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Performance Evaluation of Micro-hydro projects in Nepal using multi criteria decision analysis(MCDA)

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Abstract
Energy is one of the important necessities of the society and basic for sustainable development. The demand of electricity is increasing. Micro hydro power plants are one of the effective tools to provide rural household with energy in Nepal. Performance evaluation of Micro-hydro power plants is crucial to monitor effective functioning of the plants. Performance evaluation helps to improve functional quality and reliability of the projects. This paper aims to evaluate performance, and rank the Micro-hydro plants which are monitored this year for subsidy delivery. Eleven Micro-hydro plants namely Irkhuwa khola Bhojpur, Kalikhola Taplejung, KaramkotKhola Nawalparasi, Kholpe Khola Dhading, Muse Khola Rukum, Nandibang Khola Myagdi, Narsing Gad Jajarkot, Pire Khola Dailekh, Rol Gad Dolpa, Tuni Khola Baglung, Veri Khola Jumla are considered for study. Performance evaluation is done using 9 indicators namely annual energy per kilowatt, performance factor, net present value of the investment, self-sufficiency ratio, plant use factor, capacity factor, current number of employees per kilowatt, availability, and station loss. Analytic Hierarchy Process (AHP) is used to rank of the MHP and evaluate the performance. The trend of size of plant vs score gives a clear insight that the greater the size, larger will be the efficiency. Similarly findings shall help the projects to determine their strengths, weaknesses and provide directions for future improvements based on indicators

Keywords
Micro hydro – Analytic Hierarchy Process – Performance evaluation

1. Introduction

The difficulties has been experienced in rapid extension of the National Grid for rural electrification due to remote topography, dispersed settlement pattern and the limited financial resources of the Government of Nepal (Rural Energy Policy, 2006). To facilitate the rural people to benefit from the energy usage, the construction of the micro hydro power are chosen. The micro hydro is attracting lots of funds under CDM/renewable clean energy and its execution is becoming very easy due its history of above 30 years. The construction of micro hydro projects in Nepal is in increasing trend, particularly in districts that has not been integrated with the national grid. Figure 1shows total instillation of mini/micro hydro plants till 2016 which is about 23 MW.

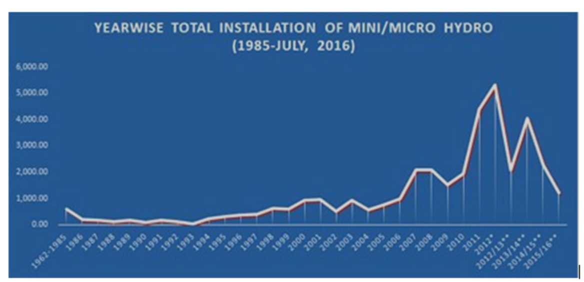


Figure 1: Total instillation of mini/micro hydro plants till 2016(source AEPC)

The subsidy will be provided to mini/micro hydropower with capacity less than 1000 kW in areas without national grid access on the basis of actual power generation (kW), households benefited or actual energy consumption (kWh). For mini/micro hydro projects with possibility of both grid supply and local distribution, subsidy will be provided for the portion of

power generation or energy consumption by consumers within the local distribution network. In addition, subsidy will be provided for distribution network construction based on actual households connected (renewable energy subsidy policy 2073).
Once complicating the project, company will hand over the plants to the community. After one year warranty they will not liable for the plants. Hence the community assigned operator for all kind of look after of the plants. This paper aim to confer about the present situations of the plants. During the course of operation, component life of various parts such as civil, mechanical, electrical are subjected to various wear and tear thus requiring repair and maintenance at regular interval. Performance measurement refers to the use of a multi-dimensional set of performance measures. The set of measures is multi-dimensional as it includes both financial and non-financial measures, it includes both internal and external measures of performance and it often includes both measures which quantify what has been achieved as well as measures which are used to help predict the future sustainability.

