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# Electricity in Eastern Africa: The Case for Mini Hydro

*by Helyette Geman*

## Summary

We argue in this paper that electricity production needs to be multiplied by a large factor in the coming years for East Africa to reach the economic growth rate it deserves after the improvement of its socio-political situation. The rural electrification rate in North Africa as represented for instance by Morocco was higher than 99.50% in the first quarter of 2017 while it was barely 10% in some parts of Western Kenya.

We also make the case for hydroelectricity as the adequate renewable source of energy, and more precisely mini-hydro as it preserves the environment and allows reaching remote regions with an optimal cost of financing. Some technicalities around run-off river hydro are presented as well as the limited risks at stake as water-at-risk, a concept we introduced in prior work, is a phenomenon that has been statistically document for millennia in the case of the Nile River, for centuries in the case of the other African rivers. Lastly, grid connections – existing and to come, large grids and mini grids - are discussed, and their crucial role in the joint development of farming, mining and industrial activities across the beautiful continent.

## Introduction

The US Department of Energy estimates that, by 2050, the world's population will reach 9.4 billion human beings and the per capita income double, as well as energy demand. Africa, the continent that is currently experiencing the highest growth in the world, critically needs new power generation and transmission capacities. Hydropower, geothermal and natural gas – derived electricity are the most efficient energy sources to address the power shortage. Our goal in this paper is to focus on Hydro Electricity, and emphasize in particular the merits of Mini-Hydro in protecting the environment while leading to low Operations & Maintenance Costs and giving access to electricity for populations and farmers located in remote regions.

As a comparison, hydro-electricity has provided a cumulative 10% of US electricity generation over the years 1950 to 2015 (which could be projected into the period 2015 to 2080 for the African continent), and 85% of cumulative US renewable power generation over the same period. By the end of 2015, the US hydro – generation included 2,198 active power plants that provided 48% of all US renewable power in 2015. The US Department of Energy emphasizes an array of virtues of hydro-electricity, which include GHG emissions, public health, energy diversity and a low cost source of electricity.

*« Hydropower, geothermal and natural gas – derived electricity are the most efficient energy sources to address the power shortage.»*

Since 1990, the continent has had an average 5.3% growth rate in the combined GDPs of its more than fifty countries. While seven of the world's ten fastest-growing economies are located in Africa, economic growth still needs to be fed by appropriate power generation and transmission infrastructure. The growth rates projected for the future at this point by the World Bank and the IMF are the following ones:

- 9% in 2017 and 2018 for the Democratic Republic of Congo
- 7.5% in 2017 and 2018 for Tanzania
- 7% in 2017 and 2018 for Burundi
- 6% in 2017 and 2018 for Kenya
- 4.5% for the whole African continent

The population growth is expected to be more than 1.2 billion by 2019 for Africa, with more than 80 million in DRC, 50 million in Tanzania and 40 million in Kenya.

*« The drip-irrigation system can boost crop yields by 300% and save up to 80% of water use.»*

Except for North Africa - Morocco, for instance, had a rural electrification rate as high as 99.15% at the end of 2015 - the continent is massively short of electricity. Energy demand in Africa has risen by half between 2000 and 2015, while total production capacity has only increased by a few per cent during that time period. According to the Africa Progress Panel (2015), sub-Saharan Africa's total annual electricity consumption outside South Africa is 139 million Megawatthours, while Spain with 47 million consumed 243 million MWhours.

McKinsey achieved in 2015 a thorough analysis to assess the situation of the sub-Saharan power development. The report, titled 'Brighter Africa – The growth potential of the sub-Saharan electricity sector, exhibited the following striking features as of 2015:

- A total installed grid-based capacity around 90 gigawatts, less than the capacity in South Korea where the population is five per cent that of sub-Saharan Africa
- Only seven countries – Cameroon, Cote d'Ivoire, Gabon, Ghana, Namibia, Senegal and South Africa – have electricity access rates exceeding 50 percent. The rest of the region has an average grid access rate of just 20 percent. The consensus is that it takes on average 25 years to reach 80% electrification rate (level below which GDP per capita starts suffering).

In November 2015, Afritech Energy, a private company, and East African Power signed a $10 million agreement to finance the construction of four hydropower plants in Rwanda.

