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Review

Status of Micro-Hydrokinetic River Technology Turbines Application for Rural Electrification in Africa

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Abstract: Energy accessibility, reliability and availability are key components of improved quality of life and human development in all spheres. As the United Nations' SDG 7 calls for access to electricity for all by 2030, Africa still has a wide gap to fill as the statistics show that 85% of the population that will not have access to electricity is in Africa. As the world tries to wean itself off non-renewable energy and transition to green through use of renewable energy sources, hydropower energy remains at the heart of Africa for this venture. With majority of the rural population in Africa lacking electricity, there is need for a low-tech system that utilizes river flow to generate just enough energy for normal operation in these regions. Micro-hydrokinetic river turbine technology (μ-HRT), which offers less intermittency, can potentially contribute to sustainably electrifying Africa rural areas. The technology has been adopted by few countries worldwide, with limited comprehensive study in Africa even though the technology seems viable for use in African rivers. This paper reviewed the status of the μ-HRT applications in Africa and some of the barriers to its development. The study found out that the technology has not been vastly developed in Africa. Despite numerous barriers, the technology is simply a low-tech technology that requires the use of local resources and capacity building for its sustainability in terms of construction, operation and maintenance requirements. It is therefore recommended that R&D and field trials be conducted for its possible adoption.

Keywords: Africa; capacity building; energy accessibility; hydrokinetic river turbine; sustainability

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1. Introduction

Energy reliability and the ease to which it is made accessible to the population improves the quality of life and promotes human prosperity. In regards to this, the United Nations' seventh Sustainable Development Goal calls for access to affordable, reliable, sustainable and timely energy for the world's population by 2030 [1–3]. Electrical energy plays a vital role in the operation of numerous devices, machines and systems as well as for the functioning of communication channels and data networks. Over-reliance on non-renewable sources of energy such as fossil fuels has tremendously led to intensive climate change, which has had an overall effect on human development [4].

As a rule of thumb, an ideal energy source should be renewable and have a minimal effect on the environment [5]. Studies conducted have revealed that one-third of the total world's population still has no access to electricity, though it has access to moving waters [6], with majority of this population living in Sub-Saharan Africa within rural remote areas [3,7], as is depicted in Figure 1 below. This population has no option but to heavily depend on fossil-fuel-based power generation means, which are seen as the cheapest alternative available sources of energy for metropolitan and rural applications [8]. Until now, there has been great progress made in implementing SDG 7. However, efforts are still insufficient to enable the attainment of the development goal by 2030. This can be attested to by the fact that majority of the population in Sub-Saharan Africa (SSA) within the African continent and in south Asia still do not have a basic energy supply [2].

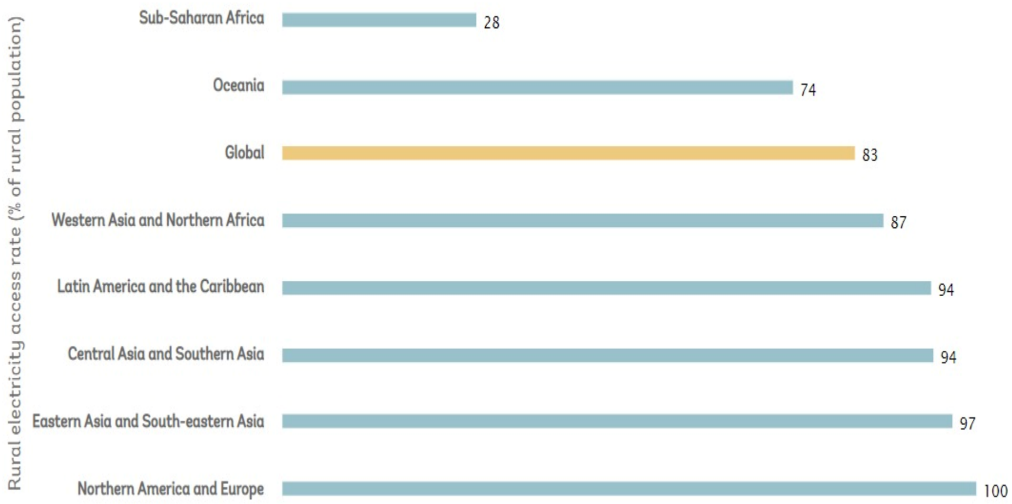

Figure 1. Access to electricity for rural (% of rural population) populations by the year 2020—adapted with permission from [1,7]. © 2022 The World Bank Group, IEA

