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Research article

Community pico and micro hydropower for rural electrification: experiences from the mountain regions of Cameroon

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Abstract: Less than 15% of rural areas of Cameroon have access to grid electricity. Only 53% of the population has access to grid electricity. Notwithstanding, Cameroon has a huge hydropower potential which could be harnessed. Mini grids, powered by pico and micro hydropower plants, are a relatively new rural electrification strategy in Cameroon. Several of such mini grids have been realized in the mountain regions of the country. Some of these systems have been more successful than others. This paper aims to share the experiences of community-based pico and micro hydropower schemes for rural electrification in Cameroon. The paper provides insight to the challenges that three of such mini grid systems powered by pico and micro hydropower plants had encountered and it attempts to identify issues related to their performances. The study was based on personal experience, field visits, participant observations, interviews and focus group discussions with key members of the beneficiary communities and documentations from the local NGO which implemented the schemes. Key findings of this study relate to the description of the main aspects about: planning of a robust system design, organizational aspects, like social cohesion at all levels of scheme management, community leadership and ownership of the system and involvement of the beneficiaries at all stages of the project cycle. These aspects were particularly addressed within the context of rural communities in Cameroon.

Keywords: Energy; Africa; access to electricity; case studies; surveys and assessment; community-based

1. Introduction

A lot of effort is needed to bring electricity to the 1.3 billion people worldwide who are still without access [1]. Most of these people (more than 75%) live in remote rural areas of developing countries where the main grid extension, most often, has reached technological and economic limits [2]. In such situations, decentralized electrification becomes the most appropriate option. Two approaches could be adopted in providing decentralized electrification solutions: *individual household solutions* and *collective solutions* [3,4]. The implementation of the collective solution usually involves the deployment of a mini grid. Several approaches exist today for the deployment of mini grids. These approaches can be categorized in terms of technologies to power the mini grid or in terms of institutional and financial arrangements. Mini grids can be powered by a single power-generation technology (solar PV, wind, hydropower, biomass or diesel) or by a hybrid system that combines two or more of these technologies. In terms of institutional and financial arrangements, four categories can be identified namely: community based, private sector operator, utility based models and hybrid business models [4-6]. Technical, financial and organizational issues often affect the success of mini grids for rural electrification. Amongst the technical issues: type of technology, demand analysis, type of distribution system (three-phase or single-phase) are crucial. Appropriate tariffs, capacity building and training in bookkeeping operations and cash flow management are the financial issues that merit considerations. Furthermore, the involvement of key stakeholders in the project life cycle, the social structure for the supervision, capacity building in the technical operations, maintenance and management are important for the organizational aspects of the mini grid systems, especially in the context of Cameroon where such approach to rural electrification is new [4]. Mini grids are not a common sight; however, their application for rural electrification in Cameroon is growing.

To overcome the challenges of rural electrification in Cameroon, decentralized mini grids powered by micro and pico hydropower plants were introduced in the mountain regions (North-West, South-West, West and Littoral regions) in 1996. Some local NGOs are currently involved in the development of micro and pico hydropower schemes to power mini grids for electrification of remote rural areas of the country. No information exist as to how many of such schemes have been realized in Cameroon, however, some of these micro and pico hydropower plants have been more successful than others.

This paper aims to share the experiences of community-based mini grid schemes powered by pico and micro hydropower plants for rural electrification in Cameroon. It provides insight to the challenges that such mini grid systems, powered by pico and micro hydropower plants, could encounter and it attempts to identify issues related to their performances. Some lessons learnt and recommendations are proposed following the discussions of these schemes. The experiences are based on three community-based mini grids powered by pico and micro hydropower in the mountain regions of Cameroon.

2. Materials and Method

2.1. The context: Cameroon development indicators and energy situation

Cameroon is a lower middle income sub-Sahara African country located in the Gulf of Guinea between latitude 2° and 13° North of the equator and longitude 9° and 16° Earth of the Greenwich meridian. It has a surface area of 475,750 km^2 with an estimated population of 22.7 million people and a Gross Domestic Product (GDP) of US $32.55 billion. In 2013, its Human Development Index (HDI) was 0.504 and Energy Development Index (EDI) of 0.13, ranking it 48th out of 64 countries reported [7]. The HDI is a measure of a country's achievement in key dimensions (life expectancy, education and income per capita indicators) of human development, while the EDI measures a country's progress in transitioning to reliable, clean and efficient fuels and energy services [8,9]. Cameroon's total primary energy supply (TPES) has steadily grown over the past three decades by over 60% from about 4500 ktoe to 7346 ktoe in 2013. The TPES by fuel share is dominated by biofuels and waste (mainly traditional biomass) (Figure 1). The total final energy consumption (TFEC) is dominated by the residential sector; biofuels & waste are mostly consumed (Figure 2).

