Consilience: The Journal of Sustainable Development
Iss. 23, 2021, pp. 1-14.

CONSILIENCE

THE JOURNAL OF SUSTAINABLE DEVELOPMENT

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

Elena Belletti* and Milo McBride

Abstract

Sub-Saharan Africa is at a crucial juncture in shaping its energy future: while two-thirds of its population lack access to electricity, the continent 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. An analysis of the energy mix in the ESA region shows that MRE could fill some of the electricity supply gaps. The largest barriers to MRE are not technological, but rather linked to policy design and financing capacity. Three complementary solutions are 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 the employment of local citizens.

Elena Belletti is with the United Nations Department of Economic and Social Affairs, Two UN Plaza New York, NY 10017 USA (email: eb3269@columbia.edu).

Milo McBride is an advisor & contributing writer with Climate & Capital Media, 189 Franklin Street Suite 593, New York, NY 10013 USA (email: mbm2227@columbia.edu).

*The views expressed in this paper are those of the authors only and do not necessarily represent those of the United Nations.

Author's Note

Renewable energy discussion in Africa revolves mostly around hydroelectric power generation, wind, and solar photovoltaic (PV). However, these resources have limitations: hydroelectricity is expected to decline and become more unreliable because of climate change, and, although wind and solar PV both have a high potential, according to IRENA they will only count for up to 15 percent of the energy mix in 2030. 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

I. INTRODUCTION

As a global push for decarbonization takes 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 shows potential for a lesser-known energy source: hydrokinetic energy.

Also known as marine renewable energy (MRE), hydrokinetic energy systems are being explored in various shapes, sizes, and configurations. Because MRE is modular and adaptable to different environments, as well as the fact that tides are predictable and have lower intermittency than other renewable sources, this technology has significant potential as a stable source of renewable energy. Additionally, this source of energy is relatively resilient and adaptable in the context of climate change.

However, the number of countries worldwide that have adopted MRE is still small, and, in Africa, there are very few MRE projects (mostly small and still in the development phase). While South Africa has early developments of wave energy, the following sections 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 to Africa's utilization of MRE are in part technological, the large capital costs required to develop 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 analyzes 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 the necessity of keeping 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 interests 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 rates analogous to 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 supply up to 22 percent of Africa's total energy consumption by 2030, there is room for improvement, especially since the continent's electricity demand is expected to triple in the same timeframe (IRENA, 2015).

Nearly half the population in sub-Saharan Africa (SSA) today is living in "energy poverty," (IEA, 2019a) a concept that can be defined as "a) lack of access to electricity networks; or b) dependence on burning solid biomass such as wood, straw, and dung, in inefficient and polluting stoves to meet energy needs" (Laldjebaev et al, 2016). In this regard, scaling diverse, sustainable, and renewable energy systems in ESA can be seen as a means to diminish future dependence on fossil fuels and reduce their consequences, namely global greenhouse gas emissions and local health concerns.

II. TRENDS IN THE ENERGY SECTOR AND POWER GENERATION IN SSA

This section analyzes the current challenges faced by power generation, including the energy sector's 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 percent per year between 2014 and 2018, a notable success. While countries such as Kenya, Ethiopia, and Rwanda are on track to domestically eliminate 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 percent 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.

A. 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 not only impeded hydroelectric power generation, but also hindered fossil fuel-powered generators that require water for cooling; during this time, the country's reserve energy margin dropped well beneath the threshold to avoid blackouts (Wang et al., 2017). Since 2015, Mozambique has been the largest producer of hydroelectric energy in SSA (EIA, 2018), generating 87 percent 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 both domestic and export demands (Kuo, 2016).

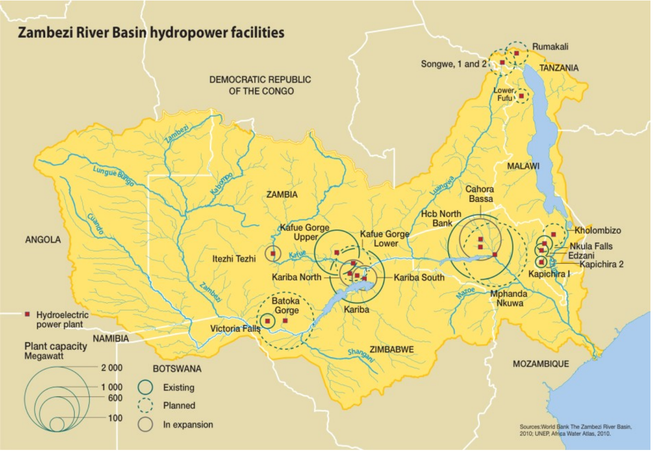

Figure 1: Zambezi River Basin hydropower facilities (World Bank, 2018)

These issues extend beyond the needs of Mozambique. The Zambezi River is considered a lifeline to the region, providing fresh water to the six SSA nations through which it flows. With a multitude of dams already constructed, the river today is at its lowest level in almost 50 years. The consequences of this drought include not just energy depletion, but also destabilized crop harvests, fishing yields, and consistent 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 frequently been unfulfilled. 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 when the country turned to gas and coal as a replacement (Hellmuth, 2019).

