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# Small Scale Hydropower Development and Sustainability: A Review of trends from Ghana

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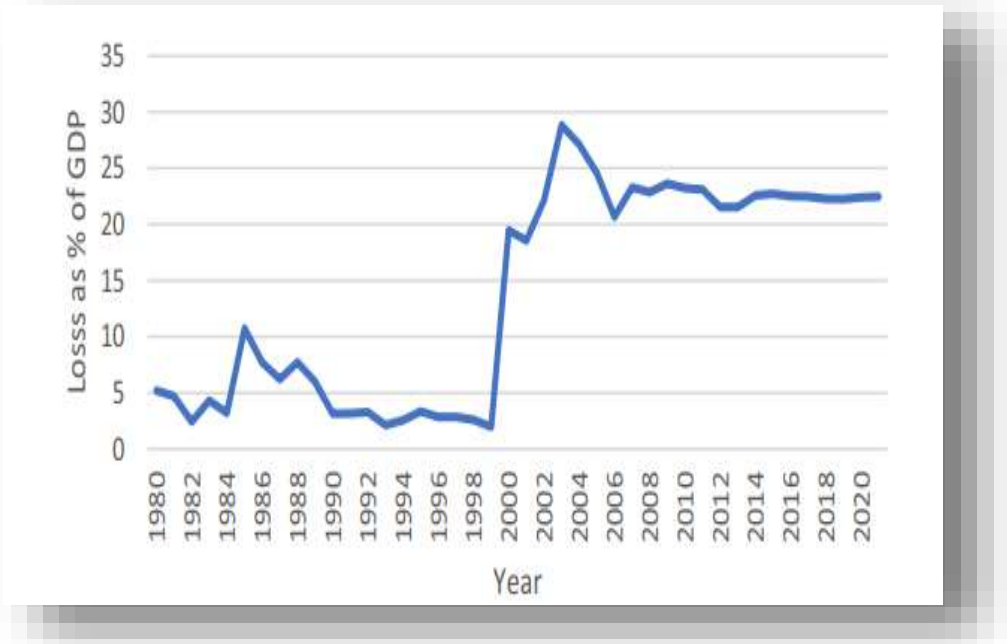
**Abstract:** *Small-scale hydropower (SHP) presents a promising solution for expanding rural electrification and enhancing energy sustainability in Ghana. However, emerging literature highlights growing concerns about the environmental and social dimensions of SHP development. The novelty of this study resides in the fact that it presents updated information on the growth and emerging trends in small hydropower projects within Ghana, highlighting some of the technologies being implemented. Also, the study reviews sustainable practices in the development of these projects, examining their environmental and social impacts. The findings reveal that the widespread assumption of minimal impact constrained efforts to assess cumulative socio-ecological effects of SHP. Moreover, climate variability, deforestation, grid expansion and other technical barriers are reshaping the viability of many proposed sites. This study offers policy recommendations to ensure that SHP can reliably and equitably contribute to Ghana's long-term energy future.*

**Keywords:** small-scale hydropower, sustainable practice, rural electrification, climate variability, impacts, Ghana

## INTRODUCTION

Access to reliable electricity remains critical in Ghana's efforts to improve livelihood in its remote areas. Over the past decades, the government, through initiatives like the National Electrification Scheme (NES), has aimed to spur development in underserved communities (Kemausuor et al., 2011). Despite this effort, over 70% of rural residents remain without electricity, necessitating substantial investment to achieve universal access under the NES goal (Quartey, 2023). Additionally, the country's centralised grid system faces severe limitations, including overloaded substations, frequent gridlocks, and high transmission and distribution losses (Kumi, 2017; Osei-Gyebi & Dramani, 2024; Arthur, J. 2024). According to the World Bank (2019), inefficiencies in Ghana's electricity transmission and distribution systems result in losses equivalent to nearly 25% of GDP (Figure 1). These challenges are particularly pronounced in remote areas, where connecting the national grid is often expensive.

To address these issues, the Ghanaian government has prioritised decentralised solutions to meet its rural energy needs (Gyabaah et al., 2021). As part of its renewable energy plan, the government will implement solar, wind, and small hydropower projects in 1,000 off-grid communities. (Renewable Master Plan, 2019). With an estimated generation potential of 800MW, SHPs are frequently mentioned and actively promoted (Aboagye et al., 2021). Unlike the intermittency of solar and wind, small hydropower stands out for its stability and reliability (Ibegbulam & Olowonubi, 2023; Berga, 2016). Additionally, it promises to be both economically viable and socially and environmentally sustainable compared to large hydropower (Tsuanyo et al., 2023; Yah et al., 2017; Adabor et al., 2023; Zhang et al., 2021).




However, the narrative of SHPs as low-impact alternatives masks inherent challenges that require careful consideration. Some studies urge caution, highlighting that improper planning can transform these projects from assets to liabilities, inciting social conflicts and environmental degradation (Venus et al., 2020).

