FRAMEWORK FOR SUSTAINABILITY ASSESSMENT OF RENEWABLE ENERGY PROJECTS IN NEPAL

Ram Prasad Dhital
Institute of Engineering
Tribhuvan University, Nepal
E-mail: rpdhital@yahoo.com

Parakram Pyakurel
Alternative Energy Promotion Centre, Nepal
Email: parakram_pyakurel@yahoo.com

Tri Ratna Bajracharya
Center for Energy Studies, Institute of Engineering
Tribhuvan University, Nepal
E-mail: triratna@ioe.edu.np

Rajendra Shrestha
Mechanical Engineering Department, Institute of Engineering
Tribhuvan University, Nepal
E-mail: rsfluid@hotmail.com

ABSTRACT

Long term sustainability of renewable energy projects in Nepal has been a challenging issue because a certain amount of investment subsidy from the government is used to build the projects. After installation of the energy system, it is the responsibility of the participating community or the users to operate, maintain and manage the system. The sustainability of renewable energy projects largely depends on how much revenue it can generate from its users. Revenue from users' depends upon multiple factors categorized as technical, financial/economic, social, institutional and environmental. As such, sustainability of the projects needs to be evaluated based on these multiple criteria in a holistic manner. This paper focuses on identifying all of the possible factors relating to sustainability of rural and renewable energy projects in Nepal in the context of climate change and a green economy. These factors are identified from the perspective of all concerned people ranging from project implementers to end users, as well as all of the stakeholders. A brief literature review is conducted on the utility of multi criteria methods for a sustainability assessment of renewable energy projects followed by an assessment of the relative standing of AHP. An appropriate AHP-based framework for a sustainability assessment of the project is recommended taking into consideration the factors related to sustainability that were identified from the perspective of a wide range of people.

Keywords: sustainability, renewable energy, multiple criteria analysis, AHP.

1. Introduction

Renewable energy technologies (RETs) have been promoted in Nepal since the early 1970s, but these technologies were only widely disseminated after the establishment of a dedicated organization called the Alternative Energy Promotion Center (AEPC) in 1996. With the support of various development partners and the firm commitment of the government, some 2000 micro hydro projects generating 20 MW electricity, 250,000 solar home systems, 250,000 biogas plants and 500,000 improved cooking stoves have been installed in different parts of the country (AEPC, 2011). These projects are a means of rural electrification and enhance energy access of rural communities. However, many remote villages in Nepal still lack access to electricity. An overwhelming majority of households (96 percent) in urban areas have access to electricity in their dwelling, while the corresponding figure for rural households is only 63 percent (CBS, 2011).

The term, sustainable development, was popularized in *Our Common Future*, a report published by the World Commission on Environment and Development (WCED) in 1987. Also known as the Brundtland report, *Our Common Future* included the “classic” definition of sustainable development: “development which meets the needs of the present without compromising the ability of future generations to meet their own needs". Acceptance of the report by the United Nations (UN) General Assembly gave the term political salience, and in 1992 leaders set out the principles of sustainable development at the UN Conference on Environment and Development (UNCED) in Rio de Janeiro, Brazil, also referred to as the Rio Summit and the Earth Summit (Drexhage et al., 2010).Sustainability is a major concern for the design of rural electrification projects because without such consideration projects can fail and waste resources. Securing a sustainable energy provision is one of the central political challenges of the present. Ever since the United Nation conferences on climate change held in Rio de Janeiro (1992), Kyoto (1997) and Bali (2007) and reports published by the Intergovernmental Panel on Climate Change sustainable energy provision has become an important topic for political decision makers throughout the world (Carrera et al., 2009).

In Nepal, rural and renewable energy projects are built with a certain amount of investment subsidy from the government. After installation of the energy system, it is the responsibility of the participating community or the users to operate, maintain and manage the system. The sustainability of renewable energy projects largely depends on how much revenue it can generate from its users. Revenue from users’ depends upon multiple factors categorized as technical, financial/economic, social, institutional and environmental. As such, sustainability of the projects needs to be evaluated based on these multiple criteria in a holistic manner. The sustainability evaluation of rural and renewable energy projects is of great importance because annually around 2 billion Nepalese rupees is spent in the renewable energy sector according to AEPC’s annual budget. It can be argued that about 30 billion Nepalese rupees have been mobilized from the Government of Nepal, many external development partners, local governments and the communities in this sector. Therefore, many people are concerned about whether or not this huge investment has had an impact on the sustainability of the energy systems installed.

ISSN 1936-6744 *http://dx.doi.org/10.13033/ijahp.v6i1.250*

While the monitoring and evaluation processes of energy systems adopted by AEPC assesses technical components of energy systems, there is no assessment tool to date which evaluates the overall sustainability of energy systems. In other words, AEPC has not developed an integrated sustainability assessment tool which can assess multiple components of sustainability including economic, environment, social and institutional components. Therefore, a framework to assess the sustainability while considering multiple components is necessary and this paper develops such a framework by applying the Analytical Hierarchy Process.

