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MULTI-CRITERIA DECISION METHODS AS DECISION AID FOR DEVELOPING HYDROPOWER IN NEPAL

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Dedication

I dedicate this work to my parents whose encouragement and support allowed me to achieve this success. Your blessings are the source of my strength, joy and inspiration.

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Abstract

Hydropower development is extremely important for the overall economic growth of Nepal. The changing national context, involvement of diverse stakeholders with conflicting interests and increased social as well as environmental awareness noticed remarkably in Nepal substantiate the multi criteria approach in hydropower decision making. Thus, selecting the “best project” from a set of options or comparing capacity categories like micro, small, medium, big and large hydropower, must be based on multiple criteria assessment. Hence, the development of a decision aid tool for hydropower assessment in Nepal, based on multiple criteria, is the main objective of this research.

The suitability of several tools assisting decision making is tested by the help of Nepalese case studies. In the first step an evidence based analytical study is executed followed by secondary data based application of Analytic Hierarchy Process (AHP), electronic survey data based AHP application and Preference Ranking Organization METHod for Enrichment of Evaluations (Visual PROMETHEE) application.

From evidence-based analytical analysis, the applications of AHP to secondary information and the electronic survey, national expert consultations (90) and observations of recent trends, a detailed list of 44 criteria could be identified together with their respective weights. This helped to compose a draft decision framework where criteria were grouped according to economic, social, environmental, and political goals. The consideration and reduction of uncertainties in the decision making process was formulated by a separate goal. To test the applicability and effectiveness of the decision framework, a sample of six Nepalese hydropower schemes was selected. Field data were collected and further processed through software based on a Visual PROMETHEE.

Visual PROMETHEE application proved successfully in comparing and ranking hydropower schemes. It was also helpful to delete null criteria (not influencing decision) elements from the long list of criteria to make decision framework more concise. The study showed that 29 criteria arranged in 5 goals are proficient to appraise, decide or rank hydropower plants in Nepal. Thus Visual PROMETHEE is effective in developing a hydropower decision aid (framework) which could be used for decision making, prioritizing and/or appraising hydropower options.

Although this research was executed for academic purposes, it could also be useful for all stakeholders, mainly decision makers involved in the hydropower sector. Because of the sample of hydropower schemes which includes only small scale schemes ranging between1-25 MW, the proposed framework needs further fine-tuning by repeating the research including a wide range of hydropower plants of various capacities and from various geographical regions.

Key words: Hydropower, prioritization, multi criteria decision framework, Perspective Analysis, Evidential reasoning, Analytical Hierarchy Process (AHP), Visual PROMETHEE, energy policy and strategy.

Zusammenfassung

Die Erschließung und Nutzung des Wasserkraftpotentials Nepals ist extrem wichtig für die wirtschaftliche Entwicklung des Landes. Der sich ändernde energiewirtschaftliche nationale Planungsrahmen, sowie die Einbeziehung von Stakeholdern mit unterschiedlichen Interessen und Präferenzen, die sowohl wirtschaftliche, soziale und ökologische Zielsetzungen beinhalten, erfordern eine multi-kriterielle Beurteilung von Wasserkraftprojekten. Die betrifft sowohl die vergleichende Beurteilung von Kraftwerken unterschiedlicher Leistung (micro, small, medium, big and large) als auch die Entwicklung einer EDV gestützten Entscheidungshilfe.

Die Eignung verschiedener Entscheidungsmethoden wird an Hand von nepalesischen Unterlagen und Fallstudien geprüft. Im ersten Schritt wird eine vergleichende Beurteilung unterschiedlicher Kraftwerksleistungen mit Hilfe eines Evidenz basierten analytischen Verfahrens durchgeführt. Im zweiten Schritt werden dann AHP (Analytical Hierarchy Process) und Visual Promethee (Preference Ranking Organisation Method for Enrichment of Evaluations) zur Evaluierung von bestehenden Kraftwerken angewandt.

Aufbauend auf der Auswertung von grauer Literatur (Projektberichte, energiepolitischer Strategien) mittels Evidenz basierter analytischer wurde ein detaillierter Fragebogen erstellt und von 90 nationalen Experten beantwortet. Daraus konnte eine Liste von 44 Kriterien und ihren Gewichten abgeleitet werden, die nach ökonomischen, sozialen, umweltbezogenen und politischen Zielsetzungen gruppiert wurden. Die Reduktion der Unsicherheit in der Beurteilung von Kraftwerken wurde als zusätzliche Zielsetzung formuliert. Dieser Beurteilungsrahmen wurde dann an Hand von sechs bereits durchgeführten Kleinwasserkraftwerksprojekten in Nepal getestet, wobei umfangreiche Felddaten gesammelt wurden.

Visual PROMETHEE bewährte sich im Vergleich und in der Reihung der Kraftwerksprojekte. Es unterstützte auch die Beurteilung der einzelnen Kriterien sowie ihre diskriminative Eignung. Die Analyse zeigte, dass 29 Kriterien ausreichten um eine Gruppierung der 5 Ziele vorzunehmen um eine Beurteilung, Entscheidung beziehungsweise eine Einstufung der Wasserkraftwerke in Nepal durchzuführen. Visual PROMETHEE wird als gut geeignet für die Entwicklung eines Beurteilungs- und Entscheidungsinstrumentes für Wasserkraftwerksprojekte angesehen.