In developed countries such as Germany, access to sufficient energy for heating, hot water preparation and the operation of electrical appliances is not only considered as a basic need but a fundamental right for all German citizens in accordance to the Federal Constitutional Court Ruling in 2012 [9]. The provision of energy by the states of developed countries has been made to be a human right and not just a mere basic want, with both urban and rural set ups having access to reliable electricity connections. On the contrary, developing countries such as those in Africa have the majority of their populations in the rural areas not connected to grid electrification. The majority of the people in these rural areas are very poor and have low living standards, limited education and little access to information. With the efforts to provide these rural populations with electrification, progress and success still remains very low. This is as a result of poor planning, a lack of research to provide low-tech solutions, political negligence and poor policies [10]. Additionally, these rural areas lack intensive state infrastructural networks since they are not industrialized and are regarded as of no importance for economic growth and development. These rural areas are also inaccessible and suffer the most from socio-cultural causes such as poverty and corruption [11,12].

Furthermore, the United Nations' SDGs 7 projection of full access to electricity by 2030 requires that 100 million people must be connected each year. This goal is currently not on track worldwide, as the International Energy Agency stated Policies Scenarios (STEPS) pronounces that some 672 million people are projected to remain without access in 2030, 85% of whom will be in Africa, as can be seen in the Figure 2. However, many developing countries in Asia are well on track to achieve near universal access by 2030 [1].

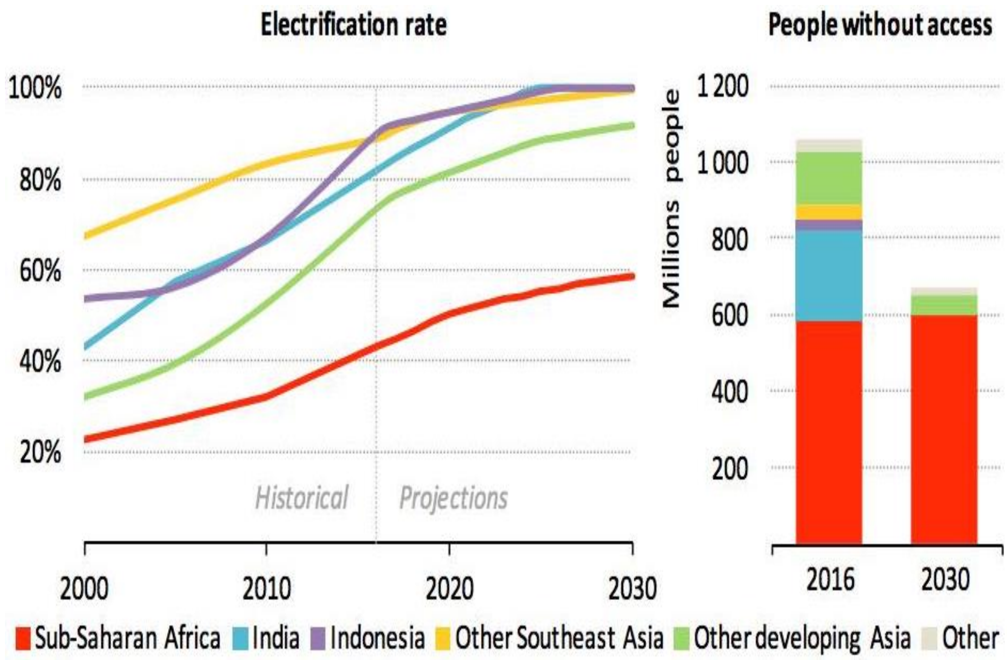

Figure 2. Electricity access rate and population without electricity by region under the IEA's central scenario up to 2030–Adapted with the permission from [1]. ©2022, IEA