The following key questions need to be addressed to assess the sustainability of renewable energy projects installed in Nepal:

1. How can sustainability of rural and renewable energy projects be measured objectively?
2. Are existing renewable energy projects sustainable?
3. What factors promote or hinder the sustainable operation of renewable energy projects?

This paper identifies various possible factors relating to sustainability of renewable energy projects in the context of climate change and a green economy. These factors are identified from the perspective of all concerned people ranging from project implementers to end users, as well as all of the stakeholders. The Analytical Hierarchy Process (AHP) is then used to build a framework of sustainability. Numerical values for the factors affecting sustainability are assigned so that sustainability can be measured objectively and the projects can be ranked and evaluated based on their degree of sustainability.

2. Literature Review

There have been a number of attempts to define criteria for the assessment of sustainability. In this respect, the Working Group of United Nations Environment Programme (UNEP) on Sustainable Development has developed qualitative criteria for the assessment of the product design (Afgan et al., 2008). In the context of rural and renewable energy, sustainability indicators have been suggested for the qualitatitive and quantitative assessments of sustainability. Efforts have been made by Hak et. al. (2012) to critically review sustainability indicators and contribute to the development of a suitable methodology for sustainability assessment. They (Hak et. al., 2012) began with a broad review of the vast body of work, both practical and academic research. Both scientists and practitioners have sought the development of methods for assessing the quality of the indicators. According to Hak et. al., (2012), both scientists and practitioners have usually defined some criteria for the assessment of the quality of indicators, however, neither have provided major support by developing reliable, practical and operative methods for indicator assessment. Therefore, it can be said that there is no general consensus among scientists and practitioners on a specific set of sustainability indicators and the methods of assessments of these indicators.

If sustainability is to be measured objectively, the indicated sustainability must be quantified. Multi Criteria Decision Analysis (MCDA) is one tool for quantifying sustainability. MCDA is a form of integrated sustainability evaluation. It is an operational evaluation and decision support approach that is suitable for addressing complex problems featuring high uncertainty, conflicting objectives, different forms of data and information, and multi interests and perspectives for complex and evolving biophysical and socio-economic systems (Wang et al., 2009). Since rural and renewable energy systems exhibit features such as conflicting objectives, multi interests and perspectives and different forms of data and information, MCDA is an appropriate tool for use with these systems. It is also necessary to link techno-economic analysis with a multi-criteria decisions support tool because of the qualitative and quantitative aspects involved in such systems. Figure 1 shows the linkage of techno-economic analysis with multi-criteria decisions support.

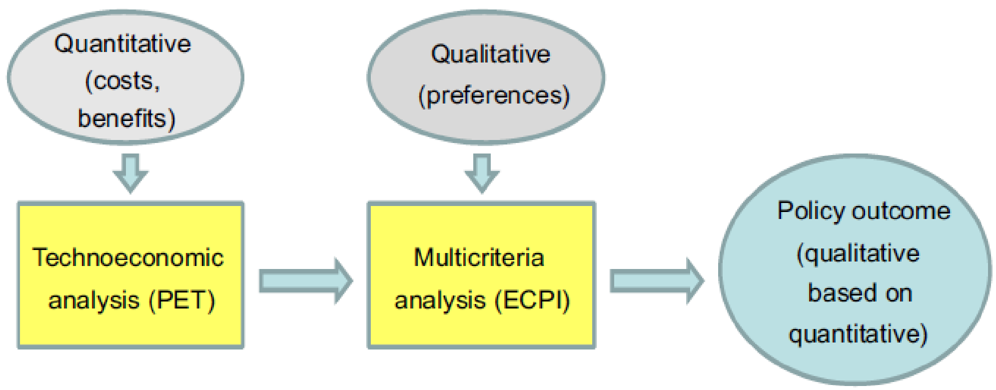

Figure 1. Linking techno-economic analysis with multi-criteria decisions support tool (Oikonomou, 2011).

Multi-criteria decision making (MCDM) may be broadly classified as multi objective decision making (MODM) and multi attribute decision making (MADM). MODM is a mathematical technique of optimization and requires all the criteria to be formulated in a mathematical framework. The MODM can evaluate infinite and continuous types of problems. Whereas problems having finite sets of possible choices and alternatives are described in terms of their attributes, and here the Multi Attribute Decision Making (MADM) methodology is used. MADM problem solving does not require the classical mathematical programming tool (Bhattarai, 1997).

Since finite sets of possible choices and alternatives are components of sustainability evaluation and decision making, MADM is the appropriate tool for this study. There are several techniques for MADM including the Analytical Hierarchy Process (AHP), the Simple Multi Attribute Rating Technique (SMART), and the Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE) to name few. The fact that AHP can use value judgments, which are obtained from experts' choices and multiple actors' choices, as inputs for analysis when there is a lack of numerical data makes the AHP the most viable alternative for sustainability related decision making. In a less developed country like Nepal, sufficient and reliable databases do not exist (Bhattarai, 1997), and decision makers, especially political and public interest groups, are

http://dx.doi.org/10.13033/ijahp.v6i1.250
ISSN 1936-6744

relatively less educated. In this context, value judgments are more applicable than numerical data for decision making. Therefore, this is another reason why the AHP is applicable for this study.

