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# Facilitating universal energy access for developing countries with micro-hydropower: Insights from Nepal, Bolivia, Cambodia and the Philippines

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ABSTRACT

Community owned micro-hydropower (MHP) is a cost-effective technology that harvests the potential energy of rivers and generates electricity that can meet the demands of isolated communities in developing countries. The feasibility of MHP schemes depends on physical, social, environmental and economic factors. Remote communities, however, cannot carry out independent pre-feasibility assessments due to lack of know-how. Local developers often identify potential sites by personal references, and perform pre-feasibility assessments by sending engineers to record essential physical variables such as the head or the river flow. No holistic and easy to use MHP pre-feasibility assessment method exists. To facilitate pre-feasibility site identification, we developed a MHP pre-feasibility assessment tool that can be used by developers as well as communities. The tool was validated using data on scheme current success scores (SCSS) gathered from interviews to users and developers of 35 communities with MHP schemes from Nepal, Bolivia, Cambodia and the Philippines. The analytic hierarchy process was used for multi-criteria decision making to incorporate 15 key quantitative and qualitative criteria that affect the likelihood of success of community owned MHP schemes. Results show a strong correlation (0.87) between the tool results and the SCSS. The tool gives equal importance to the physical, social and economic factors, which are significantly more important than the environmental factor. Water availability, terrain quality, community cohesion and financial support are identified as the most important criteria affecting the likelihood of success of schemes. The tool can be easily used and manipulated by developers and communities to generate pre-feasibility assessments.

## 1. Introduction

Around 1.2 billion people lack access to modern electricity, which has been identified as a "constraint to human and economic development" [1]. In particular, remote communities in mountain ranges of developing countries seldom have access to the national electric grid. These communities, however, often meet the requirements to successfully install and operate micro-hydropower (MHP) schemes.

Micro-hydropower (MHP) schemes are thus often recognized as a cost-effective and sustainable technology that can harvest the potential energy of rivers and generate electricity to meet the demands of those communities [2]. MHP schemes have also been associated with community socio-economic advantages, positive environmental impacts, and increased community livelihood [3–6].

Community owned MHP schemes are administrated, operated and maintained by communities through a self-formed committee. Community members contribute to the construction of the scheme and help when major repairs to the civil works are required. Periodic meetings are held to involve the community in the MHP scheme management.

Isolated communities are often unaware of MHP technology and cannot perform pre-feasibility assessments due to lack of know-how. In the context of developing countries, site identification and scheme implementation is typically done by local NGOs reliant on either government support or international aid. Generating pre-feasibility assessments is costly, as these require experts visiting the potentially remote community [7]. The lack of local expertise in MHP pre-feasibility assessments and the need for expert site visits has limited MHP adoption in many developing countries.

In countries such as Bolivia, Cambodia and the Philippines, MHP technology is not widely known by communities and growth in MHP development since the 1990's has been limited. Site identification and pre-feasibility assessments mostly occur by personal references from developers or NGO's, a phenomena that might apply to other developing countries worldwide. As a result, developers operate in confined regions, leaving other areas with MHP potential unexplored.

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On the other hand, in Nepal, the leading country in community owned MHP schemes with more than 1152 schemes built since 1962 [8], most communities are aware of MHP technology and can lodge a petition for a pre-feasibility assessment to a local governmental institution. However, the process can be slow, and still requires a team of experts to visit the community.

MHP is a site specific technology and its cost depends highly on the physical characteristics of the site [5]. The remoteness of many communities makes accurate pre-feasibility assessments a key factor affecting the project total cost [5,9]. To facilitate site identification, lower the cost of pre-feasibility assessments, increase the speed of scheme implementation, and allow communities to perform pre-feasibility assessments locally, there is a need for an easy to use pre-feasibility assessment tool that can be used by developers as well as villagers.

Developers have traditionally assessed the feasibility of MHP schemes by measuring key physical factors affecting the production of power (head and the river flow) and by assessing its economic feasibility [7]. Key qualitative (and difficult to measure) variables such as social characteristics of the community or the environmental impact of the scheme are often disregarded [10]. A more complete approach that includes human and environmental factors have been associated with increased project sustainability [11]. A holistic approach, however, seems necessary, as other factors such as the community's social attributes, or the environmental impact on the river ecosystem, have an impact on the likelihood of success of schemes. To this date, no holistic and easy to use pre-feasibility assessment method for the evaluation of MHP schemes has been published.