1.1 literature survey

Multi-criteria decision-analysis (MCDA) is a sub-discipline of operations research that explicitly evaluates multiple conflicting criteria in decision making both in daily life and in setting such as business, government, energy sector, medicine etc. If criteria are selected in terms of cost and measure of quality, they are conflicting to each other but those criteria are typical in evaluation MCDA is concerned with structuring and solving decision and planning problems involving multiple criteria in order to support decision maker facing such problem in decision making. (Patil Smita Dinkar and Morankar D.V). Typically, there is no unique optimal solution for such problems and it is necessary to make decision makers preferences in differentiate between the solutions. The concept of optimal solution is replaced by non-dominant or efficient solution which involves tradeoff of certain criteria. Criteria selection is another important issue as it is done in terms of different aspect like environmental, technical, economic, social etc. Performance evaluation is a systematic process of obtaining information to be used to assess and improve the existing project. It helps to compare the performance of a system with others or within a same system over time. The scope of MCDA may be broaden further for calculation of performance analysis. Analytical Hierarchy Process (AHP) based multiple criteria analysis deals with the relative priority of importance of each factor by pairwise comparison of all factors.
There are numerous studies on performance evaluation using MCDA methods. Since this problem is evaluating performance of Micro-hydro and selecting the best Micro-hydro plant, this study focused on following aspects of literature: Performance evaluation of Micro-hydro plant and MCDA techniques used for evaluating Micro-hydro projects performance.
Different criteria for the performance evaluation were analyzed from different sources and final criteria were selected. The general guidelines used to choose the performance indicators are as follows:

i. The indicators are based on a relative comparison of absolute values
ii. The set of indicators is small, yet reveal sufficient information about the output of the system
iii. Data which are easily available and less expensive.
iv. The indicators relate to outputs and are bulk measures of the project

Final criteria selected for performance evaluation are:

1. **Annual energy generated per megawatt:**

   This is a measure of total energy generated by plant per unit its installed capacity over a period of time. This is key performance indicator as energy generation directly indicates plant performance.

2. **Performance factor:**

   Design guideline gives a target generation to achieve for each of power plants. The design or forecast is generated on account of the previous generation trend, operation & maintenance of MHPs. Performance Factor gives the measure of the design versus actual generation.

3. **Net present value of investment:**

   This indicator is concerned with time value of money as all the value of investment done on micro-hydro is calculated in present basis.

4. **Self-sufficiency ratio:**

   Self-sufficiency (also called self-containment) is the state of not requiring any aid, support, or interaction for survival after the completion of the plants. This is important indicator for performance evaluation. This measure also includes sustainability of the project.

5. **Plant use factor:**

   The plant use factor or utilization factor is the ratio of the time that a piece of equipment is in use to the total time that it could be in use. It is often averaged over time in the definition such that the ratio becomes the amount of energy used divided by the maximum possible to be used.

6. **Capacity factor:**

   The net capacity factor is the unit-less ratio of an actual electrical energy output over a given period of time to the maximum possible electrical energy output over the same amount of time.

7. **Number of employees per Kilo-Watt:**

   Staffing Level takes in consideration of number of employees which has been allocated for the carrying out day to day operation & maintenance of power plants. The number of employee has been subjected to review from time to time.

8. **Availability:**

   The availability factor of a power plant is the amount of time that it is able to produce electricity over a certain period, divided by the amount of the time in the period. Occasions where only partial capacity is available may or may not be deducted. The availability factor greatly depends on flow available.

9. **Station loss:**

   This implies the losses occurring in Power station. This loss may be due to improper installation, equipment failure, wear and tear of mechanical parts, lack of repair and maintenance and other factor. This has direct effect in system performance.

2. Research methodology

Micro-hydro plants were taken into account and eleven plants were taken for this analysis process. They were generating power during the night time only. There is sufficient flow for the eleven months flow excedence. Data were taken from the monitoring unit of Alternative Energy Promotion Center. Power Output and Household Verification Inspector were assigned for the verification before releasing 60% subsidy amount. Hence finding out the criteria that would act as key Performance Indicators of a MHP for analysis purpose. From the literature survey, a list of criteria was prepared and managed in a hierarchical manner.

i. **Performance analysis of Micro-hydro plant**

   Performance analysis is done on the basis of power generation in KWh /MWh achieved by the micro-hydro plants, availability, staffing level, economic efficiency etc. as mentioned in the section Plant Performance Indices.

ii. **Condition Assessment of Micro-hydro Plant**

   Condition assessment is done by observation of POHVI, reports, and historical data collected. The guidelines and checklist is also followed. The scoring guide is modified as per discussion with the experts of the relative fields currently working in micro-hydro sector.