The AHP has been adopted to prepare a framework for sustainability assessment. AHP-based multiple criteria analysis deals with the relative priority of importance of each factor in comparison to a certain criteria. A hierarchical structure of these factors is formed by grouping them into different levels. The application of the hierarchical structure allows the factors to be broken down into details. AHP-based multiple criteria analysis starts with building a tree-like structure, with criteria at higher level and factors and sub-factors at lower levels. The objective of the evaluation lies at the top, and the options or alternatives to be evaluated are placed at the lowest level of the hierarchy. The AHP simplifies the process of identification and assessment of criteria, factors and sub-factors related to a problem (Panthi & Bhattarai, 2008). The hierarchical structure of the goal, dimensions and factors developed for this study is guided by the research of Bhattarai & Adhikari (2011) with rural drinking water facilities.

The literature review shows that a process similar to the AHP has been used by the World Energy Council (WEC) to produce an "Assessment Index" (AI) for energy policies and energy securities assessments of different countries. The steps adopted by the WEC to calculate AI (which are similar to AHP) are (Martchamadol & Kumar, 2013):

- *Normalization*, data are normalized via homogeneous transformation in the range 0 (low) to 10 (high) within a cluster of countries;
- *Weighting*, weighting factor are equal for each indicators of each dimension, and AI is then calculated by using averages and equal weighting of all dimensions;
- *Presentation of results*, AI gives the ranking of a country within the cluster of countries.

The following was predicted about AHP back in 2006 (Vaidya & Kumar, 2006), and time has shown that these predictions have come true.

- AHP is going to be used widely for decision making.
- AHP use is rising in developing countries. That augurs well with the economic development of this block of countries, such as India, China, etc.
- Lots of research is going on in countries like the United States where they have had a head start using the AHP. Focus there seems to be on combining other techniques with AHP. This takes advantage of the versatility of the AHP along with the focused use of the supporting techniques.
- Software applications will be used to address the issue of complexities arising out of the integrated applications of AHP and other techniques to represent the real life situations.

The sustainability framework for rural micro projects with a focus on water projects has already been developed, but there are no frameworks that focus exclusively on rural and renewable energy projects of Nepal.

3. Hypotheses/Objectives

The hypothesis of this study is that a general framework can be developed to measure the sustainability of rural and renewable energy systems of Nepal with a focus on micro hydro power technology, solar pumping and solar home systems. It is also assumed that the AHP framework is most suited for ranking projects from a sustainability and framework development perspective in the Nepalese context. The overall objective of this study is to develop a framework to measure the sustainability of rural and renewable energy projects and eventually assess the sustainability of renewable energy projects that have been installed for a year or more.

4. Research Design/Methodology

Site surveys at different villages in rural areas of Nepal where renewable energy projects have been implemented or are planned for electrification were carried out. The local management committees that are responsible for operation and maintenance of such projects were interviewed. Micro hydro power plants, solar photovoltaics and biogas systems were considered because they are the main technologies used in rural areas of Nepal. The main aim of these surveys was to identify sustainability criteria in a local/national context. Furthermore, consultations with energy experts, professionals working in the field of rural electrification and energy companies that implement rural electrification projects in Nepal were carried out. Based on surveys, consultations and literature review sustainability criteria were then identified. Finally, hierarchical structures for sustainability assessment were developed.

The hierarchical structure, as shown in Figure 6 of this paper, was constructed in order to identify the most sustainable project in the Nepalese context using AHP. The technologies considered for evaluation were micro-hydropower, solar home systems, solar PV pumping, and bio-energy (biomass/biogas). A similar approach using the AHP was adopted by Amigum et al. (2011) in South Africa to select the most appropriate renewable energy technology. Their study revealed that wind energy was most suitable in the context of South Africa. In order to select the most sustainable project using a given technology, a method of objective assessment involving quantification of data is necessary. For instance, to identify the most sustainable micro-hydro project among many micro-hydro projects, a method to select the most sustainable project has to be developed. Once a method has been developed, the most sustainable project within each of the considered technologies can be identified. Ultimately, the projects with different technologies can be evaluated using AHP by adopting the hierarchical structure developed in this paper.

5. Data/Model Analysis

The triangular approach, which takes into account the three dimensions of sustainable development -economic, social and environmental- continues to be highly influential. This approach forms the basis of the structure of the indicators of sustainable development collected by key organizations all over the world, including the UN, the OECD and the European Commission (Nieves et al., 2010). Figure 2 shows the dimensions of sustainability and their interrelationships based on the triangular approach.

