Against the Tide: Potential for Marine Renewable Energy in Eastern and Southern Africa

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Abstract

Sub-Saharan Africa is at a crucial juncture in shaping its energy future: while two thirds of the population lack access to electricity, Africa is projected to surpass China's oil demand growth by 2040.

Marine renewable energy (MRE), with far less intermittency than other renewable resources, can potentially contribute to sustainably electrifying Africa in the long-term. However, the technology has been adopted by few countries worldwide, and there are no comprehensive studies of its potential in Africa, despite seemingly promising environmental conditions in the ocean, estuaries and rivers of Eastern and Southern Africa (ESA).

This paper discusses the potential for MRE electricity generation in ESA, and how to overcome some of the barriers to its development and implementation. The discussion addresses the concerns that are often associated with electricity generation in developing countries, such as equity, accessibility and affordability considerations.

An analysis of the energy mix in the region shows that MRE could fill some of the electricity supply gaps. Barriers to MRE are mainly not technological, but rather linked to policy design and financing capacity. Three complementary solutions were outlined to set a working framework for MRE deployment in ESA: short-term, small-scale hydrokinetic river projects with public or private financing (similar to microgrid and off-grid solar projects); long-term, large scale tidal projects with public and concessional financing (similar to geothermal power generation); and capacity building to ensure employment of local citizens. In particular, small scale hydrokinetic projects can have ownership structures that favor local authorities or communities.

Authors' Note

Renewable energy discussion in Africa revolves mostly around hydroelectric power generation, wind and solar PV. However, these resources have limitations: hydroelectric is due to decline and become more unreliable, due to climate change; wind and solar PV, although there is high potential, will only count for up to 15% of the energy mix in 2030, according to IRENA. In this context, we became curious about why tidal and hydrokinetic power seem to be overlooked, despite their reliability and seemingly promising environmental conditions in Eastern and Southern Africa. Given our professional backgrounds, once we understood the barriers, we immediately started thinking about how these challenges can be overcome with policy, financing and capacity building solutions.

Keywords

- Tidal energy
- Marine renewable energy
- Eastern and Southern Africa
- Policy design

- Sustainable development
- Democratizing energy access

1. Introduction

As a global push for decarbonization has taken center stage in today's energy policy, bringing renewable electrification to low-income countries is essential to achieving the Sustainable Development Goals (SDGs). While Africa has abundant solar photovoltaic (PV) potential, the continent's 20,000 kilometers of oceanic coastline (Authors' calculation based on CIA, n.d.) also show potential for a lesser known energy source: hydrokinetic energy.

Also known as marine renewable energy (MRE), these systems are being explored in various shapes, sizes and configurations; in this sense, MRE is modular and adaptable to different environments. The technology has significant potential as a stable source of renewable energy: tides are predictable, displaying lower intermittency than other renewable sources. Additionally, this source of energy is fairly resilient and adaptable in the context of climate change.

However, the number of countries that have adopted MRE is still small worldwide, and in Africa, there are very few projects (mostly small and still in the development phase). While South Africa has early developments of wave energy, the following will focus on tidal energy, which has more regional applications and potential for market penetration.

In 2015 the International Renewable Energy Agency (IRENA) reported that "Africa's extensive coastline also suggests long-term ocean energy potential, but this is unlikely to be a significant source by 2030." (IRENA, 2015).

While barriers are currently in part technological, large capital costs required to develop some of these projects pose financing difficulties. These issues can be solved with adequate project design and supporting policies, rather than with technological advancements.

This paper discusses the potential for MRE electricity generation in the coastal countries of Eastern and Southern Africa (ESA). It analyses the barriers that prevent hydrokinetic energy, in particular tidal and river energy, from being an economically viable source in areas where environmental potential is high. In doing so, the paper provides a framework of what policy instruments might support a more prevalent introduction of this technology in the region's future energy mix.

Based on this analysis, the paper proposes and discusses a range of policy options that countries in the region could consider in order to facilitate the introduction and scaling of MRE. This discussion addresses concerns that are often associated with electricity generation in low-income countries, such as equity of access and necessity to keep costs low to promote development.

It is important to note that while countries in ESA may share issues of energy inequality and scarcity, energy resources and development fluctuate greatly throughout the region. Although traditional hydroelectricity supplies a majority of energy in some ESA nations today, many are already experiencing issues of drought and subsequently reduced electrical generation (Othieno & Awange, 2016a).

Building equitable renewable power requires a holistic perspective that can foster the best interest of local communities and the potential of their environment.

According to the International Energy Agency (IEA), Africa's oil demand is expected to grow at analogous rates of China's until 2040 (IEA, 2019a), paving the way for fossil fuels to continue playing a predominant role in the energy mix. Although renewables could potentially make up to 22% of Africa's total energy consumption by 2030, there is room for improvement considering the huge potential as the continent's electricity demand is expected to triple in the same timeframe (IRENA, 2015).

