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Flexible design of a pico-hydropower system for Laos communities

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ABSTRACT

Lao People's Democratic Republic (Laos) possesses large hydrologic resources, converting hydropower into the most important renewable energy resource in the country. Recently the Lao government, multilateral organizations and NGOs have developed large hydropower projects in tributaries of the Mekong River. These projects usually do not benefit poor people in remote areas where the prevailing source of electricity consists of private pico-hydropower units (<5 kW). These systems face several challenges such as coping with low quality hardware, risk of electrocution and damage to electronic devices and light bulbs. Non-governmental institutions like Lao Institute of Renewable Energy (LIRE) in collaboration with donor funding organizations are seeking to alleviate this situation. These institutions pursue the upscaling and improvement of quality, safety, efficiency and reliability of pico-hydro technology through projects based on the design and implementation of demonstration sites and training programs in rural areas. During the project presented in this work, a feasibility study is carried out to identify a suitable village for the implementation of a demonstration site. Possible locations are analyzed according to social, environmental and technical aspects. For each option, an electric system is designed. For the final selection of the best option, the following design constraints were considered: flexibility, cost effectiveness (to be affordable to poor communities) and easiness of reproduction by people without deep technical knowledge.

1. Introduction

The project presented in this paper aims to deliver electricity to poor villages applying pico-hydro technology and to build local know-how in the communities to maintain, replace and reproduce the system in the vicinities by means of training and monitoring programs.

The demonstration site is an electric installation designed according to the technological and economical conditions of Lao rural areas, with special emphasis on the district where the project is located. Implementation and monitoring processes are designed to acquire knowledge about the social and technical constraints of shared pico-hydropower applied to Lao poor rural districts. Shared pico-hydro is a new concept in Laos communities, where the usual pico installations provide electricity only to the owners of the turbine or exceptionally also to a few relatives. The ultimate objective of the project is the definition of semi-standardized shared pico-hydropower systems for implementation in Lao rural areas.

1.1. Shared pico-hydropower demonstration site

The project consists of four phases, 1) feasibility study and system design, 2) shared pico-hydropower implementation, 3) training and monitoring and finally 4) evaluation. These phases are planned to have a total duration of 18 months. The present paper is focused on the first phase: feasibility and system design. Collected data will be presented together with different electric system desigs. Feasibility studies have been conducted by Lao Institute of Renewable Energy (LIRE) in several villages located in Xekong province. LIRE is a non-profit Lao organization dedicated to sustainable development of a self sufficient renewable energy sector.

2. Methodology

The starting point was the selection of suitable villages where the project could be implemented. For this purpose, social and technical feasibility studies were conducted in some villages of Xekong province, which was classified by the Lao Statistics Department [1] as high-priority region for poverty reduction action. The process consisted in interviewing senior village members and each household to gain background information about energy consumption profiles of the village and to assess its

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still unmet energy needs. Additionally, social surveys served to identify local preferences regarding management systems and economic payback possibilities.

In parallel with the social survey, a technical research was carried out. The research team identified suitable sites for turbine installation. Lao rivers suffer extreme seasonal flow level differences [2–4]. Therefore, water flows were measured and data about the stream morphology and its evolution during dry and wet seasons were collected. In this project dry season measurements were taken as a reference to estimate possible minimum system power outputs. Besides the viability of the project, the criteria for selecting a suitable village are (a) the lack of access to national electricity grid (in the present or near future), (b) the real poverty reduction efficacy and (c) ecologic aspects such as CO_2 emission reduction or deforestation eradication [5]. In summary, social, environmental, technological and economic aspects have been considered, in order to ensure the sustainability of the project once donor funding and engineering consultant tasks are finished.

The next step of the project was the design of the shared pico-hydropower system. Good practice guidelines for this task can be found in a number of manuals for the design of small hydropower, which are available on-line [6–8]. During this stage, data collected in the feasibility studies are analyzed to determine pico-hydro technology and energy distribution in the villages. The hydro turbine is selected according to the stream characteristics (flow and head). The installed power P_{inst} of the hydropower system can be calculated by

$$P_{\mathrm{inst}}(W) = g \cdot Q \cdot H \cdot \eta_{\mathrm{turb}} \cdot \eta_{\mathrm{gen}} \tag{1}$$

Where g (m/s^2) is the gravitational acceleration, Q (l/s) the flow rate, H (m) the head, η_{turb} the turbine efficiency and η_{gen} the generator efficiency.

The energy distribution system will be structured according to the preferences of rural customers, electrical power levels generated by the system and the distribution of the households in the villages.

