PRIORITIZING HYDROPOWER DEVELOPMENT USING ANALYTICAL HIERARCHY PROCESS (AHP) – A CASE STUDY OF NEPAL

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ABSTRACT

Nepal possesses huge hydropower potential but lacks experience, funding and political stability which are critical to development. Different national strategies have been proposed in the past ranging from promoting small scale hydro that provides local to regional economic incentives to the recommendation of large schemes to enhance national objectives. This paper analyses the last few decades of hydropower development in Nepal and proposes a multi-criterion approach, the Analytic Hierarchy Process (AHP), to identify projects considering social and environmental concerns in addition to economic objectives. A multi-perspective look at prioritizing hydropower schemes namely micro (below 1 MW), small (from 1-25 MW), medium (from 25-100 MW), big (from 100-1000 MW) and large (greater than 1000 MW) is important in order for hydropower development to proceed in the best possible way. This perspective could be of use in strengthening hydropower related strategy and policy in Nepal.

The prioritization procedure is embedded into a multi-objective framework including six goals, namely a technical goal measured by four criteria, a social goal with five criteria, an economic goal with six criteria, an environmental goal with 4 criteria, a political goal characterised by 4 criteria and an additional goal referring to the various uncertainties, expressed by five criteria. Evidence based subjective value judgment based on secondary sources, mainly related documents and experts consultations, is used for the prioritization approach. This research could help policy makers to maximize the benefit to the country by adopting appropriate policies and strategies.

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The effectiveness of multi criteria evaluation techniques and the Analytic Hierarchy Process (AHP) for hydropower prioritization is the focus of this research. The outcome of the paper is the secondary information based on the AHP application for hydropower scale of schemes prioritization.

This paper is presented in six sections. The first section is the introduction focusing on the country context and MCDA in hydropower. The second section discusses the problem definition, and the third section describes objectives and tasks. Similarly, the fourth section details the applied methodology, and the fifth section describes the results and discussion. Finally, the sixth section presents conclusions and recommendations of the research work.

Keywords: Hydropower; alternatives; AHP, prioritize; decision making

1. Introduction

Nepal has a rich potential of hydropower with 83,000 MW available, but currently only 727 MW of that hydroelectricity has been tapped. Nepal, engraved with extreme energy poverty, has per capita energy and electricity consumption of 16 Gigajoule and 67 units respectively, which is far below the Asian average (Water and Energy Commission Secretariat, 2010a). Electricity consumption is growing at an annual rate of more than 10% (90 MW), and industrialization is halted due to the ever widening energy gap (1000 MW at present) in the country (WECS, 2010b). To overcome this problem, water resources and hydropower as a panacea for transforming the country's economy are at the top of the development agenda in Nepal.

1.1 Hydropower development in Nepal

So far, less than 1% percent of the hydropower potential has been tapped in the last 100 years. Though there could be many reasons for the underdevelopment of hydropower, the most important is a lack of understanding and poor planning. In the Nepalese context, the business approach, and the social factors need more awareness and capacity building (Sovacool, Dhakal et al., 2010). Most often the hydropower sector has been understood in a very fragmented way, dominated by techno-economics and ignoring many important aspects. Since the late 1970s, foreign aid completely dominated the power sector and until recently hydropower development was on an ad hoc basis under various models insisted upon by donors (Pun, 2008). After restoration of democracy in 1990, hydropower took on a new look. The Tenth Plan specifies eight criteria applicable for infrastructure including hydropower which demands the use of Multi Criteria Decision Analysis (MCDA) (NPC, 2002).

The Government of Nepal has committed its energy sector development for poverty reduction and economic development through hydropower (Water and Energy Commission Secretariat, 2010c). It classifies hydropower schemes as micro up to 1 MW, small from 1 to 25 MW, medium from 25 to 100 MW, big from 100 to 1000 MW, and large from 1000 MW upwards (Water and Energy Commission Secretariat 2010a). Hydropower must be viewed in multidimensional ways including irrigation, water supply, navigation, tourism, hydropower etc. in order to be used most effectively (Rees, Holmes, et al., 2006; World Bank, 2003). A decision framework should consider a net improvement of income of the lower income groups in society and avoid the traditional approach of unfair decision making (Gunawardena, 2010). Hence, MCDM could certainly be very much appropriate in decision making.

1.2 Multi Criteria Decision Analysis (MCDA) in hydropower

Hydropower development is a long term investment with high up-front costs and risks. It has a long gestation period and is full of social and environmental challenges that make decision making more complex. The hydropower decision making process extends beyond the classical model of an optimal solution and shifts the conception of a problem to a satisfactory solution (Guitouni & Martel, 1998).

Throughout the past decades, the hydropower project planning paradigm shifted from techno economics to socio-environmental (IHA, 2014; UNEP, 2007). MCDA is gaining popularity worldwide, and differs according to project nature, site and country policy (Foran, 2010). Also in Nepal, a multi criteria analysis for hydropower scheme selection is gaining attention by translating quick and tangible economic benefits under consideration of socio-economic consequences and environmental impacts. This requires an approach which encourages local participation and use of affordable, reliable and maintainable technologies. Limited natural resources, socio-ecological constraints and conflicting interest among diverse stakeholders like the community, government authorities, investors, developers, professionals, civil society, economists, sociologists, environmentalists etc. demands evaluations and prioritizing among available alternatives for the best fit. It is important during the planning of a hydropower project to identify through a social impact study who will benefit from the project and especially who will be exposed to negative impacts (Mathur, 2008).

Over the years, several MCDA methods have been proposed (Loken, 2007). Some widely applied methods are the pair wise comparison and outranking methods (Hajkowicz & Collins, 2007). MCDM is used in different subjects and AHP, ELECTRE, and PROMETHEE are some very popular tools frequently applied for natural resources, water management and energy planning including hydropower (Toloie-Eshlaghy & Homayonfar 2011; Balali et al. 2014; Mendoza & Martins 2006). One of the most popular and trusted tools, called the Analytical Hierarchy Process (AHP), is very appropriate for decision making on hydropower (Akash et al. 1999; Ertay et al. 2013; Supriyasilp et al. 2009). In the Nepalese context, AHP is applicable in decision analysis for many infrastructure developments including hydropower (Bhattarai, 1997).