Small hydropower schemes (5 MW to 20 MW) are particularly valuable as they do not require major changes to the grid infrastructure. Impact on the environment is minimal through run-off river schemes versus large dams destroying vast pieces of land, flooding valleys and implying significant civil works and displacement of communities.

Hydroelectric plants with a capacity of 20 MW or less are valuable sources of new capacity in established markets and even more so, in developing countries; small sites of 1 to 3 MW can be totally funded on equity.

## Hydro-Electricity in Eastern Africa

Kenya is the fifth largest economy in Africa and the leading one in Africa and the leading one in East Africa, with a GDP close to $59 billion in 2016 and a growth projection of 7% in 2017. Kenya is emerging as a major hub in East Africa, with world class port infrastructures in Mombasa and other ports to come. Attracting Foreign Direct Investments is the Government's priority, with steady inflows from Europe, China, India, the Middle East and South Africa. Large additional future inflows are expected from the US, China and the World Bank. Only 35 to 38% of the population has access to electricity. In Western Kenya which is predominantly rural and highly populated, the electrification rate may go as low as 6%. The current generation capacity should be multiplied nine fold to 15,000 MW by 2030 to meet anticipated demand.

*« With fuller access to capital, technology and know-how, the World Bank estimates that by 2030, farmers on the continent could create a $ 1 trillion agribusiness market. »*

Eighty per cent of the land in Kenya receives low and unpredictable rainfall, and many farmers have chosen to eliminate rain-fed agriculture from their crop rotations.

Others irrigate the land by flooding it from a nearby river or lake, which erodes the soil and its nutrients. Or they use an expensive and inefficient diesel-fueled pump for 'drip irrigation'.

SunCulture, a US company, uses solar power to pull water by electric pump from the source into a raised tank. Gravity then pushes it through irrigation pipes to water crops, with emitters regulating the flow. The drip-irrigation system can boost crop yields by 300% and save up to 80% of water use.

Most of Kenya's farmland is unsuited to agriculture which depends on regular rainfall; out of the 80% of land that needs irrigation to be productive, only 4% of Kenyan farmers irrigate. Crop yields achieved by Africa's farmers are at this moment lower than world averages by as much as 50%.

SunCulture had raised $200,000 in seed capital to start, then arrived in Nairobi in Oct 2012 and raised 4 million from grant organizations and bodies such as US Aid. But Sun Culture kits are not cheap: at almost $3,000 to cover a single acre, the upfront cost is prohibitive for many farmers.

With fuller access to capital, technology and know-how, the World Bank estimates that by 2030, farmers on the continent could create a $ 1 trillion agribusiness market. The African Development Bank, through its managed Sustainable Energy Fund for Africa (SEFA) announced in January 2017 that it had approved a $992,000 grant for the 7.8 MW Mutunguru hydropower project located on the Mutonga River in the Meru county of Kenya. The Western part of Kenya is well suited for small hydropower, with the highest rainfalls in the country and two rain seasons per year.

*« The maximum amount of electrical power that can be obtained from a river or stream of flowing water depends upon the amount of power within the flowing water at that particular point. »*

Currently, the region is supplied by a 90 MW power facility running on diesel that the Ministry of Energy wishes to close rapidly. Solar is not very attractive in Kenya; geothermal and wind potential are located in various parts of the country, while small hydropower sites are best suited for Western Kenya, on the rivers Yala and Nzoia in particular.

Kenya's Power Lighting Company is Kenya's national electric utility which owns and operates the country's transmission and distribution system. It is listed on the Nairobi Stock Exchange and is controlled at 50.1% by the Republic of Kenya. Kenya Power negotiated Power Purchase Agreements for 20-year duration and up to 20 MW capacity. The tariffs are denominated in US dollars.

The Kenyan Government has set a target of an additional 5.000 MW to be built between 2015 and 2017, for an installed capacity of 1500 MW in 2015, a number inadequate for the economic growth foreseen in the country. The existing Feed-in-Tariff policy provides a regulatory framework for Independent Power Producers (IPPs) with fixed tariffs and standardized Power Purchase Agreements. The national off-taker, Kenya Power, is seen today as one of the most reliable utilities in Africa as it has been successfully dealing with IPPs for decades.