The use of an easy to use pre-feasibility tool can facilitate the implementation of MHP schemes, helping meet the targets set by the Sustainable Development Goal 7 (Affordable and Clean energy) [1]. MHP scheme implementation can help increase access to affordable, reliable and modern energy, increasing the share of renewable energy in the global energy mix. MHP schemes are amongst the most efficient energy systems with efficiencies often between 60–80% [2], and they can thus help improve energy efficiency and upgrade sustainable energy services for developing countries.

The objective of this research was thus to create an easy to use tool for pre-feasibility assessment of the likelihood of success of a potential MHP scheme in a remote community in a developing country. The multi-criteria decision method Analytic Hierarchy Process (AHP) was used in this study to incorporate the key criteria that determine the likelihood of success of a community owned MHP scheme. Pre-feasibility assessment tools were created for each individual country as well, and the relative importance of the key criteria is discussed.

## 2. Methods and tool development

The MHP Pre-feasibility Assessment Tool (MHP-PAT) (Fig. 1) was created to assess the likelihood of success of a potential MHP scheme in a remote community. The tool was validated by comparing the results of a multi-criteria decision method (MCDM) against the results of the scheme current success score (SCSS), which is a score based on field observations and interviews obtained through site visits to 35 schemes.

Four decision factors and 15 decision criteria were selected based on the knowledge gained throughout field visits and current literature. To determine the relative importance of the selected factors and criteria of the MCDM, these are weighted against each other. The decision alternatives (i.e., the characteristics of each one of the 35 schemes) are then selected and introduced in the model.

In each computational run, a different weighting for the decision factors and criteria is tested until all possible weighting combinations are tested. The combination that renders a best match (i.e., highest correlation coefficient) between the results of the MCDM and the results of the SCSS is selected as the best MCDM that explains the 35 schemes and the tool is considered validated (Fig. 1). To evaluate how the two sets of data match, the correlation coefficient, the root mean square error (RMSE) and Nash-Sutcliffe efficiency coefficient are used.

This tool validation is thus an exercise in inverse problem solving, where a set of observed data (i.e., the SCSS) is used to find a solution that best explains a given data set.

The tool has been exclusively designed to assess the likelihood of success of MHP schemes and thus specific variables unique to MHP schemes are used as decision criteria. Thus, the tool cannot be used to evaluate other energy sources (e.g., solar PV, wind turbine).

### 2.1. Data acquisition

This study uses data gathered on 35 schemes across Nepal, Bolivia, Cambodia and the Philippines from 2015 to 2016 [12]. The information on each scheme was acquired during site visits and interviews with local developers, scheme operators and electricity beneficiaries. Developers where local NGOs specialized mainly in the installation of MHP schemes [12]. Informal interviews with developers revealed technical information on the MHP scheme salient features. For each site visit, a structured interview provided information on scheme performance, water availability, operation and maintenance, power demand and environmental and social impacts. A semi-structured questionnaire with operators and community members gathered information on the physical, social, environmental and economic factors of the community and the area. Interviews were held one-on-one and kept confidential, avoiding social desirability bias, and questions were designed to minimize cultural noise bias.

Success criteria scores of schemes from the communities' point of view were measured and a 'Current Scheme Success Score' (SCSS) was produced (Table 1). Success was measured as the degree to which a scheme accomplished its purpose of generating power in a sustainable way for the scheme and the environment while satisfying the needs of the community. Information was gathered on scheme current power generation and water availability, operation and maintenance state, environmental damage and community approval and allocated points according to the degree in which the success criteria was accomplished (i.e., the more points, the more successful) (Table 1).

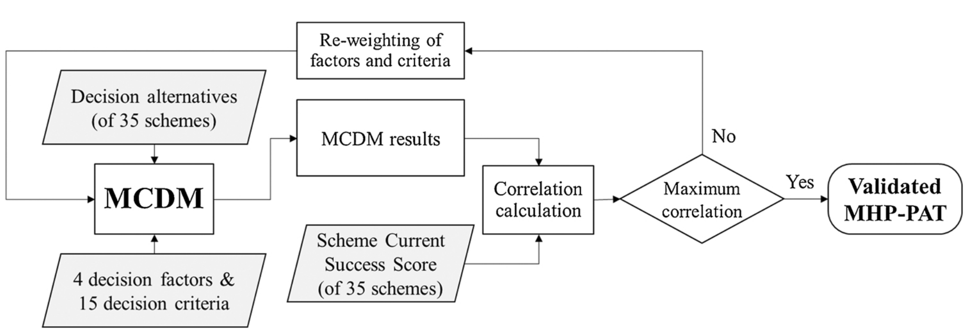


**Fig. 1.** Validation of the MHP Pre-feasibility Assessment Tool.