewable and reliable energy source that can contribute to a more diverse and resilient energy mix. It also offers a relatively lower environmental footprint compared to fossil fuel-based power generation, aligning with Nigeria's commitment to global climate goals.SHP projects can stimulate local economies by creating job opportunities and supporting local industries. Decentralized SHP installations can enhance energy access in remote and underserved areas. SHP's inherent stability, driven by water flow, contributes to grid stability and reduces energy supply uncertainties. Nigeria’s commitment to the United Nations Sustainable Development Goals (SDGs) calls for measures to ensure affordable and clean energy while fostering economic growth and protecting the environment. Additionally, Nigeria's participation in international agreements like the Paris Agreement underscores the need to transition towards cleaner energy sources to curb climate change impacts (Nwozor, 2021). The growth of SHP is faced with technical, regulatory, environmental, social, and financial challenges that hinder the widespread adoption of SHP projects in Nigeria. These challenges span multiple dimensions, including technical, regulatory, environmental, social, and financial. Identifying and analyzing these challenges is crucial for formulating effective strategies to overcome these barriers.

The small hydropower (SHP) sector in Nigeria contributes modestly to the nation's overall energy generation capacity, with an installed capacity of approximately 37.0 megawatts (MW). However, regional disparities in SHP capacity distribution reflect the country's diverse geographical and hydrological characteristics. Regions with consistent water flow and elevation differences, such as the Niger-Benue basin, attract a larger share of SHP investments, emphasizing the need for targeted development strategies that account for regional variations (Ugwu *et al*., 2022).

SHP projects in Nigeria include operational, under-construction, and planned projects. Operational projects have successfully undergone commissioning and contribute to the energy grid, serving as valuable benchmarks for assessing technical, regulatory, and socio-economic aspects of SHP development. However, the project implementation landscape is marked by diverse challenges, leading to variations in project statuses. Some projects encounter delays due to technical complexities, environmental concerns, regulatory bottlenecks, or financial limitations, which can result in project stagnation and impact the overall growth trajectory of SHP capacity. Understanding the implementation status of SHP projects is critical for assessing the sector's progress and identifying bottlenecks that hinder growth (Ismaila, 2022).

In conclusion, the assessment of Nigeria's small hydropower sector highlights its potential and challenges. By addressing these challenges and leveraging best practices, Nigeria can harness its considerable small hydropower potential to contribute significantly to the national energy mix (Ebhota and Tabakov, 2018).

Challenges of Small Hydropower in Nigeria

Small hydropower (SHP) development in Nigeria faces numerous challenges that hinder its growth and widespread adoption. These challenges encompass technical, regulatory, environmental, socio-economic, and financial aspects, all of which must be addressed to fully unlock the potential of SHP as a renewable energy source.

However, technical challenges include site suitability, grid integration, turbine technology, regulatory and policy challenges, environmental and social challenges, financial and investment challenges, and access to finance. Site suitability involves carefully evaluating factors such as water flow, head height, and environmental considerations to ensure optimal energy generation while minimizing ecological impact. Limited and outdated data on water resources pose challenges to accurate site selection. Grid integration is complex, especially in remote or underserved areas, and requires significant investments and technical expertise (Igweonu and Joshua, 2012).Turbine technology is crucial for optimizing energy extraction while accommodating site-specific conditions. Access to advanced turbine designs, particularly those optimized for low-flow conditions, is essential for improving project efficiency.

Regulatory and policy challenges include licensing and permitting processes, inconsistent policies, tariff structures, environmental and social impacts, community concerns, cultural heritage, and financial and investment challenges (Atoyebiand Isaac, 2020). The technical challenges in small hydropower development in Nigeria reflect the complex interplay of hydrological, engineering, and grid integration factors. Collaboration among hydrologists, engineers, researchers, and policy-makers is essential for addressing these challenges and building a robust and reliable small hydropower sector that aligns with the country's energy transition goals. Innovative solutions that balance technical feasibility, environmental sustainability, and socio-economic considerations are pivotal for realizing the full potential of SHP as a clean and renewable energy source in Nigeria.