## The Technicalities of Hydro Electricity Generation

Hydro-power plants use the potential energy of water to produce electricity (water head and water flow). Classical mature technologies use constrained flow in river (with civil works). The main parameters to choose the appropriate technology are:

- Available water head (mean value and variability)
- Available water flow (mean value and variability)

Other factors to consider are: technical skills for operation and maintenance; global costs including civil works; environmental laws.

Weather stations in the vicinity of a future hydropower plant collect data on annual rainfall and annual maximum daily rainfall. Data comprise also average daily and monthly discharge in m3/second, and maximum annual daily flood recordings to carry out stream flow analysis. Information relevant to the future infrastructure includes base maps, topographic maps (1/50.000); geological and foundation data; sediment transport, water quality and other data on water sources; sediment loads during normal times and during floods; erosion of soils.

Annual daily rainfall maxima, like other accidental meteorological phenomena, are usually modelled by a Gumbel distribution characterized by the pivot and the gradient of the fitting line or average.

It can be shown that the pivot is linked to the number of rainfall events explaining the annual maxima and can be viewed as constant for a given region. In contrast, the average (or gradient) varies geographically.

Waterwheels and water turbines are great for any small scale hydro power scheme as they extract the kinetic energy from the moving water and convert this energy into mechanical energy which drives an electrical generator producing a power output. The maximum amount of electrical power that can be obtained from a river or stream of flowing water depends upon the amount of power within the flowing water at that particular point. As the water is moving a hydroelectric system converts this kinetic input power into electrical output power.

### Available Power from a Small Scale Hydro System

In order to determine the power potential of the water flowing in a river or stream, it is necessary to determine both the flow rate of the water passing a point in a given time and the vertical head height through which the water needs to fall. The theoretical power within the water can be calculated as follows:

- where: Q is the flow rate in m3/s, H in meters
- **η** is the efficiency of the turbine or waterwheel
- **g** is the gravitational constant, 9.81 m/s2

The water turbine is not perfect and some input power is lost within the turbine due to friction and other such inefficiencies. Most modern water turbines have an efficiency rating of between 80 and 95%.

## Components of a Small Scale Hydro Scheme

A typical small scale hydro power scheme, needs a stream, an intake system to divert the water, a canal or channel called a penstock to carry the diverted water, a water turbine or water wheel to convert the waters kinetic energy into a rotational mechanical energy and an electrical generator to convert this rotational energy from the wheel into electricity. Although the actual components will vary for each small scale hydro power scheme, the type of scheme chosen will determine the need to build a diversionary weir or a dam or a forebay, which will ultimately depending upon the available “static head” of water and a typical small scale hydro scheme is shown.

If you are uncertain about the geographical surroundings, purchasing a local survey map of the area will enable you to obtain an idea of the amount of head available from river to turbine by measuring the details of the contours on the map.

*« More than anywhere in the world, multiple grids and mini grids would be very useful in sub-Saharan Africa to optimize the electricity needs between population needs, agriculture development and mining operations. »*

Low head schemes up to 20 meters, (65 feet) allow for a range of hydro energy options from a single plastic water pipe to a trough running downhill from a diversionary intake above shooting water directly onto a turbine (probably Pelton style), with the turbine turning a generator.

Then small scale hydro power systems consist of a channel, pipeline, or pressurized pipeline (penstock) that delivers the water. A turbine or waterwheel transforms the energy of flowing water into rotational energy and an alternator or generator to transform the rotational energy into electricity.

Hydropower systems are composed, as mentioned before, of:

- A water turbine
- A generator to produce electricity
- A transformer to deliver electricity into the network.

The turbine is connected to an electromagnetic generator which produces electricity when the turbine spins.