Obwohl diese Arbeit auf einem akademischen Zugang beruht, wird das Instrumentarium als hilfreich für Stakeholders, insbesondere für Entscheidungsträger im Bereich der Wasserkraftentwicklung, angesehen. Da bisher nur Kleinanlagen im Bereich von 1- 25 MW analysiert wurden, ist ein Fine Tuning durch wiederholte Anwendung auf größere Anlagen und in unterschiedlichen Regionen nötig.

Schlüsselwörter: Wasserkraft, Reihungsverfahren, Multi-kriterieller Entscheidungsrahmen, Evidenz basierte Analyse, analytischer hierarchischer Prozess (AHP), Visual PROMETHEE, Energiestrategie

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Abbreviations

ADB	Asia Development Bank
AHP	Analytical Hierarchy Procedure
BPI	British Power International
CBA	Cost Benefit Analysis
CI	Consistency Index
cm	Centimetre
CR	Consistency Ratio
DFID	Department for International Development
DM	Decision Maker
DOED	Department of Electricity Development
EFD	Economics, Finance and Developers
EIA	Environmental Impact assessment
ELECTRE	ELimination and Choice Expressing Reality
ER	Evidential Reasoning
GAIA	Graphical Analysis for Interactive Aid
GOLF	Global Lake Outburst Flood
hp	hydropower
ICIMOD	International Center for Integrated Mountain Development
IEA	International Energy Agency
IHA	International Hydropower association
IIPP	International Independent Power Producers
IRR	Internal Rate of Return
JICA	Japan International Cooperation Agency
Km	kilometre
kW	kilowatt
kWh	kilowatt hour
m	metre
MAUT	Multi-Attribute Utility Theory
MCA	Multi Criteria Assessment
MCDA	Multi Criteria Decision Analysis
MCDM	Multi Criteria Decision Making
MVAT	Multi-Attribute Value Theory
MW	Megawatt
NEA	Nepal Electricity Authority
NGO	Non-Governmental Organization
NHA	Nepal Hydropower Association
NPC	National Planning Commission
NRB	Nepal Rastra Bank
Nrs	Nepali Rupees
NTFP	Non Timber Forest Product
PAF	Project Affected Families
PPA	Power Purchase agreement
PPP	Public Private Partnership
PROMETHEE	Preference Ranking Organization METHod for Enrichment of Evaluations
SIA	Social Impact Assessment
UNDP	United Nation Development Programme
UNEP	United Nation Environment Programme
US$	United State Dollar
VP	Visual PROMETHEE
WEC	World Energy Commission
WECS	Water and Energy Commission Secretariat
Wt	Weight

1 Introduction

Ensuring a sustainable and cost-effective energy supply is important for developing a country. With nearly 2.27% of the world's stock for about 0.35% of the world's population, Nepal is one of the richest countries in water resources (Dahal & Guru-Gharana 1993). Hence water resource utilization is a panacea for transforming the country's economy, and subsequently hydropower is on top of development agenda (Gyawali & Dixit 2001). The Government of Nepal has committed to energy sector development for poverty reduction and economic development through hydropower (WECS 2010b). As of today, Nepal is among the poorest economies in the world and has the lowest per capita energy consumption, human development index and industrialization (Birol 2010; UNIDO 2014; Sharma 2014). Nearly 80% of its energy requirements are met through traditional sources like biomass, which adversely affect the environment and soil fertility. Electricity only contributes 2% of the total energy need (WECS 2010a). Energy issues in the country could be addressed through developing hydropower resources. Self-sufficiency in energy and thus developing more hydropower is critical factor to achieve higher GDP growth, say targeting Nepali Rupees 2500 billion (US$ 23 billion) by 2030 in the country (Bhattarai 2015). Hence, an in-depth understanding of hydropower development is essential for identifying problems and providing solutions.

Hydropower in general is an excellent option for energy production because of its high energy payback (Gagnon 2005). However, hydropower is also characterized by being long term investment, with a high upfront cost, high risk, long gestation period and being full of social as well as environmental challenges (Everard & Kataria 2010; Ribeiro et al. 2011; Sudirman & Hardjomuljadi 2011). To fast-track hydropower development, schemes in Nepal are classified as micro hydropower up to 1 MW, small hydropower at 1 to 25 MW, medium hydropower at 25 to 100 MW, big hydropower at 100 to 1000 MW and large hydropower at above 1000 MW of capacity (WECS 2010a). In depth study of the hydropower sector is necessary to understand the potential role hydropower could play in national economy and energy security. Further, for the hydropower related decisions, rankings, appraisals and recommendations, it is necessary to view hydropower within a broader spectrum. This research is focused on methodological improvements and developing a decision aid for hydropower development in Nepal. Further detail on the objectives is discussed in Chapter 3.

This dissertation is organized into eight chapters grouped into three sections, as shown in Figure 1.

