Small Hydropower Development in Rwanda: Trends, Opportunities and Challenges

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Abstract. The Rift Valley region of Sub-Saharan Africa represents a promising area for the development of small (<5MW) hydropower resources. This study compiles data from government and UN agency reports to analyze different development outlooks. The study found that there has been a rapid deployment of small hydropower in the last 10 years. From the current total deployed small hydro of 47.5 MW, 16.5MW (35%) were deployed from 1957 to 1984 while the remaining 31 MW (65%) were deployed from 2007 to 2017. While all systems constructed prior to 1985 are grid-connected, one third of the 24 facilities constructed after 2007 are connected to off-grid systems. The study provides an overview of the economic incentives for developing small hydropower systems in Rwanda and the potential contribution of that development to Rwanda’s electrification goals.

1. Introduction
Globally, the most-used definition of small hydropower is hydropower units with a rated capacity of 10 MW or less, but many countries define their own classification to meet local needs [1]. The Sector guidelines for environmental impact assessment (EIA) for Hydroelectricity Development in Rwanda by Rwanda Environmental Management Authority, classified Small hydropower plants by their capacity as: Mini hydro ranging from 500kW-10MW, Micro hydro 5-500kW and Pico Hydro which is less than 5 kW [2].
Small hydro power plants can also be classified according to head where ultra-low head of less than 3m; low-head of 3-40 m head; and medium-to-high head with more than 40 m head [3]. A recent government study estimates that Rwanda has 333 potential sites for small hydropower development and recommends medium- to high-head pico-and micro-hydro, using run-of-river plant designs [4]. According to hydropower atlas of 2007 [5], the majority of Rwanda potential hydropower sites have a capacity of 50-1000 kW of electrical production. Figure1 illustrates a small run-of-river hydropower facility designed for 300 kW. This type of facility is typical of both the location and architecture expected for many hydropower facilities in Rwanda. An upper catchment (left panel) slows the stream flow and allows some portion of the entrained silt to settle out. Design and maintenance of the silting
basins are of paramount importance in Rwanda, new to the high silt load in many streams. Water is conveyed through an open channel (upper left in left photo) for some distance (approximately 2 km in this example) along the valley wall before emptying into a 0.5 m diameter penstock that drops 30 m to the turbine house.

Impulse or cross-flow turbine types are frequently utilized for the heads seen in Rwanda. The example turbine is a gated cross-flow type (blue, right photo) driving a constant-speed synchronous generator (orange). Generation is governed by gating water flow (gray valve arms). Ingestion of silt into the turbine equipment presents significant issues for small Rwandan hydropower facilities, and may cause significant wear on both turbine blades and bearing seals.

Figure 1. Example of small run-of-river hydropower facility in Rwanda.

Hydropower is the main source of electricity generation in Rwanda. Out of a current energy generation capacity of 210 MW, renewable resources represent 53.7% of the total energy generation and hydropower contributes 48% [6]. Fig. 2 illustrates the domestic electricity generation in Rwanda.

Figure 2. Resource mix for Rwandan Current energy generation.

In Rwanda’s electrification strategy targets 512 MW installed power generation capacity by 2023/24 and universal access to electricity for all households by 2023/24 [6, 7]. Current electrification data indicate that electrification has reached 40.5% of the population, of which 29.5% are grid connected and 11% are serviced by off-grid systems [6]. Under Rwanda rural electrification strategy, mini-grids will be developed by the private sector with government assistance in identifying potential sites and establishing framework through which they can become financially viable investments. Given the distributed nature of hydropower locations, the high targets for off-grid development will likely encourage small hydropower development.

In Rwanda rural electrification strategy, the levels of access are defined in five multi-tiers as illustrated in Table 1. The government plans to finance rural electrification in partnership with private sector.
The government will provide a basic level of electricity access to those with the lowest income by providing Tier 1 (see Table 1) access to households with the lowest incomes and will help private sector reduce risks by providing a risk-mitigation facility for future projects. The government has also established a policy and regulatory framework to incentivize the private sector to recycle redundant items such as kerosene lamps and used batteries [7].

Rwanda has electrified faster than neighbouring east African member state as illustrated Table 2, catching up to neighbouring Tanzania and Kenya in 2013.