In this project yearly flow discharge patterns of the streams with daily resolution are employed, which represents an important conceptual improvement with respect to current Lao standard system design. These traditional designs are based on a unique flow discharge measurement performed during the assumed worst month of the dry season. In the present study, that value is combined with the statistics of historical hydrological data of the river to obtain yearly discharge estimations. A second innovation is to consider the turbine efficiency as a function of the flow rate, instead of applying a constant standard value of 60% for rural hydropower applications. Therefore, technical data provided by suppliers have been analyzed to obtain efficiency curves adapted to the stream parameters. Thus, it was possible to obtain more accurate estimations of annual energy production for each project option.

Another technical innovation is the introduction of the Electronic Load Control (ELC) device. The ELC maintains a constant grid voltage by dumping excess power from the generator, in particular when some appliances are turned off, which protects other appliances from damage. Although the benefits of this device are already largely demonstrated in rural pico-hydropower, users in Lao villages do not install it to avoid the extra purchasing cost, with the consequence of having frequent damages on their electric appliances [9]. One of the objectives of the demonstration site is to show Lao users the usefulness of this device.

The design phase ended with the selection of the most suitable village. The criteria for selecting the village were similar to the feasibility study phase. However, the project development depends on donor funds. Therefore, economic analysis output and donor preferences are the relevant constraints to make the final decision.

Implementation, training follow-up and evaluation phases were designed according to sociological parameters to ensure that the entire village – including women, indigenous and even illiterate people – get involved in the project. These phases aim to instruct local people to plan, manage and implement their own public investment in a decentralized manner and create village institutions to support participatory decision-making and conflict-resolution processes within the village. Although the aforementioned phases are fundamental for the sustainability of the project, they are not the object of this study and are not detailed here.

2.1. Social and environmental impact of shared pico-hydropower

As described above, social and environmental issues had the highest priority from the beginning of this project and were taken into account very carefully. In fact, the main objective was to improve living conditions of remote villages in Laos. According to results from LIRE published in [9], the following social improvements are expected:

- More hours of light permit higher family income and education (more time for craft-work and study)
- Reduction of health risks due to indoor use of open wood or kerosene fire (fire hazard, air contamination)
- Improved social services due to public character: school, meeting hall, dispensary
- New local working opportunities: maintenance technician, trade with excess electricity, expertise for installations in other villages, local fabrication of components
- Increased local commerce: neighboring villages may copy the system (components are purchased on local market)

Pico-hydro is recognized as an energy generation technology with very low environmental impact. Nevertheless, possible alterations of the river were minimized by permitting only a limited size of the dam and maintaining a minimum residual flow in the stream for aquatic life purposes. These constraints were the main reason why the use of 500 W turbines was dismissed at the end (see Section 3.4). The introduction of a draft channel with its trash rack further reduces the possibility that larger fishes may reach the turbines and get injured.

As a consequence, remaining possible negative impacts of the implementation of pico-hydropower are outweighed by its main advantage which is the reduction of emissions (CO_2 and other) and deforestation. Remember that currently the only sources of energy in these villages are wood and kerosene (see also social impact above).

Another positive environmental aspect is the introduction of safety issues (e.g. ELC device). Existing rural installations in Laos are suffering severe voltage fluctuations which finally reduce the lifetime of electrical appliances. As recycling does not exist, extended lifetimes reduce directly the volume of trash which usually is dumped without any control into the countryside.

As a summary, the following environmental aspects of the project have been identified:

- Minimized negative impacts of pico-hydro with low dams and minimum residual water flow left in the river
- Reduction of emissions (CO_2 and other) and deforestation by implementation of pico-hydro (less kerosene and wood are burned)
- Reduction of electric waste due to extended lifetime of electrical appliances by introduction of safety elements (ELC)

3. Data analysis

3.1. Socio-economic data

As a result of the feasibility studies, two options were identified: either a shared pico-hydropower system between the villages Ban Tangkaad and Ban Tangprang or a shared system for Ban Bark village. All locations are situated in the Karum District, Xekong Province. Characteristics of the villages obtained from the feasibility studies are shown in Table 1.

3.2. Local hydropower resource

Technical feasibility studies identified some stream sites for pico-hydropower implementation in each village. Due to the reduced timing and budget of the project, only a unique flow discharge measurement was performed at each site during the dry season. Flow rates and head for the sites are shown in Table 2.

These values represent a worst-case estimation and thus, are not sufficient for the evaluation of the viability of the project. Especially in the case of the joint project between Tangprang and Tangkaad villages, the donor funding organization expressed its preference for this option due to the higher number of beneficiaries compared to Bark option. However, this case presents the challenge of having a high energy demand combined with a low quality of available water resources. As a consequence, it was essential to obtain a yearly flow discharge pattern that usually is not used in rural Lao project designs. The main reason is that the Lao Statistics Department prioritize the monitoring of high flooding-risk Mekong tributary streams and thus, no flow data are available for small streams.