2. Problem definition

2.1 Different scales and broad impacts

In Nepal, two major strategies are debated as solutions to meet the energy need. The first is the development of numerous small hydropower plants with minimal external dependency, and another is the development of a more considerable size plants that offers the benefit of economies of scale (Bergner, 2013). Though each scale of hydropower development is important, it is necessary to prioritize them within the existing country context to maximize the national interest and benefit. This is an important but missing step in the Nepalese context.

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Due to specific interests and preferences of diverse stakeholders, the hydropower sector is full of controversies and conflict. There are several instances where a particular scale of hydropower scheme would fit best, but in another instance it falls far behind. There are complex and conflicting preferences related to technical, social, economic, environmental, political and associated uncertainties for different scales of schemes.

Though a high potential exists in Nepal, only 10,000 to 12,000 MW equivalents of hydropower plants are within the cost of US$1,000 -1,500 per kW and easy to implement (Shrestha, 2012). This should be a priority. Also, several attractive hydropower sites totalling 2,110 MW that are close to the middle hill road project that is under construction are attractive at a lower construction cost (Kuwar, 2013.). Further, existing hydropower plants that are integrated into the national power grid are regionally unbalanced and the transmission is inefficient with a record highest loss of 36% in 1984 (Bhattarai, 2012; Nepal & Jamash, 2012). The national power transmission system has a strong correlation with the size of the scheme that is prioritized, and so is applicable with other infrastructure like roads and bridges. The existing grid could accommodate only a small to medium plant; a big or large scale power plant integration into the grid would require enhancement of the existing grid capacity which is a time consuming and costly affair. Therefore, the problem is to choose which scale of power plant scheme should have priority.

A strong pool of more than 10,000 human resources in the hydropower sector have experience with small and medium scale plants (NEA, 2012.) . While bigger scale schemes like Upper Tamakoshi (456 MW), Kali Gandaki (144 MW), Mistri Kola are excellent examples of road access, safety enhancement, business expansion etc., micro schemes are still the preferred solution for rural energy access (Rajauriya, 2012). Medium power plant development is crucial for the nation's social capital formation in order to take the next steps to big or large schemes in the future. Employment opportunities increase with increased scale of generation except when large size plants are export oriented. Unfortunately, Nepal has very limited experience and manpower both in quantity and quality for big or large scale plants. Also, dam-related resettlement practices have failed to restore livelihoods in Nepal (Fast & Hansson, 2013). Socially, large size projects have many hurdles to overcome before they can progress. Within this context, it is critical to prioritize scale of schemes in order to maximize the national benefit.

With the availability of local construction materials and support infrastructure like bridges, roads, and grids the economic viability of hydropower has been enhanced in recent years. Although bigger schemes may benefit economies of scale in general, the cost can remain high due to the majority of materials being imported and the need for additional investment in support infrastructure. Bigger size projects can make more contribution to the national energy need if they are not export oriented. Further, foreign aid and external financing makes the projects costlier because of the mode of financing and the impact of contracting on project economies (Panday, 2003). Presently, the financing sectors are hesitant to take any huge investment risks, and prefer to test the business reliability in steps. Available financing, and the 15- 20% of the national budget allocated for the hydropower sector for coming 5 years, could bridge the energy gap (NRB, 2013; Jha, 2069 B.S.). However, several of the licenses for large size projects that were issued earlier have been cancelled because of capacity and finance constraints.

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Within the financing scenario discussed, it is challenging to maximize the economic benefits from the development of the most appropriate schemes of hydropower.

The environment is one of the important issues to be examined in all major infrastructure projects including hydropower, which is subjective to the site, type and size of the schemes (Bhatta & Khanal, 2009). In general, the bigger the plant, the bigger the environmental concerns and negative consequences will be. In this respect, the smaller plants are more environmentally friendly. Reservoir inundation and sediments are major challenges in the Nepalese context whose mitigation may demand further investment (Thapa, Shrestha, et al., 2005). Hence, prioritization with this in mind can assist in identifying an environmentally friendly hydropower scheme to develop.

2.2 Policies and strategies in hydropower development

To make best use of available resources and maximize the national interest, required policy and strategies are very important. In the absence of multi-dimensional analysis of these alternatives, efforts on hydropower development in Nepal are diffused. Government propositions about hydropower development frequently change and sometime contradict each another, specifically concerning their priority on alternative (scale of) schemes. The country is missing a clear vision with respect to hydropower development as well a profound planning procedure for best use of available resources in the country. The Government of Nepal (GON) emphasizes energy access to the majority of the people as quickly as possible. Some of the ambitious plans put forwards include an electricity crisis mitigation work plan of 25,000 MW in 20 years and 10,000 MW in 10 years. While the government is continually supporting decentralized energy programs for access, recently their interest has been for bigger size projects like Upper Tamakoshi (456MW), Budhigandaki (600 MW), Nausyalgad (400 MW) etc. There are also plans and policies favouring storage type and multipurpose medium to large hydropower plants (JICA 2013). As mentioned above, big to large single or multipurpose schemes demand a huge long term investment and careful preparation (Thut et al. 2011). Hence, the government opts for hydropower project development based on particular objectives while the country needs prioritizing the scale of hydropower development in order to maximize the national interest.

2.3 Risks related to hydropower development

In hydropower, different types of risks are applicable at different stages and are of different magnitude (World Bank, 2005). Technical risks are high, specifically in developing countries engaging in large projects. Political (policy) risks due to flaws in policy and political stability could also be damaging to hydropower development. Environmental risks arising from climate change, glaciers outbursts and seismic risk are serious in the Nepalese context (ICIMOD, 2011; Agrawala, Raksakulthai, Aalst, Larsen, Smith & Reynolds, 2003; NSC, 2012). Economic risk and mitigation strategies relating to capital investment, local currency fluctuation and market failures must be worked out in advance (Shrestha, 2014). Social risk is also very important specifically concerning resettlement and land acquisition (Messerschmidt, 2008). Delay and adverse impact on the project economy must be minimized to ensure smooth implementation of the schemes (Panthi, 2007). With society’s increased public awareness about rights concerning natural resources and possible consequences of adverse environmental impacts, hydropower development suffers from controversies, conflicts, longer gestation periods, cost overrun and slow progress. Hence, an evaluation of the uncertainties associated with hydropower schemes is another important goal in prioritization research.