The remainder of this paper will discuss the development environment for small hydropower in Rwanda. Overall development trends are discussed in Section 2, followed by a discussion of factors that have encouraged development, current challenges and opportunities. Finally, Section 6 provides conclusions and policy recommendations.

| Level | Tier 1 | Tier 2 | Tier 3 | Tier 4 | Tier 5 |
|-------|--------|--------|--------|--------|--------|
| Energy usage | Household lighting | Household lighting, Radio, phone charging and basic appliances (TV or fan) | Household lighting, Radio, phone charging, basic appliances (TV or fan), medium appliance such as low power refrigeration | Household lighting, Radio, phone charging, basic appliances (TV or fan), medium appliance such as low power refrigeration, high power appliances such as pumping. | High power suited to commercial and industrial uses. |

Source: [7]

| Table 2. Comparison of Electrification rate for the five East-African Countries. |
|-----------------|------|------|------|------|------|
| Country         | 1990 | 2000 | 2010 | 2013 |      |
| Burundi         | 0%   | 4%   | 5%   | 5%   |      |
| Kenya           | 11%  | 15%  | 18%  | 20%  |      |
| Rwanda          | 2%   | 6%   | 11%  | 21%  |      |
| Tanzania        | 5%   | 9%   | 15%  | 24%  |      |
| Uganda          | 7%   | 9%   | 9%   | 15%  |      |

Source [8]

2. Development Trends

2.1. Historical Development

There has been rapid development in small hydropower in Rwanda since 2007. A full list of operational small hydropower facilities, at least as known to the government, is provided in Appendix1. These facilities account for an installed capacity of 47.5 MW. No small hydropower facilities were built between 1985 and 2006. Facilities built prior to 1985 were more traditional developments, larger – averaging 16.5 MW/plant – and fewer – 4 facilities – than recent development (Fig 3).
Following policy changes to encourage development of generation sources, 24 facilities / 31 MW of capacity were commissioned since 2007. These facilities are smaller – averaging 1.3 MW/plant. A third of these new facilities are connected to off-grid power systems (Fig 4) in contrast to facilities built prior to 1985, which were all grid-connected. In addition, off-grid facilities tend to be smaller – averaging 0.2 MW – than on-grid facilities – averaging 1.9 MW.

2.2. Development potential

Based upon the survey data mentioned above, only a small fraction – 28 or 8% -- of potential small hydropower sites in Rwanda have been developed (Fig. 5). Therefore, a substantial number of possible development sites exist, for both on- and off-grid development. However, the survey data did not include an evaluation of potential cost or environmental conditions which might eliminate some sites from consideration. These could include sensitive watersheds, poor access to grid or population centers, or intermittent water flow.

2.3. Comparison of small hydropower and solar power development trends

All major Rwandan solar power plants are indicated in Table. 4. The table omits the many small off-grid systems, solar home systems or isolated PV-battery systems for schools, houses, clinics and other applications; no consolidated data was available for these systems.
| Plant Name | Installed capacity (MW) | Year Commissioned | Connection       |
|------------|-------------------------|-------------------|------------------|
| Mount Jali | 0.25                    | 2007              | Grid connected   |
| Rwamagana  | 8.5                     | 2014              | Grid connected   |
| Nyamata    | 0.03                    | 2016              | Off-grid         |
| Nasho      | 3.3                     | 2015              | Off-grid         |

Source[9, 10]

Comparing solar and hydropower development rate, both are developing at a high rate, but small hydropower is developing somewhat faster, due to a larger number of facilities and the relatively larger size of hydropower facilities.

3. Causes of rapid development in small hydropower

There has been rapid economic growth in sub-Saharan Africa, resulting in increased energy demand. This has pressured governments to explore all solutions to increase domestic energy supply[11].

3.1. Rwandan development incentives

Rwandan economy has performed well since 2000, with an average annual growth rate of nearly 8% [12]. The government has also identified several growth strategies, including development of the tourism and information and communications technology (ICT) sectors. Both sectors place a high priority on reliable and competitively priced energy, driving a substantial need to improve energy capacity and infrastructure [13]. Also, the Economic Development and Poverty Reduction Strategy II (EDPRS II) acknowledges that Rwanda’s current energy system creates challenges for development. The plan articulates strategic areas of improvement in the energy sector. These include rapid expansion of energy supply capacity through grid and off-grid technologies [14].