The provision of electricity is crucial for improving the living conditions of rural residents. Remote communities only require an electric supply for small loads such as lighting, refrigeration, communications and many other light duties [13]. By incorporating basic approaches/techniques, small-scale renewable energies can be a solution towards rural electrification, unlike developing a grid extension, which is economically unviable due to the low consumption and poor load or the use of diesel generators in these communities, which seems to be a cheap alternative but contributes to the accumulation of greenhouse gas emissions [10]. It is reported [14] that the European Union, for instance, set a target of 12% renewable energy as a percentage of the total electricity production by 2010. In this region, the interest for renewable energy, especially from the untouched reservoir of green energy from hydropower with a very low head difference of less than 2 m, is of significance.

Generally, renewable energy sources such as biomass, solar, wind, hydro and geothermal offer clean and reliable energy and, at the same time, help to reduce greenhouse gas emissions that have an effect on the global warming. This is highly regarded as part of the environmental requirements assumed by the Kyoto Protocol to the Framework Convention of the United Nations on Climate Change [15]. Coupled with the 2015 Paris Agreement presented on the global ambitions to achieve sustainability between anthropogenic emissions by sources and the removal of greenhouse sinks, this accord aims to cultivate an increase in the global average temperature below 2.0 °C and to enforce a limit of 1.5 °C [16]. This ambition can only be achieved if all countries reduce their consumption of non-renewable sources by integrating renewable energy supplies in energy systems [17]. From the list of considered renewable energy sources, hydropower holds a prime position in contributing to the world's electricity generation [18].

A considerable view of hydropower systems classifies this conventional technology as a power plant that requires huge and extensive land modification, causing additional environmental damages [19] such as structural intervention in watercourses (dams, headraces, rakes, powerhouses with turbines and generator storage and empty shots), which is not possible in many places with decentralized available resources and due to a lack of access to appropriately adapted conventional turbines. Additionally, conventional hydropower generation is characterized by a high initial capital outlay [20] and with seasonal variability in rivers/water courses. This may result in a severe reduction in power output depending on the site's hydrology conditions [21,22].

Usually, statistics relating to the potential of hydropower greatly refer to large-scale hydropower only. There are no proper statistics on the potential for small- and micro-scale hydropower available for the African continent [23]. To compensate for the slow-paced and low rural electrification coverage in Africa, the use of low-cost technology that is compact and modular in nature and requires low maintenance costs is necessary. The most viable solution is the use of hydrokinetic technology that utilizes the kinetic flow of water to generate sufficient energy for rural applications. Such technology is environmentally friendly and sustainable since it produces electricity for 24 h a day as long as running water is available [10]. As the technology uses flowing water, which is 800 times denser than wind, a hydrokinetic turbine is capable of extracting enough energy even at low water speeds [24,25]. Many remote villages are situated in close proximity to rivers with little to no elevation, and such conditions are unfavorable for conventional micro-hydropower generation technologies [26]. As such, these sites are very instrumental for the installation of hydrokinetic technology as opposed to traditional hydropower technology [27].

The hydrokinetic industry has developed beyond the initial testing stages to the point where fully developed projects have been introduced, constructed and tested globally [28]. Most research conducted on hydrokinetics and their applications have concentrated on large-scale technologies that utilize waves, tides and ocean currents for their operation. These have been mainly developed in developed countries [4,14]. Similarly, small-scale (also known us μ-hydrokinetic river turbines (μ-HRT)) hydrokinetic river technologies have been developed for utilization in rivers, irrigation canals and open channels [10]. In Africa, the majority of these μ-HRTs have been intensively employed in the South African economy, and their uses have been investigated for their reliability in terms of power supply, affordability and sustainability to provide electrification to rural, remote and isolated areas of South Africa [27,29].

