MULTI-CRITERIA DECISION MAKING FOR SUSTAINABILITY OF RENEWABLE ENERGY SYSTEM OF NEPAL

ABSTRACT

This paper presents an application of Analytic Hierarchy Process for evaluation of the sustainability of renewable energy sources and technology in context of Nepal. Solar energy, biogas, micro hydropower and grid technology have been evaluated based on selected criteria like technical (energy production capacity, efficiency, reliability, primary energy ratio and technological maturity), economic (initial investment, operation & maintenance cost and payback period), environmental (carbon dioxide emission, land requirement, impact on ecosystem) and social (social acceptability, job creation, social benefits). The importance weights of the criteria and sub-criteria as well as preferential ranking of options have been determined by eliciting expert judgment through pairwise comparisons. The findings show that within the technological constraints, grid technology is the most preferred option followed by micro hydropower. Biomass is the least preferred sustainable system of Nepal. The proposed evaluation will help to select the most suitable alternative assisting policy makers to form opinion on sustainability of considered energy systems and make decisions on optimum alternative. However, as time progresses and technology improves, the preferential ranking might change.

Keywords: Analytical Hierarchy Process, Sustainability, Renewable Energy, Pairwise Comparison, Alternatives

1. Introduction

The high consumption and population growth forces the inhabitants of many countries to deal with the critical problem of dwindling domestic fossil energy resources. Many countries all over the world are keeping the effort to make the effective energy planning for achieving a sustainable energy system.

In Nepal, renewable energy contributes merely 1% in total energy mix; however it electrifies 12% of the total population mostly in rural areas (AEPC, 2012). About 90% of the rural customers connected to the grid consume less than 20 kWh per month making on grid electrification financially unattractive in rural Nepal (Mainali and Silveira, 2011). In this context, renewable energy has become the viable means of rural electrification in Nepal. Realizing the importance of renewable energy in rural areas, the Government of Nepal in its interim three year plan (2010 to 2013) considers rural electrification through renewable energy technologies is an appropriate means to enhance rural livelihoods and conserve environment in rural areas.

Renewable energy is emerging as a solution for a sustainable, environmentally friendly and long term, cost-effective source of replacing conventional sources of energy in most of their applications at competitive long term prices. Selecting the appropriate source of energy in which to invest is a task that involves different factors and policies. Renewable
energy decision-making can be viewed as a multiple criteria decision-making problem with correlating criteria and alternatives. This task should take into consideration several conflicting aspects because of the increasing complexity of the technical, economic, environmental and social factors. Traditional single criteria decision-making approaches cannot handle the complexity of current systems and this problem. Multi-criteria methods provide a flexible tool that is able to handle and bring together a wide range of variables appraised in different ways and thus offer useful assistance to the decision maker in mapping out the problem. As this work demonstrates, multi-criteria analysis can provide a technical-scientific decision-making support tool that is able to justify its choices clearly and consistently, especially in the renewable energy sector.

There are several techniques now available in the literature to deal with multi criteria decision-making problem (Goodwin and Wright, 1998; Saaty, 1980). Some of the well-known techniques are Multi Attribute Utility (MAU) model, Simple Multi Attribute Rating Technique (SMART), Analytic Hierarchy Process (AHP) and Fuzzy Hierarchical Decision Making (FHDM) method. Among these AHP is possibly the most familiar and extensively used MCDM method. It is simple and easily comprehensible. In spite of some criticisms leveled against it (Van Laarhoven and Pedrycz, 1983; Belton and Gear, 1983; Belton and Gear, 1985), this method has been widely applied in many MCDM problems.

2. Literature Review

The literatures related to sustainable energy development are briefly reviewed hereunder to understand the context and develop an appropriate theoretical framework for the study. The review includes both the report prepared by professionals and a few research papers. McMenemy (1999) studied 18 community owned micro hydropower (MHP) projects located in Jumla in the far western part of Nepal as part of his master thesis to understand whether electrical energy offers net benefit to its users. The study found that it is unlikely that Micro Hydropower (MHP) with less than 20% load factor will be able to meet the goal of financial sustainability. This study is limited to micro hydro projects of a very few plants of western Nepal.