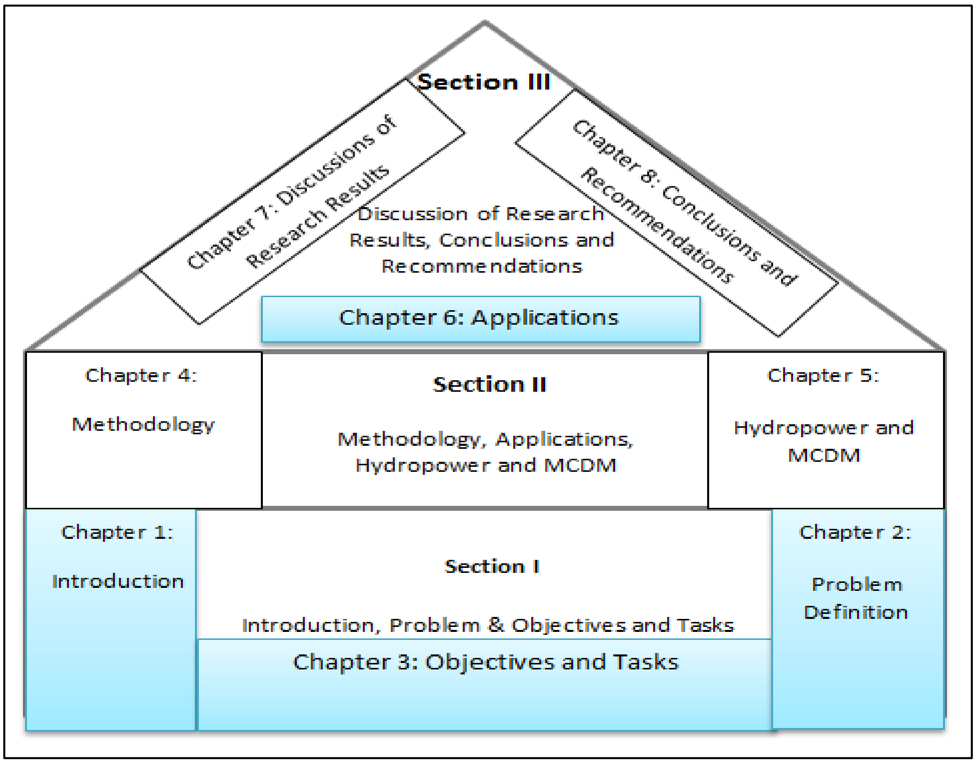


Figure 1: Organization of the thesis

The first section of the research consists of three chapters. Chapter 1 covers Nepal in general, water resources and hydropower decisions with the multi criteria decision making (MCDM) context in particular. Chapter 2 discusses problem definition of hydropower decision making and likewise Chapter 3 describes the objectives of the research in detail. It also discusses the scope (task) of the research work. The second section of the research focuses on the methodological part and also defines the study area to undertake case studies. These are presented through Chapters 4, 5and 6. Chapter 4 elaborates the requisites for hydropower analysis and details methodological aspects of different MCDM systems such as analytical analysis (evidential reasoning), Analytical Hierarchy Process (AHP) applications (based on secondary data and questionnaire surveys) and the Preference Ranking Organization METHod for Enrichment of Evaluations (PROMETHEE). Chapter 5 focuses on databases related to the research, ranging through country energy potential, supply and gaps and selected sites for field study. Similarly, Chapter 6 presents applications of the MCDM for analysing data and the questionnaire survey and comparing six hydropower schemes. This chapter also discusses the case studies from the field in more depth. The third section consists of Chapters 7 and 8 which present a discussion of the results in Chapter 7 and finally conclusions and recommendations in Chapter 8.

2 Problem definition

Nepal is endowed with vast water resources, only a fraction of which could meet the nation's energy need. However hydropower development in Nepal is facing various obstacles and the nation so far is unable to tap the existing potential. The main problems and needs related to hydropower development are presented briefly in this chapter.

2.1 Problems in hydropower development in Nepal

2.1.1 Slow development to address national energy need

Electricity demand is growing at an annual rate of more than 10% (WECS 2010a) and there is an ever-widening energy gap (1000 MW at present) between demand and supply (Thapa 2010). Unfortunately, the present hydropower growth trend (NEA 2009) is unlikely to meet such growing demand. The country is suffering from a huge energy gap, longer load shedding and heavy economic losses. This is the result of cumulative causes ranging from weak planning, poor visionary leadership to poor management, etc. (Shrestha 2010; Yang 2006). According to NEA (NEA 2013), the country was likely to face a deficit of 800 to 900 MW of capacity from 2012 to 2017 in dry season. As shown in Figure 2, the power supplied from various sources including imports from neighbouring countries is unable to meet even half of the power demanded. This issue is of paramount importance and must be addressed without delay.