This paper reviewed the status of μ-HRTs for rural electrification in Africa, especially in regions with low rural electrification coverage. Selected case studies in Africa were presented and the status of the technology discussed. Possible challenges such as a country's policies, a lack of technology, the investment costs of the technology, the availability of information and any other factors that may favour or discourage stand-alone off-grid technologies were also presented. Based on the case study findings, a low-tech cost-effective technology using local resources is planned for further investigation to determine the possibility of its application and further modifications to be conducted.

2. Literature Review

2.1. Energy Technologies for Rural Off-Grid Applications

2.1.1. Diesel Generators

Rural areas are economically unattractive in warranting a heavy investment in hydropower and provide mains power even when high-voltage lines pass by a village. Authorities normally resort to diesel-powered generators, which are noisy and require frequent maintenance, which is provided limitedly in remote areas and is thus neglected. The price of diesel is high, depending on the economic situation globally, and bringing this commodity to rural villages is hindered by poor road networks. The effects of the global carbon emissions of these diesel generators contribute immensely to greenhouse gas effects and, of course, climate change.

2.1.2. Wind Energy

Wind energy is freely available in nature and has been intensively harnessed to provide off-grid electricity. These systems are impacted by wind speed variations, and the wind turbine rating is usually higher in comparison to average electrical power demand. Their investment cost is high and is coupled with high maintenance costs and the replacement of parts. The affordability of this technology to rural communities in developing countries is out of reach, as this can only be achieved by a government's goodwill.

2.1.3. Solar Power

Solar power is gaining popularity in many parts of the world. Its effective application highly depends on the availability of solar radiation. Its suitability in humid tropical regions is limited and is only viable in regions with plentiful of sunshine throughout the year. Solar energy requires batteries for energy storage, and such components have short life periods, and this adds to electronic waste in developing countries with no proper recycling techniques or disposal options. Solar radiation is available only during the day and is affected by rainy periods.

2.2. μ-Hydrokinetic River Technology

This technology employs the kinetic energy of waves, tides, ocean currents and the natural flow of water in rivers for energy generation [5,30] without the need to impound water by constructing dams, which also causes changes to a river's ecological conditions. For small-scale electric generation, free flowing rivers are better utilized, as the size of a μ-HRT can sufficiently extract energy even at shallow depths. Of the several concepts so far developed, the concept of the utilization of turbines has been the most preferred [10], and when used for rivers or artificial waterways, the turbine technology is termed as a river current turbine (RCT) [31].

Vermaak et al. [10] reviewed in detail work involving μ-HRT in the vertical axis and in the in-plane axis (axis in the horizontal plane of the water surface) and outlined the possible application options of such turbines and their associated generators in their review work. The advantages and disadvantages of the outlined turbine configurations and various generator types were also adequately described in the document. They further made recommendations for the techno-economic and environmental analysis of the technology compared to other rural electrification supply options.

Chihaia et al. [15] gave a detailed description of past research studies conducted in different regions of the world, emphasizing the specific conditions of the studies conducted and the outcomes of the studies.

The performance of μ-HRTs has been tremendously improved through research and development as described by Anyi and Kirke [32], which has aided in overcoming major problems such as debris by using deflection devices to sweep away debris. Several large-scale prototype river turbines are available in the market that apply various techniques based on the research findings conducted. Certain specifications such as minimum/maximum operating speeds and maximum output power have been documented. The research on this topic is summarized in Table 1.

Similarly, for use in rural applications, there is need for the optimization of river current technology turbines in order to improve their energy efficiency. The technology's sustainability is enhanced through the use of locally available materials, tools and expertise [33]. For instance, the simplified construction of blades allows the technology to be made in a remote village near to where maintenance can be easily carried out. Encouraging local production aids in job creation and lowers the importation costs of the components.