In sum, droughts can significantly impact hydroelectric generation in ESA, and, as a result, threaten both the sustainable development and stability that hydroelectricity galvanized. To mitigate future disruptions in energy supply, alternative methods of sustainably harnessing energy from bodies of water and other natural resources must be considered.

B. 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 one percent 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 from geothermal production can be redirected 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 energy, the latter is now considered a more stable investment due to the severity of drought (Watts, 2019).

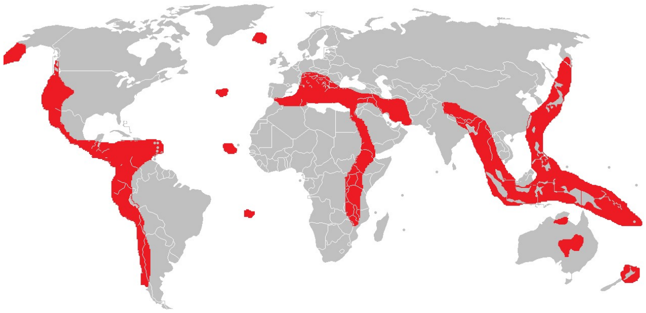

Figure 2: Global Geothermal Potential (University of Calgary, 2019)

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 wires to water pipes. Geothermal requires water to create the steam needed to spin the turbine; if not adequately replenished, overdrawing surface water can deplete ground resources. As in the aforementioned case of the region's hydroelectric dams, water scarcity and resiliency again fall into question. While geothermal production is likely to increase in areas with high potential (see Figure 2), limited water and geothermal resources could prevent this energy source from replacing hydroelectricity altogether.

III. OVERVIEW OF TIDAL AND RIVER ENERGY

A. *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 are similar to wind energy, a tidal rotor must be significantly stronger, as water is 800 times denser than air. Accordingly, if a tidal blade and a wind blade were the same size, the tidal rotor would harness more energy than its wind counterpart due to the increased force of its surroundings (EIA, 2019).

A hydrokinetic rotor is 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 continuous electricity generation (Hollaway, 2013). The rotor is mounted to the river or estuary floor or floats on 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 installing buoyed turbines is lower (Neill & Hashemi, 2018).

MRE systems, available in various shapes, sizes, and configurations, are modular and adaptable to different environments. Like their wind turbine counterparts, the size of an MRE rotor is inversely correlated to the speed at which it spins (that is, a large rotor will spin slowly and vice versa). This versatility allows the technology to be applied to different conditions and meet different needs. For example, France and South Korea have installed tidal capacities of up to 250 MW (IRENA, 2014). These power stations require a large bridge-like structure called a barrage. The barrage holds the tide and then releases it to cause the MRE propeller to spin at higher speeds. However, barrages 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 five to seven 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).

B. Market Penetration and Deployment

In recent years, tidal energy has made significant progress from a stagnant R&D stage toward becoming commercially deployable. The United States and the European Union both measure the development of technology through a metric known as the Technology Readiness Level (TRL). While the wording between U.S. and EU systems varies slightly, the general principles are the same: there are nine stages, with TRL 1 representing the initial observations of the design and TRL 9 signifying the technology's 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; EMEC, n.d.).

While there are a plethora of rotor models that have reached TRL 9, this does not imply market viability—let alone market 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 enough positive cash flow and subsequently fall victim to bankruptcy. This signals that technology innovators will need support from government bodies and multilateral institutions to ensure adequate demand for energy systems that have not yet been fully commercialized. This could mean that utility providers and consumers will not reap the benefits of nascent energy technologies without adequate support for market penetration and more realistic costs. Recent studies have indicated that it is possible to achieve a lower levelized cost of energy (LCOE) for tidal energy through economies of scale and optimized installation, operations, and maintenance (IOM) (Goss et al., 2020).

In the United Kingdom, 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, and has an overall goal of 400 MW (Frangoul, 2020; 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 percent of EU energy demand by 2050 (Frangoul, 2020).