With nearly half the population in sub-Saharan Africa (SSA) living in energy poverty (IEA, 2019a), the opportunity for equitable, sustainable renewable energy must be prioritized. In this regard, the race to scale up diverse renewable energy systems in ESA can be seen as a means to diminish future dependence on future fossil fuels and the dire consequences of greenhouse gas emissions and local pollution.

2. Trends in in the energy sector and power generation in SSA

This section analyses what are the current challenges faced in power generation, including their role in equitable energy access and climate change resilience. The discussion below will be instrumental in understanding what role tidal and hydrokinetic power can play in the energy mix, and how they can fill existing gaps.

While North Africa is mostly well electrified, around 600 million people in SSA live in energy poverty (IEA, 2018). Two thirds of people in SSA (with the exception of South Africa) do not have any access to electricity, and access for the remaining one third is unreliable, with regular blackouts and brownouts (Hafner et al., 2018). Figures vary greatly between urban and rural settings, with only one fourth of the population in rural areas having access to electricity, versus three fourths in cities (IEA, 2019a).

Eastern Africa has increased electrification rates at 4% per year between 2014-18, a notable success. While countries such as Kenya, Ethiopia and Rwanda are on track to domestically extinguishing energy poverty by 2030, the majority of nations in SSA are expected to maintain the same levels of access as in 2020 (IEA, 2019a). With around 40% of the population of SSA surviving on less than 1.90 USD a day (Castaneda Aguilar et al., 2019), energy poverty can create additional barriers to ensuring equitable development and inequality reduction.

I. Hydroelectricity and Climate Change

Like the rest of the world, the most common type of renewable energy in ESA comes from hydroelectric dams (Othieno & Awange, 2016a). In recent years, hydroelectricity in ESA countries has been increasingly threatened by climate change.

In Kenya, the effects of the 2017 drought were so dire that the country declared a national disaster. The severity of the drought did not only impede hydroelectric power, but also fossil-powered generators (which require water for cooling and, in the case of thermoelectric, for spinning the turbines), causing the country's reserve energy margin to drop well beneath the threshold to avoid blackouts (Wang et al., 2017).

Since 2015, Mozambique is the largest producer of hydroelectric energy in SSA (EIA, 2018), generating 87% of electricity through this source (around 2.1 GW) (USAID, 2020a). The Cahora Bassa Dam, the nation's largest generator, also supplies electricity to neighboring countries like

Zambia. As early as 2015, extreme drought affected the reliable generation of hydroelectricity to meet demands both domestically and for export (Kuo, 2016).

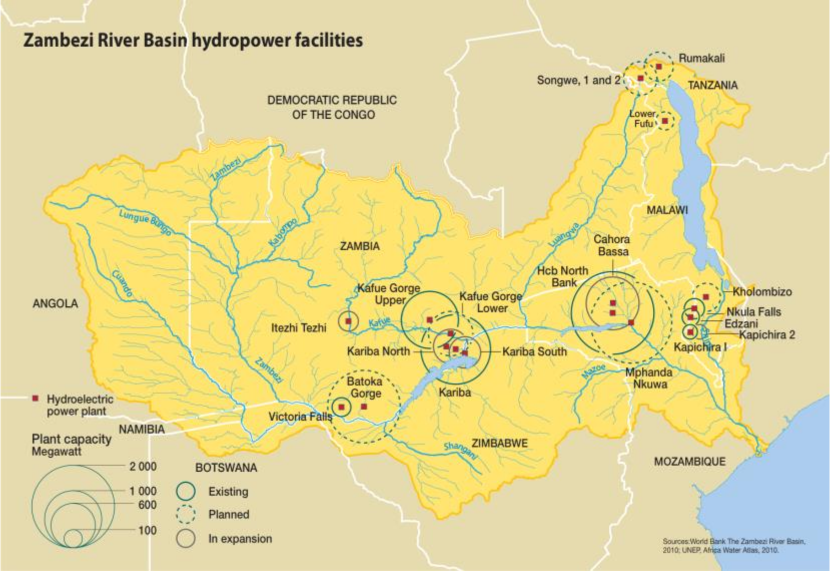

Figure 1. Zambezi River Basin hydropower facilities (World Bank, 2018).

These issues extend beyond the needs of Mozambique. The Zambezi river is considered a lifeline to the region as it provides fresh water to the six SSA nations it flows through. With a multitude of dams already constructed, the river today is at its lowest level in almost fifty years. The consequences of this drought have not just resulted in energy depletion but destabilization of crop and fishing yields, as well as access to clean drinking water (Hill, 2019).

The case of Tanzania is similar to Mozambique. More than a third of the nation's 1.5 GW comes from hydroelectricity, and that capacity has been at great risk. The dry spells have been so dire that as early as October 2015, the nation was forced to temporarily shut down the entirety of its hydroelectric generators (Makoye, 2015). Unsurprisingly, greenhouse gas emissions rose significantly because the country turned to gas and coal as a replacement (Hellmuth, 2019).