To cover this lack of information, an intensive research was carried out between the institutional statistics sources of the Mekong River Commission (MRC), Laos University and Laos National Statistic Department. As a result, historic data of a hydrologic station downstream, collected by an UNESCO study, was obtained. Studies on South Asia meteorology reveals that Xekong River and tributaries have regular flow discharge values during dry season whereas wet season values are very variable due to occasional tropical storms and typhoons [2,3]. As a result, estimated daily flow rates were obtained for the three sites described in Table 2. Using historical data of Xekong River, an acceptable approximation is obtained for flow discharge in the villages. Nevertheless, a 5% security factor was introduced to compensate for the remoteness and age of the data. In Fig. 1 resulting flow rates are represented in a logarithmic scale due to the large difference between yearly peak and minimum values. In the presented project dry season values are most decisive, because they determine the minimum power output of the system.

Table 1
Socio-economic data of selected villages.

Project option	Ban Bark	Ban Tangprang & Ban Tangkaad
Ethnic group	Ngae	Cherthong
Population	164 (89 female), 20 households	444 (217 female), 44 households
Communal buildings	School, meeting hall	2 meeting halls, 1 dispensary, 1 school
Main activities	Rice farming, livestock, fishing & weaving sin	Rice farming, livestock & weaving sin
Main energy source	Diesel generator and kerosene lamps, average expenditure: 3.24$/l	Wood burning (no fuel supplier available), average expenditure: free
Total demand	990 W	2280 W
Low tariff	30 W lighting for 20 households + 1 communal house	30 W lighting for 37 households + 3 communal houses
High tariff	120 W lighting and entertainment for 3 households	120 W lighting and entertainment for 9 households

Table 2
Flow rate and head measurements at several sites.

Village	Tangprang	Tangkaad	Bark
Site	A & B	D	C
Q_{min} (l/s)	34	21	89
H (m)	1.4	6.1	12

3.3. Turbine performance

According to Equation (1), the turbine performance is a critical value for this project. Having in mind the premise of designing a reproducible system in poor Lao communities, the components of the system must be available in Lao market. Rural customers usually purchase Vietnamese and Chinese turbines which are cheaper but also low quality and are offered normally without information on technical characteristics. For the project, Hydrotech products were selected. Although this product is medium/high price for Lao standards, the better quality and reliability – verified in previous LIRE projects [9] – is a balancing advantage. Furthermore, these products have technical information which helps to develop efficiency curves for these turbines. Technical characteristics of Hydrotech turbines are summarized in Table 3.

Lessons learned from previous projects [9] suggest the reduction of nameplate efficiency values by 5%. This effect is due to the difference between ideal laboratory test conditions and a village installation. In Fig. 2 the approximated efficiency curve is shown for Hydrotech HT-200 type. The approximation was done based on data provided by the Vietnamese turbine supplier, using a polynomial of degree two with the coefficients shown in (2).

$$\eta = -720q^2 + 1400q - 620 \tag{2}$$

Where η (%) is turbine efficiency and q (p.u.) is relative discharge rate.

Due to the lack of more detailed information, it is assumed that these normalized curves apply also to HT-500 turbines. From the experimental data it is derived that the minimum relative flow rate which permits still acceptable power output parameters (frequency and voltage) is at $q_{min} = 0.84$ approximately. This means, that these turbines have only very limited partial load capacity.

3.4. Power generation cases

Head, flow and efficiency values were used to obtain the available power output assuming several values of nominal turbine power. Results are shown in the following figures.

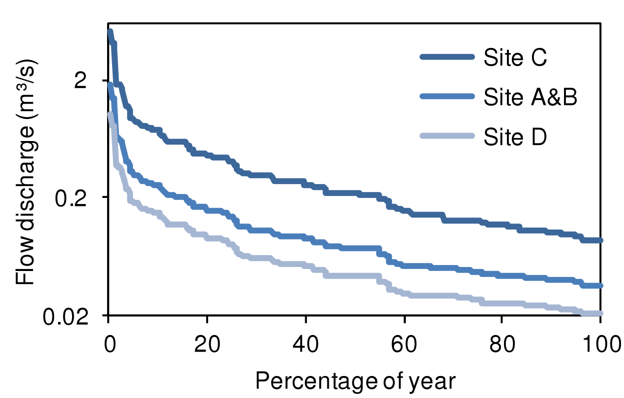

Fig. 1. Estimated daily mean flow duration curves for sites A–D.

Table 3
Extract from the technical data sheet of Hydrotech turbines.

Parameter	Axial flow				Turgo	
	HT-200		HT-500		TN-1000	
H (m)	1.3	1.5	1.3	1.5	10	12
Q_n (l/s)	24	25	58	60	19	20
P_n (W)	165	220	400	500	1080	1200
n	1000 r.p.m.					
Output	Single-phase 220 V AC, 50–60 Hz					
Generator	Permanent magnet					

Fig. 3 corresponds to Ban Bark village system. Elevated flow discharge and head at site C permit the installation of a 1000 W Turgo turbine with a constant output of 1070 W along the year (including transmission losses). This value is slightly above the desirable load demand of Ban Bark established at 990 W. As a result, this option is totally feasible.