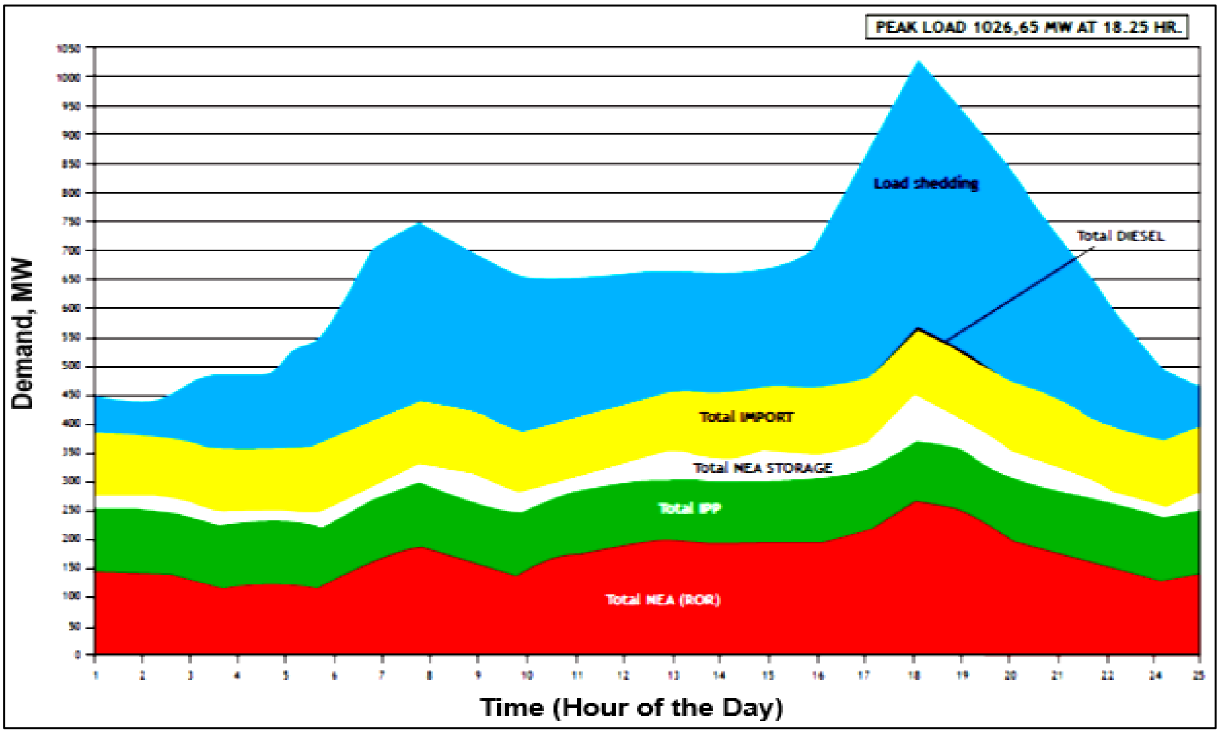


Figure 2: System load curve of peak load day (Friday 13 Jan 2012)

Source: NEA. 2012, Physical year 2011/12 – A year in Review

The hydropower development history in Nepal dates back to 1911 but the sector is growing extremely slowly. The time series of important hydropower implementation during the last century is presented in Figure 3. Since the adoption of an economic liberalization process in 1990, the private sector has been engaged in hydropower development. Private sector participation so far has been unable to contribute much and needs appropriate adjustment in existing policy. According to the Nepal Hydropower Association report (NHA 2009), over 10 years (2002 to 2012) the private sector could put only 64 MW of power into the national grid despite holding hundreds of licences.

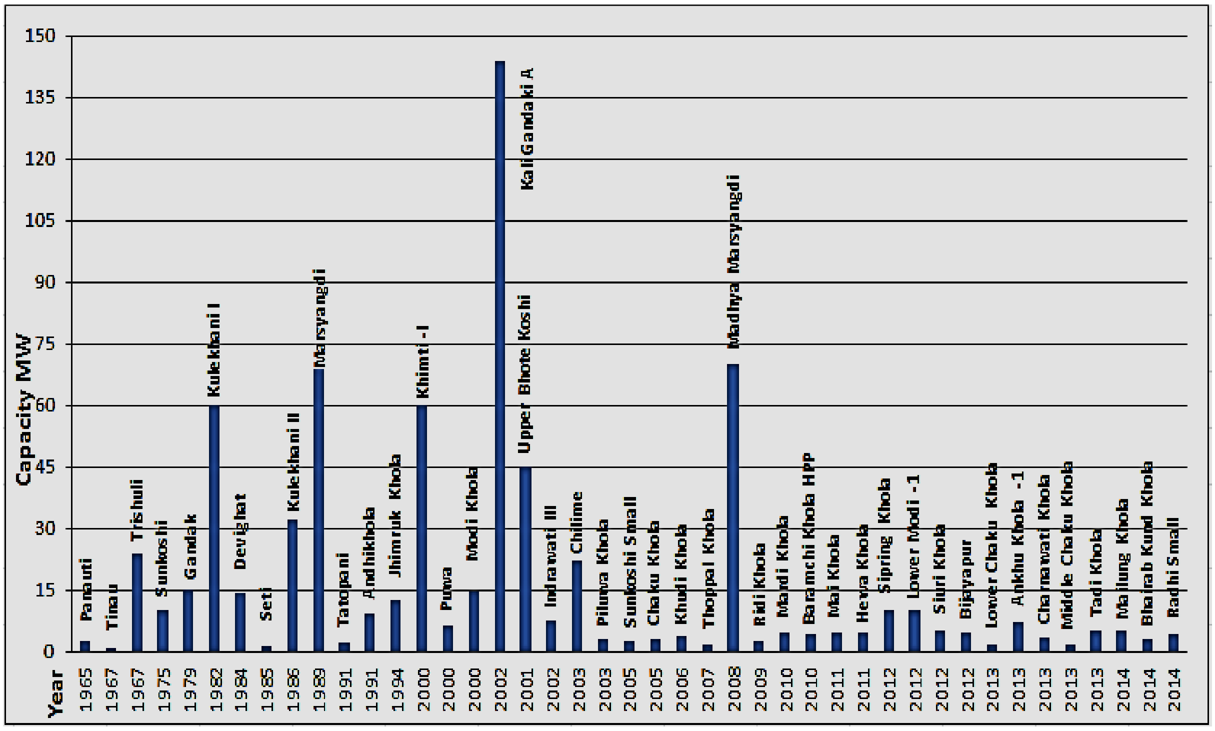


Figure 3: Timeline of construction of major hydropower projects

Source: Sharma & Awal (2013)