Additionally, financial and investment challenges such as high initial costs, limited access to financing options, project bankability, and access to finance. High initial costs require significant upfront investment, while project bankability requires reliable revenue streams and revenue collection mechanisms. Access to finance poses a barrier to project implementation, particularly for small hydropower. In order to overcome these challenges, a comprehensive and collaborative approach involving stakeholders from government, industry, communities, and international partners is necessary.

More so, regulatory and policy landscape significantly impacts the development and growth of small hydropower (SHP) projects in Nigeria. A coherent and supportive regulatory framework is essential for attracting investments, ensuring environmental compliance, and fostering sustainable energy development. However, several challenges persist that hinder the optimal realization of SHP's potential. Licensing and permitting complexity is a significant challenge for SHP developers, as the involvement of multiple regulatory agencies leads to delays and increased transaction costs. Streamlining these processes to create a unified, transparent, and efficient regulatory pathway is crucial for expediting project development. Inconsistent policies and regulations create uncertainty for potential investors and project developers, deterring long-term investments. Establishing a stable policy environment that provides predictability and consistency is essential for attracting private sector participation and unlocking the potential of SHP (Idiaghe, 2018; Imoisili et al., 2012).

Access to land and rights of way for SHP projects can be challenging, particularly in regions with competing land uses or cultural significance. Addressing land tenure issues, clarifying land ownership, and streamlining land acquisition processes are vital steps in reducing project delays and conflicts (Umar, 2022; Ibegbulam et al., 2011). Tariff design and pricing mechanisms are crucial for ensuring that SHP projects are developed responsibly. Environmental compliance and impact assessment (EIA) requirements are critical for ensuring that SHP projects are developed responsibly.

SHP projects, while considered more environmentally friendly than fossil fuel-based alternatives, can still have ecological consequences. Mitigating these impacts requires the adoption of fish-friendly turbine designs, habitat restoration, and adherence to environmental impact assessment (EIA) recommendations. Many aquatic species rely on river systems for migration and reproduction, and SHP projects can disrupt these natural patterns by obstructing fish migration routes. Incorporating innovative designs, such as fish ladders, can help maintain river connectivity and support aquatic biodiversity.

Community engagement and benefit sharing are crucial for securing local support and minimizing social conflicts. Balancing the need for energy development with the preservation of local livelihoods and cultural heritage is a challenge that requires careful planning, transparent negotiations, and equitable compensation for affected parties. Water Resource Management:

Environmental and social challenges are integral considerations in small hydropower development in Nigeria. Recognizing the potential ecological disruptions and community concerns associated with SHP projects is crucial for their sustainable implementation. By integrating best practices such as fish-friendly turbine designs, comprehensive EIAs, transparent community engagement, and adaptive water management strategies, high initial capital costs, project bankability and revenue uncertainty, limited access to finance and investment incentives, regulatory and policy risks, local currency financing, and infrastructure and grid connectivity challenges are significant barriers. To overcome these challenges, innovative financing models, clear revenue structures, risk mitigation strategies, and a stable policy environment are crucial components of an attractive investment landscape. By fostering an environment that supports private sector participation, facilitates access to finance, and provides clarity in regulatory frameworks, Nigeria can unlock the potential of SHP as a sustainable energy source while attracting the necessary investments for its realization. Collaboration among financial institutions, policy-makers, investors, and project developers is essential to create a conducive environment for sustainable SHP growth (Adelaja, 2022).