Data collection

All the raw data were collected from the monitoring and quality assurance unit of Alternative Energy Promotion Center. Which conduct the Power Output and Household Verification of the about 100 plants before releasing the 60% subsidy amount through third party this year. With Random selection only eleven plants which are within the permissible limits of verification are chosen for the analysis
The table below gives some important informations taken for the performance calculations

Table 1: Plants descriptions under study

SN	Name of Plant	Total Installation Cost (Nrs)	Subsidy Amount (Nrs)	commission date	Type of turbine	Design Capacity(kW)	Verified kW at Q_{design}	Verified HH	Power Factor	generator KVA	turbine efficiency%	Flow(l/s)	Transmission and beltloss(%)
1	Irkhuwakhola Bhojpur,	11,533,599.20	5,460,000.00	3/3/2072	crossflow T15	28	30.455	238	0.8	63	59.6	296.13	5
2	Kalikhola Taplejung	6,754,056.00	2,925,000.00	14/03/2073	crossflow T15	15	16.308	94	0.8	30	61.8	52.57	3
3	KaramkotKhola Nawalparasi	5,060,993.88	2,730,000.00	1/3/2071	Pelton 1 Jet	14	12.65	140	0.8	30	56.9	36.000	2
4	Kholpe Khola Dhading	26,528,866.92	25,500,000.00	6/6/2073	Pelton 1 Jet	100	104.64	720	0.8	200	65	65.390	2
5	Muse Khola Rukum	3,826,080.03	1,402,500.00	27/03/2072	Pelton 1 Jet	33	35.74	346	0.85	35	64	40.300	2
6	Nandibang Khola Myagdi	11,728,578.00	8,190,000.00	22/03/2073	crossflow T15	42	42.87	212	0.8	90	59.6	133.000	5
7	Narsing Gad Jajarkot	5,736,463.00	2,325,000.00	30/12/2071	crossflow T15	15	14.65	156	0.8	30	59.2	56.750	3
8	Pire Khola Dailekh	13,990,321.29	8,160,000.00	8/3/2073	Pelton 2 Jet	32	30.63	233	0.85	50	60.9	44.800	2
9	Rol Gad Dolpa	14,565,415.00	4,185,000.00	11/3/2073	Pelton 1 Jet	27	35.74	258	0.85	35	64	40.300	2
10	Tuni Khola Baglung	11,486,760.65	8,190,000.00	30/03/2073	crossflow T15	42	41.08	387	0.8	83	69.7	108.000	5
11	Veri Khola Jumla	8,236,127.00	3,255,000.00	30/03/2071	crossflow T15	21	21.106	190	0.8	200	49	281.000	3

The analytic hierarchy process (AHP), a well-known MCDA approach, has been applied to work out the exercise. Major steps used in AHP which are described as follows:

1. **Describing evaluation issues:** This includes structuring hierarchy of goal, criteria, and alternatives, with goal at the top of the hierarchy, criteria and sub-criteria at lower levels and alternatives at the bottom of the hierarchy

2. **Identify criteria which affect the issues:** This step indulges with selecting related performance criteria and selection of appropriate criteria based on the process of reviewing and the relevant literature.

3. **Construction of hierarchy Structure:** A hierarchy structure, in general, can be established from the top through the intermediate levels to the lowest level which usually contains the list of alternatives.

4. **Pair-wise comparison:** The criteria within each hierarchy should be evaluated against their corresponding criteria in the level above, and then compared in pairs between themselves. The establishment of paired matrices will lead to determining the weights of the criteria within each hierarchy.

5. **Consistency test:** The purpose of consistency tests is to ensure whether the calculation fit the condition of transitivity in priority. Consistency ratio (CR) is used to verify the credibility and reasonability of evaluation, and to check whether there is inconsistent causality or conflicts in subjective judgments. The CR is acceptable if it does not exceed 0.1. The definition of consistency index showed as follows:

   CI = $(\lambda_{max} - n) / (n - 1)$ and CR=(CI /RI)where,
   n= no of criteria,
   RI= appropriate random index

6. **Normalization:** This study normalized the weight of the interval level and connected the local weight to acquire the global weights of the criteria in each hierarchy after calculating the weights of all criteria.