Identifying and assessing all these risk elements is a challenging task. Due to limited data availability and the complexity of the problem, the application of more qualitatively expressed indicators is recommended. Several non-tangible factors need subjective judgement which is critical, and they also need proper comparison and evaluation.

To make the best use of available resources and maximize the national interest, coherent policy and strategies are very important. In the absence of multi-dimensional analysis of these scale dependent alternatives efforts on hydropower development in Nepal are diffused. Government propositions about hydropower development frequently changes and sometime they contradict to each other and specifically the priority of scale changes.

3. Objective and tasks

In the previous section, the contribution of different sized hydropower plants to economic development, the social implications and the environmental consequences were discussed together with the associated uncertainties. It is obvious that for a sound assessment and subsequent prioritization of schemes a set of tasks together with descriptive indicators from which some are qualitatively expressed is needed The final evaluation or project prioritization must be based on the overall performance obtained by ranking the accumulated and weighted project outputs.

The primary objective of this study is to recommend the most appropriate scale (micro, small, medium, big or large) hydropower for Nepal in the present context and immediate future using AHP. As mentioned in Section 1.1, hydropower is classified into five groups depending upon its generation capacity.

- Micro Hydro: up to 1 MW
- Small Hydro: 1 to 25 MW
- Medium Hydro: 25 to 100 MW
- Big Hydro: 100 to 1000 MW
- Large Hydro: 1000 MW upwards

In other words, this set of development options, constituting our alternatives has to be evaluated with respect to a set of goals, each of them described by several criteria. Thus, a multi-objective framework with these goals together with their respective criteria will be identified. Several similar studies found from scientific publications are used in drafting a framework (Nachtnebel et al. 1994; Ganoulis 2008).

Though each scheme, independent from its scale, is contributing to development prioritization is very important to make a decision for the best outcome. Therefore, for the prioritization of hydropower among the five available alternatives several goals and criterion contributing to prioritization must be taken into account simultaneously. The involvement of numerous stakeholders with different priorities and criteria with differing weights that are able to reach a compromise is important (Haralambopoulos & Polatidis, 2003).

Since the 1980's, there have been several methods invented to solve decision problems. The MCA methods used most often that focus on hydropower are fuzzy set analysis, distance to ideal point, pair wise comparison and outranking methods, multi criteria value function, distance to ideal point and out ranking method, weighted summation / multiplication (Strin & Groselj, 2010). Though more than one method is recommended to verify the decision results, some studies show that the various methods used for decision analysis mostly produce similar results (Shajari, Bakhshoode et al., 2008). Therefore, in order to minimize the complexity of some of the methods based on nonlinear forms and complex mathematics, the multi-criteria analysis (MCA) based on pair wise comparison was chosen for this research. There are several advanced tools applied in pairwise comparison for alternatives ranking like AHP, ELECTRE, PROMETHEE etc. One of the most widely applied tools called the Analytical Hierarchy Process (AHP) is used in the present study. The AHP methodology has been accepted by the international scientific community as a robust and flexible multi-criteria decision making method that deals with complex decision problems (Strin & Groselj, 2010). AHP is widely used in decision making, particularly for the hydropower context (Subramanian & Ramanathan, 2012; Rosso, 2014; Vucijak, 2013 and Ahmed, 2014).The AHP is effective as a decision aid that can assist decisions makers in choosing the best alternative or ranking a set of alternatives specifically in a sector like hydropower where group conflict among different stakeholders exists. With the increased application of AHP in the Nepalese context, some of the earlier hydropower related studies based on AHP and multi criteria endorse the suitability of the AHP application in the present research (Bodin & Gass, 2004;. Bhattarai, 2003; Bhattarai and Fujiwara, 1995; USAID-SARI, 2002).

Hydropower prioritization and planning requires appropriate data input, and in the absence of the required data available literature and second hand information could be organized to understand the sector. Hence, this study needs secondary information gathered from several published water resources and hydropower related studies, peer reviewed scientific and professional journals, academic researches, news articles, project reports and publications.

4. Methodology

This study focuses on analysing hydropower development in Nepal and contributing to a sound strategy for hydropower development. In order to achieve this task a framework is developed containing goals and criteria, and then a method is proposed to achieve a ranking of the alternatives with respect to their size.

The present research approach uses evidence based secondary sources of information which gives better insights than what could be available from other approach like opinion survey, workshop, expert views, group or actors opinion etc. Secondary data sources could be cross checked from various sources to minimize error and fill information gaps which enhance the reliability of the research. In the present study, information pertaining to different aspects of hydropower, associated with several stakeholders, belonging to different groups is collected. Different stakeholders that belong to different groups may have different preferences and could be analysed with respect to their particular group such as economist, sociologist, and environmentalist and so on, but in order to make the research simple, the present study treats all responses as a single group of respondents for analysis. It is a research problem dealing with several alternatives, one decision maker (main author of the paper as researcher), and numerous outcomes and thus using MCDM.

4.1 Identifying goals and criteria

To meet the overall objectives set for the present research, keeping in mind the problem described earlier, the hydropower analysis in the present study should be viewed with respect to certain goals and measured on specific criteria. While economic, social, environmental and political goals are very common in MCDM applications, two additional goals are included. Due to the fact that hydropower requires a sound technical education and training at several levels, this being especially relevant for Nepalese conditions, technology has been integrated as a specific goal that is relevant for decision making. Similarly, hydropower is binding over a long time and a huge investment, while at the same time is full of uncertainties throughout its life. Hence, uncertainties have to be evaluated in the decision making. Finally, the following six goals with their characterising criteria and desired directions (expectations) are considered in the present study:

- Technical: Maximize self-reliance
- Social: Maximize social benefits
- Economic: Enhance country economy
- Environmental: Minimize adverse impact
- Political: Maximize national progress
- Uncertainties: Increased safety against risks

Following the problem definition discussed in section 2 and information gathered so far from various sources, criterion are identified and placed with corresponding goals to achieve the overall objective set in this research. In Table 1 the final grouping of criteria with respect to goal, along with the symbol and expected objective is presented.