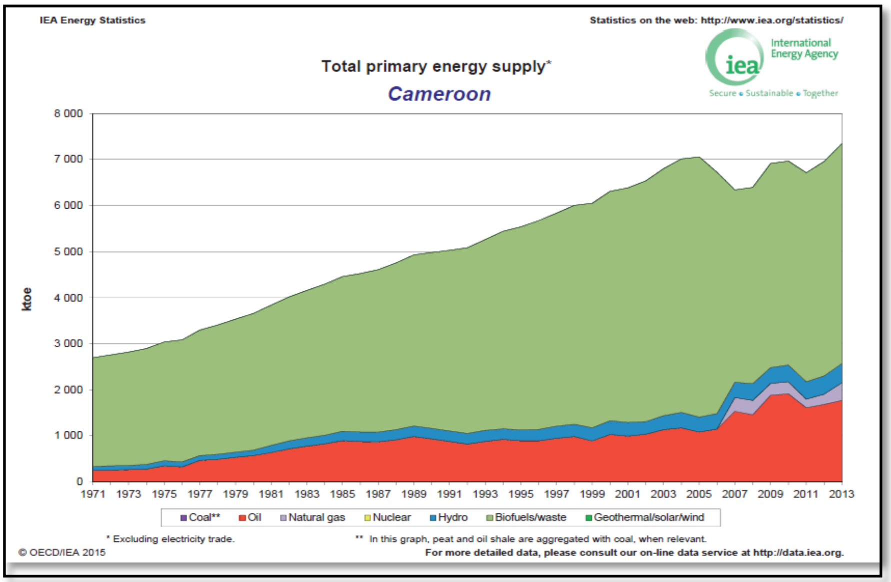

Figure 1. Fuel share of TPES IEA, 2014.

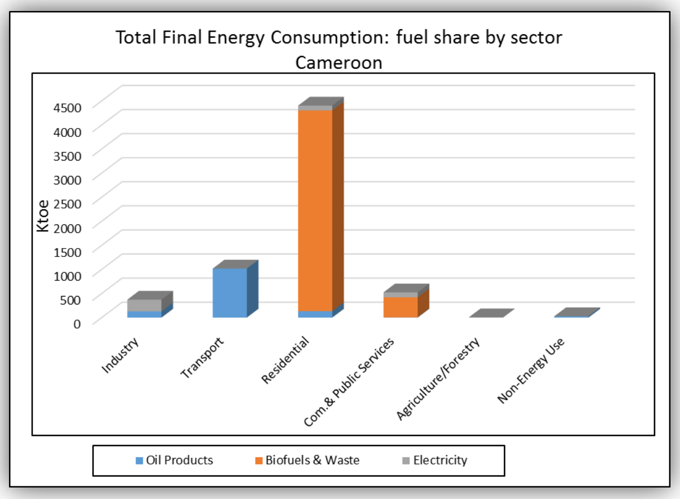

Figure 2. TFEC, fuel share by sector Authors with data from IEA, 2014.

In 2010, the installed electricity generation capacity of the country was 1007 MW producing 5552 GWh of electricity. The electricity demand was projected to reach 5000 MW by 2020; mostly to satisfy the needs of major industrial projects within the country's development vision up to 2035 [10]. The generation comes from four sources: Hydro (71%), Oil (19%), Gas (9%) and Biofuels (1%) (Figure 3). The final consumption is by four main sectors: industry (54%), Commercial and Public Services (23%), Residential (22%) and Agriculture/Forestry (1%) (Figure 4)[1].

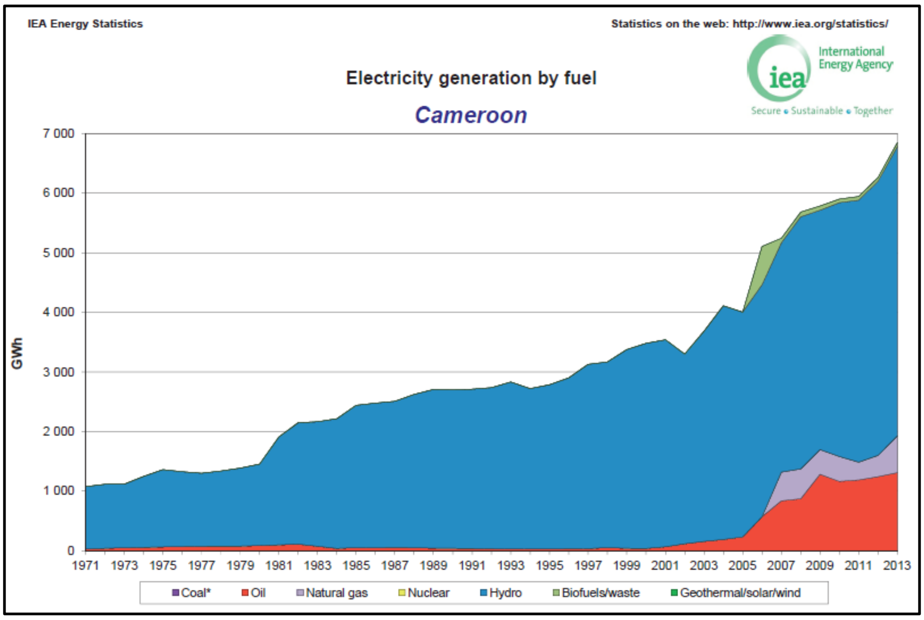

Figure 3. Electricity Generation by fuel type.