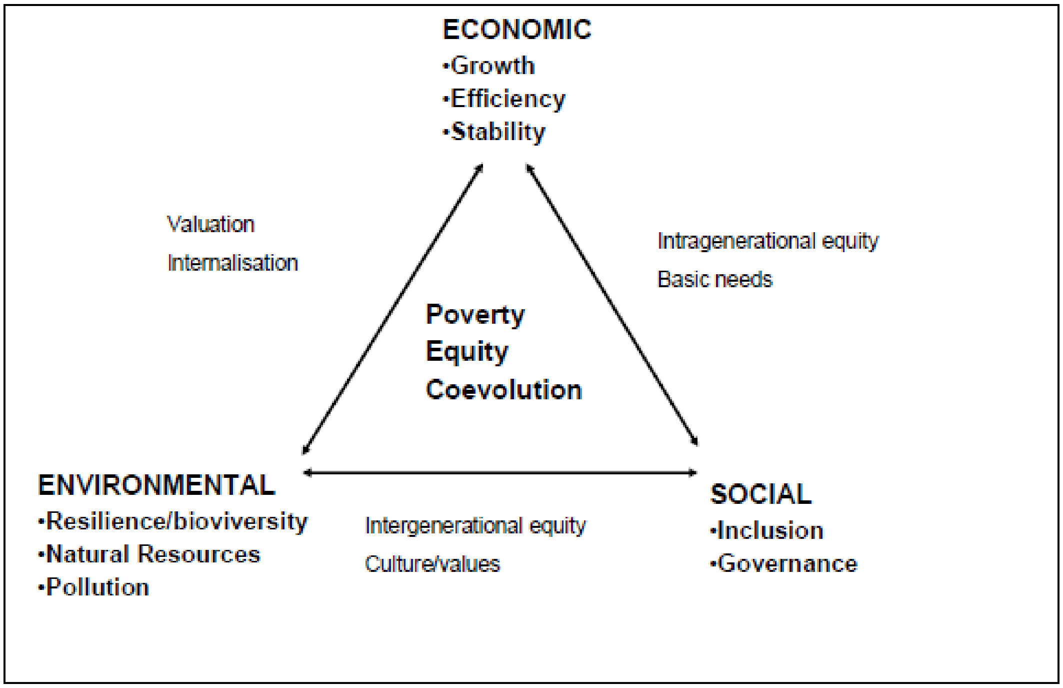

Figure 2. Dimensions of sustainability and their interrelationships (Nieves et al., 2010).

Other dimensions have also been suggested in different studies. The United Nations Commission on Sustainable Development (CSD) devised a framework for monitoring the various sustainability indicators for assessing the performance of governments towards sustainable development goals. The structure of the framework comprises four dimensions including social, environment, economic and institutional, and is broken down into 38 sub-indicators and 15 main indicators. The Institution of Chemical Engineers (IChemE) has also developed sustainability metrics covering three dimensions including environmental, economic and social which are further sub-divided into a set of indicators. These metrics were initiated to assess the sustainability performance of the process industry (Singh et al., 2012). The Wuppertal Institute also developed a framework of sustainability by addressing the four dimensions of sustainable development, as defined by the United Nations CSD. These four aspects are linked through a set of various indicators (Singh et al., 2012). Overall, based on the literature review presented above, it can be said that different sets of indicators have been developed by various research organizations to assess sustainability. There is no universally adopted, rigid set of dimensions and indicators, and the indicators can change on a case by case basis.

For rural and renewable energy projects, efforts have been made by various researchers to identify the dimensions of sustainability. A total of five dimensions/indicators suggested for rural electrification (Ilskog et. al., 2008) are listed below.

- **Technical** sustainability focused on maintaining the energy services during the economic lifetime of the initial investment;
- **Economic** sustainability focused on survival of the service beyond the economic lifetime of the initial investment;
- **Social** sustainability focused on equitable distribution of the benefits offered by electrification;
- **Environmental** sustainability focused on the conservation of natural resources, avoiding degradation of the environment and preventing in- door air pollution;
- **Institutional** sustainability focused on survival of the organization and its ability to maintain adequate performance with respect to the other dimensions of sustainability.

A study to determine qualitative factors that contribute to sustainability of rural and renewable energy projects has been carried out which suggests the following features as part of successful and sustainable renewable energy projects (Sovacool, 2013):

- Selecting appropriate technology through feasibility studies and surveys that, by asking local users what they want, are able to identify community needs and desirable energy services;
- Coupling renewable energy with income generating activities and partnering with livelihood groups such as farmers and crop processors, small businesses, restaurants, and community cooperatives;
- Providing access to financing and micro credit to overcome the first cost hurdle with purchasing systems; Having political leadership and a requisite alignment of national and local policies;
- Building capacity and investing in local institutions rather than merely providing technology; being flexible in terms of deadlines and changing circumstances, including the avoidance of promoting technology selected only by donors;
- Conducting outreach and marketing campaigns and research to ensure that economic, social, and policy issues are addressed alongside traditional engineering and environmental aspects;
- Encouraging active participation (and feedback) from communities, essentially creating as much interaction among designers, producers, and users as possible;
- Avoiding giving away systems for free and instead requiring community contributions and cost-sharing;
- Enforcing technical standards and certifications so units, components, installation practices, and maintenance procedures are all sufficient to ensure reliable system operation.