Nigeria's Policy and Masterplan towards SHP

Hydroelectric power (HEP) is a significant renewable energy source, producing about a quarter of the world's electricity and providing power to over one billion people. It is the most common form of renewable energy and plays a significant role in global energy production. In 2011, the global generation of electricity from hydropower was 3,402.3 TWh, accounting for 17% of total global energy production. Nigeria has three main hydropower plants, Kainji, Jebba, and Shiroro, with installed capacities of 760 MW, 560 MW, and 600 MW respectively, contributing 35.6% to the National Grid. However, the installed capacity of these plants has remained stagnant due to lack of proper maintenance and seasonal fluctuations in water flow. Hydropower has the most potential for development in rural areas of Nigeria due to its abundance and technology. Table 5 shows the SHP scheme in Nigeria.

Table 5: Small hydro scheme in existence in Nigeria (Aribisala, 2011)

S/N	RIVER	LOCATION	INSTALLED CAPACITY (MW)
1	River Bagel (I and II)	Plateau	1.0; 2.0
2	River Kurra	Plateau	8.0
3	River Lere (I and II)	Plateau	4.0; 4.0
4	River Bakalori	Zamfara	3.0
5	River Oyan	Ogun	9.0

Nigeria has significant hydro potential, with large rivers, small rivers, and streams distributed throughout the country. The country has potential sites for hydropower schemes serving urban, rural, and isolated communities. The Kaduna, Benue, and Cross Rivers have a total capacity of about 4,650 MW, while the Mambillla plateau has an estimated capacity of 2,330 MW. A large number of untapped hydropower potential of about 12,190 MW has been identified in various locations across the country. The federal government of Nigeria signed a $1.293bn contract with a Chinese company for the development of a Zungeru power plant, aiming to generate about 700 MW. Small hydropower (SHP) has been in existence in Nigeria since 1923, but is still at its infancy in Nigeria. If properly deployed, SHP can be the most affordable and accessible option to provide off-grid electricity services, especially in rural communities. However, little attention is given to its significance in Nigeria despite its vast potential and high energy demand. The Federal Government has put in place a framework to explore available potentials for SHP, requiring the efforts of every sector (Akorede et al., 2016).

Nigeria's policy framework and masterplan towards small hydropower (SHP) aims to harness its abundant water resources for clean energy generation. The country's commitment to SHP development is based on its renewable energy policies, which emphasize diversification, energy security, and climate change mitigation. Key policies include the National Renewable Energy and Energy Efficiency Policy (NREEEP), Nigerian Electricity Regulatory Commission (NERC) Regulations, and the Rural Electrification Strategy and Implementation Plan.The masterplan for SHP development includes resource assessments, technical and financial viability, environmental and social impact assessment, regulatory streamlining, capacity building, and investment and financing strategies. These assessments consider factors such as water flow, topography, environmental impacts, and technical feasibility. The masterplan evaluates the optimal capacity, turbine technology, and infrastructure required for each site, ensuring efficient and cost-effective energy generation (Ayangeaor, 2022).

Regulatory streamlining aims to streamline permitting and licensing processes for SHP projects, enhancing investor confidence and expediting project implementation. Capacity building initiatives involve training programs for engineers, technicians, and local communities. Investment and financing strategies include exploring public-private partnerships, accessing international funding, and promoting incentives for renewable energy investments. Nigeria's policy framework and masterplan for SHP demonstrate the country's commitment to harnessing its abundant water resources for clean energy generation. By aligning renewable energy policies with strategic plans, Nigeria can unlock the potential of SHP to drive energy access, economic growth, and environmental sustainability.

Opportunities of SHP in rural and urban development: Growth of industries, improved standard of living

Nigeria's diverse and abundant water resources offer significant opportunities for small hydropower (SHP) development. To fully realize this potential, a systematic assessment of potential sites and available resources is crucial. A comprehensive resource assessment is essential for identifying viable SHP sites, considering factors such as water flow, head height, topography, and sedimentation patterns. Nigeria's river basins, including the Niger, Benue, and Cross River basins, hold untapped hydroelectric potential. By conducting detailed assessments of these basins, the country can identify suitable locations for SHP projects that align with existing hydrological conditions. Off-grid SHP solutions in remote and underserved areas can also contribute to energy access and rural development.