Table 1. List of companies and associated technologies in the market adapted with permission-from [10], under Open Access content copyright permission. © 2022, Elsevier Ltd.

Device Name	Manufacturer	Turbine Type	Min/Max Speed	Power Output
Gorlov helical turbine	Lucid Energy Ltd. (Dallas, TX, USA) [26]	Helical Darieus axis	(0.6 m/s) to no limit	Up to 20 kW, depends on size
Water current turbine	Thropton Energy Services (Northumberland, UK) [34]	Axis flow propeller	(0.6 m/s)/depends on the diameter	Up to 2 kW at 240 V
Davidson–Hill (HDV) turbine	Tidal Energy Ltd., (West Perth, Australia)	Cross-flow turbine	Min. 2 m/s	From 4.6 kW
Stream	Seabell Int. Co., Ltd. (Tokyo, Japan)	Dual, cross-axis	(0.6 m/s) to no limit	0.5–10 kW models
EnCurrent hydro turbine	New Energy Corporation Inc. (Calgary, AB, Canada)	Cross-axis	Max. 3 m/s	5–10 kW
Free-stream Darrieus turbine	Water Alternative Hydro Solutions Ltd. (Toronto, OT, Canada)	Cross-axis	(0.5 m/s)/depends on diameter	2–3 kW

2.3. Economic Analysis

The considerable socio-economic profitability of the technology's application in developing countries is of great importance. The installation of such technologies needs to satisfy the minimum energy requirements, needs to be affordable to acquire and needs to have low maintenance costs. A review of three small-scale HKT's [35] outlines that the technologies in consideration have price ranges between USD 4000–12,500 per unit [36,37], a relatively expensive renewable energy source that can achieve just few hundred watts compared to less than USD 500 for wind or solar technology with equal capacity. In addition, most of the technologies designed in developed countries have customized system components, which are extremely expensive to acquire in terms of their repair and maintenance costs for villages in developing countries, for instance, those in Africa.

A priority in terms of operation and maintenance costs reduction should be of importance while increasing affordability and sustainability. Suggestions from the cost and performance of renewable energy technologies have been immensely pinpointed in various researchers' views with a desire for river HKTs, applying a simple design using off-the-shelf materials and avoiding importation as much as possible [38,39].

A case study of the socio-economic situation of a hydrokinetic installation examined for two different scenarios, an economic power (USA) and a developing country with a mixed economy (Brazil), is adequately described in [40]. The resources of the two countries are vividly described, and the energy-harnessing processes and potentials are well explained. The analysis of the initial investment costs, maintenance costs and operation costs are presented in the Table 2 below.

Table 2. Calculation of the initial investment, maintenance and operation cost for HKT technologies in USA and Brazil (case study) adapted with permission from [40] under Open Access rights and contents. © 2022 the Author(s). Published by Elsevier Ltd.

Concept	Cost (US $)
SMART free stream turbine generator, structure against debris, anchor cables and 50 m of electric cable	14,988.00
SMART electrical cabinet grid-connected system inverter, controller, dump load and fuse box	3912.00
Total equipment	18,900.00
7% industrial profit	1323.00
Import t**axes**	2000.00
Total initial investment, I_o	22,223.00
Annual maintenance	250.00
Average electricity price per kWh (USA/Brazil)	0.132/0.121
Annual electricity price per household (USA/Brazil)	1414.40/317.00
Discount rate (USA/Brazil)	2%/10%

The cost and performance of a locally produced HKT turbine using off-the-shelf materials has been proven to be practically viable. In the study, the capital cost was greatly reduced to less than USD 750 (less than USD 300 for materials and USD 450 for labor) [41]. In the study, a 0.585 m reprofiled industrial fan rotor produced 92 W of power from a 1.3 m/s current velocity. A potential daily power generation of 2.2 kWh was possible, which is sufficient enough to power up several DC light bulbs and to charge a battery bank for a household in a remote area.