II. The Rise of Geothermal

In the midst of depleting hydroelectric resources, geothermal is a renewable energy source that is becoming more prevalent in the region with its massive, untapped potential: less than 1% of African geothermal is currently utilized (Othieno & Awange, 2016a). It draws parallels to hydrokinetic power in that it has a more continuous baseload than solar or wind and can require massive capital investment.

Unlike tidal energy, this source has already been successfully deployed in ESA. Kenya uses geothermal energy for nearly half of its electrical production (Ministry of Energy of Kenya, 2018) and is expected to double its installed generation by 2030 (IEA, 2019c). Furthermore, the heat of geothermal production can be applied to low-temperature industries like manufacturing and, in Kenya's case, insulated flower farms (IRENA, 2015). While Kenya is home to traditional hydroelectric and geothermal, the latter is now considered a more stable investment due to the severity of drought (Watts, 2019).

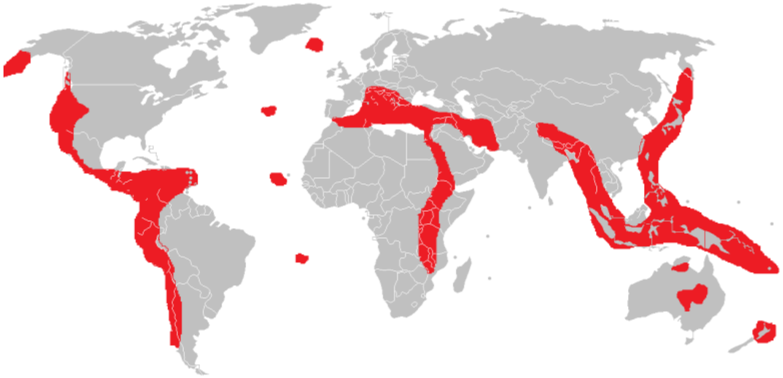

Figure 2. Global Geothermal Potential (University of Calgary, 2019)

While geothermal resources are abundant in Eastern Africa (as shown in Figure 2), they are not a silver bullet solution to growing renewable energy demands. Environmental groups in Kenya have raised concerns over infrastructure from electrical wire to water pipes. Geothermal requires water in creating the steam needed to spin the turbine, which can deplete ground resources if not adequately replenished. As in the aforementioned case of hydro dams in the region, issues of water scarcity and resiliency again fall into question.

3. Overview of tidal and river energy

I. Technology

Tidal and river energy come in several forms, but the general principle is analogous to a wind turbine. The momentum of the water current spins the blade to create electrical generation. While the physics is similar to wind energy, a tidal rotor must be significantly stronger as water is 800 times denser than air. Accordingly, if a wind and tidal blade were the same size, the tidal rotor would harness more energy than its wind counterpart due to the increased force of its surrounding (EIA, 2019).

A hydrokinetic rotor can be deployed in a continuously flowing river; the rotor is capable of spinning 180 degrees as the tide changes direction, thus capturing the energy in the opposite flow. It is important to note that unlike PV and wind turbines, the intermittency is highly predictable (as it correlates directly to lunar patterns) making it more easily harnessed for continual generation (Hollaway, 2013).

A rotor is mounted to the river or estuary floor or floating from the surface. There are advantages to placing tidal rotors on the river or estuary floor, including safety of navigation for ships and boats, lower ecological impact and protection from storms (Charlier & Finkl, 2009). However, the cost of installation of buoyed turbines is lower (Neill & Hashemi, 2018).

MRE systems are modular and adaptable to different environments, being available in various shapes, sizes and configurations. Like their wind turbine counterparts, the size of an MRE rotor is inversely correlated to the speed at which it spins (a larger rotor will spin quite slowly and vice versa). This implies that the technology can be applied to different conditions and needs.

For example, France and South Korea have installed tidal capacities of up to 250 MW (IRENA, 2014). These power stations however require a barrage or a large bridge-like structure that holds the tide and then releases it causing the propeller to spin at higher speeds. Such structures are capital intensive, disruptive to shipping channels and pose environmental risks to marine life (Charlier & Finkl, 2009).

Most tidal projects deployed today are in the form of rotors - either a single one, or a cluster. With operational maintenance every 5-7 years, the turbines are expected to last around 20-25 years (Roberts et al., 2016), although some sources claim this could be longer (Husseini, 2018).

II. Market Penetration and Deployment

In recent years, tidal energy has made significant progress from a stagnant R&D stage towards becoming commercially deployable. The United States (US) and the European Union (EU) both measure the development of technology through a metric known as the technology readiness level (TRL). While the wording between US and EU systems varies slightly, the general principles are the same: there are 9 stages with TRL 1 representing the initial observations of the design and TRL 9 signifying the technologies' proven ability to deliver operational capabilities. The majority of tidal specific rotors sit at TRL 7 (prototype demonstration), TRL 8 (system completion) and TRL 9 (proven operation) (U.S. DOE 2008; and EMEC, n.d.).