Based on work carried out by previous researchers the five dimensions/criteria considered to prepare the sustainability framework in this paper are as follows: Technical, Economic, Environmental, Social and Institutional. The qualitative factors of renewable energy projects listed above can be incorporated under the five dimensions considered for this study. For instance, capacity building can be included under the institutional sustainability dimension. Various sub-criteria have been identified within each of the 5 dimensions to measure the sustainability. The sub-criteria identification was based on the literature review and findings from field visits in rural areas of Nepal. In addition, consultations with local village communities where rural and renewable energy projects operate were carried out to ensure that the sub-criteria identified for this research are strongly relevant in the Nepalese context. The typical evaluation criteria of energy supply systems are suggested in Figure 3 (Wang et al., 2009).

Aspects	Criteria
Technical	Efficiency
	Energy efficiency
	Primary energy ratio
	Safety
	reliability
	Maturity
	Others
Economic	Investment cost
	Operation and maintenance cost
	Fuel cost
	Electric cost
	Net present value (NPV)
	Payback period
	Service life
	Equivalent annual cost (EAC)
	Others
Environmental	Nox emission
	CO_2 emission
	CO emission
	SO_2 emission
	Particles emission
	Non-methane volatile organic compounds (NMVOCs)
	Land use
	Noise
	Others
Social	Social acceptability
	Job creation
	Social benefits
	Others

Figure 3. Evaluation criteria of energy supply systems (adapted from Wang et al., 2009)

ISSN 1936-6744 *http://dx.doi.org/10.13033/ijahp.v6i1.250*

The sub-criteria in Figure 3 have been modified to fit the context of Nepal in order to make the sustainability framework highly relevant for rural villages in this country. For example, NOx, SO_2 emission and particles emission is not relevant in context of the technologies used in Nepal and has therefore been eliminated.

Decision making to ensure the sustainability of rural and renewable energy systems can be a difficult task because of the complex interaction of the technical, economic, environmental, social and institutional dimensions. Therefore, Multi-Criteria Decision Analysis (MCDA) can be applied to this kind of decision making, and AHP is a MCDA tool used in energy systems (Kahraman et al., 2010). The AHP is a multi-criteria decision making (MCDM) method which helps a decision-maker facing a complex problem with multiple conflicting and subjective criteria (e.g. location or investment selection, projects ranking, etc) (Ishizaka et al., 2011). The fact that AHP helps in decision making when there are subjective criteria involved makes it very applicable to rural and renewable energy systems' sustainability assessment because such energy systems entail subjective criteria like social and institutional components. Besides, AHP has broken through the academic community and is widely used by practitioners. This widespread use is certainly due to its ease of applicability and the structure of the AHP which is intuitive to how managers solve problems. The hierarchical modeling of the problem, the possibility to adopt verbal judgments and the verification of the consistency are its major assets. Expert Choice, the user-friendly supporting software, has certainly largely contributed to the success of the method (Ishizaka et al., 2011).

The AHP has been used in the energy sector for energy policy formulation, energy planning, power plant selection, power plant location selection, energy resource allocation, integrated resource planning, energy exploitation, controlling greenhouse gas (GHG) emissions, and developing energy management systems (Amer et al., 2011). For Pakistan, the following hierarchical structure has been proposed by Amer et al. (2011) and is shown in Figure 4.

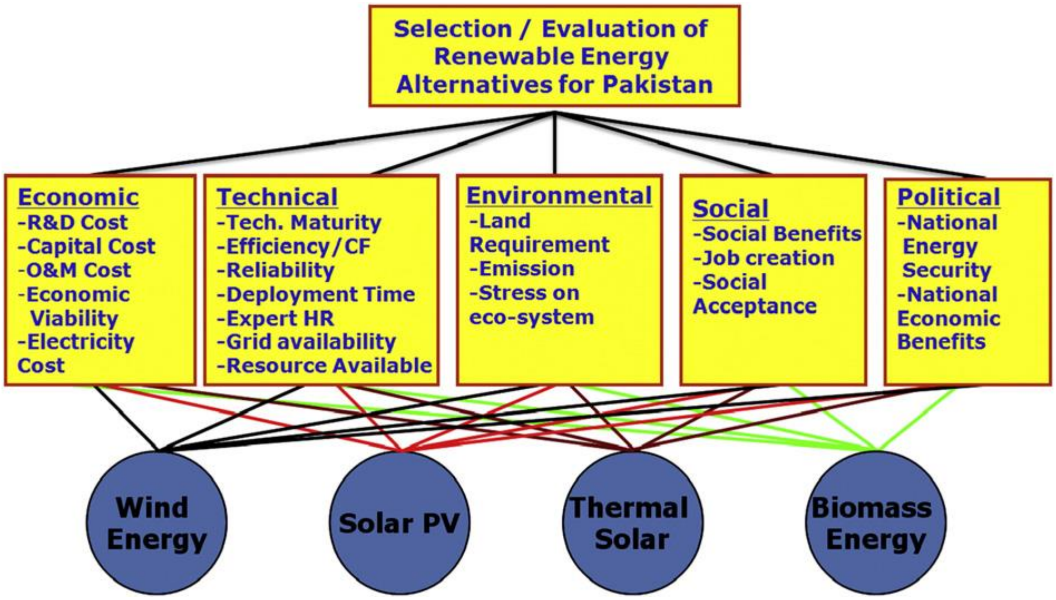

Figure 4. Proposed decision model for selection, evaluation and ranking of renewable energy technologies for electricity generation (Amer et al., 2011).