In contrast, Tangprang and Tangkaad systems will have a variable power output depending on the season, as shown in Figs. 4 and 5. Once discounted transmission losses, the maximum power that each turbine can supply is 200 W, which divided by the number of households will correspond to a unique tariff of 14 W per household (Trf1). As the flow discharge increases in the wet season, there would be enough water to run a 500 W turbine, enabling a higher power tariff (Trf2). However, this will be possible only during 61% of the year in case of sites A&B (Fig. 4) and 39% in case of site C (Fig. 5), which does not fit the project constraints. Additionally, the requirements for the size of the dam in order to operate 500 W turbines are incompatible with the ecological aspects, mentioned before.

The obtained power output curves determine the system structure and available load profiles for each village which will be discussed in the next section.

4. Discussion

4.1. System configuration

As seen in Fig. 3, in the case of Bark, a unique Turgo turbine of 1000 W (Hydrotech TN-1000) can supply village load demand even with the estimated 6% of losses in transmission lines for the selected 10 mm^2 wire. The shared pico-hydro system will consist in a Turgo turbine, an Electronic Load Controller (ELC) and a 230 V AC mono-phase grid of around 630 m. The schema of this system is shown in Fig. 6. The turbine will be placed 400 m away from the intake point to avoid damages caused by wet season flooding and will be connected to the forebay by means of a purchased penstock. All these components are available in Lao market from Hydrotech branch. Civil works will include roughly 600 m of forest clearance to create the access to the power house and penstock placement.

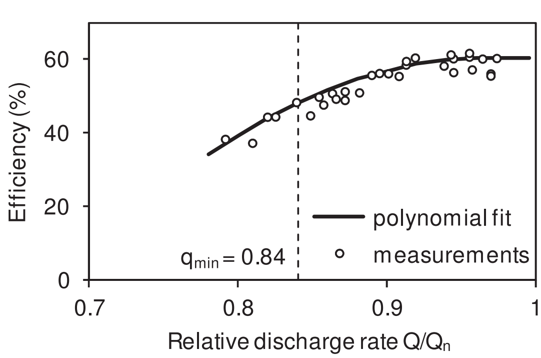

Fig. 2. Approximated efficiency curve for Hydrotech turbine HT-200.

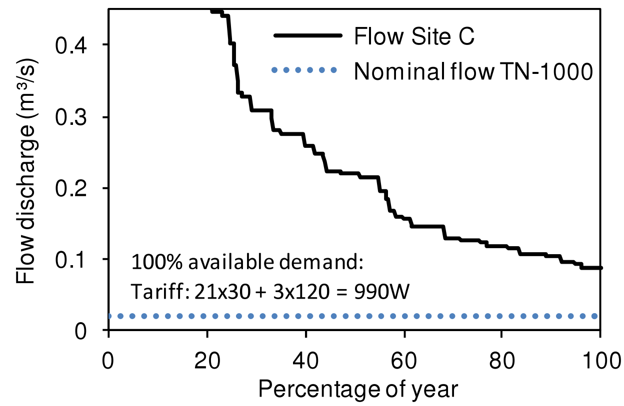

Fig. 3. Estimated daily flow rates for site C (Bark village) and nominal flow of Hydrotech turbine TN-1000.

The system has great expansion opportunities in the future by only installing more similar turbines in parallel. Flow stream is suitable to install up to 3 additional 1000 W turbines. No specific social issues were detected for this project option.

On the other hand, as expected, the shared system for the villages Tangprang and Tangkaad will not cover the desired load demand due to the low level of minimum stream flow (Fig. 1). Also transmission line losses represent a problem due to the different distances to cover (between 120 m and 1700 m) according to the site and the village. As donor funding constraint, the system should provide all households in the village with electricity. As LIRE constraint, the system should provide electricity 24 h/365 days and must be easy to reproduce in other poor villages even without the help of an external consultancy. These conditions lead to design a very simple system with a low power capacity of only 14 W per household. The structure is composed of four independent grids connected to the villages. As a result, one turbine will supply electricity to half of each village. Each grid will be composed of an axial 200 W turbine (Hydrotech HT-200), a draft tube and a draft channel (for increasing the efficiency), the ELC and a 230 V AC mono-phase grid of 6-mm^2 wire. As shown in Fig. 7 turbines at sites A and B will supply Tangprang village (120 m and 360 m away respectively) and two turbines at site D will supply Tangkaad