AHP method

The Analytical Hierarchy Process based multiple criteria analysis deals with the relative priority of importance of each factor by pairwise comparison of all factors with respect to criteria. A hierarchical structure of these factors is formed by grouping them into different levels. The hierarchy incorporates the knowledge, the experience and the intuition of the decision-maker for the specific problem. The hierarchy evaluation is based on pair-wise judgment between the factors. The decision maker compares two alternatives using a criterion and assigns a numerical value to their relative weight. The result of the comparison is expressed in a fundamental scale of values ranging 1 to 9. The values of these pairwise comparisons to create the pairwise comparison matrix shown in Figure were used.

Value Preference

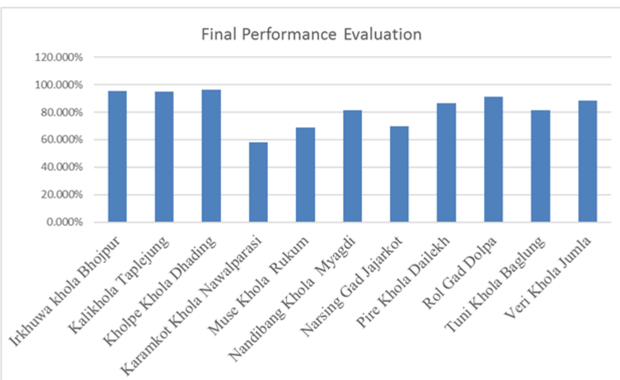
1. Equally Preferred
2. Equally to Moderately Preferred
3. Moderately Preferred
4. Moderately to Strongly Preferred
5. Strongly Preferred
6. Strongly to Very Strongly Preferred
7. Very Strongly Preferred
8. Very Strongly to Extremely Preferred
9. Extremely Preferred

Swing method

This method is use to range the partial data within the range of minimum to maximum by interpolating linearity. Here, it has given the minimum values as 0.5 within each range of data and maximum values as the 1 for the highest value within each range of data for each criteria. And, the values lie in between the maximum to minimum is given their partial values with the linear interpolating method.

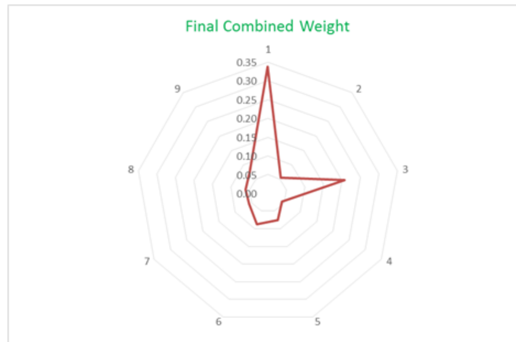
3. Results and discussion

After analytical study of different MHPs and criteria selection for different alternatives, giving weight highest to the Generation energy/Mw and other priorities weights are shown below. In AHP model, the weight is ranging from 1-Equally preferred to the 9-Extremely preferred.



- It is found that the highest performance among the considered MHP was of Kholpe Khola Dhading i.e.96.289%
- The highest performance of the Kholpe Khola Dhading is because of highest Annual energy, Plant factor, capacity factor and availability factor.
- The lowest performance among the considered hydropower was Karamkot Khola Nawalparasi. i.e.58.267%
- The lowest performance of the Karamkot Khola Nawalparasi is because of low Annual energy, Plant factor, capacity factor and availability factor.

After giving the respective weight and Pairwise Comparison Model, calculating the Combined Weight, with in consistency level below 10%, final results are found as below.



4. Conclusions

As a conclusion, we took data of Micro-hydro ranging from 14 KW to 100 KW and also cross flow and peloton type turbines. Also that have 94 to 720 houses are benefited from the plants. They all plants are different in terms of energy generation and energy profile.
The trend of size of plant vs score gives a clear insight that the greater the size, larger will be the efficiency.
Overall, the performance of all of the power plants are satisfactory. The losses in the pelton turbine is less than cross flow turbine. For sustainability of the plant, it is necessary to run plant day and night shift. The end use promotion will help for the energy consumption.

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