Table 1
Goals and criterion with their objective

Goals	Criterion description	Symbol	Objective
Technical	Experience and expertise to study, design, implement, operate and maintain hydropower projects	**T1**	Maximize
	Project development dependency on outsider's technical assistance to design, implement and operate	**T2**	Minimize
	Grid readiness for Transmission and distribution to accommodate new projects	**T3**	Maximize
	System and business handling capability to manage contracts, negotiations, agreements and logistics	**T4**	Maximize
Social	Equity and benefits distribution, induced safety and services to participating communities	**S1**	Maximize
	Inclusiveness of beneficiaries specially poor and women and good governance of project in terms of transparency in decision and information sharing	**S2**	Maximize
	Social capital formation enhancing people capability to replicate and participate in new projects development	**S3**	Maximize
	Energy access to beneficiaries and enhancing reliable energy availability in the country	**S4**	Maximize
	Heritage and culture preservation against adverse influence or loss	**S5**	Conserve
Economic	Generation capacity to avail more energy and combat energy import from outside	**E1**	Maximize
	Investment and operation Cost of power generation	**E2**	Minimize
	Enterprise strengthening by number and capacity and flourishing many economic activity	**E3**	Maximize
	Use of locally available construction materials, human resources and existing infrastructure like road, bridge etc.	**E4**	Maximize
	Finance resources availability and conditionality on investment	**E5**	Maximize
	Developers interest and readiness to develop the project	**E6**	Maximize
Environmental	River morphology conservation to preserve ecosystem and riparian ecology	**e1**	Conserve
	Terrestrial (land, forest) environment protecting from encroachment and inundation due to project	**e2**	Conserve
	Water quality, availability and connectivity ensuring peoples need in the vicinity	**e3**	Maximize
	Waste and pollution management during project construction and afterwards	**e4**	Minimize
Political	Policy & strategy support in country to attract more projects implementations	**P1**	Maximize
	Time plan to meet power deficit and also ensure power development target plan for future	**P2**	Minimize
	Contribution to overall national development agenda like industrialization, transport, new cities, participation to the international grid	**P3**	Maximize
	Regional balance of power system to avail power in every parts (region) of the country	**P4**	Maximize
Uncertainties	Technological risk due imported technology and scale of schemes	**U1**	Minimize
	Political risk to instability in the country and fluidal hydropower policy or strategy	**U2**	Minimize
	Environmental risk due to climate change and geophysics of the region	**U3**	Minimize
	Social (implementation) risk arising due to peoples dissatisfaction and revolts against project development	**U4**	Minimize
	Financing (market) risks due to weaker financing capability of national financing institutions and harsh conditionality posed by international financers	**U4**	Minimize

4.2 Assessment and ranking procedure

In this paper there are five alternatives (capacity range of hydropower schemes) to be ranked by one decision maker with respect to a set of six goals and 28 criteria. Numerous multi-criteria techniques are at hand (Toloie-Eshlaghy & Homayonfar, 2011). The selection procedure to identify an appropriate technique is again an MCDM approach (Ozernoy, 1997). Here, the ability to handle qualitatively expressed criteria, to analyse the sensitivity of ranking, the visual support of the method and the proven applicability to hydropower project assessment were decisive. The Analytical Hierarchy Process satisfies these conditions using a software called Expert Choice. Subsequently, the fundamentals of AHP are discussed briefly to facilitate its understanding and application (Saaty, 1986).

The MCA model is represented by an evaluation matrix X of n decision options and m criteria. The raw performance score for decision option i with respect to criterion j is denoted by xi,j. The importance of each criterion is usually given in a one dimensional weights vector W containing m weights, where wj denotes the weight assigned to the jth criterion. It is possible for X and W to contain a mix of qualitative and quantitative data.
A great variety of MCA algorithms can be used to either rank or score the decision options. The MCA algorithms will define, by some means, one or both of these functions:

$$r\mathrm{i} = f\,1\,(\mathrm{W}, \mathrm{X}) \quad \text{and} \quad u\mathrm{i} = f\,2\,(\mathrm{W}, \mathrm{X})$$

Here *r*i is an ordinal number representing the rank position of decision option i and *u*i is the overall performance score of option i. The solution of *r*i and *u*i occurs within a broader MCA decision making process.

The MCA process generally contains the following stages: choosing decision options and evaluation criteria, obtaining performance measures (xi,j) for the evaluation matrix, transforming them into commensurate units, weighting the criteria, ranking or scoring the options, performing sensitivity analysis and finally making a decision (RAC, 1992). One of the most widely applied techniques is the Analytic Hierarchy Process is pairwise comparison (Saaty 1987). This approach involves comparing criteria and alternatives in every unique pair giving n (n-1) / 2 comparisons. The comparisons can be made to attain criteria weights and decision option performance scores. Various scaling systems can be used. AHP decision makers are asked to express a preference for one criteria/option over another in each pair on a nine point scale.

The AHP is based on the axiomatic foundation as follows (Saaty, 1986):

1. The reciprocal property that is basic in making paired comparisons
2. Homogeneity that is characteristic of people's ability for making paired comparisons among things that are not too dissimilar with respect to a common property and, hence, need for arranging them within an order preserving hierarchy
3. Dependence of a lower level on the adjacent higher level
4. The idea that an outcome can only reflect expectations when the latter are well represented in the hierarchy.