Figure 1. Trends in electricity transmission and distribution losses in Ghana from 1980 to 2021 (source: World Bank, 2019)

While SHP potential is vast in Ghana, implementation lacks a long-term sustainability perspective (Dernedde et al., 2002). Moreover, concerns have been raised over the country's long-term reliability of hydropower under climate change (Boadi & Owusu, 2019). Therefore, this paper reviews sustainable practices in the development of small hydropower in Ghana. It also identifies implementation gaps and institutional limitations in SHP development, aiming to offer valuable insights into areas for improvement and provide policymakers with a comprehensive reference for decision-making on ensuring a sustainable and reliable energy supply to rural communities.

The study is structured as follows: It begins with an exploration of existing hydropower projects, shedding light on critical sustainability challenges, including socio-economic displacement, environmental impacts, and climate vulnerabilities. It then assesses the current state of SHP implementation, highlighting both its transformative potential and the barriers that hinder its growth. Ultimately, it provides strategic recommendations designed to enhance SHP viability and ensure long-term sustainability within Ghana's energy landscape.

## 1. Background

Ghana's journey with hydropower has long been hailed as a developmental success—powering industries, expanding the national grid, and enabling electricity exports to neighbouring countries. Today, the country's hydropower dams —Akosombo, Kpong, and Bui —collectively contribute approximately 33% to the national grid (ITA, 2023; Eshun & Amoako-Tuffour, 2016). However, behind the perceived national progress lies a pattern of uneven development, marked by social and ecological costs that have been disproportionately borne by downstream communities (Afful-Dadzie et al., 2020).

From the outset, Ghana's hydropower dams imposed significant burdens on local communities. The Akosombo Dam, completed in 1965, submerged 3% of the national landmass and displaced over 80,000 people (Gyau-Boakye, 2001). While resettlement programs were introduced to mitigate impacts, these efforts largely failed to reestablish sustainable livelihoods. Instead, two-thirds of project-affected people experienced deteriorating living conditions (Amoah et al., 2024). For instance, in farming, the colossal struggle for fertile land in newly designated areas marked a shift from sustainable—though largely subsistence-based—livelihood systems to short-term, unsustainable alternatives. Similarly, restrictions on fishing and boat mobility along the Volta Lake eroded income sources, triggering significant outmigration (Miine, 2021; Amoah et al., 2024).

Additionally, the dam's inundation shifted local climate conditions, contributing to increased flood events in surrounding areas (Amoah et al., 2024). The public health consequences were no less important. Water-borne illnesses—previously uncommon in the region—have surged to endemic levels, with infections such as bilharzia and malaria rising from a prevalence of under 5% before the dam to over 75% in the decades after (Darko et al., 2019). Parallel to this, sedimentation within the reservoir has impaired the dam's performance and further complicated its long-term management (Gyau-Boakye, 2001).

Unfortunately, these setbacks are not isolated incidents. Commissioned in 1982 and located just 24 km downstream from the Akosombo Dam, the Kpong Dam also displaced about 6,000 people. The submergence of thousands of hectares of land further exacerbated existing socio-economic vulnerabilities and contributed to increased incidences of bilharzia, roundworm, and hookworm infections (Darko et al., 2019). Similarly, the Bui Dam envisioned as a modern corrective—a flagship project promising innovation and inclusive growth—ultimately fell into the same pattern of unmet expectations. Promises of job creation, regional irrigation, and urban transformation were largely aspirational as implementation faltered (Adjei et al., 2022). Moreover, labour conditions during the dam's construction were poor, community engagement was limited, and capacity building for local workers remained an afterthought (Mortey et al., 2017; Adovor Tsikudo, 2021). It is also reported that about 20% of Bui National Park was submerged, resulting in habitat destruction and the displacement of key species, including hippopotamuses and leopards (Darko et al., 2019). Methane emissions also from decaying biomass have raised critical concerns about the cleanliness of the Bui hydropower system (Adovor Tsikudo, 2021; Kuriakose et al., 2022).

Beyond these, rainfall variability severely impacts water inflows, disrupting the generation capacity of hydropower systems in Ghana (Kabo-Bah et al., 2016; Gocking, 2021; Bekoe &

Logah, 2013; Acquaah, 2021; Kwakwa, 2015; Yira et al., 2021; Adu-Poku, 2024; Prempeh, 2020). Between 1970 and 2010, electricity production at Akosombo declined due to fluctuating rainfall and El Niño-Southern Oscillation (ENSO) events (Boadi & Owusu, 2019) (Figure 2). Bui's energy output has also suffered a 23.2% reduction in production, triggering nationwide power rationing (WASCAL, 2019). As it stands, all three dams —Akosombo, Kpong, and Bui —operate below their full installed capacities of 1,020 MW, 160 MW, and 400 MW, respectively. The current outputs are recorded at 900 MW, 140 MW, and 342 MW (Owusu-Adjapong, 2018). Hence, these outcomes have prompted a reassessment of Ghana's SHP systems to critically evaluate whether this shift genuinely represents a sustainable and just alternative or simply a scaled-down version of the same challenges.