Criteria/dimensions and sub-criteria were identified and a hierarchical structure was prepared in order to develop a framework for sustainability assessment for this study. Five dimensions, technical, economic, environmental, social and institutional, have been considered and sub-criteria/factors were then identified for each of the dimensions. The guidelines of AEPC, consultations with energy experts and project management committees and a literature review were used to identify the factors. For the context of Nepal, 2 factors have been identified for the technical as well as the economic dimensions, 5 factors have been identified for environmental, 4 for social and 3 for the institutional dimension. Figure 5 shows the AHP hierarchical structure prepared for this study.

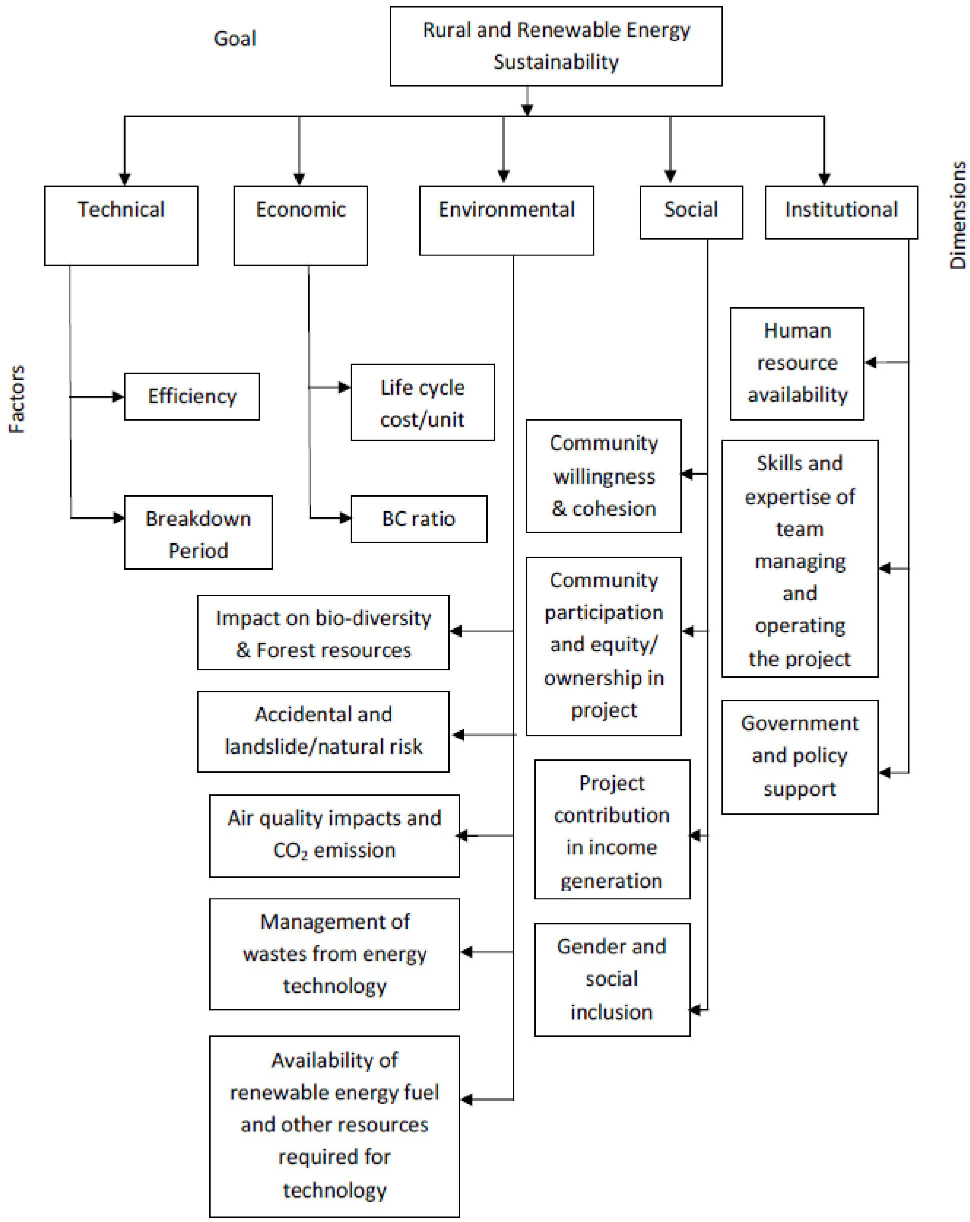

Figure 5. Hierarchical structure of goals, dimensions and factors with their weights for rural and renewable energy sustainability

It is necessary to assign a weighting factor to each of the dimensions for AHP analysis. Saaty's 1 to 9 scale (Ishizaka et al., 2011) as shown below was used for pairwise comparison.