Since1990, thousands of micro schemes have been developed all over the country (Riti Aptech 2004; Gurung et al. 2011), mostly below 100 kW capacity, their cumulative power contribution to the national energy demand still remains very small. Numbers of small schemes are increasing as per the department of electricity generation web (http://www.doed.gov.np/) updates. With regard to medium scale, only few schemes have been implemented but many such plants are under construction or planning. So far the country has completed only one big scheme, Kaligandaki (144 MW) and few are under construction. Large schemes have not been implemented yet but serious discussions are on-going for their development. Hence, looking into the track record of hydropower development over the century, the pace of its development has been very slow.

2.1.2 Lack of coherent strategy and poor coordination

Due to lack of required capacity and fluidity in policy (Nepal & Jamasb 2012; Dixit 2008) the hydropower sector is unable to achieve the required progress. Some adequate policy adjustment like that adopted in neighbouring countries would attract many industries and enterprises to invest and benefit from the hydropower sector (Sharma et al. 2013). Such a policy would make substantive progress in the sector. Unfortunately strong policies attracting private investors are still not effectively implied in the Nepalese context. So far policies in the country have been weak to meet the ambitious delivery targets set by the government during different periodic plans (Pradhan 2010). This can be seen in Figure 4, where the target set against each periodic planned development by the government and its actual achievements are plotted.

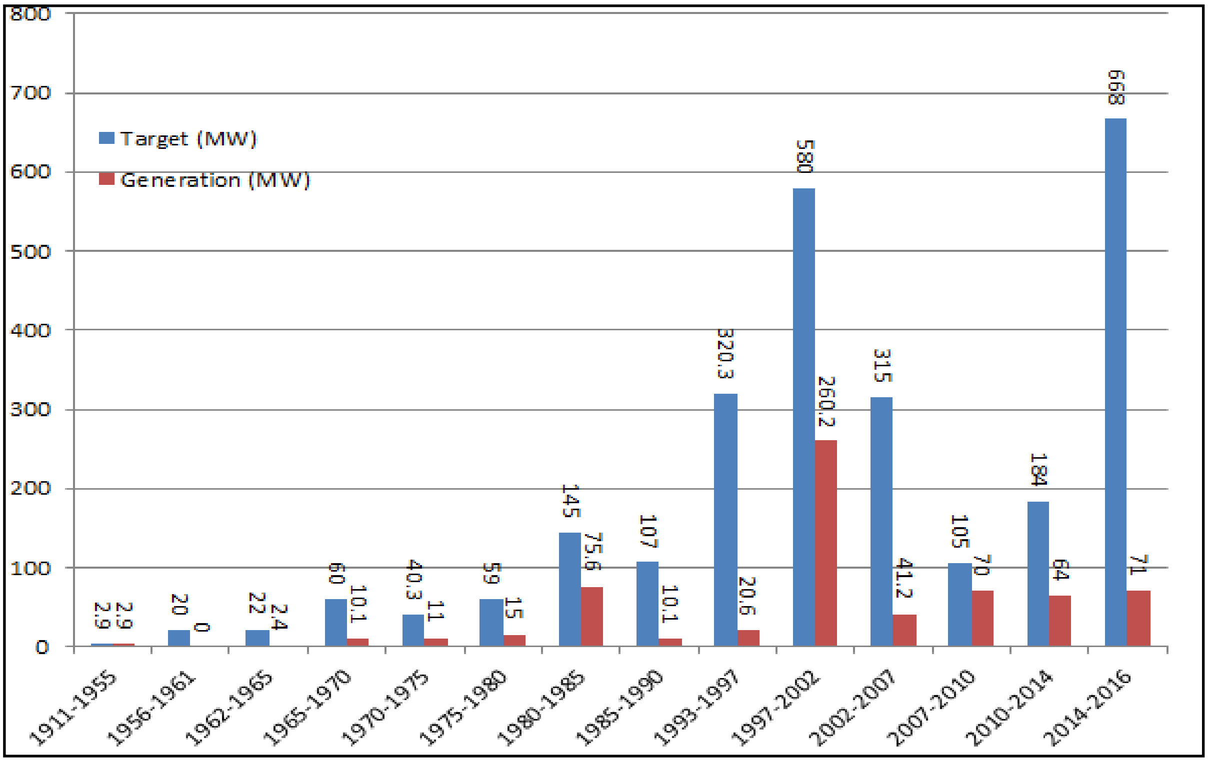


Figure 4: Planned and actual hydropower development in Nepal

Source: Author compiled data from various plan documents from the National Planning Commission and reports from the Ministry of Energy, Govt. of Nepal

In general, hydropower policy in a country lays emphasis on basin wise development, harnesses available potential, geological and other risk mitigation plans, improves resettlement or rehabilitation, simplifies the procedure for transfer of clearance, encourages joint ventures and private investments, creates a standard framework for tariff fixation and facilitates the financial viability of hydropower development. Many or almost all activities mentioned in the Nepalese context need attention to manage the smooth growth of the hydropower sector (Shrestha 2014).