While there is a plethora of rotor models that have reached TRL 9, this does not imply market viability - let alone penetration. In fact, tidal energy is likely entering the "valley of death", a period in technology transfer that describes the gap between operational capacity and market viability. As in the case with OpenHydro, an early tidal pioneer (Offshore Energy, 2018), firms without public sector subsidization might not generate positive cash flow. Recent studies have indicated that a lower levelized cost of energy (LCOE) can be achieved by building economies of scale and optimizing installation, operations and maintenance (IOM) (Goss et al., 2020).

In the United Kingdom (UK), SIMAC Atlantis Energy has successfully deployed the world's largest tidal generator as part of the MeyGen tidal farm. The project is composed of four 1.5 MW turbines, powering an estimated 4,000 homes in 2019; the project has a goal of 400 MW (Frangoul, 2020; and Power Technology, 2018).

While these advancements in deployment are largely due to government grants like Scotland's Saltire Tidal Power Fund (Renewables Now, n.d.), the firm claims that their momentum on the MeyGen project will open opportunities for commercial investors after 2020. Additionally, they estimate that the next stages of development could create around 5,000 new jobs, many of which can be repurposed from the oil and gas sector, likely from offshore rigs (Hanley, 2020). These forward motions come as the European Commission has promoted the potential for MRE to contribute 10% of EU energy demand by 2050 (Frangoul, 2020).

While UK firms have dominated the space for large-scale rotor deployment, different approaches are being taken elsewhere. In the US, Verdant Power deployed three 35 KW rotors in the East River, a tidal estuary in New York City. While production can take 1-2 years, deployment can be set back 7-10 years by regulatory processes, although, according to Verdant, environmental impacts are negligible (T. Taylor, Co-Founder and Chief Commercial Officer at Verdant Power, personal communication, July 25, 2020).

German-based Smart Hydro has specialized in small, 5 KW modular hydrokinetic generators ideal for rivers. The rotors are easily removed from their position in the river and IOM does not require heavy machinery or construction (for example, in case a river runs dry due to drought). The firm has deployed 40 projects across the world and has begun connecting hydro rotors to generate irrigation pumps, purified water, internet access, as well as small village electrification. While these smaller systems generate a small fraction of the energy that Verdant and Atlantis have displayed, they allow for modular integration to technologies critical for sustainable development (Smart Hydro Power, n.d.-b).

4. Tidal energy: opportunities, barriers and potential solutions in ESA

Tidal rotors have the potential to provide climate-resilient, stable baseload energy in areas such as the coast of ESA – where energy poverty and inequality negatively affect the livelihoods and health of around 525 million people (author's calculations based on UN Population Division, n.d.). It also has the potential to sustainably meet future energy demand, rather than with fossil fuels or biomass (both of which exacerbate climate change and health issues).

Figure 3 shows the high environmental potential for tidal energy along the oceanic coast of Eastern and Southern Africa, given the high tidal amplitudes.

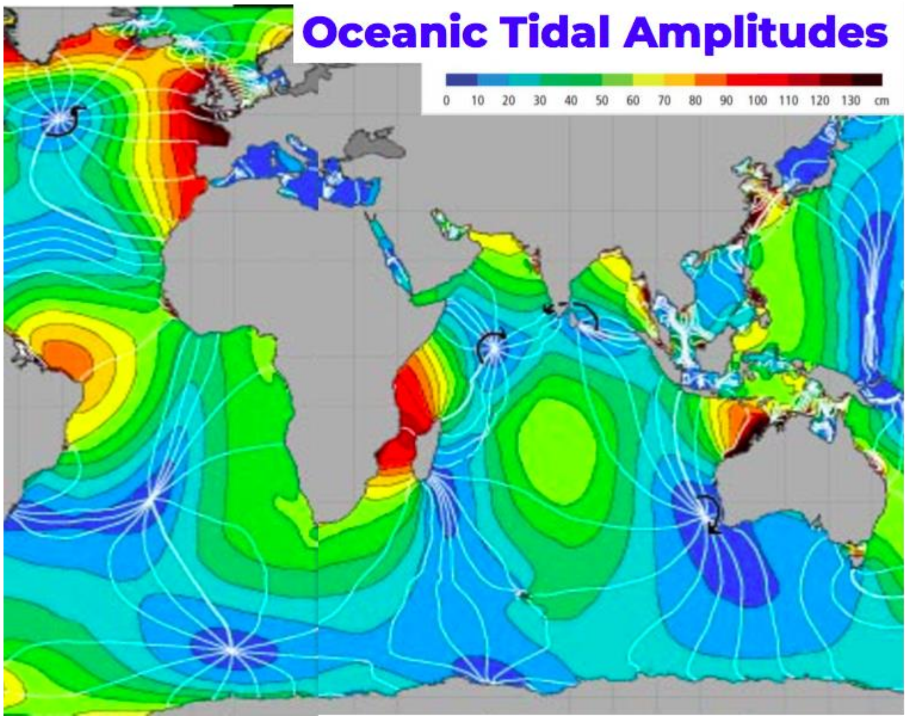

Figure 3. Tidal range resources worldwide (NASA, 2006)