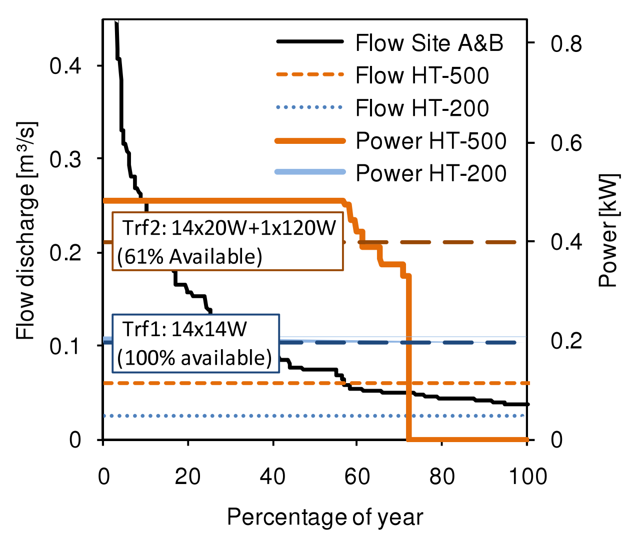

Fig. 4. Estimated daily flow rates for sites A&B (Tangprang village), nominal flow and power output of Hydrotech turbines HT-200 and HT-500 with two tariff options Trf1: 196 W and Trf2: 400 W (dashed lines).

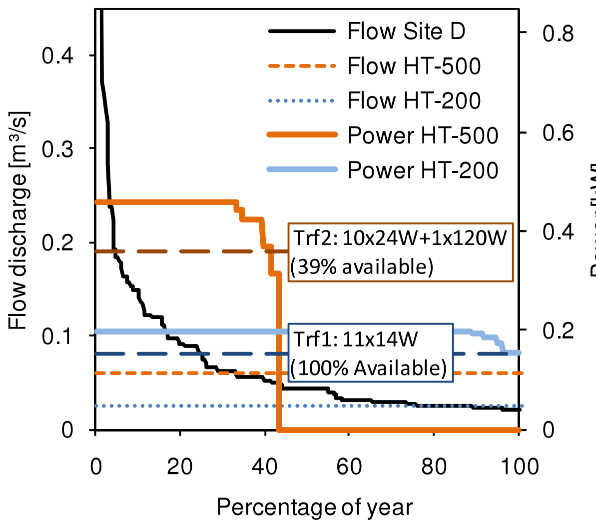

Fig. 5. Estimated daily flow rates for site D (Tangkaad village), nominal flow and power output of Hydrotech turbines HT-200 and HT-500 with two tariff options, Trf1: 154 W and Trf2: 360 W (dashed lines).

village and the communal dispensary (1700 m away). The schema of this system is shown in Fig. 8. Turbines are distributed according to the power-load balance without regarding land owner considerations which could imply some social issues. Also the fact of having independent grids can generate discussions in the case of temporary failure of one of the turbines.

Civil works include the construction of the grid following existent routes, the conditioning of the stream to avoid flooding damage, the draft channel and draft tube. Those last components are available as purchase parts. However, both parts can be constructed by the inhabitants of the villages following the turbine supplier design to reduce expenses. For similar purposes, in both project options the smallest diameter wire (6 mm^2) is selected, fitting the conditions of voltage drop (10% for transmission line and 5% for drop line), current carrying capacity and mechanical resistance.

Derived from the low flow values at the sites at Tangprang and Tangkaad, the system will have very limited expansion opportunities. They are only applicable in wet season when 500 W turbines could run without a dam. In this case 200 W and 500 W turbines would alternate in operation according to seasonal flow values. However, this option only yields a moderate power gain which would possibly not justify the additional cost, due to increased wire section and the purchase and installation of the 500 W turbines.

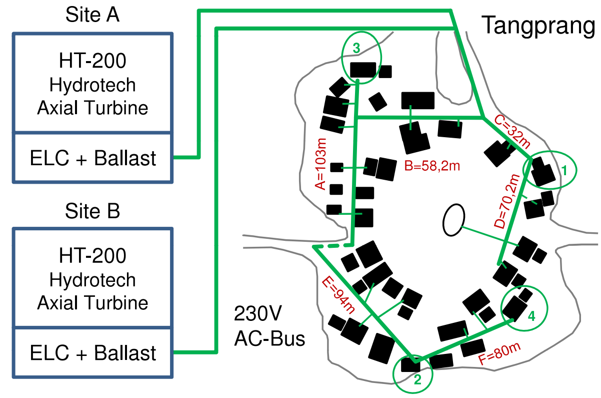

Fig. 7. Tangprang system with two Hydrotech axial turbines HT-200, to be installed at sites A and B.

The efficiency of the system could be increased by adding bidirectional inverters connected to a common DC Bus to equilibrate load and power, which opens the additional opportunity of installing a battery storage system. Unfortunately, this solution was dismissed due to the high cost, although the benefits for supply quality would be significantly high.