Khennas and Bernett (2000) synthesized the experience of micro hydro developments in Sri Lanka, Peru, Nepal, Zimbabwe and Mozambique in a report called best practices for sustainable development of micro hydro power in developing countries. The report provides a rigorous comparative micro economic analysis of the cost and financial returns of a sample of plants across the five countries. The report reveals that micro hydro technology is most likely to be financially sustainable if it includes (a) a high load factor; (b) a financially sustainable end-use; (c) costs are contained by good design and management; and (d) effective management of the installations. This study looks at financial and institutional aspects of selected micro hydropower projects but it is silent on technical and environmental aspects. Dhital (2002) conducted a study on financial sustainability of micro hydro projects taking a case of a 16 kW micro hydro project of Nayagau, a small village of Kabhre District, located in central region of Nepal. Moreover it touches only on financial sustainability but recommends further study on assessment of RE system to understand long term sustainability.

Banerjee et al. (2011) conducted a study to develop an evaluation system that measures the impact of micro hydro installation on rural livelihoods and to establish a monitoring
system to measure the results of the renewable energy programs. Artur (2011) conducted a study of 33 micro hydro project sites to assess enhancing prospects for long term sustainability. Wang et al. (2009) wrote a paper on review on multi criteria decision analysis aid in sustainable energy decision making. This paper summarizes the criteria of energy supply systems from technical, economic, environmental and social aspects. Mainali (2012) on Renewable Energy markets in rural electrification: country case Nepal examines renewable energy based rural electrification supply models and the formation of market for solar home systems and micro hydro.

3. Objectives

The main objective of this study is to evaluate the sustainable system of different renewable energy source in Nepal.

The specific objectives of the study are to:

- Develop assessment/evaluation criteria for evaluating the sustainable system of different renewable energy source in Nepal
- Establish the most important priorities of different renewable energy source based on evaluation criteria.

4. Research Methodology

![Research Methodology Diagram]

Figure 1: Research Methodology

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The research methodology is based on co-relational approach. The process starts by describing the problem in a hierarchical structure including in the highest level an overall (quantifiable) goal further decomposed in criteria and sub-criteria whereas in the lowest level alternative solutions to attain the goal are found. This hierarchical structure was determined from literature findings (published journal and articles) and pilot testing through expert’s opinion. Pairwise comparison questionnaire were prepared for comparing each pair of the criteria, sub-criteria and alternatives used in the selection and to identify to what extent one criterion or alternative is more or less important or preferred to another. The respondents to this questionnaire were a committee of experts in the field of energy sectors.

Pairwise comparison matrixes are constructed starting from the first level of criteria and continuing to lower levels, comparing criteria on the same level under the same nod. Individual preferences are converted into ratio scale weights that generate linear additive weight for each alternative. All the criteria have been rated from scale 1 to 9 versus all other criteria, as stated in the Table 1 (Crowe et al., 1998; Saaty, 2000; Hafeez et al., 2002). Then, consistency ratio is checked for verification and weightage are generated.

<table>
<thead>
<tr>
<th>Preference Weights</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Equally Preferred</td>
</tr>
<tr>
<td>3</td>
<td>Moderately Preferred</td>
</tr>
<tr>
<td>5</td>
<td>Strongly Preferred</td>
</tr>
<tr>
<td>7</td>
<td>Very Strongly Preferred</td>
</tr>
<tr>
<td>9</td>
<td>Extremely Preferred</td>
</tr>
<tr>
<td>2,4,6,8</td>
<td>Intermediates Values</td>
</tr>
<tr>
<td>Reciprocals</td>
<td>Reciprocals for Inverse Comparison</td>
</tr>
</tbody>
</table>

Based on the ratings obtained through the questionnaire, matrixes are formed and the priorities are synthesized using the methodology of AHP. The decision maker compares the weightage given to several alternatives and selects the best alternative that meets the decision criteria. Numerical scores are assigned to rank each decision alternative based on how well the alternative meets the decision maker’s criteria. AHP is viable to formulate the desired decision making criteria, to determine the level of importance of different decision-making criteria, and to obtain the best decision (Guller, 2008).