While U.K. firms have dominated the space for large-scale rotor deployment, different approaches are being taken elsewhere. In the United States, Verdant Power deployed three 35 KW rotors in the East River, a tidal estuary in New York City. Though production can take as little as one to two years, deployment can be set back seven to ten years by regulatory processes, despite the fact that, according to Verdant, environmental impacts are negligible (Taylor, 2020, personal communication).

German-based Smart Hydro has specialized in small, modular five KW hydrokinetic generators that are ideal for rivers. The rotors are easily removed from their position in the river, and IOM does not require heavy machinery or construction (a design consideration for if a river runs dry due to drought, for example). The firm has deployed 40 projects across the world, and has begun installing hydro rotors to run irrigation pumps, purify water, provide internet access, and bring electricity to small villages. While these smaller systems generate a small fraction of the energy that Verdant and Atlantis have displayed, they incorporate modular integration into technologies critical for sustainable development (Smart Hydro Power, n.d.-b).

IV. 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 (authors' calculations based on UN Population Division, n.d.). Tidal energy also has the potential to meet future energy demand sustainably 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 area’s high tidal amplitudes.

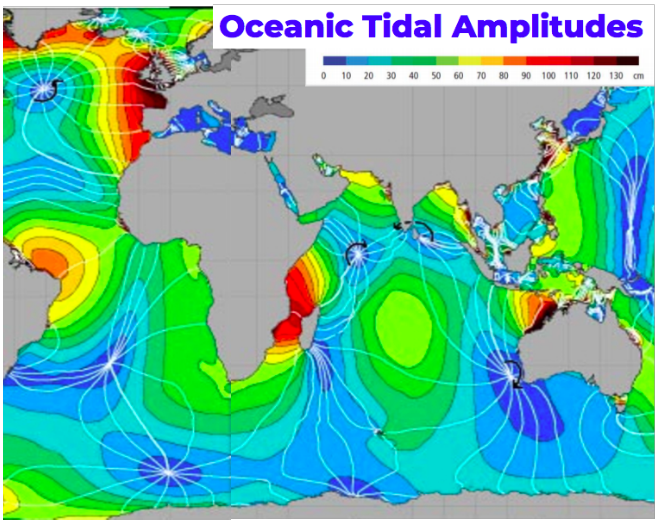

Figure 3: Tidal range resources worldwide (NASA, 2006)

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. This oversight is largely due to the significant challenges of introducing this source of energy that often impede implementation. In this section, we will analyze the main barriers to deploying tidal energy in ESA and discern 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 make 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 for private investors.
3. The manufacturing and IOM of turbines and other equipment needed for supplying energy need specialized local knowledge, which is currently absent—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 still be exceedingly complex—or even 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, potentially resulting in 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. Figure 4 shows an overview of rivers with a yearly discharge of over 10km^3, demonstrating the significant potential for river tidal energy generation in ESA.

Figure 4: Potential for river tidal energy generation 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 has been deemed low in ESA (IRENA, 2015). However, these projects could benefit from future advancements of projects in other countries, such as in the United States or the United Kingdom, where technologies are currently close to commercialization and are increasingly being deployed. ESA's larger ocean tidal projects can also benefit from lessons learned from other high-investment renewable energy projects, such as geothermal (as we will discuss in Section 5(C)).

V. PROPOSED POLICY OPTIONS TO INTRODUCE MRE IN ESA

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

A. Small Hydrokinetic Projects in Rivers 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 costs as low as 1 million USD (Taylor, 2020, personal communication). Thus the scale of investment can be appropriate for public investors, donors, or even private investors (including those financed under non-recourse energy loans).

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

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 one MW wave energy power station is in the 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 still at an early stage and the logistics remain extremely unclear (Balaji, 2014; Harris, 2018).

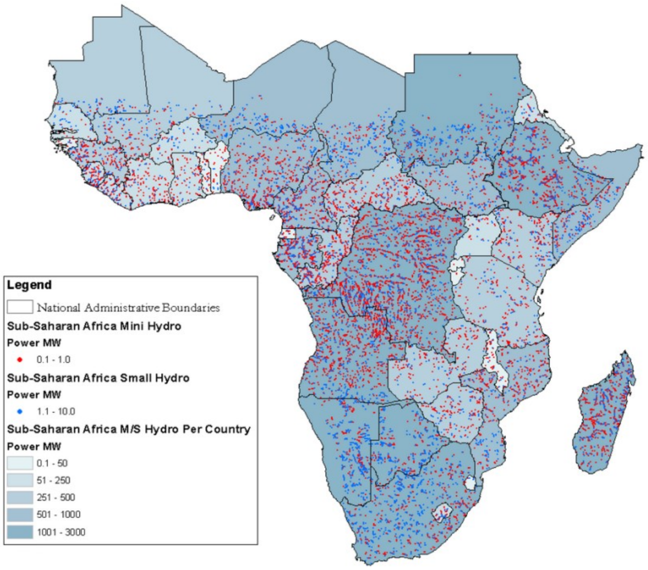

Figure 5: Small-scale hydropower potential in Africa (Korkovelos et al., 2018)

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 at a speed of at least two meters per second. If the turbine is to be mounted to the river floor, the body of water should be at least seven meters deep (Taylor, 2020, personal communication). This constraint can be circumvented if the turbine floats, as is the case of SmartHydro.