The country is politically very unstable and the government changes almost every year. With a new government in power, hydropower-related targets and strategies are modified according to their political vision and interest. A recent example is electricity crisis mitigation plan targeting 10,000 MW in 10 years, which was re-targeted to 25,000 MW in 20 years and keeps on changing with changing governments. Without serious planning and requisites in place, such targets had never been achieved, as discussed earlier. The lack of a sound policy (K.C. et al. 2011) and strategy is distracting investors (BPI 2009). So far there are almost no framework or robust detailed research reports enabling the best schemes to be identified. A strong policy with a detailed framework is important specifically when dealing with outside investment, agreements or treaties on a large scale and multipurpose schemes. Many project proposals in the past like those at Arun, Karnali and West Seti could not progress because of a lack of clarity in the policy and decision framework.

Different studies have prioritized hydropower schemes according to specific interests (WEC 2001; UNDP 2011). Reviewing the hydropower development policy of 2001 and 1992 which classified hydropower schemes in three categories namely (a) micro (b) small and medium and (c) large, all policies or strategies supported micro schemes for rural energy access; small and medium schemes for the urban and rural Terai region; and big or large schemes for export. Later, the hydropower development strategies of 2009 and 2010 redefined hydropower into five classes based on installed generation capacity and their development was targeted from public, private and international developers. The latest strategy (WECS 2010b) identifies large as well as big hydropower projects for energy export; big, medium and small schemes for urban as well as industrial supply; and small and micro-scale plants for rural energy access. Such recommendations are based on targeted end users. Unfortunately, no one is discussing in detail, specifically based on multiple criteria, how to identify the best scheme among the set of alternatives. In addition, each scheme or each category of hydropower schemes has its own importance but it is important to understand which category among the five fits the national interest best. Coordination among ministries and with various non/governmental institutions is another challenge for hydropower development. Overlapping or lack of clarity on their roles and responsibilities causes severe delays in hydropower development right from conception to commissioning. Investors or developers have seriously raised such issues on several occasions, but so far the government is unable to overcome them effectively. As a consequence, in spite of the private sector entering the hydropower sector from the early 1990s, they only put 64 MW of power into the national grid over 10 years (2002 to 2012). Similarly, in spite of strong interest from the private sector, which holds hundreds of licences, as shown in Figure 5 (comparison of status in years 2009 and 2012), it is unable to implement them. One primary reason is the lack of required capacity and fluidity in policy. Frequent changes in licensing procedures and royalties raise questions on trust and policy stability. Similarly the differences in power purchasing agreement (PPA) among developers is very much a subjective decision, even though a standardized procedure exists. Due to such a personalized decision on such an important aspect, every developer is trying different means to achieve the highest PPA with the national electricity authority (NEA), a public institution, raising the financial burden on consumers. In the absence of procedural clarity and a strong decision framework, hydropower policy and regulatory aspects seems vulnerable due to the vested interest of funding agencies or developers (Dixit & Gyawali 2010; Pandey 2003). Eliminating a monopoly by creating competition among developers (mainly private sector) to achieve efficient and cost-effective hydropower in Nepal is not realized because of weak policies and regulatory mechanisms. Some studies on hydropower plants constructed after 2000 have also found that the average cost of construction is US$ 1725 per kW and, interestingly those developed by private or independent power producers are costlier (Lako et al. 2003). Any change in policy or regulation, specifically ignoring past efforts and investment could be counterproductive. For instance, documentation and reports prepared earlier could save investments and time for the new licences for the same site (BPI 2009; Pandey 2012).