Major steps used in AHP which are described as follows:

1. **Describing Evaluation Issues**: It is the initial step where an unstructured problem is defined and goal is determined. This includes structuring the hierarchy from the top (objectives from a decision-makers viewpoint) through intermediate levels (criteria on which subsequent levels depend) to the lowest level, which typically contains a list of alternatives.

2. **Identification of Criteria**: This step indulges with selecting related performance criteria and selection of appropriate criteria based on the process of reviewing and the relevant literature and interviewing experts. These criteria should be
mutually exclusive and their priority or importance does not depend on the elements below them in the hierarchy (Fu and Lin, 2009; Bahurmoz, 2006).

3. **Construction of Hierarchy Structure**: A hierarchy structure is established from the top through the intermediate levels to the lowest level which usually contains the list of alternatives. In order to lessen the complexity of the consistency, the criteria for each alternative should contain no more than seven elements, and keep independence individually (Fu and Lin, 2009).

4. **Pair-wise Comparison**: The pair-wise comparisons of elements are made in each group. Saaty developed the fundamental scale for pair-wise comparisons (Saaty, 2000). The pair-wise comparison matrix $A$, in which the element $a_{ij}$ of the matrix is the relative importance of the $i^{th}$ factor with respect to the $j^{th}$ factor, could be calculated as

$$ A = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ 1/a_{12} & 1 & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ 1/a_{1n} & 1/a_{2n} & \cdots & 1 \end{bmatrix} \quad (1) $$

Where, $a_{ij}$ is the comparison between element $i$ and $j$.

$$ a_{ii} = 1; \quad a_{ji} = \frac{1}{a_{ij}} \quad \text{for i, j = 1, 2, \ldots, n} $$

There are $n(n-1)/2$ judgments require developing the set of matrices. Reciprocals are automatically assigned to each pair-wise comparison, where $n$ is the matrix size. The establishment of paired matrices ‘$A$’ lead to determining the weights of the criteria within each hierarchy (Bahurmoz, 2006).

Through pair-wise comparison the ratio-scaled importance or priorities of each alternative is calculated. Eigenvalues are calculated after pairwise comparison is done.

Hierarchical synthesis is now utilized to weight the eigenvectors according to weights of criteria. The sum is for all weighted eigenvectors corresponding to those in the next lower hierarchy level. Having made all pair-wise comparisons, consistency is identified by using the Eigen value $\lambda_{\text{max}}$, to calculate the consistency index. Saaty (1994) proposed that the largest Eigen value (Saaty, 1994),

$$ \lambda_{\text{max}} = \sum_{j \neq i}^{n} \frac{W_j}{W_i} \quad \text{......... (2)} $$

Where, $\lambda_{\text{max}}$ is the principal or largest Eigen value of positive real values in a judgment matrix; $W_j$ is the weight of $j^{th}$ factor and $W_i$ is the weight of $i^{th}$ factor.

Priorities obtained from the comparison are used to weigh the priorities in the level immediately below. This is done for every element. Then for each element in the level below, its weighed values are added to obtain its overall or global priority. It process is continued to until the final priorities of the alternatives in the bottom most level are obtained.

5. **Consistency Test**: Each pair-wise comparison contains numerous decision elements for the consistency index (CI), which measures the entire consistency judgment for each comparison matrix and the hierarchy structure. Saaty (1994)
utilized the CI and consistency ratio (CR) to assess the consistency of the comparison matrix. The CI and CR are defined as,

$$CI = \frac{\lambda_{\text{max}} - n}{n - 1} \quad \ldots \quad (3)$$

Where, n is the matrix size.

$$CR = \frac{CI}{RI} \quad \ldots \quad (4)$$

Table 2
Average Random Consistency (RI) (Balaji et al., 2012)