Despite discussion on the potential of MRE in Africa since the 1980s (UNECA, 1980), comprehensive studies of how to implement tidal energy in the continent have not been conducted. The reason for this overlook is that challenges to introducing this source of energy are significant, and they often represent a barrier to implementation.

In this section, we will analyse the main barriers to deploying tidal energy in ESA, and what could be some of the practical solutions to these challenges. In the following section, we will discuss potential policy measures that could support the introduction of tidal energy in ESA.

This paper identifies four main barriers to the implementation of MRE in ESA:

1. High initial investments are a substantial obstacle. Domestic resources and public financing in ESA countries are generally scarce (OECD, n.d.), and interest from official development assistance has not been significant in the development of tidal energy in Africa.
2. The relative newness and under-exploitation of the technology makes it difficult to correctly estimate both capital and operational costs, as well as expected returns on investments. This uncertainty can further decrease the appeal of these projects to private investors.
3. Manufacturing and IOM of turbines and other equipment needed for supplying energy need specialized local knowledge, which is currently not present – and might take years to develop.
4. Finally, regulatory complexity (for example, in terms of environmental permits) can represent a significant barrier as it causes delays in the deployment of technology.

While regulatory complexity and specialized personnel are relatively straightforward issues to address, once there is the political will to overcome these barriers, it can be exceedingly complex – or downright impossible – to finance large projects or attract suitable investors. In fact, the energy return on investment (EROI) of tidal and wave projects is currently considered quite low, indicating low interest from investors (Capellán-Pérez et al., 2019).

Larger projects, which can provide a stable source to satisfy baseline energy demand in ESA, can be appealing for institutions like a green bank or a multilateral development bank. However, hydrokinetic projects can be scaled down and installed in a river rather than in an estuary, with lower costs and significantly higher geographical potential (see Figure 4 for an overview of the geographical potential of river tidal energy generation).

Figure 4. Potential for river tidal at the global level (based on world rivers with over 10km^3 of yearly discharge) (McGlynn, 2014).

Due to the significant investment required, the potential for larger ocean tidal projects have been deemed low in ESA, as discussed (IRENA, 2015). However, these projects could benefit from future advancements of projects in other countries (e.g. US and the UK), where technologies are currently close to commercialization and being deployed at increasing scale; they can also benefit from lessons learnt from other high-investment renewable energy projects, such as geothermal (as we will discuss in section 5.III).

5. Proposed policy solutions to introduce MRE in ESA

This paper outlines three proposed policy and financing solutions that can support the adoption of MRE in ESA. The proposals should not be seen as mutually exclusive; rather, they intend to fill several gaps in the electrification of the region, through complementary solutions that respond to different energy needs (urban vs. rural, low-investment and low supply vs. high-investment and large supply), investment opportunities and ownership modalities.

I. Small hydrokinetic projects in river and estuaries

As mentioned in section 4, hydrokinetic projects can be scaled down to the level of a single turbine; however, even a medium-sized project (providing up to 35 MW of energy) has manufacturing and installation cost as low as 1M USD (T. Taylor, personal communication, July 25, 2020), making the scale of investment potentially appropriate for public investors, donors or even private investors (including those financed under non-recourse energy loans).

Small projects, although they might not contribute significantly to the baseline energy of the future, have the potential to support a range of sustainable development outcomes, and to democratize access to energy. Several countries in Africa have been implementing local, small scale solutions that rely on different renewable energy sources. Currently, around 15M people are connected through micro-grids; this is still a very low number compared to the 600M people who have limited or no access to electricity (IEA, 2019a).

In fact, as it stands today, the only hydrokinetic project in SSA is extremely small. Smart Hydro, a German firm specializing in small modular rotors has successfully deployed one of its systems in the Nigerian village of Akwanga along the Mada River (Smart Hydro Power, n.d.-a).

In the Western Cape of South Africa, a 1 MW wave energy power station is in early stages of construction; it is intended as the first stage of a power plant eventually reaching a 3.5 MW capacity (Creamer, 2019). Ghana has signed a deal with Swedish firm Seabased to supply MRE energy to the Ada Estuary. The project is likely at an early stage and the logistics are extremely unclear (Balaji, 2014; and Harris, 2018).