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The work on the AHP involves the estimation of priority weights of a set of criteria or alternatives from a square matrix of pair-wise comparison $A = [a_{ij}]$, which is positive and if the paired comparison judgment is perfectly consistent it is reciprocal, i.e.

$$a_{ij} = 1/a_{ji} \text{ for all } ij = 1, 2, 3,.., n.$$

The final normalized weight of its i-th factor, w_i, *is* given by

$$w_i = a_{ij} \Big/ \left(\sum_{k=1}^{n} a_{kj}\right) \qquad \forall \; i = 1, 2, ..., n.$$

In real life judgments an error on the judgment is unavoidable. The suggested Eigen value method computes *w* as the principal right Eigen value of the matrix *A* or w satisfies the following system of n linear equations:

$A\,w = \lambda\,max\;w,$ where $\lambda\,max$ is the maximum eigen value of *A.*

This is to say that

$$w_i = \frac{\sum_{j=1}^{n} a_{ij} w_j}{\lambda_{max}} \qquad \forall i = 1, 2, ..., n.$$

The natural measure of inconsistency or deviation from consistency, called consistency index *(CI)* is defined as

$$CI = \frac{\lambda_{max} - n}{n-1} \quad .$$

The consistency index of a randomly generated reciprocal matrix from scale 1 to 9, with reciprocals forced, for each size of matrix called random index (*RI*) is presented in Table 2.

Table 2
Random Index (RI)

Matrix order	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Source: Saaty, (2007)

Then the consistency ratio is (*CR*) = *CI* / *RI*, where RI value applied corresponding to the matrix size. The value of $CR < 0.01$ is typically considered an acceptable limit If this limit is not reached one should reduce the inconsistencies by revising his judgments.

The other task in the hierarchy is the synthesis of the judgments throughout the hierarchy in order to compute the overall priorities of the alternatives with respect to the goal or objectives. The weights are created by summing the priority of each element according to a given criterion by the weights of that criterion. A pair-wise comparison scale for an evaluation of the relative importance of factors used in the AHP subjective judgment in accordance is given in Table 2 (Saaty, 2007).

Table 3
Scale of pair-wise comparison

Intensity of Importance	Definition	Explanation
1	Equal importance	Two activities contribute the equally to the objective.
2	Weak	
3	Moderate importance	Experience and judgment slightly favour one activity over another.
4	Moderate plus	
5	Strong importance	Experience and judgment strongly favour one activity over another.
6	Strong plus	
7	Very strong or demonstrated importance	An activity is favoured very strongly over another; its dominance demonstrated in practice
8	Very very strong	
9 (absolute)	Extreme importance	The evidence favouring one activity over another is of the highest possible order of affirmation.

Source: Saaty, 2007.

4.3 Research work flow

The research work flow followed in the present study is described below in Figure 1.

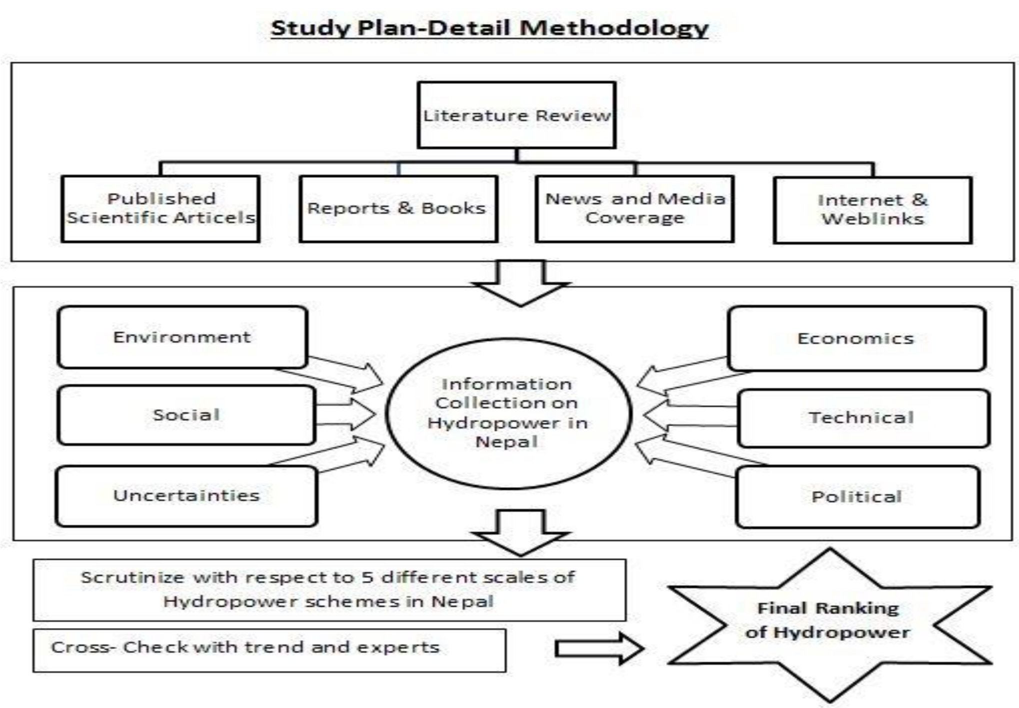

Figure 1. Study work flow

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First, information was collected from various reliable secondary sources like government institutions, published reports, electronic media etc. The information obtained was organized by criteria, and further reviewed against five alternatives of hydropower schemes. Secondary information was entered into a table with the goals and criteria against the alternatives which ranged from excellent to worst. This was used later to make pair comparisons. In the third stage, the organized data was used for pair comparisons and weight allocations which are required in AHP using software called Expert Choice for further processing. The AHP used in this research is presented in following Figure 2.