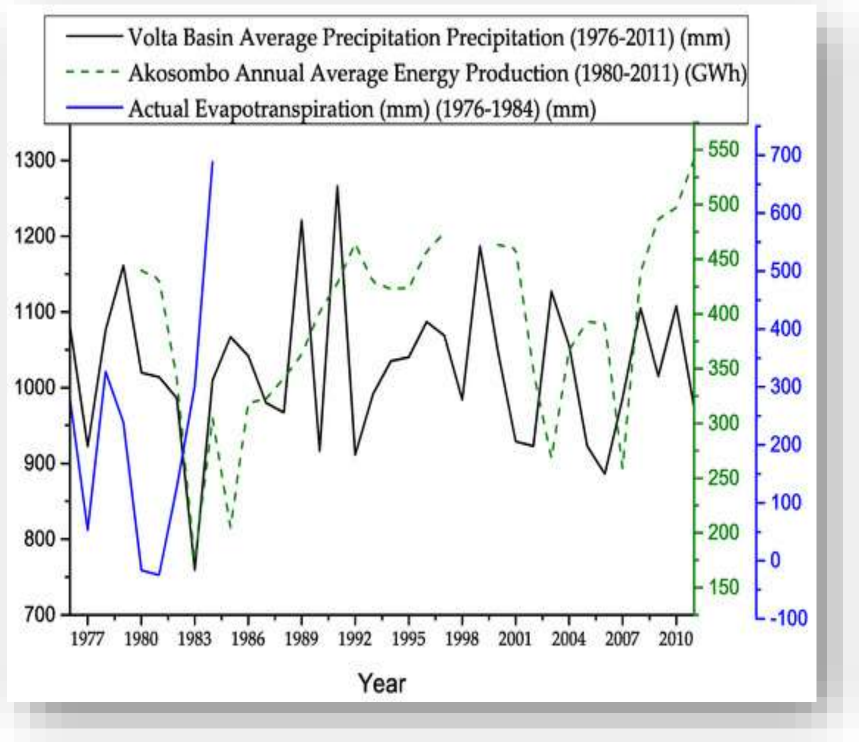



Figure 2. Average precipitation, discharge, water level, and energy production at Akosombo dam (source: Kabo-Bah et al., 2016)

## 2. Methodology

This study takes on a systematic review approach and summarises academic reports, policy papers, stakeholder events, and press articles. The databases used to assess the literature were SCOPUS and Google Scholar search engines. The search process revealed 1120 academic articles through searching for "small hydropower and sustainability," "climate change and hydropower in Ghana," and" Hydropower challenges in Ghana."

The SCOPUS search returned 705 articles. Of these, 61 were found to be relevant based on titles and abstracts, with 13 duplicates and 631 irrelevant articles excluded. Google Scholar returned 419 articles, of which 40 were relevant, with 10 duplicates and 369 articles excluded. After removing duplicates, 101 articles were reviewed in full. From this pool, 39 articles were again removed for not addressing the core themes of the study. A final set of 62 articles was selected for inclusion based on their empirical focus, regional relevance, and contribution to understanding the intersections of small hydropower and sustainability. The results were limited to articles published in English and their relevance to the challenges of small hydropower in Ghana. Notable reviewed studies, such as those by Kelly-Richards et al. (2017) and Manders et al. (2016), provided reviews of SHP development, examining its impacts and policy challenges worldwide. The article by Dernedde et al. (2002) was key to analysing challenges related to small hydropower in Ghana.

In addition to academic sources, relevant reports from governmental and development organisations were also used. These were primarily identified through citation chaining of online publications and official databases. Key sources included Ghana's Energy Commission (2016), the Ghana Renewable Energy Master Plan (Renewable Master Plan, 2019), and the United Nations Industrial Development Organisation (UNIDO, 2022), as well as the International Hydropower Association (IHA, 2022). These documents offered critical insight into national energy planning, regional renewable energy trends, and relevant policy frameworks.

## 3. Findings and Analysis

Increasing the share of sustainable electricity generation to 10% is among Ghana's energy transformation goals (Sakah et al., 2017). However, the current reality reveals a stark contrast. As of 2017, sustainable energy accounted for just 0.6% of the national energy mix, highlighting a substantial gap between policy targets and actual implementation (Mahama et al., 2021; Sakah et al., 2017). This section explores the role of SHP in achieving Ghana's sustainable energy goals and outlines key pathways to accelerate its development.

### 3.1. Role of SHP in Sustainable Energy Transitions

The concept of sustainable energy is rooted in the Brundtland Commission's widely accepted definition of sustainable development: "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Frey & Linke, 2002). In the energy context, sustainability extends beyond the use of renewable sources; it encompasses the social equity of access, the economic effectiveness of projects, and the environmental integrity of ecosystems (Gunnarsdóttir et al., 2021). A sustainable energy system must, therefore, address not just carbon emissions and fuel supply but also broader societal and ecological concerns, such as biodiversity health, livelihoods and community rights (Gürbüz, 2006).