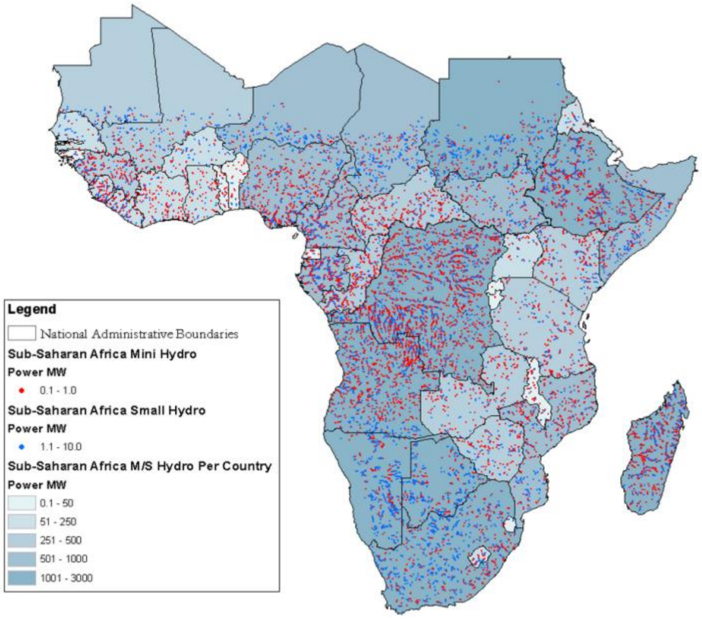

Figure 5. Small-scale hydropower potential in Africa (Korkovelos et al., 2018)

While Figure 5 shows the potential for small-scale hydropower projects in the region, further research is needed to effectively assess which rivers in ESA would be ideal to implement small rotor MRE technology. For optimal cost-effective performance, rivers should flow with a speed of at least 2 meters per second. If the turbine is to be mounted to the river floor, the body of water should be at least 7 meters deep (T. Taylor, personal communication, July 25, 2020) - this constraint can be circumvented if the turbine floats like in the case of SmartHydro.

The initial investment for these projects is small-scale enough that it can be funded with grants from multilateral development banks or with government funds (IRENA, 2012); this model is already largely employed by the International Finance Corporation (IFC) to bring low-carbon electricity to SSA. It is an approach that bypasses large scale electrical grids and allows for development to be centralized in smaller regions (Lawrence, 2020). As traditional, monolithic hydropower becomes more precarious, there is room to reimagine how hydrokinetic energy production is financed and deployed.

These projects have a number of benefits, including that they can be owned by the local community and used to provide basic services, such as water purification or telecommunication hubs. They also have the advantage of not requiring extensive distribution grids. Being more localized, these projects can electrify remote, non-urban areas with sparse population.

Once the solidity of these projects is proven, they can also become interesting for more complex instruments, including green bonds and international carbon offset schemes.

In terms of ownership and financing of small-scale MRE projects, we propose a model whose ultimate goal is to promote equity and sustainability, and not just deliver power to final consumers:

a. <u>Private ownership and/or financing</u>

This first option reduces the need for public financing of the projects. The capital investment would be supplied by private investors, and essentially work as a loan to the local community – while the central government would intervene just as a regulator, and not as a lender.

To ensure the attractiveness of investment in these projects, governments could introduce a series of supporting measures, including incentives (in the form of full or partial tax deductions) to investors. Initial ownership of the project stays with the private company and is gradually passed to the local authority as the power generated from the project is sold (at regulated rates) and repays the investment over time, plus a reasonable rate of return. This option could be made less risky through the use of collateral from the central government. It could be extremely attractive for investors and private companies of any kind, while requiring limited administrative efforts as the repayment of the loan is essentially operated through a fee collection in the local community.

The Beyond the Grid Project, promoted by Power Africa, is an example of how the role the private sector can play in powering Africa. With a goal to double access to electricity in Africa by 2030, Beyond the Grid brings together 40 private sector partners to support and finance (or facilitate access to private financing) to off-grid renewable energy companies (USAID, 2020b).

b. <u>Public ownership and/or financing or public-private partnerships (PPP)</u>

A second option can be the public financing of projects (or a public participation in a private partnership) by the central government. This option can be particularly useful in cases where the EROI is low or there is too much risk for private investors. The process should still be inserted in a context of policies to increase community participation and ownership; for example, building the project can be seen as a loan from the central government, which has to be repaid by the community through a percentage of collected electricity fees over a specified period of time; at the end of this period, fees can be administered by the local community and used for social purposes. As in the previous case, fees should be regulated.