The initial investment for these projects is small-scale enough to be funded with government funds or grants from multilateral development banks (IRENA, 2012); this model is already frequently 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, notably that they can be owned by the local community and used to provide basic services, such as water purification or telecommunication hubs. They do not require extensive distribution grids; since they are localized, these projects can electrify remote, non-urban areas with sparse populations. Once the solidity of these projects is proven, they can become more complex instruments and be incorporated into 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:

i. Private ownership and/or financing

This first option reduces the need for public financing of the projects. Private investors would supply the capital investment that would essentially work as a loan to the local community—the central government would intervene solely as a regulator, 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; it is gradually passed to the local authority as the power generated from the project is sold (at regulated rates), repaying 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 while requiring limited administrative efforts, since the repayment of the loan is essentially operated through a fee collection system in the local community.

The Beyond the Grid Project, promoted by Power Africa, is an example of the significant role that the private sector can play in powering Africa. With a goal to double the 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 for) off-grid renewable energy companies (USAID, 2020b).

ii. Public ownership and/or financing or public-private partnerships (PPP)

A second option can be the public financing of projects (or public participation in a private partnership) by the central government. This option can be particularly useful in cases where the project's EROI is low (which might discourage investors) or there is too much risk for private investors. The process should still be inserted in the 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 favorable 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 percent of its electricity from hydroelectric power (Othieno & Awange, 2016b). 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 of 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 pose a significant political problem to the power dynamics 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, the project must maintain a certain degree of autonomy of municipalities or other local entities and their ability to collect fees, have sufficient transparency, and be accountable. In this respect, Kenya could be a good candidate for a pilot project, since 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 government levels.

B. 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 earlier, the potential for ocean tide MRE is particularly ripe in coastal countries of Eastern Africa (see Figure 3).

From 2030 to 2040 when ocean power projects will have already been deployed in a number of countries—indicating that costs and risks have decreased due to more extensive commercial penetration—the potential for MRE will be even more interesting. 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 for identifying 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 plans to develop over 5,000 MW of its 7,000 MW potential from geothermal (currently, only 200 MW are on stream) (Climate Investment Funds, 2015).

In harnessing geothermal power, Kenya has positioned itself as a leader in a geothermal-rich region, and 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 the 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), in addition to a promising overall environment for the energy source (Onundo & 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 two centimeters per second required for economically viable tidal development.

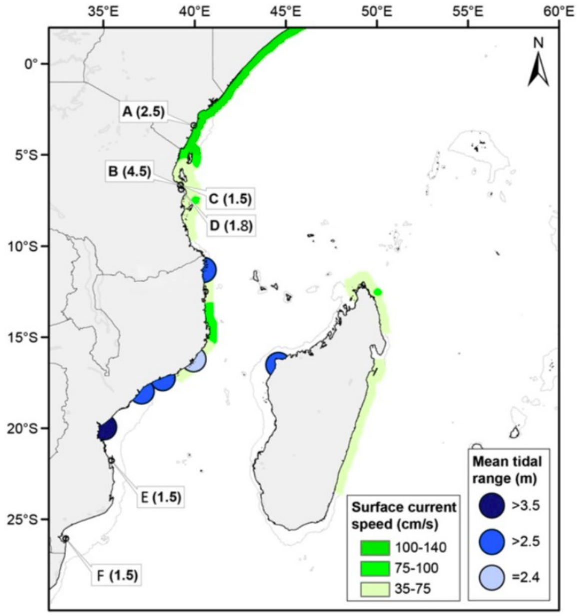

Figure 6: Seasonal average surface current speed in Eastern Africa (Hammar et al., 2012)

With the bay of Dar es Salaam, Tanzania also has a high potential for tidal power (Dubi, 2007); the city's current electrical struggles are due primarily to an outdated grid rather than inadequate supply (Garside & Wood 2018). Still, the city's electrical supply 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), establishing tidal technology here would likely be an exceptionally lucrative move.

Mozambique also has a 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 prime deployment locations.