Small hydropower has gained increasing prominence in global energy and climate policy as a supposedly sustainable, low-carbon, and decentralised solution for rural electrification. International institutions, such as the International Hydropower Association (IHA) and the United Nations Industrial Development Organisation (UNIDO), promote SHP as a critical enabler of Sustainable Development Goal 7—ensuring access to affordable, reliable, sustainable, and modern energy for all. The Hydropower Sustainability Assessment Protocol developed by IHA and widely adopted by international financing bodies frames SHP as a "low-impact" alternative to large hydropower, suitable for environmentally sensitive and energy-deficient regions (IHA, 2022). Similarly, the World Small Hydropower Development Report (UNIDO, 2022) highlights SHP's potential to deliver climate mitigation benefits, rural employment, and energy security—particularly in low- and middle-income countries. In academic literature, SHP is broadly defined as an energy technology that embodies the key principles of sustainability. It utilises a non-depleting resource, operates at relatively low carbon intensity, and is cost-effective due to its modest infrastructure requirements (Azimov & Avezova, 2022; Hazmin & Mustapha, 2024; Anfom et al., 2023; Shu J. et al., 2018; Ibegbulam & Olowonubi, 2023).

SHP is recognised as a pivotal element of Ghana's national renewable energy agenda. The Renewable Energy Master Plan (2019) identifies it as critical to achieving rural electrification, reducing transmission losses, and minimising dependence on fossil fuels and wood. Policy discourse frequently frames SHP as a clean, community-oriented technology capable of delivering equitable development benefits. Its installations—especially those intended for off-grid and mini-grid applications—are envisioned as decentralised systems managed by local cooperatives, potentially empowering communities with training, income opportunities, and autonomy over energy use (UNIDO, 2022).

Technically, no universally standardised definition exists. However, it is typically considered capable of producing one megawatt or more and categorised into different generating capacities, such as mini (0.1–1 MW), micro (5–100 kW), and pico (<1 kW) (Kelly-Richards et al., 2017; Ibegbulam & Olowonubi, 2023). In Ghana, however, it is defined more narrowly as installations generating up to one megawatt of electricity.

Since the 1980s, numerous studies have identified potential SHP sites in Ghana (Dernedde et al.,2002). According to a review by Kalitsi (2003), early surveys by the Architectural and Engineering Services Corporation (AESC) and the University of Science and Technology (UST), Kumasi, focusing on rural electrification, identified 16 sites for development. Subsequently, the Ministry of Energy's evaluations in the mid-1990s, along with the German turbine manufacturer Ossberger, identified feasible sites despite funding and implementation challenges (Dernedde et al., 2002). By 2000, the Hydro Department identified approximately 70 potential SHP sites, although questions about technical and economic feasibility remained unresolved (Dernedde et al., 2002). As of 2024, over 30 sites (both small and medium scale, see Figure 3) are listed in the policy documents of the Ghana Energy Commission, reflecting the country's commitment to developing these projects (Renewable Master Plan, 2019).