Table 6 summarizes the SHP potentials in Nigeria.

Table 6: Summary of SHP potential in Nigeria (Ugwu *et al*., 2022)

State	River Basin	Sites	Total (MW)
Adamawa	Upper Benue	38	162.7
Bauchi	Upper Benue	20	42.6
Benue	Lowe Benue	19	69.2
Borno	Chad	29	20.8
Kaduna	Niger	19	59.2
Kano	Hadejia-Jamaare	28	46.2
Kastina	Sokoto-River	11	8.0
Kwara	Niger	12	38.8
Niger	Niger	30	117.6
Plateau	Lower Benue	32	110.4
Rivers	Cross River	18	28.1
Sokoto	Sokoto-River	22	30.6
Total		**278**	**734.2**

Therefore, data-driven decision making is crucial for informed decision-making, with historical flow data, climate models, and water availability forecasts providing insights into potential changes in water resources over time. Thorough environmental impact assessments (EIAs) help identify potential disruptions to aquatic ecosystems, fish migration routes, and biodiversity, which inform the design of mitigation measures and the incorporation of fish-friendly turbine technologies. Local engagement and indigenous knowledge are essential for incorporating indigenous knowledge in the resource assessment process, as they often possess valuable insights into river behavior, seasonal variations, and potential risks. This knowledge fosters collaboration, minimizes conflicts, and aligns projects with community needs.

Government support and incentives play a crucial role in driving the growth of small hydropower in Nigeria. A stable and transparent policy framework, competitive pricing mechanisms, streamlined regulatory processes, access to finance and investment incentives, and capacity-building initiatives are essential for attracting investments, reducing risks, and creating an enabling environment for sustainable energy transition (Sani and Sambo, 2019). A collaborative approach involving regulatory bodies, policymakers, energy developers, and financial institutions is essential for creating an enabling environment that capitalizes on the country's SHP potential, contributing to sustainable energy development and economic growth. International collaboration and funding are crucial for unlocking the full potential of small hydropower (SHP) projects in Nigeria. Partnering with international organizations, development banks, and foreign investors can provide access to financial resources, technical expertise, and best practices that accelerate SHP growth. Global partnerships and funding sources, such as the World Bank, African Development Bank, and International Finance Corporation (IFC), can provide concessional loans, grants, and technical assistance that facilitate project development and implementation.

Participating in climate finance mechanisms offers opportunities to attract funding for SHP projects, as aligning SHP projects with climate mitigation goals can tap into funding sources dedicated to reducing greenhouse gas emissions. Registering SHP projects as Clean Development Mechanism (CDM) or Verified Carbon Standard (VCS) initiatives enables the sale of carbon credits, providing additional revenue streams. Technical expertise and knowledge exchange are essential for SHP projects, as international organizations and experts can offer insights into advanced technologies, environmental and social standards, and project management approaches. Attracting foreign direct investment (FDI) is a valuable avenue for funding SHP projects, as it builds investor confidence through transparent regulations, clear policy frameworks, and a stable investment environment.

Project co-financing and risk sharing are also vital for capitalizing on the global resources and knowledge available for sustainable SHP development. Collaborative efforts between government agencies, development banks, private investors, and technical institutions are pivotal for capitalizing on the global resources and knowledge available for sustainable SHP development. Empowering communities for sustainable SHP development is a transformative approach that enhances project sustainability, social acceptance, and economic benefits. Community participation and inclusion are crucial for building trust and securing support, as local communities possess valuable insights into local water resources, seasonal variations, and potential challenges. Equitable benefit sharing and socio-economic impact are keys to ensuring that SHP projects positively impact local communities.