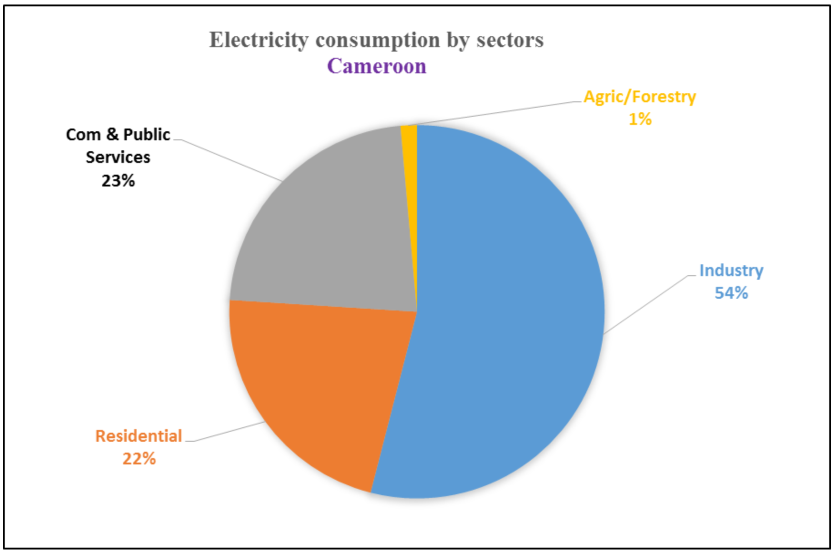

Figure 4. Electricity consumption by sector.

1 http://www.iea.org/statistics/statisticssearch/report/?country=Cameroon&product=balances

Although hydropower is the dominant source for electricity generation in Cameroon, its exploitation is still very small compared to the huge resources estimated to be between 20 and 23 GW with a production potential of about 103 TWh/year [11]. In fact, only 5% of this potential is currently exploited. The national grid is composed of three distinct networks: the South interconnected network, the North interconnected network and the East network; covering a total distance of 2030 km of high voltage transmission. These three networks are not interconnected [10].

Notwithstanding the enormous energy potentials of the country, only 53% of the total population has access to electricity with a per capita electricity consumption of 262 kWh. About 90% of the population with access to electricity live in the urban and semi urban areas while less than 15% of the rural population have access to grid electricity. The apparent high rate of access to grid electricity in urban areas masks the disparities amongst the regions of the country and the different socioeconomic groups. The regions with the least grid electrification include: Adamawa, East, Extreme North, North, South-West and North West Regions. In these regions the average access rate to grid electricity is 10% amongst the poor and 33% amongst the non-poor [12].

2.2. Data collection

This paper is based on the personal experiences of the first author who worked as a technical adviser on implementation of renewable energy projects with a local NGO in Cameroon. The NGO had realized several pico and micro hydropower plants in the mountain regions of Cameroon. Three of these plants: *Tongou* and *Baleng* in the West Region and *Bellah* in the South West Region are the objects for the study.

Technical data about the schemes were obtained through desk study of existing documentation from the NGO and field visits. Field visits were conducted to each of the schemes in order to gather primary technical data about the plants. Electrical power delivered were determined by direct metering of the line voltage and current by means of the electronic control boards installed in each of the power houses. Daily and weekly operating hours (hours during which the turbine-generator set were in function), applied tariff systems, number of houses connected, year of plant construction were obtained using checklists, interviews with the local operators and focus group discussions with key local persons. The end-uses of electricity in the beneficiary communities were obtained through field visits and surveys. The daily and weekly operating hours were used to estimate the yearly operating hours. Accordingly an estimate of the annual energy produced and of the load factors were computed [3]. Technical issues that affected the operation of the schemes were obtained from the reports kept by the operator, from reports about field visits made by local NGO technicians and other documentations of the NGO. Organizational issues which affected the functional performances of the schemes were noted through focus group discussions with the respective Local Project Management Committee (LPMC).

3. Results

3.1. Implementation strategy

The implementation of the three mini grid systems, here after referred to as “schemes”, started in 2006 with financial participation of the beneficiary communities, foreign donors, and the NGO as the local technical implementing partner. In particular, the Bellah and Tongou schemes were financed by a zero interest loan and community contributions, but each community had to make an upfront payment of 10% of the loan as commitment to the project; the Baleng scheme was financed by a grant and community contributions. The community contributions were mainly in terms of provision of locally available materials and labour needed for the realization of the schemes. The loans came from a revolving fund provided by foreign donors and managed by the implementing NGO. The projects that aimed at building these schemes were planned and implemented by the NGO adopting the following steps:

- *Step 1*: Identification of the sites and power capacity estimates.
- *Step 2*: Meetings between the implementing NGO and the beneficiary communities to explain the technology, roles, responsibilities, benefits and the need for community participation before initiation of the projects.
- *Step 3*: Formal acceptance by the communities to participate in the project. *Step 4*: The implementing NGO managed the funds on behalf of the communities for the realization of the schemes.
- *Step 5*: A Local Project Management Committee was formed by each of the beneficiary communities to coordinate the participation of the local population in the realization of the project and the management of the systems once installation was completed.
- *Step 6*: Local technicians were trained by the implementing NGO to operate and undertake minor maintenance of the schemes.