C. Facilitating an Equitable Technology Transfer of Tidal Energy

The deployment of hydrokinetic energy in ESA must coincide with the empowerment and employment of local citizens. Education in tidal technology should be a critical component of sustainable projects. The aforementioned 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 the 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 is already advanced in geothermal adaption, it could also be 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 potential for capacity building. 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 and can be paired with adjacent processes such as water treatment or telecommunication (Kestrel Renewable Energy, n.d.). Having manufacturing infrastructure already in place can help ensure the feasibility of a local content requirement in the event the production of small-scale hydrokinetic energy is scaled up.

VI. CONCLUSIONS

While Africa is projected to surpass China's oil demand growth at 3.1 mb/d by 2040 (IEA, 2019a), solar PV and wind energy are only projected to supply around 15 percent of the electricity demand in the continent in 2030 (IRENA, 2015)—leaving a huge gap in the energy mix. There is evident potential for additional renewable resources to supply clean energy. In this context, MRE technologies can offer some solutions for the long-term strategy of sustainably electrifying the region. However, despite hydrokinetic potential in the rivers and estuaries of ESA, power stations harnessing MRE in the region have not yet been fully developed.

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 the suitable design of projects, the political will to build financing options, an incentivizing policy environment, and capacity building. In a nutshell, the penetration of MRE will be based on political commitment backed by sufficient public resources, rather than on revolutionary innovation and technological development. Both of these essential ingredients can be provided by governments, but should be supported by the commitments of multilateral financial institutions invested in a long-term vision of diversifying renewable energy sources and expanding their potential.

In this paper, we outline three complementary solutions 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 measures to ensure the employment of local citizens. In particular, small scale hydrokinetic projects can have ownership structures that favor local authorities or communities.

As the world moves away from greenhouse gas-emitting energy sources, it is imperative to conceptualize long-term visions of how various RE energy can work together synergistically. It has been argued that when PV reaches between 30-40 percent penetration of the electrical grid, issues of balancing intermittent generation with storage could reduce the value of solar energy and thus prevent further momentum toward its generation (Sivaram et al., 2018). In the long run, advancing other renewable energy systems will be required to help ensure progress towards net zero decarbonization goals, an area in which MRE can play an important role.

One of the most promising examples of how MRE can be accelerated is alongside offshore wind. Developers are currently testing how MRE technologies could be attached beneath floating offshore wind turbines. It is believed that this hybridization could help wind farms balance out periods of low-velocity wind, since MRE systems will generate a more continuous baseload. For MRE firms, this could be a prime means of building their systems to a greater scale and thus catalyzing necessary advancements in technology, expertise, and cost reduction (Deign, 2020). According to IRENA, “the theoretical potential for wind in Africa exceeds demand by orders of magnitude, and about 15 percent of the potential is characterized as a high-quality resource. This enormous capacity is not evenly distributed: Eastern, Northern, and Southern Africa have particularly excellent wind resources” (IRENA, 2015). A more recent study in *Renewable and Sustainable Energy Journal* concludes that the coast of ESA has the highest offshore wind speeds in the continent (Elsner, 2019). Thus, as ESA is ripe with offshore wind resources that geographically overlap with the aforementioned tidal potential, there could be ample opportunity for the implementation of MRE alongside wind farms, helping propel the technology forward.

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

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 their colleagues at the International Conference on Sustainable Development (held virtually on September 22, 2020), where the paper was presented, for their useful feedback.

REFERENCES

Balaji, S. (2014, July 22). *Ghana to harness tidal energy to generate 1,000MW of power.* African Review. https://www.africanreview.com/energy-a-power/renewables/ghana-to-harness-tidal-energy-to-generate-1000mw-of-power.

Burger, A. (2017, January 21). *Nigeria Bank of Industry pumps up mobile pay-go, solar microgrid financing.* Microgrid Media. http://microgridmedia.com/nigeria-bank-industry-pumps-mobile-pay-go-solar-microgrid-financing/.

Canhanga, S., & Dias, J. (2005). Tidal characteristics of Maputo Bay, Mozambique. *Journal of Marine Systems*, *58*, 83–97. https://doi.org/10.1016/j.jmarsys.2005.08.001.

Cape Peninsula University of Technology, CPUT. (n.d.). *South African Renewable Energy Technology Centre (SARETEC).* https://www.cput.ac.za/academic/shortcourses/centres/saretec.

Capellán-Pérez, I., de Castro, C., & Miguel González, L. J. (2019). Dynamic Energy Return on Energy Investment (EROI) and material requirements in scenarios of global transition to renewable energies. *Energy Strategy Reviews*, *26*, 100399. https://doi.org/10.1016/j.esr.2019.100399.