To support development of energy sources, Rwanda has established laws meant to promote private sector involvement in energy development. The country has developed regulations including a renewable energy feed-in tariff for hydropower between 50 kW and 10 MW [15] and a simplified licensing method which exempts generation facilities of less than 50 kW from most licensing requirements [16]. Additionally, the government has initiated a privatization of public services, including the main electricity utility. Benefits are provided to foreign investors, including tax holidays, import tariff reductions, assistance to access water and electricity, and assistance with obtaining visas and work permits [17]. Finally, the Rwanda Development Board (RDB) has launched a program to assist with business registration, licensing and obtaining tax incentives.

Stakeholder support promoting private sector involvement in energy sector investments has boosted power generation. An example is “Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) in English German Corporation for International Cooperation” which promotes private investment in the energy sector through the Energising Development (EnDev) fund. Results-based financing was introduced into Rwanda by the UK Department for International Development (DFID) and implemented by EnDev in several countries, including Rwanda. The idea behind the approach is to reward companies for their previously-agreed and delivered results. For off-grid electrification, results-based financing provides companies incentives in form of subsidies for either in increasing sales of small electric systems (typically small PV systems) or in developing isolated village grids.
powered by renewable energy sources. Financing mechanisms are implemented by Urwego Opportunity Bank on behalf of EnDev Rwanda [18].

4. Opportunities

The combination of topology and hydrology make Rwanda an excellent location for small hydropower, while population density and other constraints likely would not encourage larger hydropower development that requires significant flooding of major valleys. As indicated earlier, many sites with power-producing potential remain undeveloped. The distributed nature of these sites could be complimentary to micro-grids, including off-grid power systems, as small hydropower facilities could be integrated into these facilities to provide 24/7 generation to compliment photovoltaic generation sources.

An upper bound on the potential for small hydropower can be estimated with several assumptions. First, of 333 identified sites, 28 have already been developed and we assume that 25% will prove unsuitable for environmental or other reasons. For example, some sites are likely to be in areas with sensitive plants or animals, or are in areas that are restricted from development, such as national parks or military installations. This leaves a total of 229 possible locations for development. If we further assume that new facilities will average 75% of the size of sites developed since 2007, potential generation capacity can be estimated as shown in Table 5. We assume 63%, or 143 facilities, would be grid-connected and average 1.5 MW, while 38% or 86 facilities, would be connected to off-grid systems and average 150 kW. Obviously, actual construction may deviate significantly from these assumptions, but they serve to scope the potential of small hydropower as guide to policy discussions.

Given that Rwanda seeks to add approximately 300 MW of generation (from current 210 MW to 512 MW), potential generation from small hydropower sources could represent a non-trivial fraction of the solution – up to 60% of the desired increase in generation. Further, the distributed nature of the sites could support development of off-grid electrification, and thus not require extension of grid distribution systems.

Table 4. An estimate of potential generation possible from small hydropower in Rwanda.

| Possible Sites: | On Grid | Off-Grid | Total | Units |
|----------------|---------|----------|-------|-------|
| Approximate Size: | 1.5 | 0.15 | 1.0 | MW/site |
| Total Potential Gen: | 209 | 13 | 222 | MW |

Producing energy domestically also provides a strategic advantage to Rwanda, as it does not require foreign currency reserves to pay for imported power in the case of electricity imports, or for fossil fuels, in the case of diesel-fueled generation.

Finally, the site survey [5] indicated that most small hydropower sites could be developed utilizing run-of-river methods. These methods do not require large dams to impound water – expensive and environmentally challenging construction projects.

5. Challenges

Small hydropower in Rwanda also faces several non-trivial challenges. First, the mountainous topology in Rwanda makes transmission and distribution relatively expensive. Mountain ranges up to 3,000m in height run across the country. Therefore, not all larger sites with multi-megawatt potential can be cost-effectively connected to Rwanda’s transmission system, shown schematically in Fig. 6.
Few vendors provide equipment for small hydropower sites, and significant custom engineering is required for each facility. A 2012 study of hydropower in Colorado, USA, irrigation systems indicated that, while equipment existed, manufacturers for key components were few, were internationally-dispersed, and often required custom engineering for each installation [19, 20, 21]. As a result, installation engineering, and post-installation maintenance expertise and spare parts, present a challenge for Rwandan hydropower developers.