3.2. Technical description of the plants: design and installation

All of the schemes were run-off-river schemes, meaning that the turbine generate electricity according to the availability of the flow of the river [13]. Weirs or mini dams were constructed to divert part of the river into the intake. From the intake the water flow is channeled into the forebay from whence it entered the penstock to be delivered at the turbine-generator set located in the powerhouse for production of electricity (Figure 5). A detailed description of some of the essential components (i.e. penstock and turbine-generator set) which could pose serious challenges to the operation of the schemes and an estimate of the cost of each scheme is presented in the following paragraphs.

In Bellah, the penstock was made up of used metal pipes; the turbine was a 4-jet Pelton type locally fabricated from aluminum, however, only three of the four jets were in operation. The turbine was directly coupled to a used 7.5 kW synchronous generator. In Tongou, the penstock was made of two parallel old irrigation asbestos pipes. The turbine was a 4-jet Pelton type locally fabricated from aluminum. The turbine was connected to a used 5 kW synchronous generator by a V-belt pulley system. Also located in the powerhouse there was a maize grinding mill which was connected to the turbine via a V-belt pulley system. In Baleng the penstock was of high density PVC material. Initially PVC pipes of PN6 were used. However, with repeated damages due to the high pressure (water head of 120 m), they were replaced with PVC pipes of PN16 in 2009. The turbine was a 2-jet Pelton type locally fabricated from aluminum. The turbine was initially coupled to a used 5 kW synchronous generator by a V-belt pulley system. In 2009, the V-belt coupling of the turbine to the generator was replaced by a direct coupling. A maize mill was planned to be installed in the power house, however, it was not realized due to lack of financial resources. In all three schemes, the electrical energy distribution systems were single-phase systems with a supply voltage of 230 V at a frequency of 50 Hz, however at the point of the consumers these values varied.

Figure 5. Component of the micro hydropower schemes; top left-Weir to divert part of the river into the intake; top right-penstock to convey water from the forebay to the powerhouse; bottom-left- power house; bottom right- turbine-generator set in the powerhouse.

The power capacities of the schemes were determined by the available river flow rate with the minimum flow rate taken as the design flow. Like in most developing countries, no long term flow data exist for most small rivers in rural Cameroon [14]. Thus, the flow rates were assessed using the spot reading method whereby the "Floating Object Test" (velocity-area) approach was used to determine an average flow rate during a single month of the year, usually when the river was assumed to be at its minimum flow [15] according to qualitative data provided by the community. The schemes were design as constant flow rate schemes and the power produced had to be consumed by the load. No control devices (i.e. dump loads, electronic load controllers) were installed to regulate active and reactive power. Development of energy systems usually involved a detailed assessment of the energy demands in order to carry out an effective planning of the energy demand-supply system. In these schemes, no previous electrical energy demand assessments were done.

The estimated costs[2] of the schemes were US $26,000 for the Bellah and US $17,000 for the Tongou and Baleng schemes. Summary and additional technical information on the schemes are provided in Table 1.

[2] Based on an estimated cost of US $3500/kW obtained for reports from the NGO. No details of the cost of each scheme were reported.

Table 1. Technical description of the plants.

Name of Community	Bellah	Tongou	Baleng
Year of realization	2007	2006	2006
Net height (m)	41	120	20
Design flow rate (L/s)	60	30	20
Installed generator capacity (kW)	7.5	5.0	5.0
Generator type	synchronous	synchronous	synchronous
Turbine type	Pelton	Pelton	Pelton
Power Output (kW)	4.9	2.0	1.9
Operating hours in a year (h)	8585	7446	4745
Total estimate energy produced (kWh/yr)	42,000	14,800	9000
Number of households connected	50	30	20
estimated Load Factor	0.64	0.34	0.20
Estimated Cost (US $)	26,000	17,000	17,000
Estimated cost of electrification per household (US$/household)	500	600	900
Major energy end-use services	Domestic lighting, food processing, light of a school, cooling and entertainment.	Domestic lighting, light of a school, kiosk for local provisions and entertainment.	Domestic lighting, milling of grains, and entertainment

As already mentioned in section 3.1, the beneficiary communities participated in the civil, electro-mechanical installations of hydropower systems and installation of the electrical energy distribution network. In the civil engineering construction works, the communities provided locally available materials like sand, stones and wood required. The main role of the beneficiary communities in the installation of the electro-mechanical components were to provide the necessary labour for the last mile transportation of the equipment to the powerhouse and assisting the engineers and technicians provided by the NGO. Their contributions in the installation of the electrical energy distribution network were to provide the poles, labor for planting of the poles and pulling of the cable line. More technical aspects of installing the electric cables and accessories were the responsibilities of the electrical engineers and technicians provided by the implementing NGO. The beneficiary communities were also expected to make an upfront 10% financial contribution to the cost of the mini grid system as commitment towards the realization of their respective schemes and subsequent refund of the loan. The loans were given to the communities on an interest-free basis and for a monthly repayment of FCFA 500,000 (about US $1000). The duration of the loan was not clearly stated. Both the in-kind and financial participation of the beneficiaries in the early stages of the projects ensured the later transfer of ownership to them.