Castaneda Aguilar, R. A., Mitchell Jolliffe, D., Fujs, T., Lakner, C., & Beer Prydz, E. (2019, October 3). 85% of Africans live on less than $5.50 per day. World Bank. https://blogs.worldbank.org/opendata/85-africans-live-less-550-day.

Central Intelligence Agency, CIA. (n.d.). *The World Factbook - Central Intelligence Agency*. Accessed 1 August 2020. https://www.cia.gov/library/publications/the-world-factbook/.

Centre for Renewable and Sustainable Energy Studies, CRSES. (n.d.). *Postgraduate Programmes Coursework*. https://www.crses.sun.ac.za/studies-postgraduate-programmes-coursework.

Charlier, R. H., & Finkl, C. W. (2009). Environment and economics. In R. H. Charlier & C. W. Finkl (Eds.), *Ocean energy: Tide and tidal power* (pp. 153–160). Springer.

Climate Investment Funds. (2015, August 25). *Kenya*. https://www.climateinvestmentfunds.org/country/kenya.

Creamer, T. (2019, June 13). *Pioneering 1 MW wave-energy pilot project being built in Hermanus*. Creamer Media's Engineering News. https://www.engineeringnews.co.za/article/pioneering-1-mw-wave-energy-pilot-project-being-built-in-hermanus-2019-06-13.

Dedan Kimathi University of Technology. (n.d.). *Geothermal Training and Research Institute (GETRI)*. https://getri.dkut.ac.ke/.

Deign, J. (2020, November 18). *Developers look beyond floating wind to hybrid power-generation platforms.* Greentech Media. https://www.greentechmedia.com/articles/read/developers-look-beyond-floating-wind-to-hybrid-power-generation-platforms.

Dubi, A. (2007, October). Tidal power potential in the submerged channels of Dar Es Salaam coastal waters. *Western Indian Ocean Journal of Marine Science 5*(1), 95-104. https://doi.org/10.4314/wiojms.v5i1.28501.

Energy Information Administration of the United States, EIA. (2018). *Hydro and fossil fuels power electricity growth in Sub-Saharan Africa*. Today in Energy. https://www.eia.gov/todayinenergy/detail.php?id=37153

EIA. (2019). *Tidal power*. https://www.eia.gov/energyexplained/hydropower/tidal-power.php.

Elsner, P. (2019). Continental-scale assessment of the African offshore wind energy potential: Spatial analysis of an under-appreciated renewable energy resource. *Renewable and Sustainable Energy Reviews*, *104*, 394–407. https://doi.org/10.1016/j.rser.2019.01.034.

European Commission. (2018, March 21). *OceanSET Implementation Plan*.

European Marine Energy Centre, EMEC. (n.d). *Technology Readiness Levels.* https://www.emec.org.uk/services/pathway-to-emec/technology-readiness-levels/.

Frangoul, A. (2020, January 27). *A tidal project in Scottish waters just generated enough electricity to power nearly 4,000 homes*. CNBC. www.cnbc.com/2020/01/27/tidal-project-generates-electricity-to-power-nearly-4000-homes.html.

Garside, B., & Wood, D. (2018, June 19). *Improving Tanzania's power quality: Can data help?* International Institute for Environment and Development. https://www.iied.org/improving-tanzanias-power-quality-can-data-help.

Goss, Z. L., Coles, D. S., & Piggott, M. D. (2020). Identifying economically viable tidal sites within the Alderney Race through optimization of levelized cost of energy. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, *378*(2178), 20190500. https://doi.org/10.1098/rsta.2019.0500.

Hafner, M., Tagliapietra, S., & de Strasser, L. (2018). *Energy in Africa: Challenges and opportunities*. Springer Nature.

Hammar, L., Ehnberg, J., Mavume, A., Cuamba, B. C., & Molander, S. (2012). Renewable ocean energy in the Western Indian Ocean. *Renewable and Sustainable Energy Reviews*, *16*(7), 4938–4950. https://doi.org/10.1016/j.rser.2012.04.026.

Hanley, S. (2020, January 29). *MeyGen tidal power facility exported 13.8 GWh of electricity to the UK grid in 2019*. CleanTechnica. https://cleantechnica.com/2020/01/29/meygen-tidal-power-facility-exported-13-8-gwh-of-electricity-to-the-uk-grid-in-2019/.

Harris, M. (2018, March 21). *Seabased signs deal to install 100 mw wave energy park in Ghana.* Hydro Review. https://www.hydroreview.com/2018/03/21/seabased-signs-deal-to-install-100-mw-wave-energy-park-in-ghana/.