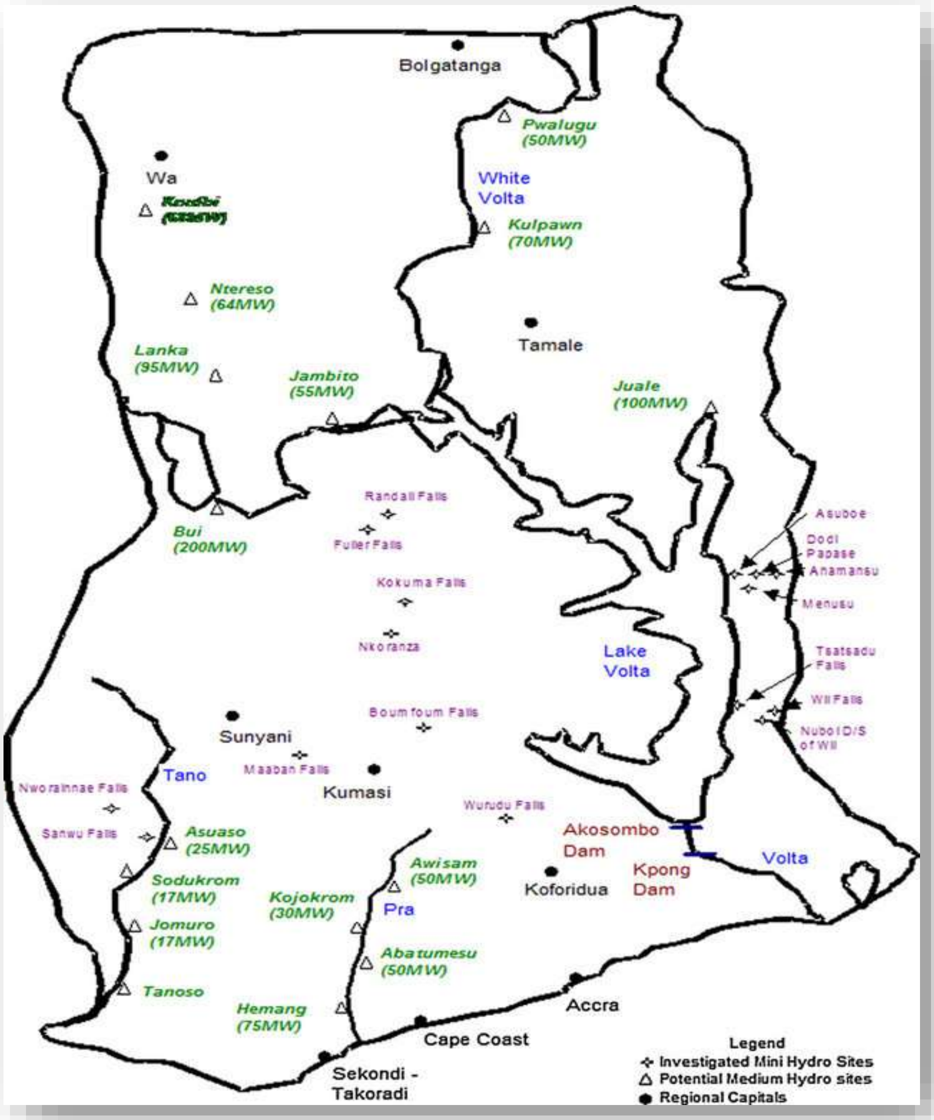



Figure 3. Proposed and existing hydropower plants in Ghana
(source: Kemausuor et al., 2011)

### 3.2. Rethinking the Sustainability Assumptions of SHP

As previously mentioned, Ghana's policy embrace of small hydropower has been both enthusiastic and strategic, framing it as a win-win solution addressing rural electrification needs while signalling alignment with national and international climate goals. This positioning reflects a broader global trend in which SHP is marketed as inherently sustainable. However, the central question that emerges from this optimism is not whether SHP holds potential but whether its development in the country is being grounded in evidence-based sustainability or whether "sustainability" is being treated more as an aspirational narrative than a demonstrated practice.

Indeed, a growing body of scholarly work challenges the oversimplified assumption that SHP is universally clean, green, and sustainable. Kelly-Richards et al. (2017) argue that one of the central issues lies in the definitional looseness of SHP itself. Unlike technologies governed by consistent global standards, SHP is typically defined by shifting criteria that vary by jurisdiction and are influenced by technical thresholds or capacity limits rather than by ecological or social impact assessments. Such flexibility, while politically convenient, creates regulatory grey areas where sustainability is presumed rather than verified. It opens the door for projects to be fast-tracked with minimal oversight, particularly when negative consequences are localised or slow to materialise. Frey and Linke (2002) also contend that such terms "clean," "green," and "sustainable" often function more as rhetorical tools than substantiated outcomes. Particularly in contexts where large dam projects have faced historical criticism, SHP gains legitimacy by default. Its relatively smaller scale lends it an aura of benignity, allowing it to bypass scrutiny even when its impacts may be significant and poorly understood.

In fact, the impacts of SHPs are more complex and highly variable than their benign reputation suggests. Manders et al. (2016) argue that SHP impacts, in some cases, rival or exceed those of large dams on a per-kilowatt basis. Moreover, multiple projects within a single river basin can interact and compound their effects on the environment. For instance, in Turkey, SHP development has found to restrict forest and water access, damage traditional livelihoods, and spark community protests (Baris & Kucukali, 2012). Similarly, Norwegian projects, often cited as models of clean energy, have nonetheless drawn criticism for undermining biodiversity, landscape aesthetics, and recreational uses (Bakken et al., 2012). In addition, case studies of village-scale small hydropower in India reveal that the distribution of benefits is often inequitable, leading to local conflicts and power imbalances that remain largely invisible to regional and national policymakers and scholars (Kumar & Katoch, 2015; Manders et al., 2016).

Unfortunately, these dynamics are not absent in the Ghanaian context. Many projects proceed based on incomplete environmental knowledge, risking unintended consequences for ecosystems and communities. The work of Dernedde et al. (2002), for instance, remains alarmingly relevant: SHP sites identified decades ago continue to feature in official planning despite dramatic shifts in Ghana's climatic and ecological conditions. Yet, there is little indication that these sites have been meaningfully reevaluated. Unfortunately, this inertia reflects deeper structural tendencies within Ghana's energy governance. As Mortey et al. (2017) have shown, hydropower development in the country has historically prioritised technical and economic metrics, while social and ecological considerations are relegated to secondary status (Figure 4). SHP, under the guise of sustainability, seems to be following a similar path, undermining the very values it purports to champion. For example, during the development of the Tsatsadu Generating Station (TGS), the Bui Power Authority (BPA) stated that the project had no adverse environmental impacts (Zhang, J et al. 2018). However, no independent monitoring mechanisms or cumulative watershed assessments were instituted to substantiate this claim. Instead, it epitomises how the "green" reputation of SHP is used rhetorically to justify minimal review. Moreover, unresolved concerns, such as the potential impact of the TGS on a nearby pilgrimage site and the degree of community consultation, raise questions about whose interests are being served and who gets excluded from the process.

Essentially, this abstract sustainability claims only allow the state to promote SHP as evidence of climate action while sidestepping the contentious debates that typically surround large dam projects. The political insulation, however, comes at a cost. Many of the SHP sites identified in national planning documents face severe technical, ecological, and social limitations that cast doubt on their viability.