4.2. Possible demand profiles

Taking into account the characteristics of the villages and the available power generation, possible demand profiles have been developed, as shown in Fig. 9. More detailed data is given in Appendix A.

The consumption of ‘Meeting Hall’, ‘Extra common use’ and ‘Dispensary’ are light bulbs of different size and number, while ‘Light’ refers to light bulbs installed in the households. The dotted line (P_{min}) represents the minimum power available from the pico-hydro installation. In Tangkaad, Pmin is with 308 W lower than in Tangprang (400 W) despite the fact that the installed power is the same. This is due to the very low flow levels at site D, resulting in reduced power output during approximately 10% of the year, as shown in Fig. 5.

In Ban Bark, given the larger turbine, more appliances can be used at the same time, including TV and music. On the other side, in Tangprang and Tangkaad, only the most basic services, such as lighting for households and the meeting hall are possible. In the case of Tangkaad, also the dispensary is included.

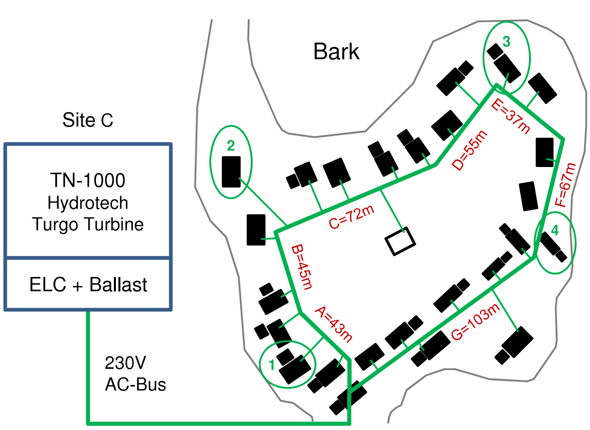

Fig. 6. Bark system with Hydrotech Turgo turbine TN-1000, to be installed at site C.

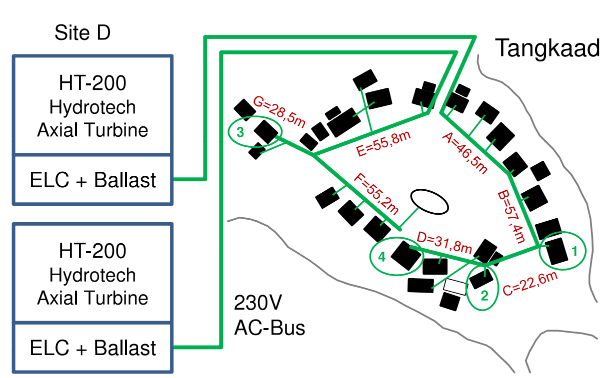

Fig. 8. Tangkaad system with two Hydrotech axial turbines HT-200, to be installed at site D.

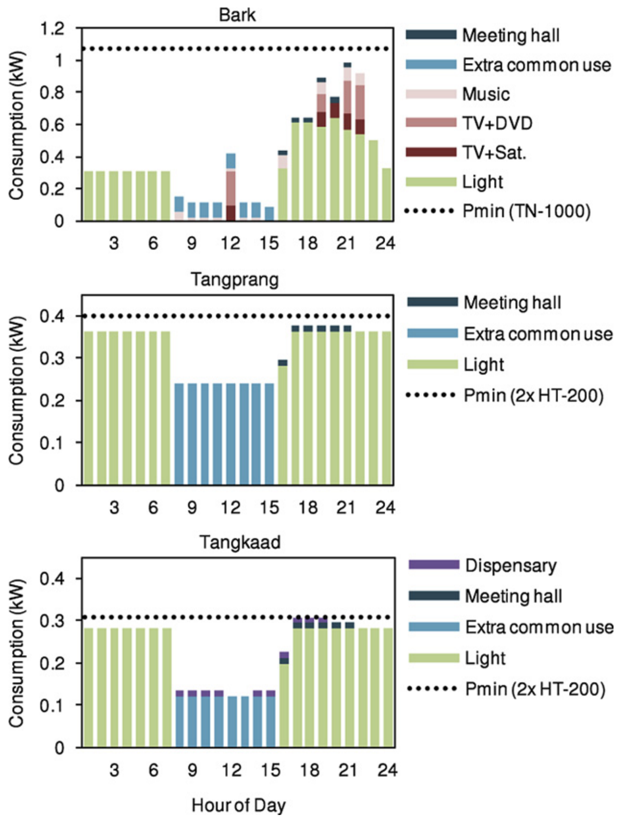

Fig. 9. Estimated demand profiles for Bark (above), Tangprang (middle) and Tangkaad (below).

4.3. System costs

Once defined the systems, the next step is to establish the budget for each option. Budget is structured according to each of the four project phases with an additional section for administrative and support activities. Total project costs are 35,993$ for Bark and 55,947$ for Tangprang/Tangkaad. This leads to a cost of installed electric power of around 31 $/W and 85 $/W respectively.