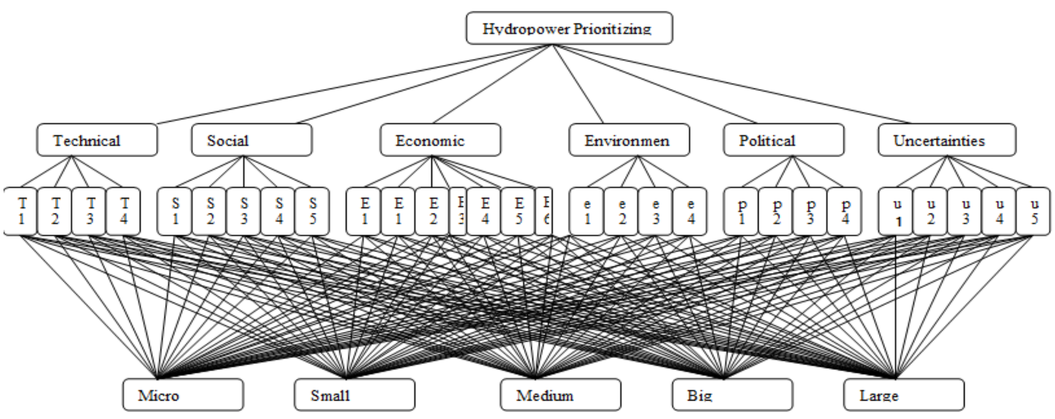

Figure 2. The AHP Model

At this stage, consistency in data entry at each step was checked and maintained within an acceptable level. At the end, the software provided results. These results are reviewed and further discussed in detail with the experts working in hydropower sector of Nepal for cross verification of the data entered and results obtained. This will enhance reliability of the results obtained by the AHP application in the hydropower study. Finally, corresponding scores for alternatives were obtained which were then used for their ranking or comparison. The highest score has the most priority, whereas the lowest score is the least prioritized scale of hydropower in Nepal. Similarly, a sensitivity analysis was carried out for obtaining delegates decisive elements in hydropower prioritization in Nepal.

5. Results and discussion

A large amount of data was required in this research which may be of qualitative or quantities type. Lack of sufficient data and subjectivity in data entry was a critical challenge in this research. Since reliability varies considerably among various sources of information, this may have had an impact in final results obtained in this research. Further, weights assigned to goals and criteria are logged from reviewed documents and experts' suggestion which is again subjective and dynamic within the country context. This could have also influenced the results of the research. Hence, in these situations, as much as possible, several secondary sources of information that were collected were

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reviewed carefully and discussed frequently with professionals working in this sector to minimize error and enhance the reliability of the results.

Every type of hydropower developed in the country could contribute in different ways. For example micro scale plants work well for remote energy access, but could not contribute much to the national energy need. Big or large schemes certainly need a huge amount of funding and a long gestation time while small or medium power plants managed domestically could result better benefit for the country. Thus each scale of scheme could best fit in some context and benefit the country in different ways. The trends indicate a shift of interest from an earlier preference for small and medium scale towards medium and big scale hydropower development. The government focuses on big size projects and already initiated super 10 projects as the nation's priority. Economies of scale in power generation are attracting more medium and big size plants. While large size projects are under consideration and discussion, several micro to medium schemes are being implemented. Considering all of these complicated aspects of hydropower in Nepal, an AHP application to prioritize scale of schemes is important.

The results of this AHP based study take into consideration the individual preference or importance of each goal, and criteria and alternatives with respect to the overall objective of the problem. The researcher as the decision maker in the present study uses his best understanding about the goals and criteria contribution to realize the main objectives of the research. In this analysis, the bottom level pairwise comparisons among criteria with respect to the main objectives are carried out by the decision maker. The same approach is followed while making mid-level comparisons. At the top level the weight assigned to the goals was followed based on reviewed papers and practice applicable to hydropower in LCDs including Nepal.

5.1 Goals, weight and alternatives rankings

If each goal in the present study was weighted equally it would weigh in at 17%. The strong importance of economy in project selection is found in several project reports and scholarly articles (Bhattarai, 1997; Marttunen et al., 2010). Accordingly, economy is weighted at 25%. In same manner, the importance of the political goal is estimated at 20%, slightly above average. This is the same for the social goal. The technical goal is weighted at 15%, which is close but slightly below average weight. The environmental goal and its associated risks are weighted at 10%. Overall the weight assigned to each goal and its corresponding prioritization can be viewed in Figure 3. At present, the majority of factors found medium and big scale schemes as the priority, while environmental factors and uncertainties favoured micro and small scale hydropower plants. One can note that big scale hydropower development was in the interest of social, economic and political factors, whereas the technical factor preferred medium scale plants. Both for environmental and uncertainties, the preference order was from micro towards large scale hydropower development in Nepal. Among the factors, in terms of importance, economic factors remain the highest (25% weightage) and were found to be the most sensitive. Sensitivity with respect to change in economic factor weightage is further discussed in Section 5.3.

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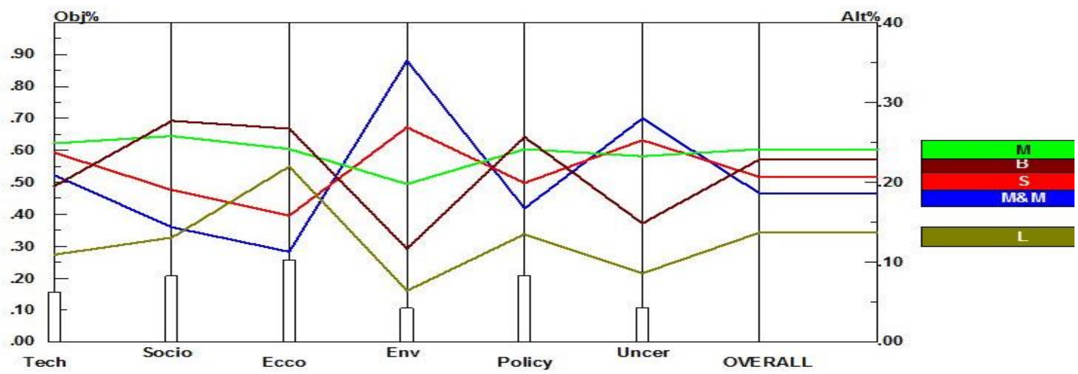

Figure 3. Prioritization with respect to various goals and weight

Analysis found that a change in economic weightage of 20% could change the priority order; this is a big jump and may happen in long run but not in immediate future. All other factors were found to be stable within a foreseeable change in weightage. Hence, this analysis was found to be sound and could be adopted for policy formulation and strategy. Nepal could definitely maximize the benefit from hydropower development in the country by adopting the appropriate backup for the top scoring scale of schemes. Further, in the long run, with the strengthening of Nepal's economy big schemes (100 to 1000 MW) will take priority surpassing medium schemes which are currently the highest priority. Maybe one day large schemes (>1000 MW) will be highly beneficial to the country with the changing country context and preferences of schemes. Therefore, the most beneficial policy and strategies must be able to be tuned according to whatever the current situation in the country is.