3. Case Studies

Salleh et al. [42] comprehensively presented μ-HRT field test case studies for remote electrification in Australia, Brazil and the UK. The study intended to showcase the practical aspects of the turbines' implementations, performances, efficiencies, reliabilities and problems encountered. For instance, the case study in Australia evaluated the performance of small axial flow turbines for the Nguiu community in Apsley Strait to replace the use of diesel fuel [43]. The works of Chihaia [15] also give a detailed review and present the works of numerous case studies performed by researchers from the inception of the technology conducted in Brazil until the concept's acceptance in Indonesia. In the case studies below, certain countries in Africa were selected from different regional boundaries to showcase the status of the technology and its adoption for rural remote electrification. Not all the countries are presented, but selected countries per region were selected depending on the status of rural electrification according to International Energy Agency data [1].

3.1. Southern Africa Region

In the southern African region, the use of small hydropower dates back to as early as 1892, when such technology was utilized in earlier electrification, although clear documentation is lacking [23]. However, the small hydropower technology utilized the potential energy of water via a penstock to generate electricity at rates between 6–45 kW [44]. An overview of Malawi, Mozambique, Lesotho, South Africa and Swaziland were considered. South Africa, for instance, has conducted multiple studies and indicated numerous unexploited potentials of hydrokinetic river technology [27]. A pilot HRT has been recently developed and implemented within the existing South African irrigation canal located on the Boegoeberg scheme and tested for its optimum functionality and application. The output has promoted the evolution of a development process for further implementation of HK devices in existing water infrastructure in South Africa [45]. Other countries in the region have no documentation on the development or utilization of the technology or even plans to do so. Table 3 below summarizes the status of μ-HRTs in operation and under development and potential development sites in selected southern African countries.

Table 3. Southern African region's μ-HRT capacity and potential adapted with permission from [23,46]. © 2022, CSRI/(Wim Jonker Klunne, free database access).

Country	Hydropower Category	Operational (MW) *	Under Development (MW) *	Potential Site (MW) *
South Africa	Pico	0.05	0.1	0.002
	Micro	2.3	0.4	0.47
Zimbabwe	Pico	0.03	-	-
	Micro	0.33	-	-
Lesotho	Pico	-	-	-
	Micro	0.2	-	-
Malawi	Pico	0.01	-	-
	Micro	0.1	-	-
Swaziland	Pico	-	-	-
	Micro	-	-	4.0
Mozambique	Pico	0.1	-	-
	Micro	0.4	0.02	-

* The power output of each category is the summation of the individual μ-HRT power output.

3.2. Western Africa Region

Out of the 17 countries in western Africa, only 10 have operating small hydropower plants. The region has the highest population percentage that has no access to electricity. There are efforts by the Economic Community of West African States to serve over 25% of the rural population by the use of decentralized renewable energy solutions by 2030 (mini-grids and stand-alone systems) according to their renewable energy policy [47]. There exists very minimal information regarding the potential of μ-HRTs in this region. Studies conducted, for instance, in Ghana recommended the need of developing the technology for rural electrification [48] with no further information on any river technology availability. Studies conducted in Nigeria on the other hand depicted the challenges experienced, especially in terms of the resistance to develop such micro-turbine technology from field players, thereby limiting the technology's development [49]. However, there exists a Monofloat hydrokinetic river turbine that was installed in Akwanga village that has been providing year-round energy for seven households close to the river Mada, even during the dry seasons [50].

3.3. Northern Africa Region

The countries in this region are the most electrified, owing their success to their rich gas, solar, wind and oil sources. Due to the climatic factors, only five out of the seven countries use hydropower. Morocco and Tunisia's small and mini hydropower capacity amounts to less than 10 MW, while the output from micro- and pico-hydropower ranges between 5–20 kW. Morocco has greater potential and motivation for micro- and mini-hydropower. There is also significant potential for small hydropower stations in Tunisia, as the government is motivated even though the efforts are obscured by a lack of awareness and incentives [47].