A 28% of the project will be covered by the inhabitants of the villages in-kind. In-kind contributions consist in local material for poles and civil works, manual labor and also lodging and food to LIRE and external staff in the occasion of field trips and the system implementation period. This strategy reduces global cost and local people are directly involved in the project development.

From the global cost, around 7% is due to the feasibility study and about 55% correspond to the hardware and installation cost. This data is an important figure to consider. In order to assure the sustainability of the project, rural customers will have to pay a monthly fee to cover the expenses for maintenance as well as to ensure sufficient cash to cover the cost of equipment replacement after a period of 10 years. Monthly fee expenses will depend on the management system chosen by the users. Medium values are around 4.5$ for low tariff (30 W) and 11.4$ for high tariff (120 W) in Bark and about 4$ for the unique 14 W tariff in Tangprang/Tangkaad. Although monthly fees are apparently more suitable for the Tangprang/Tangkaad option, it should be remarked that nowadays these villages are not used to pay for the energy (see 'Main energy source' in Table 1) and this could be a social inconvenience for the project.

5. Conclusions

The project presented in this paper has been developed in an attempt of reducing Lao rural energy deficiencies. The promoters are funding donor associations and LIRE. This partnership determines the project constraints which lead to the identification of a suitable location to implement the shared pico-hydropower demonstration site.

The main objective of the project is to supply electricity to an isolated village in a poor district of Laos. At the same time, the installation is used as a demonstration site to show neighboring communities the benefits of shared pico-hydro systems in order to encourage them to reproduce the system.

Following this purpose, the demonstration site must be composed of equipment available in Lao market and its design must be simple so that it can be reproduced easily by people with low technical knowledge. Pico-hydropower is the ideal technology for this purpose due to its simplicity and its current implementation in the country which reduces difficulties in end-user acceptance.

Several villages were pre-selected as project options. The feasibility studies concluded that only two of these options were suitable, namely Ban Bark village and a shared system for the villages Ban Tangprang and Ban Tangkaad. The demonstration site is intended to be an example of accessible rural electrification of poor villages. Therefore, the design priority is electric generation 24 h/365 days without complex installations. As a result, two technical solutions are identified: (1) a grid fed by a unique 1000 W Turgo turbine, in the case of Bark village, and (2) four separate grids, each fed by a 200 W axial turbine, in case of the shared project in the villages Tangprang and Tangkaad.

Potential demonstration sites for shared pico-hydropower are sized according to yearly flow discharge patterns. Power output estimations take into account the variation of turbine efficiency as a function of the flow discharge. Both techniques are conceptual improvements with respect to standard rural pico-hydropower designs in Laos. An additional improvement is the introduction of the ELC device to stabilize the grid voltage and thus, reduce the risk of damage to electric appliances.

This demonstration project intends to show poor Lao communities the usefulness of shared pico-hydropower systems. That makes social issues important criteria to determine the best project option. The Tangprang-Tangkaad option was preferred by donor funding due to the larger number of beneficiaries implied in the project. However, the inconveniences found during the project design, such as low power availability, land owner social issues and the unlikely predisposition of rural customers to cover the monthly fees, suppose a high risk for the sustainability of the project. On the other hand, the Ban Bark option satisfies all project constraints and is the best candidate to reach the project goals. This leads the authors to recommend Ban Bark village for project implementation.

Acknowledgments

The authors of this paper would like to express their gratitude and sincere appreciation to LIRE organization for the opportunity of working in this project and the valuable comments and suggestions about the system design and the knowledge passed on Lao culture.

We would also express our gratitude to the authors of Catalog of rivers for Southeast Asia for the hydrologic statistical data without which the project completion would not have been possible.

Appendix A. Estimated load profile data

Table A.4
Estimated load profile (W) for Ban Bark.

Hour	Ban Bark										
	Household light bulbs				Light	TV + Sat.	TV + DVD	Stereo music	Extra common use	Meeting hall	Total
	1st 14 W	2nd 14 W	2nd 8 W	3rd 8 W							
1	308	0	0	0	308	0	0	0	0	0	308
2	308	0	0	0	308	0	0	0	0	0	308
2	308	0	0	0	308	0	0	0	0	0	308
3	308	0	0	0	308	0	0	0	0	0	308
4	308	0	0	0	308	0	0	0	0	0	308
5	308	0	0	0	308	0	0	0	0	0	308
6	308	0	0	0	308	0	0	0	0	0	308
7	308	0	0	0	308	0	0	0	0	0	308
8	0	0	0	0	0	0	0	60	90	0	150
9	0	0	0	0	0	0	0	20	90	0	110
10	0	0	0	0	0	0	0	20	90	0	110
11	0	0	0	0	0	0	0	20	90	0	110
12	0	0	0	0	0	95	210	20	90	0	415
13	0	0	0	0	0	0	0	20	90	0	110
14	0	0	0	0	0	0	0	20	90	0	110
15	0	0	0	0	0	0	0	0	90	0	90
16	182	98	40	8	328	0	0	80	0	30	438
17	322	168	80	40	610	0	0	0	0	30	640
18	322	168	80	40	610	0	0	0	0	30	640
19	266	168	80	72	586	95	105	80	0	30	896
20	322	168	80	72	642	95	0	0	0	30	767
21	266	168	72	64	570	95	210	80	0	30	985
22	266	168	72	32	538	95	210	80	0	0	923
23	322	98	48	32	500	0	0	0	0	0	500
24	322	0	0	0	322	0	0	0	0	0	322