5.2 Overall and goal wise prioritization of alternatives

Each scale of schemes could best fit in some context and benefit the country in different ways. In the present context, considering all goals and respective criterion, ranking of alternatives are shown in Figure 4. It was found that medium scale schemes in Nepal ranked first, followed in decreasing priority by big, small, micro and large scale schemes. The two extreme scales of schemes fell at the lowest priority namely micro and large scale hydropower.

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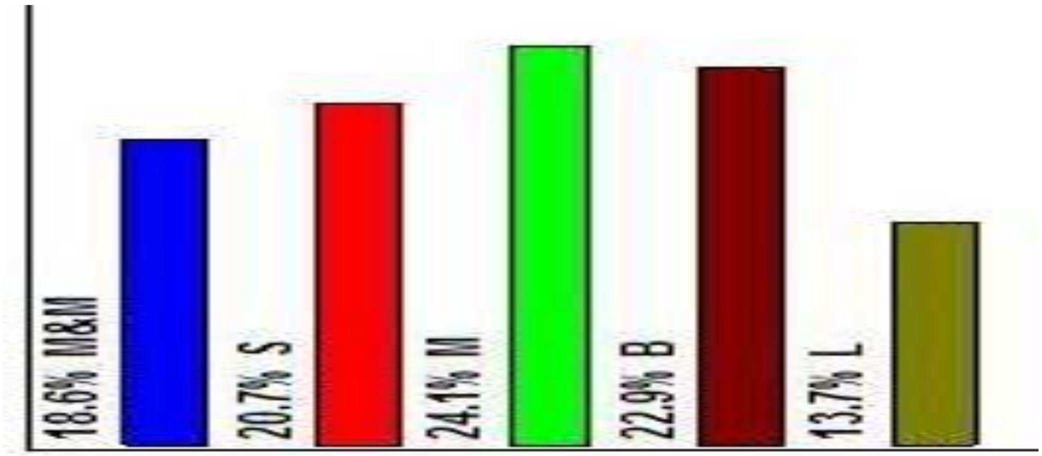

Figure 4. Overall syntheses on prioritization of hydropower in Nepal

Micro schemes, though excellent on the environmental goal and uncertainties measures, was poor on the economic and social expectations because of very low generation capacity. In the case of large schemes, in spite of excellent economies of scale, due to its energy export and external financing requirement, its overall contribution to the country and ranking is lowest. Although big and small schemes are ranked second and third, they are in competition with the highest ranking medium schemes. These schemes could be managed and implemented domestically to meet energy needs and benefit the country.

The AHP results help in understanding the relative prominence of available alternatives with respect to goals. The overall synthesis on prioritization with respect to various goals prioritizing alternatives is presented in Figure 5. It is interesting to note that large scale schemes are least preferred with respect to every factor except economics. Future changes in priority ranking are very much dependent on changing economics in the country. If such large schemes are developed within the need and the resources originate in-country, the priority of this scale will change. Unfortunately, this scenario is very unlikely because large projects, in view of Nepal’s limited financial resources, would require as a pre-requisite power exports contracts with neighbouring countries. Micro schemes are excellent with respect to technical, environmental and uncertainties, but fall behind on economic and social goals. Small schemes perform best on technical, but poor on economic goals and yield an average performance on the rest of the goals. Similarly, big schemes are excellent on economic, social and political goals, whereas medium schemes are the best performer on technical, social and political goals. This analysis also indicates that the country’s technical capacity is possibly capable of handling up to big scale schemes. In days to come, if funding is organized and modality of project development ensures more resources and benefits to circulate within the country, big schemes could become a priority very soon.