Nigeria has been spearheading this approach through the Rural Electrification Agency and a combination of micro-grid and large-scale electricity projects, mostly focused on solar PV (Nigeria Rural Electrification Agency, 2017). The effort is a good example of a mix of development assistance and lending: through the Green Energy Project, the UN Development Programme (UNDP) provides funds to Nigeria’s Bank of Industry (a national

> development bank), which in turn provides loans, at favourable terms, to local businesses for the installation of off-grid solar projects (Burger, 2017).
>
> Another successful example of this model is the Scaling Solar project in Zambia. Zambia receives nearly 80% of its electricity (Othieno & Awange, 2016b) from hydroelectric power. As a result of their high dependence on hydro and continuing climate disruption, Zambia has been working alongside the IFC to rapidly deploy solar PV with a current mandate of 600 MW and 2030 goals of reaching 6,000 MW installed capacity (World Bank, 2019). The project promotes private sector growth and low-cost electricity supply.

Both options would also require investment in building the capacity in the local community to operate the project and to conduct related administrative tasks (such as fee collection).

While these solutions are relatively simple from a financing and technological point of view, they do pose a significant political problem between the local and central government, as the central government may not be willing to relinquish control (and potential revenue) over the supply of energy. Additionally, suitable pre-existing conditions must be in place – for example, a certain degree of autonomy of municipalities or other local entities; their ability to collect fees, sufficient transparency and accountability.

In this respect, Kenya could be a good candidate for a pilot project, as the country has strong potential for river deployment, coupled with a rising degree of grid decentralization and reliable administrative capacity at the central and local level.

II. Large MRE projects in the ocean

In scenarios of increasing droughts, it will not be possible to rely solely on small-scale or conventional hydropower. It is therefore important to also consider complementary sources of energy to counter hydro depletion. For this reason, coastal countries should start investigating large projects that use ocean tides to generate energy. As mentioned, the potential for ocean tide MRE is particularly ripe in coastal countries of Eastern Africa (see Figure 3).

The potential for this scale is likely to be more interesting in 2030-2040, when ocean power projects will have already been deployed in a number of countries – indicating that costs and risks will have likely decreased due to more extensive commercial penetration. Ocean tidal technology is expected to overcome the “valley of death” in the EU market and become commercially viable by around 2025 (European Commission, 2018).

The question for larger projects, which aim to supply an extended geographical area, remains how to build the distribution infrastructure necessary for the population to use the generated power. Therefore, this technology would be best suited to supply electric power to urban areas, rather than sparse communities.

Geothermal energy generation in Kenya can provide a useful parallel to identify strategies and mechanisms to deploy and finance large-scale tidal energy. Kenya has invested in long-term infrastructure and capacity-building like the Geothermal Training and Research Institute (GETRI) in Nyeri (Dedan Kimathi University of Technology, n.d.). Relying on a mix of public finance and concessional funding from several multilateral development banks, Kenya is planning to develop over 5,000MW of its 7,000MW potential from geothermal (currently, only 200MW are on stream) (Climate Investment Funds, 2015).

In harnessing geothermal power, Kenya has positioned itself as a leader in the geothermal-rich region; Tanzania and Ethiopia are also exploring projects. Not only will geothermal energy play an essential role in decarbonization and hydro replacement, but it could also help with the deployment of tidal energy in the country. While Kenya has potential for river and stream tidal systems, it is also a strong choice to deploy marine tidal power. Research has identified ideal locations in the estuaries of Lamu, Mombasa and most notably, Watamu (Onundo, 2017), and high overall environment for the energy source (Onundo, L.P., & Mwema, 2017). As illustrated in Figure 6, the tide in Watamu (listed as location “A”) moves at a rate of 2.5 meters per second (Hammar et al., 2012), which exceeds the aforementioned minimum speed of 2 centimeters per second required for economically viable tidal development.