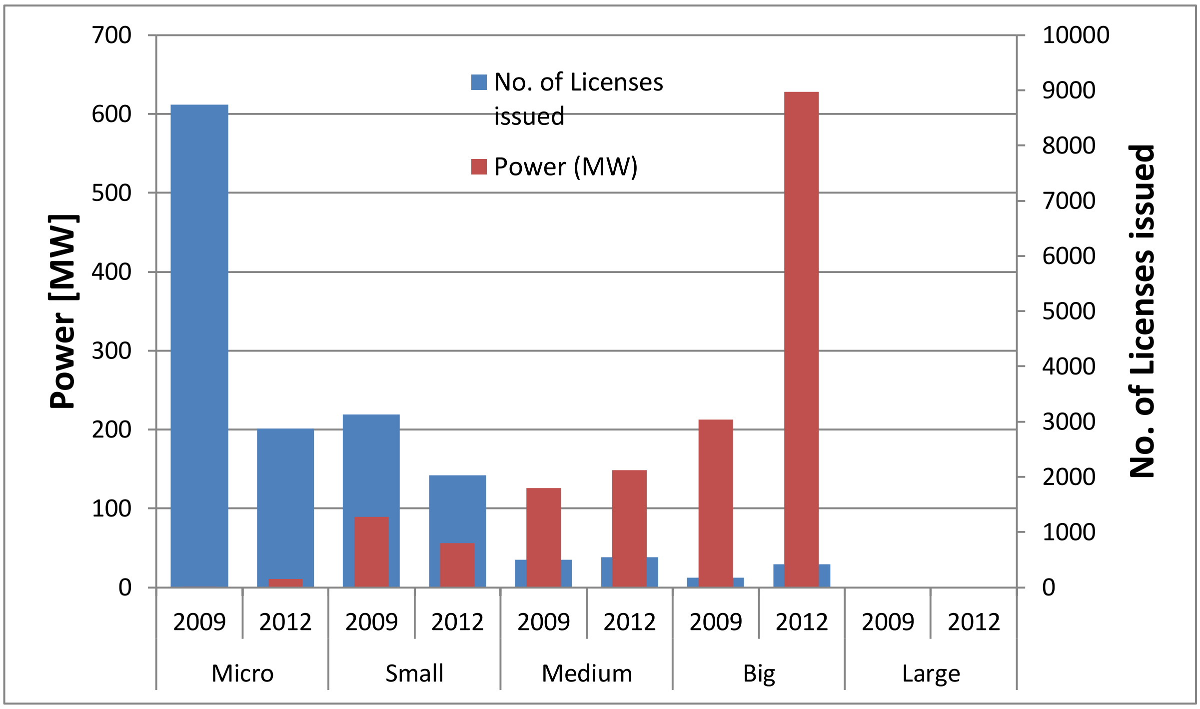


Figure 5: Comparing licence numbers and generation capacity

Source: NHA (2009) and DOED website (retrieved on July 2014)

Figure 5 compares the status of different scales of generation in 2009 with 2012. Here the number of licences is in blue while cumulative power generated is in red. The many licence holders for micro schemes found earlier is reducing in number and increasing towards small schemes. Investors for large schemes are missing while medium and big scheme licence holders are present in the country.

The government has based hydropower development on targeted users (not on installed generation capacity), later classified by installed generation capacity. With changing classifications, the country opted for policies and strategies accordingly. Such frequent changes does not favour the investor, as hydropower investment is a long-term venture.

Principally all schemes are important to address certain needs in the country and for development. However when one considers funding constraints, limited experience, immediate need and associated risks then it is important to review the sector in such a way as to prioritize such schemes, Based on a prioritization exercise, the country could formulate the required strategies in order to maximize the national benefit. In Nepal there is lack of clarity on project evaluation and a framework for project selection or prioritizing.

2.1.3 Adverse impacts (economy, social domain and environment)

In hydropower development, economic factors like cost benefit have dominated whereas social and environmental concerns have been ignored or minimized in Nepal. Several adverse impacts are important to consider but are mostly under-mentioned.

Economic benefits from a project are one of the most important aspects. Detailed accounts of direct and indirect benefits are important to assess the economic viability of the project. Every plant with its specific location, scale of generation, implementation modality and funding mechanism should be reviewed for its respective economics. In the Nepalese context, possible over-exaggeration to justify a project was very commonly followed in many instances by the projects in reality never being able to generate the estimated benefit, and this could be one reason why the hydropower sector has not developed so far.

Generally project economy focus is on investment aspects, i.e. on the investor point of view, whereas the natural resources (river, land, forest, etc.) which belong to the local community are mostly ignored or undervalued for the possible equity share of the community in the project. However, the community has to bear all the adverse impact of such projects in their daily life. This could lead to social issues and could become more serious when local resources are used for benefit transfer in the national interest (Gunawardena 2010), ignoring the local community's needs (Shah 2008), which provokes disputes resulting in disturbances in hydropower development by the local communities. Similarly for resettlement (Fast & Hansson 2013), the government is only able to provide limited consultations and this issue must get more attention. Further lack of public participation in decision making in planning, implementing, running and owning appropriate responsibility in hydropower development raises concerns and transparency issues (Forbes 1999). This could lead to poor project selection and thus even project rejection or public revolt. National news and media quite often report that preparation and even implementation of several such projects have been frequently disturbed or even stopped, for example, Arun III, West Seti, Upper Karnali, etc.(Koirala 2017).

The construction and operation of hydropower dams (storage type) or weirs (run-of-river type) could have significant and often irreversible, effects on many rivers, riverine ecosystems and communities. Hydropower dams may transform landscapes and create risks of irreversible impacts. Option assessment and decision making around river development prioritizes the avoidance of impacts, followed by the minimization and mitigation of harm to the health and integrity of the river system. Avoiding impacts through good site selection and project design should be a priority. The environmental consequences of a dam, as shown in Figure 6, need attention, and appropriate mitigation of which often leads to conflicting objectives with the project economy (Vučijak et al. 2013).