Hellmuth, M. (2019, August 14). *Hydropower in Tanzania*. Climatelinks. https://www.climatelinks.org/blog/hydropower-tanzania.

Hill, M. (2019, October 30). *Life on the Zambezi is hard. The climate crisis is making it deadly*. Bloomberg. https://www.bloomberg.com/features/2019-zambezi-river-climate-crisis/.

Hollaway, L. C. (2013). 19 - Sustainable energy production: Key material requirements. In J. Bai (Ed.), *Advanced fibre-reinforced polymer (FRP) composites for structural applications* (pp. 705–736). Woodhead Publishing.

Husseini, T. (2018, October 26). *Tidal energy advantages and disadvantages: Key points to consider*. Power Technology Energy News and Market Analysis. https://www.power-technology.com/features/tidal-energy-advantages-and-disadvantages/.

International Energy Agency, IEA. (2018). *World energy outlook 2018*. https://www.iea.org/reports/world-energy-outlook-2018.

IEA. (2019a). *Africa energy outlook 2019.* https://www.iea.org/reports/africa-energy-outlook-2019.

IEA. (2019b). *World energy outlook 2019*. https://www.iea.org/reports/world-energy-outlook-2019.

IEA. (2019c). *Kenya energy outlook*. https://www.iea.org/articles/kenya-energy-outlook.

International Renewable Energy Agency, IRENA. (2012). *Renewable energy cost analysis - hydropower.* IRENA Renewable Energy Technologies: Cost Analysis Series. Vol. 1, Issue 3/5.

IRENA. (2014). *Tidal energy: Technology brief.*

IRENA. (2015). Africa 2030: Roadmap for a renewable energy future.

Kestrel Renewable Energy. (n.d.). *Kestrel Renewable Energy*. https://www.kestrelwind.co.za/.

Korkovelos, A., Mentis, D., Siyal, S. H., Arderne, C., Rogner, H., Bazilian, M., Howells, M., Beck, H., & De Roo, A. (2018). A geospatial assessment of small-scale hydropower potential in Sub-Saharan Africa. *Energies*, *11*(11), 3100. https://doi.org/10.3390/en11113100.

Kuo, L. (2016, December 14). *Africa's biggest hydropower plant may soon run out of water*. Quartz Africa. https://qz.com/africa/862789/mozambiques-hydropower-dam-supplies-south-africa-and-zimbabwe-may-soon-run-out-of-water/.

Laldjebaev, M., Sovacool, B., & Kassam, K. (2016). 7 - Energy security, poverty, and sovereignty: Complex interlinkages and compelling implications. In L. Guruswamy and E. Neville (Eds.), *International energy and poverty* (pp. 97–112). Routledge.

Lawrence, D. (2020, June). *Investors forecast bright future for mini-grids in Africa*. IFC Insights. https://www.ifc.org/wps/wcm/connect/NEWS_EXT_CONTENT/IFC_External_Corporate_Site/News+and+Events/News/Insights/africa-mini-grids.

Makoye, K. (2015, December 29). *As hydropower dries up, Tanzania moves toward fossil fuels*. Reuters. https://www.reuters.com/article/us-tanzania-hydropower-drought-idUSKBN0UC0SS20151229.

McGlynn, J. (2014, June 17). *River hydrokinetic energy overview*. Inter-American Development Bank Innovation Center, ESMAP Training Program.

Ministry of Energy of Kenya. (2018, October). National energy policy.

Nairobi Technical Training Institute. (n.d.). Electrical and electronic engineering. https://nairobitti.ac.ke/index.php/departments/electrical-and-electronic-engineering.

National Aeronautics and Space Administration, NASA. (2006). *TOPEX/Poseidon: Revealing hidden tidal energy, Greenbelt, Maryland.* https://svs.gsfc.nasa.gov/stories/topex/tides.html.

Neill, S. P., & Hashemi, M. R. (2018). Chapter 3—Tidal energy. In S. P. Neill & M. R. Hashemi (Eds.), *Fundamentals of ocean renewable energy* (pp. 47–81). E-Business Solutions, Academic Press.

Nigeria Rural Electrification Agency. (2017, July 4). *The Agency*. Rural Electrification Agency (blog). https://rea.gov.ng/theagency/.

Offshore Energy. (2018, July 27). *OpenHydro another casualty of innovation "valley of death", EMEC says.* https://www.offshore-energy.biz/openhydro-another-casualty-of-innovation-valley-of-death-emec-says/.

Onundo, L.P. (2017). *Estimating tidal energy resource potential for power production along Kenyan coast-line*. University of Nairobi, School of Engineering.