Rwanda is a landlocked country, increasing transportation costs for all imports, and particularly for heavy equipment. Since most hydropower plant components are manufactured outside of Africa, this increases the cost of hydropower plant investments. For example, of hydropower investment cost is estimated at 4000 US$/kW in Rwanda compared to 3829 US$/kW in Kenya [22, 23]. The integration and control of many small hydropower facilities into the national grid may present control challenges. Assuming a high penetration of small hydropower sites, the national grid control center may need automated mechanisms to dispatch small hydropower facilities. These mechanisms are not currently in place.

Finally, it is expected that climate change may reduce precipitation and flow Rwanda’s from interconnect lakes, leading to a decline of electricity generation from small hydropower plants [24].

![Figure 6. Approximate location of electricity transmission lines in Rwanda, 2012 data.](image)

### 6. Conclusions and Policy Recommendations

Strong evidence indicates that small hydropower could contribute significant electricity production in Rwanda. The government actively encourages development, in contrast to many countries with more developed electricity systems. Many promising sites exist, distributed throughout the country. Considering the need for energy development and available hydropower resources, our analysis suggests several possible policy recommendations:

1. Due to the difficulty of building energy transmission in Rwanda, it is advisable to encourage small hydropower use in off-grid systems;
(2) Investments should be made to develop the necessary support expertise for small hydropower technologies, including expertise for community-based micro-grids and training for plant maintenance to reduce operational cost.

(3) Small hydropower remains a niche business worldwide. Policies should be considered to attract investors willing to design and manufacture some hydropower plant components in Rwanda. This would allow solutions to be customized for Rwandan conditions, including:
   a. Standardizing designs for run-of-river systems.
   b. Improving designs to deal with high silt loads in Rwandan streams.
   c. Providing local expertise, repair, and spare part service.

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Appendix1

Table 5. Small hydropower plants currently operation in Rwanda.

| S/N | Hydropower plant name | Commissioned Year | Installed capacity (MW) | Grid connected |
|-----|-----------------------|-------------------|-------------------------|---------------|
| 1   | RUZIZI                 | 1957              | 3.5                     | Grid          |
| 2   | GISENYI               | 1957              | 1.2                     | Grid          |
| 3   | MUKUGWA               | 1982              | 10                      | Grid          |
| 4   | GHIHRI                | 1984              | 1.8                     | Grid          |
| 5   | NYAMYOTSI I           | 2007              | 0.1                     | Off-Grid      |
| 6   | MUTOBO                | 2009              | 0.2                     | Off-Grid      |
| 7   | AGATOBWE              | 2010              | 0.2                     | Off-Grid      |
| 8   | MURUNDA               | 2010              | 0.1                     | Grid          |
| 9   | RUKARARA I            | 2010              | 9                       | Grid          |
| 10  | NYAMYOTSI II          | 2011              | 0.2                     | Off-Grid      |
| 11  | RUSHUKI               | 2011              | 0.04                    | Off-Grid      |
| 12  | KEYA                  | 2011              | 2.2                     | Grid          |
| 13  | NKORA                 | 2011              | 0.68                    | Grid          |
| 14  | KIMBILI               | 2011              | 0.3                     | Grid          |
| 15  | RUGEZI                | 2011              | 2.2                     | Grid          |
| 16  | NYABAHANGA            | 2012              | 0.2                     | Off-Grid      |
| 17  | NSHILI                | 2012              | 0.4                     | Grid          |
| 18  | MAZIMERU              | 2012              | 0.5                     | Grid          |
| 19  | JANJA                 | 2012              | 0.2                     | Off-Grid      |
| 20  | GASHASHI              | 2013              | 0.2                     | Off-Grid      |
| 21  | NYIRABUHOMBOOMBO      | 2013              | 0.5                     | Off-Grid      |
| 22  | MUKUNKWA II           | 2013              | 2.5                     | Grid          |
| 23  | MUSARARA              | 2013              | 0.4                     | Grid          |
| 24  | RUKARARA II           | 2014              | 2.2                     | Grid          |
| 25  | GICIYE I              | 2014              | 4                       | Grid          |
| 26  | GICIYE II             | 2016              | 4                       | Grid          |
| 27  | GASEKE                | 2016              | 0.5                     | Grid          |
| 28  | KIGASA                | 2016              | 0.2                     | Grid          |
| Total|                      |                   | 47.5                    |               |

Source [25, 26]