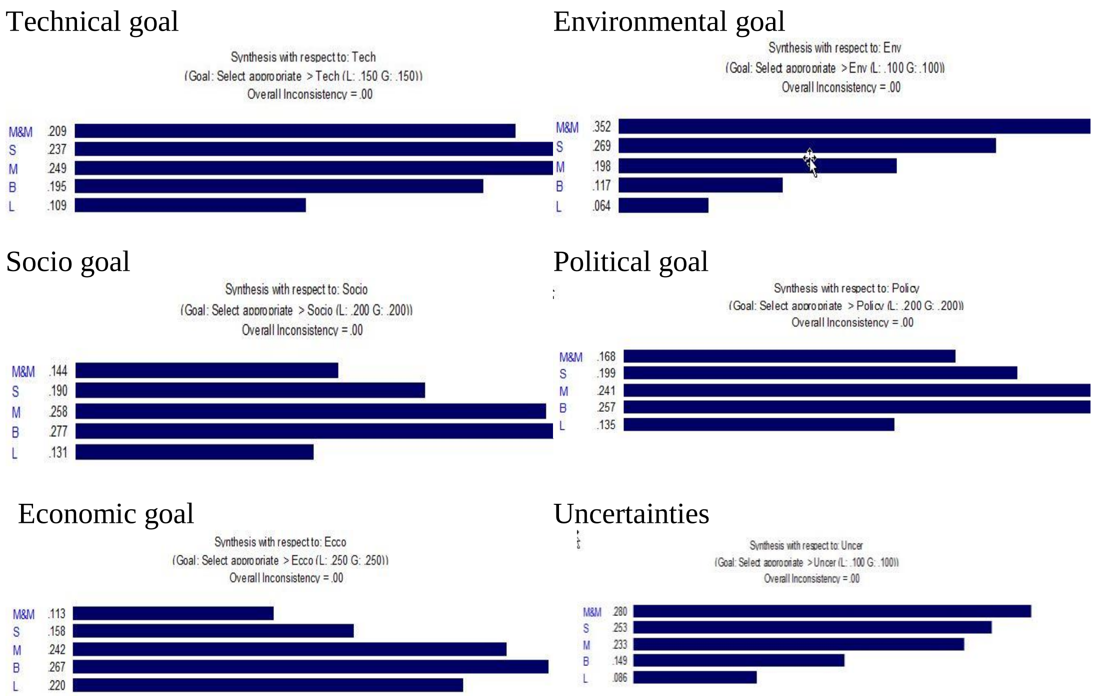

Figure 5. Prioritization with respect to various goals

5.3 Sensitivity analysis

In general, there are uncertainties in the data, models (e.g. transferring data into impacts) and in preferences. Further, some of the information and data used may not be correctly understood, expressed or reviewed. Allocations of weight to the goals and corresponding criteria might have errors because of subjectivity in its assessment. All these factors could be a major source of error and cause the end result to be different than it would otherwise be. It is thus important to check that slight variations of the parameters (weight allocated) don't have a large influence on the analysis results (rankings). Thus, the objective of the sensitivity analysis is to determine the change in the alternative ranking with the change in the weight allocated to the goals and criteria. The sensitivity could be analysed only with the factor of one level below the objective. Hence, the sensitivity analysis, another important feature of AHP application, will verify the trustworthiness of ranking obtained.

As shown in Figure 3 with respect to the economic goal whose weightage changed from the allocated 25% by +/- 5% to observe a change in ranking. Although the ranking values are slightly changing it is not enough to make a change in the overall ranking obtained earlier. Hence, the economic weight allocation is stable. If the weight is increased (changed) to 35%, then the ranking order is changed and big schemes would be the top priority as shown in the Figure 6. This sensitivity could be performed directly by varying the weight allocated (in Figure 3) to the goals one at a time to observe the overall impact on the ranking of alternatives. Alternatively, the gradient sensitivity with respect to each goal could be analyzed separately to observe the influence on ranking order of alternatives. Alternatively, the gradient sensitivity with respect to each goal could be analyzed separately to observe the influence on ranking order of alternatives. A gradient sensitivity of each and every criteria was reviewed with a change in weightage to determine the sensitive factors as shown in the case of the economic goal in adjacent Figure 6. Here, the economic goal seems sensitive to weight change if it exceeds 35% weightage and the decision or ranking of alternatives could be influenced. However, the presently allocated weight of 25% to economy is unlikely to change in the near future, but could receive higher weightage with a strengthened economy in the long run. Similarly, we can vary the weightage allocated to other goals. It was found that varying the weightage with +/- 5% over the allocated one does not change the ranking except by varying the alternatives value slightly. Hence, those weight allocations for the goals are also stable and the ranking obtained is trusted.

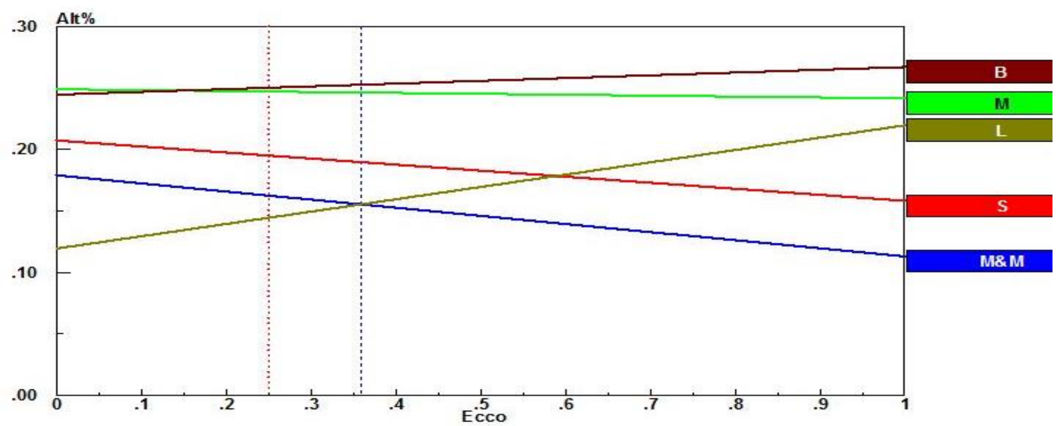

Figure 6. Sensitivity with respect to economic factor

6. Conclusions and recommendations

The main objective of the study was to assist in the development of a sound strategy for hydropower development in Nepal. AHP based on secondary information is an easy and reliable approach to prioritize hydropower planning. It is far more informative than a workshop or survey based approach. Additionally, this approach helps to understand the relative prominence of alternatives with respect to set criteria in more detail with evidence and references.

Within a framework of six goals including 28 criteria applied for the five alternative scales of hydropower schemes medium scale power generation is the best option followed by large hydropower in Nepal's present context and immediate future. Small hydropower is the third priority followed by mini and micro in the fourth ranked position.

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Large hydropower of more than 1000 MW is at the least preferred in the Nepalese context at the moment.

Among the considered goals, the economic goal is of the most important and likely to remain highly weighted. It may even increase further with a strengthened economy and neighbouring market expansion. As such change takes place slowly the prioritization order will remain constant for the near future (say the next fifteen years). Though this factor is currently stable for a wide variation (15%-35%) it could change the priority in the long run which would put big hydropower on top and even enhance large hydropower in the priority order.

This research methodology of secondary information based AHP application in hydropower prioritization is a new approach. It produces reliable results in the Nepalese context and could be applied in a similar context. It could be of use for the researchers, professionals, planners and other hydropower stakeholders in Nepal and similar countries. Specifically, this analysis could help the hydropower policy maker in the country to opt for the appropriate policy and strategy to maximize the benefits from hydro resources. This exercise is important to conduct from time to time in order to assess the prioritization which may slowly change within the evolving country context.

Though the AHP applied in this study helped the prioritization of available hydropower alternatives in Nepal, it is recommended to further crosscheck the results by using other scientific tools like PROMETHEE, ELECTRE etc. to validate the conclusions of the study.

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