Local capacity building and skills development are a sustainable approach, as training community members in SHP operation, maintenance, and management not only creates job opportunities but also fosters a sense of ownership. Community-based ownership models, where local communities have a stake in the project's ownership or management, enhance sustainability and accountability, aligning project outcomes with community interests, creating incentives for proper operation, maintenance, and long-term success. Conflict resolution and social acceptance are essential for addressing conflicts and concerns during project development. Early engagement and open dialogue ensure that potential disputes are resolved amicably, fostering social acceptance and project continuity.

Respecting cultural heritage, traditional practices, and local customs is essential for building positive relationships with communities and demonstrating a commitment to preserving local identity and values. The community participation and local ownership are cornerstones of sustainable SHP development. By involving communities, sharing benefits, building capacity, and respecting cultural values, SHP projects can transcend being mere infrastructure initiatives and become vehicles for positive social change and local empowerment. Collaborative efforts between project developers, government agencies, and local communities are vital for ensuring that SHP projects contribute not only to Nigeria's energy goals but also to the well-being and development of the communities they serve.

CONCLUSION

Nigeria faces numerous challenges in the development of small hydropower (SHP), including technical, regulatory, environmental, financial, and social dimensions. Technical challenges include variability in water flow and head height, while regulatory complexities involve complex permitting processes, inadequate policy support, environmental concerns, and financial constraints. Environmental concerns involve dams and infrastructure affecting aquatic ecosystems and disrupting river habitats. Financial constraints include high initial investment costs and limited access to suitable financing mechanisms.

To unlock SHP's potential, a holistic approach is necessary, combining technical expertise, policy reform, environmental stewardship, community engagement, and innovative financing models. International collaborations and partnerships can provide a platform for sharing best practices, technical knowledge, and funding resources.

Balancing energy needs and ecology in SHP projects requires rigorous environmental impact assessments (EIAs) and a multifaceted approach to mitigate potential ecological effects, foster community acceptance, and uphold biodiversity. Community engagement and social acceptance are crucial for the success of SHP projects, as they enable them to voice concerns, share insights, and contribute to project design.

Financial and capacity constraints also require strategic solutions, such as innovative investment models, risk-sharing approaches, climate finance initiatives, and capacity development efforts. Building and nurturing local capacity is essential for navigating technical complexities and ensuring project viability.

Small hydropower has the potential to unlock numerous opportunities in Nigeria's energy landscape, including contributing to energy security, enhancing rural electrification, stimulating local economies, supporting climate commitments, and promoting a resilient energy future. Collaboration across various sectors, including government bodies, private sector stakeholders, research institutions, local communities, and international partners, is essential for addressing challenges and seizing opportunities.

In conclusion, the journey towards realizing the potential of SHP in Nigeria is a collective endeavor that transcends individual interests. A collaborative approach weaves diverse strengths into a cohesive tapestry, fostering a resilient energy future that harmonizes national and international goals.

Research implication of the work, Purpose and Novelty: The purpose of the paper is to assess small hydropower development in Nigeria with emphasis on the challenges and opportunities that SHP have in the speedy development of Nigeria. This forms the key contribution to knowledge of the work. The novelty lies in the detailed assessment of the SHP potentials, the challenges such as bureaucracy, policies, and framework. Also, a detailed list of SHP potentials, existing framework are listed in this paper. The justification of the review is owing to the untapped potential of SHP in Nigeria and Africa despite the huge availability of water bodies and good sites needed for setting-up small hydropower.

Future Research Work: Nigeria have a great potential to generate electricity from small hydropower, but policies and cost of fabrication continue to hinder the adoption of small hydropower for industries and small-scale enterprises. Future work in this regard will be to include emerging technologies such as 3D printing for the fabrication of key components such as the rotor and other essentials parts of the SHP. The application of 3D printing will improve the efficiency and reduce the cost of fabricating and maintaining SHP in Nigeria. This will encourage more companies and even communities to adopt and implement SHP for electricity generation.

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