Onundo, L.P., & Mwema, W.N. (2017). *Estimating marine tidal power potential in Kenya*. Zenodo. https://doi.org/10.5281/zenodo.1131790.

Organisation for Economic Co-operation and Development, OECD. (n.d.). *Revenue statistics, African countries: Comparative tables*. Oecd.stat https://stats.oecd.org/Index.aspx?DataSetCode=RS_AFR.

Othieno, H., & Awange, J. (2016a). Global energy perspective. In H. Othieno & J. Awange (Eds.), Energy resources in Africa: Distribution, opportunities and challenges (pp. 1–32). Springer International.

Othieno, H., & Awange, J. (2016b). Energy resources in southern Africa. In H. Othieno & J. Awange (Eds.), *Energy resources in Africa: Distribution, opportunities and challenges* (pp. 139–163). Springer International.

Power Technology. (2018, June 28). *Talking tidal as MeyGen kicks into gear.* Power Technology Energy News and Market Analysis. https://www.power-technology.com/features/talking-tidal-meygen-kicks-gear/.

Renewables Now. (n.d.) *Atlantis' MeyGen wins GBP-1.5m grant for tidal turbine connection hub.* https://renewablesnow.com/news/atlantis-meygen-wins-gbp-15m-grant-for-tidal-turbine-connection-hub-692459/.

Roberts, A., Thomas, B., Sewell, P., Khan, Z., Balmain, S., & Gillman, J. (2016). Current tidal power technologies and their suitability for applications in coastal and marine areas. *Journal of Ocean Engineering and Marine Energy*, *2*(2), 227–245. https://doi.org/10.1007/s40722-016-0044-8.

Sivaram, V., Dabiri, J. O., & Hart, D. M. (2018). The need for continued innovation in solar, wind, and energy storage. *Joule*, *2*(9), 1639–1642. https://doi.org/10.1016/j.joule.2018.07.025.

Smart Hydro Power. (n.d.-a). *Rural electrification in Nigeria*. https://www.smart-hydro.de/decentralized-rural-electrification-projects-worldwide/nigeria-rural-electrification/.

Smart Hydro Power. (n.d.-b). *Smart turbines*. www.smart-hydro.de/renewable-energy-systems/hydrokinetic-turbines-river-canal/.

The Technical University of Kenya. (n.d.). *Homepage.* http://tukenya.ac.ke/.

United Nations Economic Commission for Africa, UNECA. (1980). *Ocean as a source of energy in Africa*. https://repository.uneca.org/handle/10855/7767.

United Nations Population Division. (n.d.) https://population.un.org/wup/DataQuery/.

United Nations University, UNU. (2018). *Short course on geothermal exploration and development in Kenya*. https://unu.edu/news/news/short-course-on-geothermal-exploration-and-development-held-in-kenya.html.

United States Agency for International Development, USAID. (2020a, April 16). *Power Africa in Mozambique.* https://www.usaid.gov/powerafrica/mozambique.

USAID. (2020b, July 21). *Beyond the grid*. Power Africa. https://www.usaid.gov/powerafrica/beyondthegrid.

United States Department of Energy, U.S. DOE. (2008). *Technology readiness assessment report*.

U.S. DOE. (2012). *Turbines off NYC East River will provide power to 9,500 residents*. Energy.Gov. https://www.energy.gov/articles/turbines-nyc-east-river-will-provide-power-9500-residents.

University of Calgary. (2019, January 4). *Geothermal electricity.* Energy Education. https://energyeducation.ca/encyclopedia/Geothermal_electricity.

University of Oxford. (n.d). *Tidal Energy Research Group.* https://www2.eng.ox.ac.uk/tidal.

Wang, J., Schleifer, L., & Zhong, L. (2017, June 29). *No water, no power.* World Resources Institute. https://www.wri.org/blog/2017/06/no-water-no-power.

Watts, J. (2019, April 26). *The joys of springs: How Kenya could steam beyond fossil fuel*. The Guardian, sec. World News. https://www.theguardian.com/world/2019/apr/26/the-joys-of-springs-how-kenya-could-steam-beyond-fossil-fuel.

World Bank. (2016, December 6). *Increasing electricity access in Tanzania to reduce poverty*. https://www.worldbank.org/en/results/2016/12/06/increasing-electricity-access-in-tanzania-to-reduce-poverty.

World Bank. (2018). *Batoka Gorge hydroelectric scheme: A macroeconomic assessment of public investment options (MAPIO)*.

World Bank. (2019, May 14). *Unlocking low-cost, large-scale solar power in Zambia*. The World Bank Feature Story. https://www.worldbank.org/en/news/feature/2019/05/14/unlocking-low-cost-large-scale-solar-power-in-zambia.