<table>
<thead>
<tr>
<th>Size of Matrix</th>
<th>Random Consistency</th>
</tr>
</thead>
<tbody>
<tr>
<td>1,2</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>0.58</td>
</tr>
<tr>
<td>4</td>
<td>0.9</td>
</tr>
<tr>
<td>5</td>
<td>1.12</td>
</tr>
<tr>
<td>6</td>
<td>1.24</td>
</tr>
<tr>
<td>7</td>
<td>1.32</td>
</tr>
<tr>
<td>8</td>
<td>1.41</td>
</tr>
<tr>
<td>9</td>
<td>1.45</td>
</tr>
<tr>
<td>10</td>
<td>1.49</td>
</tr>
</tbody>
</table>

The CR is acceptable if it does not exceed 0.10. The CR is > 0.10, the judgment matrix is inconsistent. To acquire a consistent matrix, judgments should be reviewed and improved.

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 (Fu and Lin, 2009).

Calculation of norms for each j column of the matrix of decision making:

$$Norma_j = \sqrt{\sum_{i=1}^{m} x_{ij}^2}$$

$$j = 1, 2, \ldots, n$$

Where: \(x_{ij}\) - value of the j attribute by the i alternative.

Calculating the normalized matrix elements of decision making.

For attributes of type max: \(n_{ij} = \frac{x_{ij}}{Norma_j}\)

For attributes of type min: \(n_{ij} = 1 - \frac{x_{ij}}{Norma_j}\)

7. **Linearization**: The linearization is doing with the aim of reducing the value of the attribute at the interval (0,1) and translation of various units of measure in the unnamed number.
5. Model Analysis

Figure 2: The Hierarchy for the Selection of the Best Sustainable System with Renewable Energy Source

5.1 Pairwise Comparison and Computations for Criteria
A survey questionnaire approach was used for gathering the data to assess the order of importance of the evaluation criteria. From the hierarchy tree, we developed a questionnaire to enable pairwise comparisons between all the selection criteria at each level in the hierarchy. The pairwise comparison process elicits qualitative judgments that indicate the strength of a group of decision makers preference in a specific comparison according to Saaty’s 1-9 scale. A group of experts from energy sector was requested to respond to several pairwise comparisons where two categories at a time were compared with respect to the goal. Result of the survey questionnaire technique was then used as input for the AHP. It took a total of 6 judgments (i.e. $4*(4-1)/2$) to complete the pairwise comparisons. The other entries are 1’s along the diagonal as well as the reciprocals of 6 judgments. The shown in the matrix can be deployed to derive estimate of the criteria priorities. The priorities provide a measure of the relative importance of each criterion. Essentially, the following three steps can be utilized to synthesize the pairwise comparison matrix.

1. Total the elements or values in each column.
2. Divide each element of the matrix by its column sum.
3. Determine the priority vector by finding the row averages.

5.2 Result and Discussion
Initially, pair-wise comparison of criteria with respect to the goal was done. Results of the weight obtained for different is shown in Table 3. Technical criterion is identified as the most important criteria (33.44%). Economic criterion is the second most important criterion with 26.61% weight. Social criterion has the lowest weight amongst all criteria. The overall consistency ratio (CR) were than 0.1 (desirable value), so the model was validated. Priorities weights of sub-criterion are illustrated in Figure 3. The criteria were breakdown into sub criteria where the weightage are shown in the Figure 3. Reliability was the most important sub criteria for evaluating the alternatives while Primary Energy Ratio contributes least for ranking the alternatives.