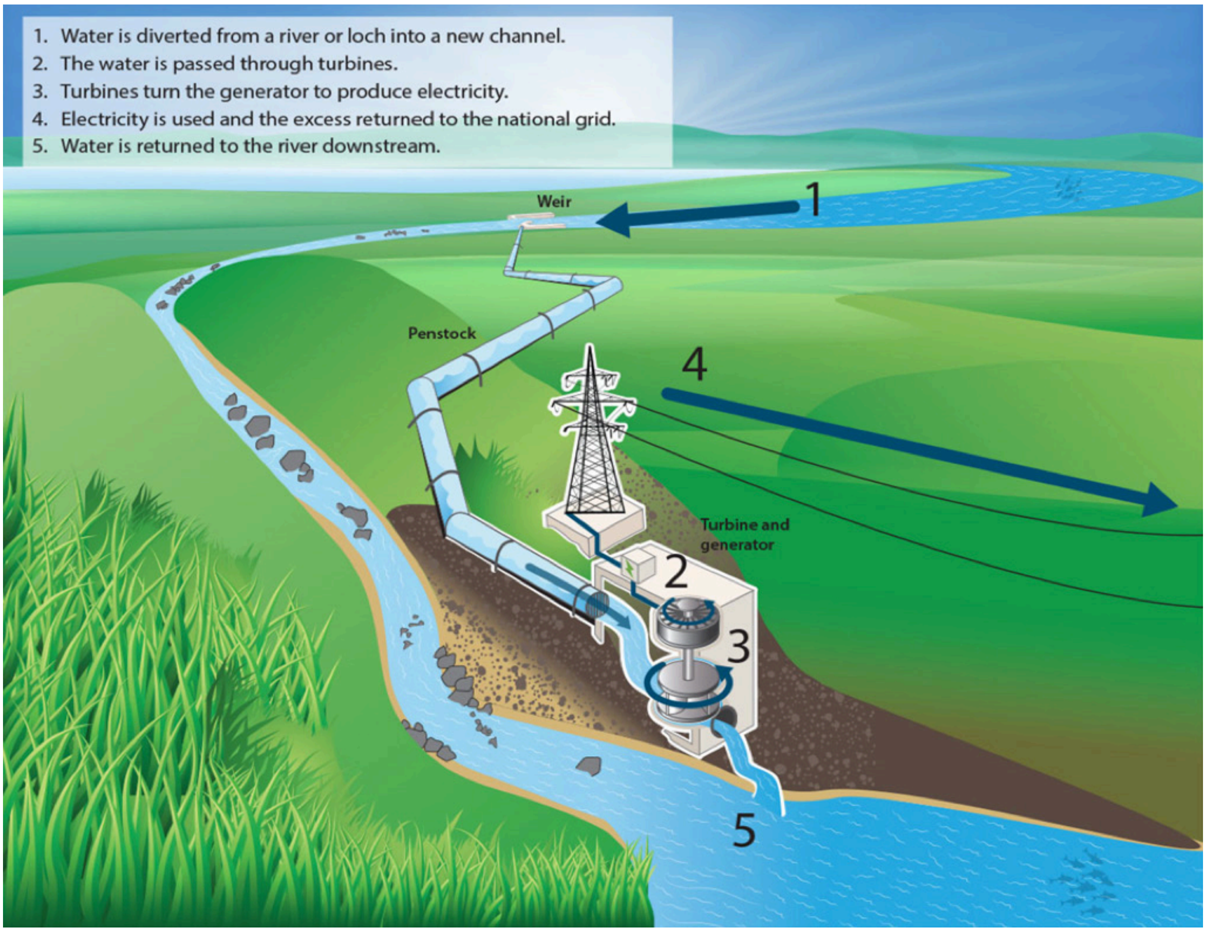
Depending on the hydropower plant environment and characteristics, complementary works are necessary, like:

- Civil works (intake, weir, dam, canal, anchorage, power house)
- Metal works (penstock, gates, trash racks)

Hydropower systems can be installed:

- As run of the river, with no reservoir
- On a derivate canal or penstock (with a dam)

Hydropower technologies applicable for very large power generation (10 MW to 750 MW) are also applicable to small to medium power generation (10 kW to 10 MW).




The following technologies are well established and turbine choice is induced by the available water head or water flow:

- Pelton (high water head)
- Francis (medium water head)
- Kaplan (low water head)
- Bulb (very low water head)

For micro to medium power generation (1 kW to 1 MW), turbine choice is often a compromise between

- available water head and flow mean value and standard deviation
- power need
- location (site, local laws, environment)
- possible investment capacity
- environmental obligations
- local maintenance capacities

Small tidal turbines have recently been developed, ranging from a few watts to 2.5 MW. They require no dams nor head differential and the course of the river remains in its natural state. The turbines can be installed either in the riverbed or floating on the surface in order to minimize the amount of civil work. They may be vertical, horizontal or perpendicular to the current flow and have 3 to 15 blades.