Intensity of importance	Definition
1	**Equal importance**
2	Weak
3	**Moderate importance**
4	Moderate plus
5	**Strong importance**
6	Strong plus
7	**Very strong or demonstrated importance**
8	Very, very strong
9	**Extreme importance**

The pairwise comparison among the dimensions can be done through expert's judgments. A 5 by 5 matrix can be prepared based on Saaty's 1 to 9 scale, and this weight vector can then be determined by the normalization of the 5 by 5 matrix.

Similarly, pairwise comparisons between the factors of each dimension can be carried out based on experts' judgments. Finally, comparisons among various projects can be performed. Four projects developed for use with different technologies were considered for analysis. In Nepal, solar PV based home electrification systems, solar PV based water pumping schemes, micro-hydro power plants and bioenergy projects (improved cooking stove or biogas plants) are the most commonly implemented renewable energy systems. These four systems were considered for AHP analysis. The most successful projects under each of the above mentioned systems were then selected and these selected projects were evaluated using the AHP. In this way, the AHP evaluation helped ascertain the most sustainable project among projects constructed using different technologies. The hierarchical structure of the projects is shown in Figure 6.

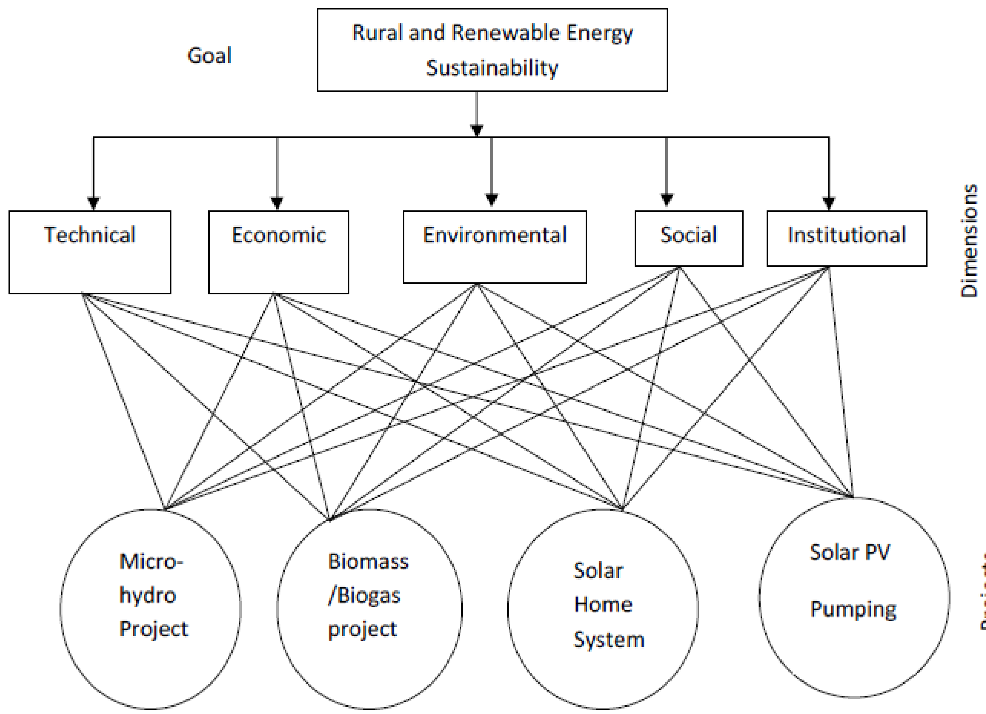

Figure 6. Hierarchical structure with selected projects

An alternative approach to Saaty's 1 to 9 scale is to develop a weighting factor based on practical experience and consultations with project users, managers and operators. The following pre-determined weighting factor in terms of percentage has been suggested.

Technical dimension: 25%
Economic dimension: 18%
Environmental dimension: 17%
Social dimension: 20%
Institutional dimension: 20%

Samplings of rural and renewable energy projects throughout Nepal are required to fine tune the weighting values suggested above. These weighting factors are based on informal monitoring and evaluations of projects by AEPC that suggest that the technical dimension is the most critical; hence, requiring the highest weighted value. The social and institutional dimensions follow the technical dimension in terms of criticality. Case studies of successful and failed projects are required to substantiate the weighting values. An AHP analysis can be performed on projects starting with the weighting factors suggested above, and a sensitivity analysis can then be performed to identify the critical dimensions.

A total score of 10 can be assigned to each of the dimensions, and then multiplied by the corresponding weighting value to quantify the sustainability assessment. Since the factors or sub-criteria have been identified for all the dimensions, scores out of 10 for any given dimension can be obtained by adding the scores assigned to each factors within the given dimension.