Table 3
Priorities of Criteria and Sub-Criteria for Evaluating Alternatives

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Global Weightage</th>
<th>Sub-Criteria</th>
<th>Local Weightage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technical (A)</td>
<td>33.44%</td>
<td>Energy Production Capacity (A1)</td>
<td>17.99%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Efficiency (A2)</td>
<td>15.52%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Reliability (A3)</td>
<td>31.01%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Primary Energy Ratio (A4)</td>
<td>14.97%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Technological Maturity (A5)</td>
<td>20.51%</td>
</tr>
<tr>
<td>Economical (B)</td>
<td>26.61%</td>
<td>Initial Investment (B1)</td>
<td>37.08%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Operation and Maintenance Cost (B2)</td>
<td>29.60%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Payback Period (B3)</td>
<td>33.32%</td>
</tr>
<tr>
<td>Environmental (C)</td>
<td>21.63%</td>
<td>CO₂ Emission (C1)</td>
<td>29.66%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Land Requirement (C2)</td>
<td>28.41%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Impact on Ecosystem (C3)</td>
<td>41.92%</td>
</tr>
<tr>
<td>Social (D)</td>
<td>18.32%</td>
<td>Social Acceptability (D1)</td>
<td>28.05%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Job Creation (D2)</td>
<td>35.92%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Social Benefits (D3)</td>
<td>36.03%</td>
</tr>
</tbody>
</table>
Table 4 shows the weight received by alternatives for each criterion. Grid Technology is ranked at the top of the priority which is followed by Micro Hydropower and Solar. Biomass is the least sustainable system with renewable energy sources of Nepal.

Table 4  
Weight Received by Alternatives for Each Criterion

<table>
<thead>
<tr>
<th>Alternatives</th>
<th>Technical</th>
<th>Economical</th>
<th>Environmental</th>
<th>Social</th>
<th>Total</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar</td>
<td>5.35%</td>
<td>6.66%</td>
<td>7.55%</td>
<td>3.49%</td>
<td>23.05%</td>
<td>3</td>
</tr>
<tr>
<td>Biomass</td>
<td>3.37%</td>
<td>6.27%</td>
<td>3.34%</td>
<td>2.63%</td>
<td>15.61%</td>
<td>4</td>
</tr>
<tr>
<td>Micro Hydro</td>
<td>10.57%</td>
<td>7.29%</td>
<td>5.18%</td>
<td>6.38%</td>
<td>29.42%</td>
<td>2</td>
</tr>
<tr>
<td>Grid Technology</td>
<td>14.16%</td>
<td>6.38%</td>
<td>5.56%</td>
<td>5.82%</td>
<td>31.92%</td>
<td>1</td>
</tr>
</tbody>
</table>

Normalized performance scores of the sustainability of energy system are shown in the Figure 4 where alternatives are ranked in the order from top to below. It depicts grid technology were performing better while biomass were an underperforming energy system based on selected criteria and sub-criteria.

5.3 Sensitivity Analysis
Sensitivity analysis as shown in figure lets evaluator to observe how final evaluation is likely to change. It also helps in measuring how much changes made by certain extent of deviation in weights of criteria. Simulation of sensitivity analysis is carried out by making gradual changes on values of each criterion, whether Technical, Economic, Environmental or Social, and then observing the rank order due to such changes.

![Figure 5: Final Evaluation of Sustainable Energy System with Sensitivity Analysis](image)

The result of the validation shows that Grid Technology (31.9%) is the most efficient sustainable energy system of Nepal. The main reason for such a result is the highest local priority of the technical Criteria, which were recognized as the most important criteria’s from the developed model. Biomass (15.6%) is deemed to be least efficient sustainable energy system. Biomass has to improve its technical, environmental and social criteria so as to improve its ranking.

### 6. Limitations

- Result generated is based on the stakeholder’s contribution and expectation regarding the sustainability of the energy system.
- Conclusion drawn confines only to the Nepalese contexts.
- The study is carried to remove problems related to the sustainable operation of renewable energy system in Nepal.

### 7. Conclusions

Renewable energy sources and new technologies which use these sources are becoming increasingly important segment in all areas, especially in the energy sector. Using renewable energy has reduced consumption of nonrenewable energy resources. Result indicate that grid technology is the most sustainable energy system (overall normalized...
efficiency = 100%) while biomass is the least sustainable energy system with normalized efficiency of 48.89%.

Experts have emphasized on technical criterion as the technical expertise present in the country is well below par. Since, Nepal is a developing country with limited financial resources; economic criterion has weighted very high compared to environmental and social criteria. Social criterion is the least important criterion. This could be because of the fact that proclivity of the end users to adopt these technology is comparatively low. The sensitivity analysis shows that biomass has to improve its technical, environmental and social criteria so as to improve its ranking. Overall, based on sensitivity analysis, it can be concluded that the final decision is consistent and reliable.

8. References