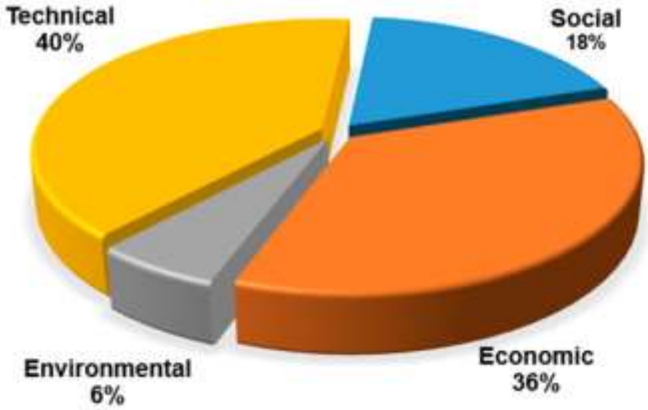



Figure 4. Decision-making priorities for the Bui Dam. (source: Mortey et al., 2017)

### 3.3. The Limitations of SHP in Ghana

Small hydropower is frequently promoted not only as a clean energy solution but also as a catalyst for broader environmental co-benefits, including watershed rehabilitation and reforestation in Ghana. However, in practice, these critical ecosystems are increasingly under pressure. As Afele et al. (2022) note, riparian degradation across Ghana is accelerating, undermining the very ecological conditions that SHP systems depend on. Alarmingly, several SHP project sites earmarked for development—particularly in the Ashanti, Western, and Brong Ahafo regions—have experienced active deforestation rather than the restoration often anticipated in project narratives. Dernedde et al. (2002) observed that nearly half of the river basins identified have already been negatively impacted, leading to flow disruptions, sedimentation, and reduced water reliability (Figure 6). Additionally, reduced rainfall patterns and increasing temperature variability are contributing to less water availability and less predictable hydrological regimes. For example, data from the Boumfoum and Nkoranza sites indicate that streamflow is only available for two to four months annually, significantly constraining the workability of future SHP installations.
Beyond these concerns, certain SHP locations encroach upon areas of ecological or spiritual importance. The case of Wli Falls is instructive. With an estimated generation potential of 300 kW (or 1,000 kW if grid-connected), the site has been targeted for small hydropower development. However, strong resistance from local communities and conservation groups has emerged, rooted in concerns about ecological degradation and cultural loss (Dernedde et al., 2002). Since the surrounding villages are already grid-connected, the rationale for SHP development is further weakened. Also, the Energy Foundation advise against altering the landscape unless no alternative options are available (Dernedde et al., 2002).
Another major constraint is also the lack of skilled labour, which has left some projects in precarious developmental states. A notable example is the Likpe Kukurantumi project (Figure 5), which was initially designed for a 400-kW capacity but later downgraded to 150 kW (see Table 1). Nonetheless, construction halted when the project engineer left the country. Meanwhile, the expansion of the national grid has transformed the economic feasibility of most sites. In the Volta region, for example, areas once isolated and economically justifiable as standalone power projects are now integrated into the national grid. Similarly, since 1996,

substantial grid expansion in the Western region has reshaped the regional energy landscape, reducing the economic rationale for SHP deployment in those areas (Dernedde et al., 2002).
In addition to these shifts, the sector faces limited access to long-term capital. This challenge is compounded by the depreciation of the Ghanaian cedi and persistently high bank interest rates, reportedly exceeding 30% in some cases (Mahama et al., 2021). According to the Energy Commission (2016), these macroeconomic pressures increase development costs and limit private sector participation. Without any financial incentives, SHP widely perceived as a high-risk investment with low investor appeal. For instance, low-head sites like Menusu and Ahamansu face flooding risks and prohibitively high construction costs, making them less attractive for development (Dernedde et al.,2002). Additionally, the execution of the Randall Falls site is hindered by a lack of technical expertise and insufficient funding (Zhang, J. et al., 2018).

Figure 5. The abandoned Likpe Kukurantumi SHP project
(source: Dernedde et al.,2002)

Figure 6. Aerial view of a degraded river body in Ghana, showing extensive deforestation in the surrounding landscape. (source: shutterstock.com)

| | | | Former Reports | | Present Estimation | | |
|---|---|---|---|---|---|---|---|
| | | | Isolated Grid | | Grid Connected | | |
| | Location | River | Size | Power Generation | Size | Power Generation | remarks |
| | **Volta Region** | | | | | | |
| 1 | Wli Falls, Afegame | Nuboi | 300 kW | 2,600,000 kWh | (1,000 kW) | (3,500,000 kWh) | should not be developed due to touristic attraction |
| 1a | Downstream Wli Falls | Nuboi | 45 kW | 145,000 kWh | 80 kW | 300,000 kWh | **grid connected development possible** |
| 2 | Alavanyo-Abehensi "Tsatsadu Falls" | Tsatsadu | 200 kW | 1,752,000 kWh | 320 kW | 1,200,000 kWh | **interesting site for development** |
| 3 | Likpe Kukurantumi | Dayi | 400 kW | 876,000 kWh | 100-150 kW | 400,000-500,000 kWh | based on old flow data; still assuming a 5 m high dam |
| 4 | Dzolo | Dayi | no information | | no natural head | | similar to Kukurantumi |
| 5 | New Ayoma | Dayi | no information | | no natural head | | similar to Kukurantumi |
| 6 | Menusu | Menu | 500 kW AESC | 4,380,000 kWh | 13 m high weir is unrealistic | | not recommended for further consideration |
| | | | 65 kW (ACRES) | 209,000 kWh | | | |
| 7 | Ahamansu | Wawa | 125 kW (ACRES) | 403,000 kWh | | | not recommended for further consideration |
| 8 | Dodi Papase | Wawa | 500 kW (AESC) | 4,380,000 kWh | 14-16 m high weir is unrealistic | | |
| | | | 210 kW (ACRES) | 676,000 kWh | | | |
| 9 | Asuboe | Wawa | 100 kW (ACRES) | 322,000 kWh | 10 m high dam was required | | |
| 10 | Dodo Tamale | Asuakawkaw | unknown | | | | 13 m high irrigation dam was foreseen |
| 11 | Dodo Amanfron | Jelem | unknown | | | | 13 m high irrigation dam was foreseen |
| | | | | | | | |
| | **Eastern Region** | | | | | | |
| 12 | Wurudu Falls Moseaaso | Wurudu | 25 kW | 219,000 kWh | dries out completely | | not recommended for further consideration |