3.4. Eastern Africa Region

The countries in this region have not developed their micro- and pico-hydropower technologies. With a few exceptions, the region has vastly developed mini and small hydropower stations, which are essentially connected to the grid. However, there also exist privately owned small hydropower stations that are off-grid and are mainly used for running small estates. Uganda, for example, has identified over 60 potential sites on rivers within the region, which lie in hilly and mountainous areas, for the development of small hydropower stations including micro- and pico-hydropower stations [51]. Kenya, like any other country within the region, has a large potential for harnessing energy from running rivers as it is well endowed with rivers spanning from mountainous sources. Assessments conducted on Rwanda's resources determined the country to have an estimated potential capacity of 96 MW from micro-hydro projects. Additionally, over 192 sites have been identified for pico-hydropower plants, with an overall combined capacity (from all the 192 identified sites) of not less than 50 kW [52].

3.5. Central Africa Region

This region enjoys the most favorable rainfall pattern of all the studied regions with harmoniously distributed waterways with several tributaries. However, overall hydropower generation is underdeveloped in the region. There are constant civil wars and coups that have rendered most countries in the region politically unstable. Site assessments revealed 30 potential sites for hydropower potential with varying sizes (including micro- and pico-hydropower technology) [53]. Off-grid electricity plants as well as multiple micro- and pico-hydropower units exist, but no data is available on their installed capacity or generation potential [54] Such small-scale hydrokinetic river technologies, when developed, can benefit remote villages, which are generally less developed as compared to other regions in Africa.

4. Discussion

4.1. Barriers to μ-Hydrokinetic River Technology Development in Africa

μ-HRT remains a viable solution to provide sufficient energy for the needs of rural communities who have low income and at the same time require low amounts of energy. Most of the energy demands in these remote areas are meant for basic operations such as communication, refrigeration, lighting, etc. As a result of the remoteness of these villages, it is uneconomical, especially for African governments, to spend money on the establishment of intensive power infrastructures. At the same time, governments are not fulfilling their mandates of achieving the United Nations' SDG 7, which requires access to electricity for the whole global population by 2030. Despite the hydrokinetic river turbine technology's suitability to bridge this gap, there are challenges that hinder the adoption of this technology. These are summarized as:

(1) A Lack of local skills and technology to ensure the sustainability of the system. Most of the hydrokinetic turbines are industrially manufactured in industrialized nations by utilizing sophisticated components, and the technology is also complex in nature. The initial costs of such technologies are expensive. Coupled with a lack of technical expertise and skills in developing countries, the operation and maintenance costs of imported technologies are expensive in cases of breakdowns, as the expertise need to be imported.
(2) The legal and institutional framework in developing countries is very complex. For instance, the installation of such a technology requires approval from the water resources authority of a given country. The procedure is unfavorably long, such that stakeholders tend to lose motivation for obtaining approval.
(3) A lack of political goodwill in developing countries has contributed to the low-paced adoption of the technology. For instance, Kenya's political atmosphere at all levels involves the use of people's situations to win their votes. The provision of electricity is one of the priorities used by the politicians in Kenya. In order to remain relevant after getting into power, they tend to thwart any development agendas so that they use the same issue again for their gain. The community also lacks general information and awareness.
(4) Limited to no research has led to a lack of hydrogeological data that would provide baseline information on suitable/potential sites for the installation of hydrokinetic river

turbines for rural electrification. Similarly, a lack of innovation due to the low level of research makes it impossible to develop local prototypes for tests and validation.