In the powerhouse of each of the schemes an electrical control board was installed. This board consisted of a voltmeter and ammeter to record the line voltage and current respectively, and a main switch to turn off the scheme during maintenance. The installation of the electrical control board was executed by the NGO electrical engineers and technicians. These engineers and technicians were assisted by a resident electrical technician who was trained to manage the electrical system after commissioning. In Tongou and Baleng schemes power limiting devices were not installed at the level of the households unlike in the Bellah scheme where power limiting fuses were installed at the level of each household. The sizes of these power devices were determined based on the predetermined number of electric consumers in the households. The average power installed in the households was 150 W, to power mainly incandescent bulbs for lighting, operation of TV-set and radio for entertainment. The average radius of the mini grid systems was 2 km.

3.3. Operation and maintenance

From the initiation of the projects, the beneficiary communities were sensitized on the need and role of a Local Project Management Committee (LPMC) to operate, maintain and manage the schemes. The beneficiary communities, then democratically elected LPMC members. This committee was responsible for the Operation and Maintenance (O&M) of their respective scheme, however, the implementing NGO continued to provide them with technical assistance. The LPMC selected persons (males and females) were trained by the NGO to carry out activities related to the daily operations and basic technical maintenance. These activities included: turning the turbine on and off, greasing the turbine bearings, cleaning the intake, replacement of damaged lamps and fuses, bookkeeping of problems and actions taken encountered in the operation of the schemes. More complicated technical issues related to the operation of the schemes were referred to the implementing NGO. The NGO undertook quarterly visits to the sites to ensure the functioning of the power plants and to advise the LPMC on issues related to their technical management. However, implementation of this management strategy varied amongst the three communities.

In Bellah, the scheme was managed by a seven-member LPMC made up of three operators and four steering members. Members of this committee were responsible for the collection of the tariff from the households, payment of the operators and repayment of the loan. The three operators worked in alternating shifts and each shift lasted one month. Each of the operators was paid a token of 5000 FCFA/month (US $8/month). The LPMC rendered account of their activities to the village head who managed the affairs of the village. The village head had a lot of authority; was well respected by the community and was very involved in the O&M of the system. In Tongou, the LPMC was made up of eight persons: four persons from the Village Development Committee (VDC) and four local operators. Each operator was paid a token sum of 4000 FCFA (US $6.5) per month. The other members of the LPMC worked on non-compensated voluntary services. In *Baleng*, the scheme was managed by a five- member LPMC which included two operators and three steering members. The operators were not paid for their services; however, they were exempted from payment of electrical energy used in their homes. The other three members of the LPMC were not compensated for their services and the households of some of the members were not connected to the mini grid. Unlike the technicians in Bellah, who worked in alternating shifts, the operators in the Tongou and Baleng schemes did not have such an alternating work schedule for their activities. Furthermore, although these communities had a village head, they had little authority over their community members and were not directly involved in the O&M of their respective scheme. This was mainly due to the fact that their households were very far from the geographical limits of the scheme and so were not connected to it. The households of some of the members of the LPMC in Tongou and Baleng were not connected to the schemes; therefore, they were not direct beneficiaries of the project.

3.4. Tariff system in the schemes

An "end-use" or "service" based tariff structure was adopted in all three communities, rather than the usual "charging per kWh of electricity consumed" approach [15]. However, the implementation of this tariff system varied amongst the three communities.

In Bellah, the tariff system adopted was such that each household paid a flat rate of 1500 FCFA/month (US $2.5/month). This flat rate was shared between the husband (man) and the wife (woman) of the household. The man paid 1000 FCFA (US $1.6) and the woman paid 500 FCFA (US $0.8). A household where one of these persons was absent paid just the amount which the person present were to pay, i.e. 1000 FCFA (US $1.6) if only a man were present or 500 FCFA (US $0.8) if only the woman was present. Other consumers, mainly retail kiosks, paid a flat rate of 3000 FCFA (US $5). In Tongou, only households constituted the consumers pool. The tariff applied varied between 1000 FCFA to 3000 FCFA (US $1.6 to US $5) flat rates per month depending on the number of lamps installed. In Baleng, each household also paid a flat rate ranging between 1000 FCFA to 3000 FCFA (US $1.6 to US $5) per month depending on the number of lamps installed in the household, while retail kiosks paid a flat rate of FCFA 5000 (US $11).