Table A.5
Estimated load profiles (W) for Ban Tangprang and Ban Tangkaad.

Hour	Ban Tangprang				Ban Tangkaad				
	Light	Extra common use	Meeting hall	Total	Light	Extra common use	Meeting hall	Dispensary	Total
1	364	0	0	364	280	0	0	0	280
2	364	0	0	364	280	0	0	0	280
2	364	0	0	364	280	0	0	0	280
3	364	0	0	364	280	0	0	0	280
4	364	0	0	364	280	0	0	0	280
5	364	0	0	364	280	0	0	0	280
6	364	0	0	364	280	0	0	0	280
7	364	0	0	364	280	0	0	0	280
8	0	240	0	240	0	120	0	14	134
9	0	240	0	240	0	120	0	14	134
10	0	240	0	240	0	120	0	14	134
11	0	240	0	240	0	120	0	14	134
12	0	240	0	240	0	120	0	0	120
13	0	240	0	240	0	120	0	0	120
14	0	240	0	240	0	120	0	14	134
15	0	240	0	240	0	120	0	14	134
16	280	0	14	294	196	0	14	14	224
17	364	0	14	378	280	0	14	14	308
18	364	0	14	378	280	0	14	14	308
19	364	0	14	378	280	0	14	14	308
20	364	0	14	378	280	0	14	0	294
21	364	0	14	378	280	0	14	0	294
22	364	0	0	364	280	0	0	0	280
23	364	0	0	364	280	0	0	0	280
24	364	0	0	364	280	0	0	0	280

References

[1] Messerli P, Heinimann A, Epprecht M, Souksavath P, Chanthalanouvong T, Minot N. Socio-economic atlas of the Lao PDR – an analysis based on the 2005 Population and Housing Census; chap. Section A: Geographical overview. Swiss National Centre of Competence in Research (NCCR) North-South and Geographica Bernensia; 2008, pp. 1–17. URL www.laoatlas.net.

[2] Burnhill TJ, Adamson PT. Floods and the Mekong River system (Part 3). Catch and Culture 2008;14(3):25–30, http://www.mrcmekong.org/download/programmes/fisheries/Catch_Culture_vol14.3.pdf.

[3] Burnhill TJ, Adamson PT. The 2008 flood season. Chap. 5.2. In: Burnhill TJ, editor. Annual flood report 2008. Meteorological conditions. Mekong River Commission (MRC). p. 39–43, http://www.mrcmekong.org/flood_report/2008/table_of_content08.htm; 2009.

[4] Ibbitt R, Takara K, Nor bin Mohamed Desa M, Pawitan H. The Lao peoples Democratic Republic. In: Catalogue of rivers for Southeast Asia and the Pacific; vol. IV; catalogue Lao 9: Nam Sekong. UNESCO; 2002, pp. 191–205. URL http://flood.dpri.kyoto-u.ac.jp/ihp_rsc/riverCatalogue/Vol_04/index.html.
[5] King P, Bird J, Haas L. The current status of environmental criteria for hydropower development in the Mekong region. Consultancy report pp. 10–20; ADB, MRCS and WWF; 2007. URL http://www.mrcmekong.org/download/free_download/ECHD_Technical_Document.pdf.
[6] ESHA. Guide on how to develop a small hydropower plant. European Small Hydropower Association, http://www.esha.be; 2004.
[7] Jorde K, Hartmann E, Unger H. Good & bad of mini hydro power, vol. 1+2. The ASEAN Centre for Energy (ACE), http://agmhpv1.aseanenergy.org/en/download/8/tahun/2009/bulan/07/tanggal/31/id/51/; 2009.
[8] Maher P, Smith N. Pico hydro for village power. 2.0 ed. University of Nottingham, http://www.eee.nottingham.ac.uk/picohydro/documents.html; 2001.
[9] Vongsaly TB, Smits M, Jordan M, Soulineyadeth S. Pico hydropower in Xieng Khouang province. Internal report 1; ETC and Lao institute for renewable energy (LIRE); Vientiane; 2009. URL http://www.ease-web.org/?p=66.