6. Limitations

The factors/indicators affecting the sustainability have been developed mostly by considering micro hydro power technology, solar PV technology and bioenergy- specifically improved cooking stove and biogas- technology. Therefore, the indicators may not be fully applicable for other energy technologies. Weighting factors have been given to all the 5 criteria based on experts' judgments, and need corroboration from other stakeholders.

7. Conclusions

The capability of a rural electrification project to sustain itself is one main criterion to be considered before project development in order to prevent any premature failure of the project. The AHP has been used to develop a sustainability framework for rural and renewable energy systems of Nepal in this study. AHP-based hierarchical structure of goals, dimensions and factors with their weights for rural and renewable energy sustainability have been formed, and this structure provides a framework to help in decision making related to project development and also rank various projects based on their sustainability. Weighting factors to each dimension of sustainability has also been proposed based on AEPC's project evaluation and monitoring. Expert Choice should be used in order to determine the criticality of each dimension. It is expected that the framework for sustainability developed in this paper will provide input to the integrated rural and renewable energy planning and policy making.

REFERENCES

AEPC (2011). *Annual Report for 2010.* Alternative Energy Promotion Centre (AEPC).

CBS (2010-2011). *Nepal Living Standards Survey*. Central Bureau of Statistics, Volume I, 2010-2011, Government of Nepal.

Drexhage, J., & Murphy, D. (2010). *Sustainable development: From Brundtland to Rio 2012*. United Nations Headquarters, New York.

Carrera, D.G., & Mack, A. (2009). Sustainability assessment of energy technologies via social indicators: Results of a survey among European energy experts. *Energy Policy, 38 (2)* 1030–1039.

Afgan, N. H. et al. (2008). Sustainability assessment of a hybrid energy system. *Energy Policy, 36(8),* 2903– 2910.

Hak, T. et al. (2012). A method to assess the relevance of sustainability indicators: Application to the indicator set of the Czech Republic's Sustainable Development Strategy. *Elsevier Ecological Indicators, 17,* 46–57.

Oikonomou, V. (2011).Linking least-cost energy system costs models with MCA: An assessment of the EU renewable energy targets and supporting policies. *Elsevier Energy Policy, 39,* 2786–2799.

Bhattarai,S. (1997). Appropriate scale of hydropower development for Nepal: A multi-criteria decision making approach. *Masters of Engineering Thesis*, School of Civil Engineering, Asian Institute of Technology.

Bhattarai, S., & Adhikari, B.K. (2011). Analytic Hierarchy Process for rural micro project sustainability monitoring in Nepal. *Proceeding of International Symposium on Analytic Hierarchy Process 2011 – ISAHP 2011,* Pittsburgh, Creative Decision Foundation.

Panthi, K. & Bhattarai, S. (2008). A framework to assess sustainability of community-based water projects using multi-criteria analysis. *First International Conference on Construction In Developing Countries (ICCIDC-I),* Karachi, Pakistan.

Martchamadol, J. & Kumar, S. (2013). An aggregated energy security performance indicator. *Elsevier Applied Energy, 103,* 653–670.

Vaidya, O.S. & Kumar, S. (2006). Analytic hierarchy process: An overview of applications. *European Journal of Operational Research, 169(1),* 1–29.

Amigum, B. et al. (2011). Multi criteria analysis for sustainability assessments of electricity generation systems in a rural community in South Africa. *Micro*

Perspectives for Decentralized Energy Supply (MPDES), Proceedings of the International Conference, Technische Universität Berlin.

Wang, J.J et al. (2009). Review on multi-criteria decision analysis aid in sustainable energy. *Renewable and Sustainable Energy Reviews, 13(9)*, 2263–2278.

Singh, R.K. et al. (2012). An overview of sustainability assessment methodologies. *Elsevier Ecological Indicators, 15(1),* 281–299.

Nieves, L.J & Rio, P. del. (2010). Contribution of renewable energy sources to the sustainable development of islands: An overview of the literature and a research agenda. *Open Access, Sustainiability, 2,* 783-811.

Ilskog, E. and Kjellstrom, B.(2008). And then they lived sustainably ever after? Assessment of rural electrification cases by means of indicators. *Elsevier Energy Policy 36(7),* 2674-2684.

Sovacool, B. K. (2013). A qualitative factor analysis of renewable energy and Sustainable Energy for All (SE4ALL) in the Asia-Pacific. *Elsevier Energy Policy, 59,* 393–403.

Kahraman, C., & Kaya, I. (2010). A fuzzy multicriteria methodology for selection among energy alternatives. *Expert Systems with Applications,* In Press, Corrected Proof, DOI: 10.1016/j.eswa.2010.1002.1095.

Ishizaka A., & Labib, A.(2011). Review of the main developments in the analytic hierarchy process. *Expert Systems with Applications, 38(11)*, 14336-14345.

Amer,M., & Daim, T.U.(2011). Selection of renewable energy technologies for a developing county: A case of Pakistan. *Elsevier Energy for Sustainable Development, 15,* 420–435.