4. Challenges to the operation of the schemes

The challenges faced by the three schemes could be grouped into two main categories: technical and organizational challenges. The technical issues included: flow rate, penstock, turbine and generator failures. Flow rate related issues were mainly due to insufficient availability or complete dry-off of the river because of climatic changes. Penstock related issues included bursting of the pipes, major leakages and disconnection of the pipes at the joints. Turbine related issues included fracture of the runner cups and erosion of the cups as a result of corrosion by sand particles in the water. Generator related issues were mainly burning of the stator-coils and break down of bearings. The organizational challenges included: non-cohesion amongst community members, especially members of the LPMC, lack of community leadership and sabotage from non-benefiting community members.

The frequency of these issues, in terms of percentage fraction of the numbers of days the scheme did not operate to the normal operational window of the scheme, for each of the schemes are reported in Figure 6. In the following paragraphs the technical challenges in each of the schemes are presented.

No flow issues were observed with the Bellah scheme. The Tongou and Baleng schemes suffered flow rate issues during the month of January and February of 2007, 2008. In 2009, the river dried off completely during the months of January, February and March.

In the Baleng scheme, some portions of the penstock burst and some joints got disconnected in 2006, 2007 and 2008. This was largely due to poor dimensioning of pipe thickness to bear the relatively high pressure head and poor local skills in pipe joinery. The pipes initially used were PVC–N8 type which could bear a maximum of 80 m of water head. In 2009, the community benefited from an extra external grant and the penstock pipe was completely replaced with a PVC-N16 which could support pressure up to 160m of water head. The extra grant was mobilized by the implementing NGO with very little contributions from the beneficiary community. Although the penstock in the Bellah and Tongou schemes had some leakages, these leakages were minor and did not prevent the operation of the generator.

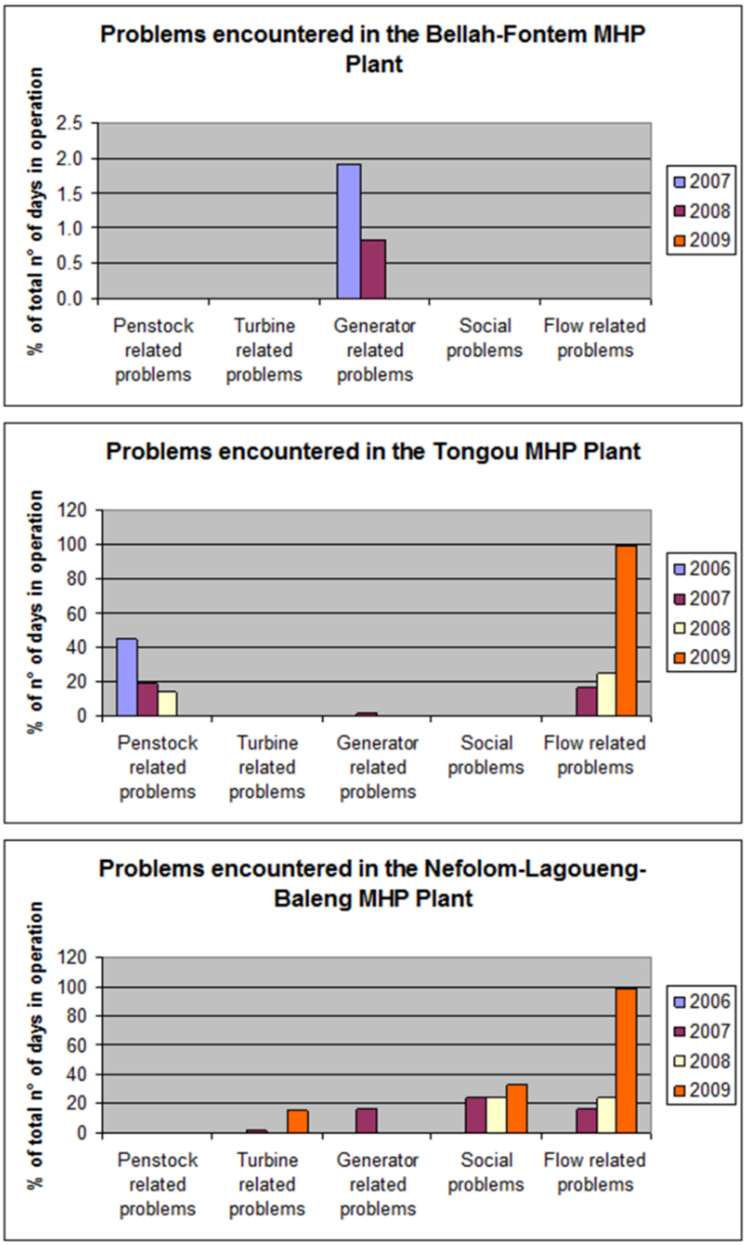

Figure 6. Frequency of challenges faced by the schemes.