Table 1: Summary Comparison of Historical and Current Site Conditions (source: Dernedde et al., 2002)

| | | | Former Reports | | Present Estimation | | |
|---|---|---|---|---|---|---|---|
| | | | Isolated Grid | | Grid Connected | | |
| | Location | River | Size | Power Generation | Size | Power Generation | |
| | **Ashanti Region** | | | | | | |
| 13 | Boumfum Falls Kumawu | Ongwam | 225 kW | 1,970,000 kWh | Dries out completely | | not recommended for further consideration |
| 14 | Barekese Dam (GWC) | | | | to be evaluated | | **see report!** |
| 15 | Maabang | Kwasu | 200 kW | 1,75,000 kWh | has not been located | | requires 25 m high flood control dam |
| | | | | | | | |
| | **Brong-Ahafo Region** | | | | | | |
| 16 | Nkoranza | Fia | 60 kW | 525,000 kWh | Dries out completely | | not recommended for further consideration |
| 17 | Kokuma Falls | Edam | 45 kW | 390,000 kWh | 75 kW | 375,000 kWh | **interesting site for isolated plant, grid connection possible** |
| 18 | Fuller Falls | Oyoko | 90 kW | 788,000 kWh | 380 kW | 1,900,000 kWh | **grid connected development possible** |
| 19 | Randall Falls "Kintampo Falls" Kintampo | Pumpum | 80 kW | 700,000 kWh | 160 kW | 810,000 kWh | **interesting site for development** |
| | | | | | | | |
| | **Western Region** | | | | | | |
| 20 | Sanwu Falls Sefwi Boinzah | Sanwu | 60 kW | 525,000 kWh | not suitable for grid connection | | interesting location for isolated site, however the village is grid connected |
| 21 | Nworannae Falls Asampanaye | Nworannae | 40 kW | 350,000 kWh | not suitable for grid connection | | possible site for isolated plant, however not suitable for grid connection |
| 22 | Sefwi Asanwinso | Benchema | 45 kW | 394,000 kWh | could not be located | | area is grid connected |

Table 1(Continued): Summary Comparison of Historical and Current Site Conditions (Source: Dernedde et al.,2002)

## 4. Recommendations for improvement

Ghana has identified 22 potential small hydropower sites (Dernedde et al., 2002). However, only one of these—the Tsatsadu Generating Station—has been developed to date (Yang et al., 2021). This section outlines a set of recommendations aimed at addressing the key challenges and reorienting SHP development toward more effective and context-sensitive implementation.

A. Watershed health and long-term climate studies

Hydropower and climate change exist in a delicate interplay. Since SHP relies on smaller river flows that are highly variable, it is even more sensitive to climate impacts (Shu J. et al., 2018). For instance, small changes in temperature or precipitation can cause large percentage changes in SHP generation, making it especially vulnerable to climate-induced fluctuations in runoff. Moreover, disruptions such as reduced water availability for agriculture and domestic use are likely to be intensified when these sites are developed without adequate Environmental Impact Assessments (EIAs), which are essential for identifying ecological thresholds and competing water demands. As streamflows diminish and reservoirs become increasingly stressed, the exposure of sediments may lead to the emission of greenhouse gases, such as methane, complicating prevailing assumptions about SHP's environmental sustainability and its carbon neutrality (Kuriakose et al., 2022). Projections indicate that the continued expansion of hydropower could inadvertently narrow the country's available carbon budget and undermine its broader climate mitigation commitments (Kuriakose et al., 2022). Therefore, adaptive planning—guided by climate models will be key to ensuring long-term functionality.

More importantly, the Ghanaian government should prioritise watershed management practices during SHP development. One of the important lessons from large hydropower projects is the issues with sedimentation and reduced water availability, which affect energy production and increase maintenance costs. Research indicates that a 1% increase in environmental degradation results in a 0.4% decrease in hydropower generation in Ghana (Kwakwa, 2015). Thus, the study recommends that the government enforce environmental laws to protect SHP river systems, especially in areas with intense mining activity. The protection programs should also include community involvement and mass media campaigns to encourage public participation in these efforts.