4.2. Future Prospects

This review pointed out certain barriers that can be alleviated through continuous research and development (R&D) and further field trial tests for optimized products that suit a country's specific site needs. The implementation of a μ-HRT in the Boegoeberg case study in South Africa and in Akwanga village in Nigeria have both utilized Smart Free Stream and Smart Monofloat turbines, respectively, as manufactured by Smart Hydro Gmbh [45,50,55] based in Munich, Germany. The approximate costs for these commercial micro-turbines are estimated at EUR 12,490 and EUR 14,580, respectively, for the two projects. Considering a village with no political goodwill and a working individual earning a daily income of below USD 5, villagers may not be in a position to share the cost of the turbine in an effort to alleviate themselves from the challenges of a lack of electricity at the village level without expecting much from politicians. To overcome such obstacles, a locally fabricated and manufactured μ-HRT using local labour, materials and tools is likely to be more affordable to rural dwellers.

The Chair of Hydraulics Engineering at TU Darmstadt has designed and tested the potential of a pico-hydrokinetic river turbine for possible application in rural electrification at the laboratory-scale level. The investigation focused on the use of e-waste materials to develop, construct and carry out flume trials of a pico-turbine assembled from e-waste components [12] as shown in Figure 3 below. Components such as motors from ventilation fans, air conditioners, car alternators, motor-boats, etc., can be easily found from the recycling industries or dumping sites that are widely spread in developing countries such as those in Africa and modified to make small-scale turbines for generating electricity. This has been aimed at encouraging the use of local resources for low-cost technology for rural applications.

Based on the doctoral research findings of pico-turbine laboratory investigations, the setup generated between 40–60 W of power, which is sufficient enough to light a house bulb and charge a mobile phone [12]. It was shown that the use of e-waste is technically feasible for use in this research focus. Further field trial tests for a small hydrokinetic turbine are planned based on the laboratory investigation at TU Darmstadt. A transfer into practice through a field test facility in Kenya is planned. Further investigation into the drive potential of turbines with electrical or mechanical energy transmission for small plants and equipment is required to substantiate the application possibilities and limits of small turbines.

It is envisioned that the planned concept and test facility in Kenya will provide a training avenue for locals in terms of the system's sustainability. Knowledge transfer is key for sustainable development through brain-gain and reduces the dependency of acquiring technical expertise from abroad. It is anticipated that, through R&D, a prototype will be developed that can be replicated and upscaled to suit specific needs. This will enhance the achievement of the United Nations' sustainable development goal for the provision of affordable and clean energy in industry, innovation and infrastructure.

Figure 3. Flume investigation of pico-turbine performance in the Hydraulics Lab at TU Darmstadt (Photo courtesy by authors).

5. Conclusions

While Africa is anticipated to remain behind in terms of achieving the projection of the SDG 7 by the year 2030 in terms of full access of electricity to all [2], there is hope of providing rural connections using off-grid systems through the utilization of river resources and the aforementioned technology. Considerable studies already conducted place South Africa at a better position in terms of the utilization of μ-HRT, which is a low-tech solution for areas with difficult conditions [10,27,29]. μ-HRTs have greater potential in African rivers; however, this has not yet been fully developed.

The adoption of μ-HRTs does not present extreme technological challenges, since the use of local materials, labour and tools can be adopted to solve the challenge of sustainability. There is a dire need for incorporating capacity-building, acceptability by the community and the goodwill of local authorities. Integrating the technology into education would further enhance sustainability through offering programs in renewable energy as well as environmental studies [56].

The status of μ-HRTs for rural electrification in Africa was outlined in this paper. The findings showed that the technology has not been vastly developed, even though there are great potential sites for its development and implementation in various parts of the continent's rivers. With the adoption of this technology through capacity-building and the promotion of local participation, small-scale hydrokinetic development is a favorable option in alleviating rural electrification poverty that is sustainable to these local communities. It is therefore recommended that intensive pilot field trials be tested in these localities and scaling up be carried out through the findings of the field trials in Africa. This can be compared to the eminent growth, development and adoption of the technology in south Asia, through which the region has managed to significantly eradicate energy poverty.

Through the planned R&D at the laboratory scale level and the implementation of field trials on turbines made from e-waste, it is anticipated that the findings will give a better understanding of the technology and provide an avenue for optimization to improve performance.

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