In the Tongou scheme, some of the turbine runner-cups were fractured in 2007, and in 2009 some had major erosion due to the poorly filtered sandy water. These issues were, however, timely resolved by the technician from the NGO who lived a few kilometers from the scheme. No turbine related issues were recorded in the Bellah and Baleng schemes.

During the period from 2006 to 2008, the generator of the Baleng scheme suffered several failures. These failures were caused by vibrations resulting from weak foundation to support the turbine-generator installations and the poor V-belt pulley coupling strategy. Another cause of generator failure was the frequent unauthorized changing of the loads at the level of the households. No load limiters were installed in the households during this period, so the household often change their load. In the Bellah scheme, the stator-coils of the generator got burnt once in 2007 and 2008. These failures were linked to the vibrations of the turbine which was installed on a weak steel frame. It took a couple of weeks for the damaged generator to be transported to the headquarters of the NGO for repairs. These two incidences made the community to mobilize extra funds to acquire a second generator as stand by. With a second generator, subsequent generator failures did not affect the operation of the scheme, since it was timely replaced by the stand by one. The mobilization of the community to source the extra funds for a second generator was facilitated by a dynamic local leadership and a supportive external elite group. Most of the mobilized funds came from the external elites most of who lived abroad, particularly in Europe and the United States of America. Although, the generators in Baleng and Tongou schemes had similar problems, they were timely resolved by the technician of the NGO whose proximity to the sites facilitated the timely intervention. In 2009, the generator and turbine set in Baleng were replaced and the coupling changed from the V-belt coupling to direct coupling and the foundation for the installation of the turbine-generator set was reinforced. Funds for these repairs were sourced by the implementing NGO.

The organizational challenges observed in each of the schemes are presented in the following paragraph. The challenges identified were grouped into three categories, namely: *cohesion amongst community members (especially the LPMC), community leadership, and ownership of the scheme*.

4.1. Cohesion amongst community members

In Bellah, a relatively very high level of cohesion existed amongst community members, i.e. village head, LPMC, external elites and the rest of the community members. This cohesion was demonstrated by the community's ability to mobilized own funds to acquire a second generator and also with the arrangement of alternate work schedule amongst the technicians. Decisions taken by the LPMC were binding to all. In Tongou, although a community leader and LPMC existed, their influence on the management of the scheme could not be noticed. The O&M of the scheme was done almost entirely by only one of the four local technicians. In Baleng, a relatively high level of non-cohesion amongst community members, especially the LPMC, was observed. From the focused group discussions with the LPMC, it was noted that decisions taken by this committee were often not respected by all. For example, some households which defaulted monthly payments of their electricity consumption, could not be sanctioned because they received the support of some of the members of the LPMC, especially those whose households were not connected to the mini grid.

4.2. Community leadership

The presence and influence of a community leadership varied amongst the three communities. In Bellah, the village leader commanded and received a lot of respect from all his community members and was fully committed in overseeing the smooth functioning of the scheme. The members of the LPMC were very dedicated and their decisions were binding to all. This committee rendered account of their activities to the village head. In Tongou, although a community leader was present; his influence on the O&M of the scheme could not be noticed. His household was not connected to the scheme due to the geographical distance from it. He delegated his role to the LPMC. In Baleng, although the community had a village head, interviews and discussions with the community members indicated that the procedure which brought him to the head of the community was not unanimously accepted. Thus the community leader commanded little or no respect from his community members and had no direct involvement in the O&M of the scheme. Furthermore, his own household was not connected to the scheme.

4.3. Ownership of the scheme

The field focused group discussions and interviews with the community members showed that awareness and feeling of ownership of the scheme varied amongst the three communities. In Bellah, there was a very strong awareness and feeling of community ownership of the scheme. Such strong awareness and feeling of ownership was made evident by the community mobilizing funds to acquire a second generator. In Tongou, community awareness and feeling of ownership of the scheme was low. The scheme was more or less managed by only one technician, notwithstanding the existence of a LPMC. The interviews with the community members further revealed that, in the minds of most of the community members, the scheme was owned by the implementing NGO. In Baleng, the awareness and feeling of ownership of the scheme was the lowest of the three communities. This community felt that the scheme was owned by the implementing NGO notwithstanding the multiple meetings held with them. Thus they were less committed to the O&M of the scheme. The failure of the scheme during the period from 2006 to 2008 and its rehabilitation in 2009 with funds sourced by the NGO was evidence to the very low level of awareness and feeling of ownership. In addition, some of the poles supporting the electrical energy distribution network cables were often damaged or even completely cut down by some non-benefiting community members. Such acts of sabotage were a result of low feeling of ownership of the scheme by the beneficiary communities.