B. Project feasibility considering sustainability and national grid expansion

There is a recognised need for SHP reassessment to determine its environmental sensitivities and socio-economic trade-off. To date, no comprehensive literature review on the environmental and social impacts of SHP has been conducted in Ghana. Many articles focus on identifying optimal sites and estimating energy potential for identified locations (Anfom et al., 2023; Agyemang-Boakye et al., 2024; Yankey et al., 2023; Arthur E. et al., 2020). Thus, a detailed review of the socio-ecological impact of SHP should be conducted. For instance, it is crucial to conduct detailed analyses of how projects will impact local livelihoods, restrict land access, and threaten indigenous autonomy, biodiversity, and landscape integrity. Such assessments are necessary to ensure that project-affected people receive fair compensation for potential displacement or damage.

Also, the economic rationale for SHP deployment is shifting due to the expansion of the national grid. This trend has significant implications for SHP investment. Grid-based electricity typically generates and distributes electricity at a lower per-unit cost, making it a more attractive option for consumers. As a result, SHP projects in these areas may be viewed as financially unviable due to competition with cheaper grid electricity. Hence, alternative sources that integrate more efficiently with the national grid are likely to receive greater investment and policy support. Kwakwa (2015) highlights this transition, noting that a 1% increase in alternative energy sources is associated with a 0.32% decline in hydropower production. Given these dynamics, this paper recommends reassessing proposed SHP projects in grid-connected areas for alternative local applications such as irrigation, agro-processing, or eco-tourism. The Ghanaian government should support this transition by funding applied research to ensure projects deliver meaningful benefits. It is also important that the government promote early engagement and open dialogue, ensuring that communities are active partners in the developmental process.

C. Increasing access to finance and local capacity building

SHP projects in Ghana are driven by public investment. The private sector is showing no interest in investing in it. Attracting private capital will require a targeted risk-sharing framework that includes guarantees, concessional loans, and stable feed-in tariffs. Additionally, the government could utilise innovative funding mechanisms, such as green bonds and environmental investment funds, which support SHP ventures by offering targeted credit schemes and low-interest loans. For example, international organisations such as the World Bank, the African Development Bank, and the International Finance Corporation (IFC) provide vital financial resources through concessional loans and grants. Climate finance mechanisms, such as the Clean Development Mechanism (CDM) and the Verified Carbon Standard (VCS) initiatives, provide additional funding opportunities through carbon credit sales (Ibegbulam & Olowonubi, 2023).

However, the study recommends that policymakers carefully balance investor incentives with local capacity building to reduce over-reliance on foreign expertise. Often, foreign workers are employed to work on hydropower projects in Ghana. While this approach ensures technical expertise during construction, it does little to build local capacity. As a result, the local workforce often lacks the skills needed to operate and maintain projects effectively. Moreover, hiring foreign experts is costly and consumes a large portion of available funds. Hence, the Ghanaian government must encourage collaboration among local universities, energy agencies, and private firms to enhance knowledge exchange and develop cost-effective, locally adaptable SHP solutions. Such efforts will also create job opportunities and foster a sense of ownership, ensuring the project's success.

## 5. Conclusion and Policy Implications

Small hydropower in Ghana occupies a critical yet complex position within the country's broader renewable energy strategy. While its potential for rural electrification and decentralised energy provision is well recognised, the current planning and implementation frameworks are insufficiently aligned with the principles of sustainability. This study, based on a systematic review of academic and policy sources, identifies several structural limitations that undermine the viability and long-term impact of SHP projects. Moreover, it shows that the assumption that small hydropower systems are inherently "green" and low-risk has contributed to weak integration of environmental and social impact assessments in project planning.

Moving forward, Ghana must reevaluate proposed SHP sites with current hydrological data, integrate watershed protection into energy planning, and ensure that affected communities are not only consulted but empowered in project design and benefit sharing. Above all, the designation of SHP as a sustainable technology must be subjected to empirical scrutiny. Treating sustainability as an assumed attribute rather than rigorously evaluated outcome risks overlooking significant socio-environmental trade-offs. This approach not only weakens project legitimacy but also jeopardises the very goals of equity and resilience that SHP is intended to support. Hence, the sustainability of SHP should not be treated as a decision-making that lists the costs and benefits of a dam project. Ultimately, with the right policy frameworks, community engagement, and scientific support, SHP can make a significant contribution to Ghana's sustainable energy future.

## 6. Future Research

Small hydropower (SHP) stations often face significant efficiency challenges under low-flow river conditions. This limitation reduces overall energy output and limits the viability of SHP development in areas with seasonal or inconsistent water availability — a common characteristic of many rivers in Ghana. To address this, future research should explore the integration of emerging technologies designed to enhance performance in such conditions. One promising solution is the use of a permanent magnet synchronous generator (PMSG) directly coupled to the turbine (eliminating the need for gears). This configuration, when combined with advanced control systems, enables variable-speed operation and maintains a constant-frequency output, thereby enhancing power generation efficiency even when water flow is low. Investigating the practical deployment of such technologies in Ghana’s river systems could offer a transformative pathway for the sector's growth.

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