A small stream can be suitable for the construction of a small hydropower facility; a weak water flow can be compensated by a high water head. A dam is not necessary, nor is a reservoir. A reservoir is used for energy storage (exhibiting a swing optionality in the production of electricity, in the case of a large output), water regulation and increase the water head, but is not necessary to have a running power plant. Hydropower electricity is often criticized for its damage on the environment, but the impact is quite low in the case of mini - hydroelectricity. In run-of-river facilities, just a portion of the river water is sometimes diverted through turbines.

## Electricity Transmission

Grid interconnection is also a vital aspect in the development of hydropower. Factors that must be considered include the market into which the electricity will be sold, interconnection voltage, number of interconnecting lines, and magnitude of the local load service in the distribution network and the ability of the system to reliably absorb new generation. A close match between generation and load should be maintained to ensure no voltage regulation problems arise.

Interconnection costs can be large enough to affect the viability of a hydropower facility project.

An ambitious plan to connect the North and South points of Africa with a single power line linking Cairo to Cape Town was announced in January 2017 and should be achieved by the end of 2019.

*« Since run-of-river hydro is subject to natural water variability, it is more intermittent than dammed hydro and a thorough analysis of the most probable rainfalls at various probability levels is mandatory. »*

In 2005, the Energy Ministers of seven Easter countries – Burundi, Democratic Republic of Congo, Egypt, Ethiopia, Kenya, Rwanda and Sudan – recognized the potential benefits of a regional pool and signed an Inter-Governmental Memorandum of Understanding for the establishment of the Eastern Africa Power Pool. Its formal launching took place with the signature of an Inter-Utility MOU by the countries' power utilities. Tanzania, Libya and Uganda joined in 2010 and 2011. As of 2017, the Eastern Africa Power Pool had a number of interstate connections, including the ones linking Ethiopia and Kenya, Ethiopia and Sudan, Kenya and Tanzania, Sudan and Egypt, Tanzania and Zambia. This shows that Kenya was already connected in 2017, directly or indirectly, to six other countries, in agreement with its central position in Eastern Africa. More than anywhere in the world, multiple grids and mini grids would be very useful in sub-Saharan Africa to optimize the electricity needs between population needs, agriculture development and mining operations.

Unfortunately, Egypt pulled out of the EAPP in 2016 until its concerns over the use of the Nile waters have been addressed: a major disagreement has existed between Egypt and Ethiopia since the beginning of the construction in 2011 of Ethiopia's Grand Renaissance Dam on the Nile River. The high storage capacity of the dam – up to 74 billion cubic meters – is a concern for Egypt's national water security; this supports our general case in favor of mini hydro. Ethiopia, whose economy has remarkably improved in the last few years with the major development of agriculture and in absence of natural resources like crude oil or metals mines, aims to add 12,000 MW to its grid by 2020 and become a major power exporter.

## Hydro Electricity and Water-at -Risk

In the financial markets, the quantity which characterizes the maximal loss that a portfolio may experience over a given horizon with a given probability is called Value at Risk. In the world of Hydro, one can use the concept of 'Water at Risk' introduced by Geman & Kanyinda (2006) in the context of agriculture. The major risk for hydropower generation is indeed water variability. Climate change, in particular, is likely to increase climate extremes such as floods and droughts, and variability of precipitations in general. The probabilistic study of rainfall and floods over a significant number of years is part of the analysis; but simulations, such as Monte Carlo simulations, are necessary to add to the analysis of the past the inclusion of future changes.

In particular, dry and wet scenarios will be established for each catchment's plant; as well as the projection of the most probable water floods and droughts. Climate-influenced water availability has to be examined by combining 'wet' and 'dry' scenarios with other combinations of parameters accounting in particular for seasonal and regional hydropower water availability. Since run-of-river hydro is subject to natural water variability, it is more intermittent than dammed hydro and a thorough analysis of the most probable rainfalls at various probability levels is mandatory. Rainfall-flood probabilistic relations are then applied in the study area.

Lastly, let's note the safe passage of fishes and useful organisms through power dams and turbine blades has been a subject of concern for many decades, and even more so recently given the importance and virtues of fish in human diet. Mini-hydro drastically reduces the risk of fish injuries after going through hydropower turbines, as fish diversion devices may more easily be put in place.

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