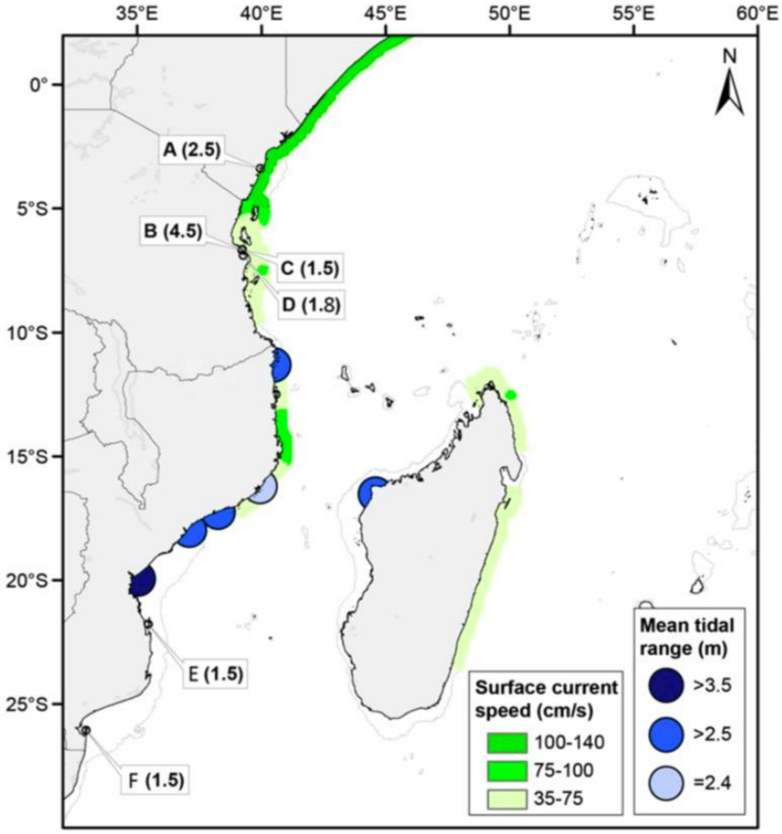

Figure 6. Seasonal average surface current speed in Eastern Africa (Hammar et al., 2012)

While the bay of Dar es Salaam, Tanzania has potential for tidal power (Dubi, 2007), the city’s electrical struggles are due primarily to an outdated grid rather than inadequate supply (Garside & Wood, 2018). This being said, the capital cities’ electrical stability comes at the cost of expanding gas consumption and infrastructure (World Bank, 2016). In the Dar es Salaam district, the resort town of Kunduchi (location “B” in Figure 6) has tidal speeds of around 4.5 meters per second (Hammar et al., 2012), which would likely be an exceptionally lucrative point to establish this technology.

Mozambique also has large potential for tidal development. In particular, Maputo Bay has already been researched for its tidal patterns (Canhanga & Dias, 2005) and can contribute to the large energy demand of Maputo. However, more research is needed to conclusively establish locations

III. Facilitating an equitable technology transfer of tidal energy

Deployment of hydrokinetic energy in ESA must coincide with the empowerment and employment of local citizens. Education in tidal technology should be regarded as a critical component to sustainable projects. The above-mentioned GETRI geothermal program in Kenya is a prime example of how to build the necessary workforce for the IOM of projects.

For example, the United Nations University (UNU) hosted a geothermal workshop in Kenya through UNU's Geothermal Training Program, GTP (UNU, 2018). Similar programs could help disseminate expertise on MRE, potentially in collaboration with institutions such as Oxford University, which has a leading tidal research program (University of Oxford, n.d.).

Because Kenya is a prime location for tidal deployment and already advanced in geothermal adaption, it could also work as a location to integrate tidal technology into education. Nairobi is already home to a Technical University (The Technical University of Kenya, n.d.) and a Technical Training Institute (Nairobi Technical Training Institute, n.d.), both of which could have early programs in renewable energy as well as environmental studies.

South Africa also shows capacity-building potential. For example, the Cape Peninsula University of Technology has a program known as the South African Renewable Energy Technology Centre (SARTEC) that specializes in wind turbine technician certification (CPUT, n.d.). Stellenbosch University's Centre for Renewable and Sustainable Energy Studies (CRSES) is already teaching a course on hydro and ocean energy (CRSES, n.d.).

Additionally, South Africa is the only African nation to produce wind turbines. Kestrel wind turbines are extremely small but function in an analogous manner to Smart Hydro rotors: they can be paired with adjacent processes like water treatment or telecommunication (Kestrel Renewable Energy, n.d.). Down the line, having the manufacturing infrastructure already available could help ensure a local content requirement be attainable if production of small scale hydrokinetic will be scaled up.

6. Conclusions

Given that Africa is projected to surpass China's oil demand growth at 3.1 mb/d by 2040 (IEA, 2019a), MRE technologies can offer potential solutions in the long-term strategy to sustainably electrify the region. Despite ocean tidal potential along the coast of ESA, as well as hydrokinetic potential in its rivers and estuaries, power stations harnessing MRE in the region have not yet been developed to scale.

Barriers to the implementation of MRE in the region are mainly not technological, but rather linked to policy design and financing capacity. These challenges can be addressed through suitable design of projects, political will to build financing options, an incentivizing policy environment, and capacity building.

Three complementary solutions were outlined to set a working framework for MRE deployment in ESA: short-term, small-scale hydrokinetic projects with public or private financing (similar to microgrid and off-grid solar projects); long-term, large-scale tidal projects with public and concessional financing (similar to geothermal power generation); and capacity building to ensure employment of local citizens. In particular, small scale hydrokinetic projects can have ownership structures that favor local authorities or communities.

While these programs would be both environmentally and socially beneficial, further research is required to assess feasibility and potential costs of specific tidal energy locations in the region. Additionally, deployment of both small and large projects would need a better understanding of ecological impacts on the specific environmental conditions of ESA countries.

7. Acknowledgments

The authors would like to thank Trey Taylor, Co-Founder and Chief Commercial Officer at Verdant Power, for providing useful background material and advice; as well as the colleagues at the International Conference on Sustainable Development (held virtually on 22 September 2020), where the paper was presented, for their useful feedback.

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