5. Discussions

The three schemes, although, managed on the same financial model (community-based) produced different results. The Bellah scheme ran for closed to three years without major problems. The Tongou scheme ran continuously, however, with frequent interruptions due to households tampering with the load. The Baleng scheme had known more interruptions compared to the Tongou scheme. These different performances could be attributed to *community management*, that is, the execution of the organizational aspects of the project. In Bellah, there was a clear and coherent social organization, where there was a committed community leader who had authority over the community members and was fully involved in the O&M of the scheme. This cohesion descended to the level of the LPMC team and the operators. The operators were organized such that they took shifts in executing their tasks, thus allowing them time to do other productive activities to compensate for the very low but regular remuneration. The relatively higher remuneration of the operators gave them a high level of motivation to provide their services to the benefit of the community. Regular tariff collection led to timely maintenance operations and even acquisition of a standby generator. Also, its external elites remained connected in solidarity to development efforts in their village. In the Baleng and Tongou scheme, the social organization was weak and incoherent; the local leadership had no authority over community members and was not involved in the O&M of the scheme. The team of operators had to work without shifts and with little remuneration. The time demanded from these operators and the low remuneration left them with low motivation to provide their services. The LPMC members were not very motivated and these resulted in irregular tariff collection. In these two communities, connection to and solidarity of external elites was completely absent.

The differences observed in the practical realities within the social organizational frame around the different schemes reflected in the operational performance of the schemes. The Bellah scheme with a more cohesive social organization performed far better than the Tongou and Baleng schemes where the social organization was less cohesive.

The design of the three schemes was not based on a robust river flow and electrical energy demand assessment. They were designed as instantaneous systems [14]. The poor dimensioning of micro hydropower components had been identified as a factor that could affect the success of the scheme [16]. The complete dry off of the river in the Tongou and Baleng schemes during some periods of the year (January to March) and penstock failure problems observed, especially with the Tongou scheme, was evidence of the poor dimensioning of these schemes.

The schemes were financed differently. While a revolving fund was placed at the disposal of the implementing NGO to manage by giving out interest-free loan to beneficiary communities, the terms and conditions of these loans were not transparent, especially loan duration and regularity in repayments and penalties if there were defaults. The Bellah community felt the obligation to repay the loan, and so felt a strong ownership of the scheme and thus were committed to make it work. In Tongou, the community did not feel oblige to repay the loan and so did not assumed ownership of the scheme. The Baleng community had no obligation to repay the loan since theirs was mostly financed from a grant, so they also did not assumed ownership of the scheme.

6. Conclusions and Recommendations

Decentralized collective electrification solutions based on mini grids powered by pico and micro hydropower plants and managed under the community-based model could be a viable option to overcome the rural electrification challenges in Cameroon. The case of three community-based mini grid systems powered by pico and micro hydropower plants implemented in the mountain regions of Cameroon have demonstrated three key issues that could affect such rural electrification solutions, namely:

- *Organizational aspects:* These aspects include, social cohesion at all levels of management of the scheme, community leadership and ownership of the scheme. The Bellah scheme demonstrated that with a good community organization and management, mini grids powered by pico and micro hydropower plants could be very successful. The Tongou and Baleng schemes demonstrated that for such schemes to be successful for rural electrification, ownership by the community was crucial.
- *Comprehensive planning:* Non robust hydropower resource assessment (in particular river flow) and electrical energy demand assessment, lack of system control techniques and power limiting devices at the level of the consumers, affected the technical performances of the schemes. This has been demonstrated by similar projects in rural areas in other developing countries [14].

- *Financing:* Also, crucial to the success of community based mini grids powered by pico and micro power plants is the method of financing. The Baleng scheme demonstrated that financing schemes through grants would probably lead to poor management and subsequent technical failure of the scheme. On the other hand, the Bellah scheme demonstrated that a sufficiently high community financial participation plays a significant role in the better management and success of such solution strategy.

From these experiences, to improve on the viability of community-based mini grids powered by pico and micro hydropower and their upscaling as a collective solution for rural electrification in Cameroon the following are recommended:

- *Comprehensive planning of the scheme:* This will involve local capacity building for a robust system design, i.e. hydropower resource (river flow) assessment, electrical energy demand assessment, appropriate dimensioning of the system components and demand side management strategies. Credible academic and research institutions could be involved in creating a database of hydrological data which could support the assessment of the hydropower resources in rural areas.
- *Community organization and management:* The political organization and functional cohesion of beneficiary communities must be given serious considerations. Also, creation of and building the management capacity of a smaller management unit (like the LPMC) which shall be directly responsible for the operation of the scheme should be seriously considered. The community leadership and the management unit (LPMC) should be involved at all stages of the project management cycle to guarantee community cohesion and ownership of the scheme. In the case where some community members could not be directly connected to the scheme, individual solutions like battery charging using the scheme should be used to include such members in the scheme. This would limit sabotage actions as observed in some of the schemes in the case study. The Bellah organizational model could serve as an example for upscaling of this approach to rural electrification.
- *Financing:* The investment cost of a mini grid powered by a pico or micro hydropower plant could be beyond the affordability of most rural communities in Cameroon where poverty level is quite high. Thus developing a viable financing option for such schemes is recommended. A mixed financial strategy should be adopted in the development of a viable financing option, however, the beneficiaries should make significantly high in-cash contributions. This together with their involvement at all the stages of the project management cycle will guarantee community ownership of the system.

Conflict of interest

All authors declare no conflicts of interest in this paper.

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