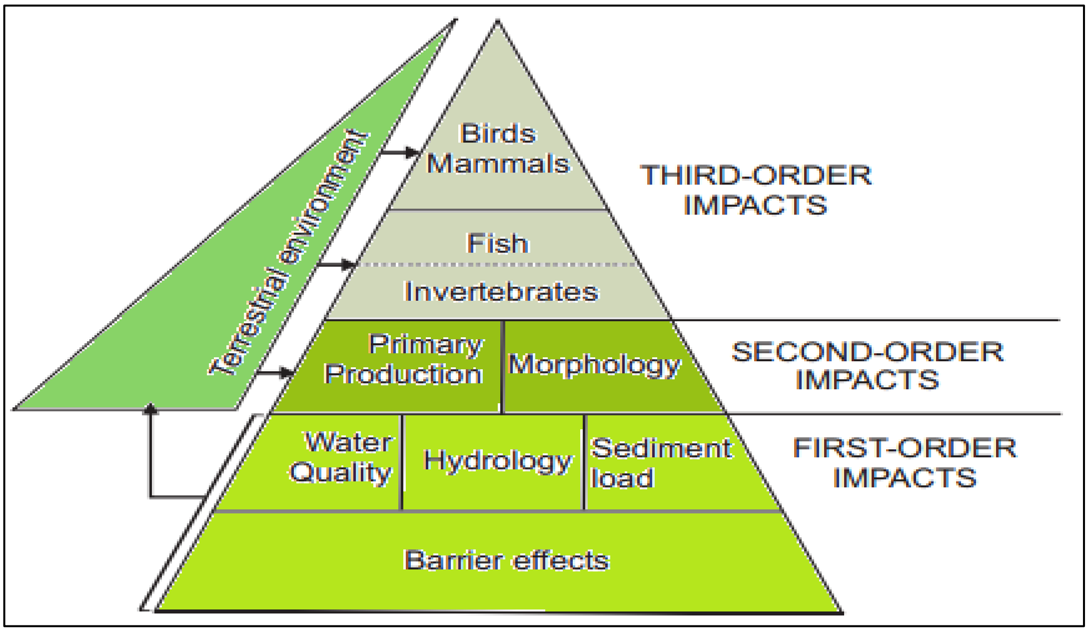


Figure 6: Framework for assessing the impacts of dams on river ecosystems

Source: Petersson (2007)

A hydropower plant may impact upstream, around the site and downstream. For example, water storage upstream could reduce the surrounding fertility (LRMP 1986) and increase the risk of flooding with glacier melt or heavy precipitation (Dent 1984; Adhikari 2013). Around the project site the sediment deposited can adversely affect the life and economy of plants (Thapa 2004; Thapa et al. 2005; Poudel et al. 2012) and water-borne diseases in the vicinity (Pradhan 2012). Similarly, downstream (also upstream) may lose biodiversity (Sharma et al. 2007; Jha et al. 2007; Sigdel et al. 2013) and river connectivity (Ledec & Quintero 2003). In the broader area, a hydropower plant could impact the livelihood of the population and soil productivity due to the high water level upstream or scarcity of water downstream (MDC 1999). Hydropower could also give an adverse environmental impact due to the effect of climate change on water resources (Sharma 2012; WECS 2011) and snow coverage (ICIMOD 2011; Shrestha & Aryal 2011). All of these factors are important in a hydropower analysis framework and many of them need inclusion in the Nepalese context.

2.1.4 Donor domination and dependency

Donors have played an important role both with funding and knowledge support for hydropower development in Nepal from the very beginning. The country is heavily dependent on such donors and their domination in project decisions as per their interest makes the country suffer further. The adverse impact of dependency can be understood through the recent fact that development partners have shifted their priority (Sovacool et al. 2011) from infrastructure to social services. The donors' priority shift from funding earlier available for infrastructure such as hydropower being diverted to other social activities slowed down the hydropower sector's growth from what it would have achieved if infrastructure remained their priority. Country preparedness and capability to benefit from project negotiations, minimizing unwanted interference and withstanding uncertainties is extremely important. A few examples of poor preparation and suffering are the Arun III cancellation due to an unfair agreement proposed by the World Bank(Thut et al. 2011), a poor power purchase agreement (PPA) on Bhotekoshi and Khimti with international independent power producers (IIPP) (Arya 2005), and a heavily criticised agreement on Koshi, Gandaki and Mahakali with neighbouring India and also Karnali Chisapani (Shrestha & Paudyal 1994).

Hydropower development needs huge investment and technical capacity, which is not adequately available within the country. Infrastructure like bridges, roads and the power grid are underdeveloped in the country. Hence huge infrastructural investment in addition to the funds is required for land acquisition, resettlement of people and environmental mitigation which requires external support. In a situation where private investment and entrepreneurship in the country is at a very low level (ADB 2009), dependency on donors or external parties increases. It may barricade the country from the full potential benefits of hydropower because of ill compromises, negotiations and agreements. A huge fund invested in the hydropower sector (billions of US dollar) in terms of loans, grants and development aid in the last 30 years(Ghimire 2012), but still the sector is heavily indebted, poorly performing and people are paying one of the costliest tariffs in the world (Xinhua 2014). High-budget, glamorous, aid-funded projects, which in fact are costlier (Pandey 2003) than smaller, locally financed projects, remain attractive to policy- and decision makers. The mode of financing may have a much stronger impact on a project than the volume of funding and hence must be worked out in detail for better negotiation. In-country available financial resources at the present time could meet the significant funding required for hydropower provided an appropriate financing model is put in place.

2.1.5 Weak decision practices

One serious aspect of decision practices is a top-down approach which completely dominates or even ignores the bottom-up decision approach in Nepal. Very little attention is paid to public participation and the inclusion of their opinion in decision making. Such forced practice in hydropower decisions causes mistrust and could disrupt the development.

A serious concern in hydropower development decisions is vested preferences of donors, politicians or influential interest groups creating controversies and conflicts in the country (Thut et al. 2011; Permananet secretariat of the Alpine convention 2011). The result is not only a low level of utilization of resources but also unsustainable sector development. Hydroelectricity is sometime treated as a commodity for export and financial revenue, but this ignores the value of regulated water from the proposed reservoirs. If hydropower plants are assessed based on their economic benefits alone, ignoring many other associated benefits and advantages, the country may not make best use of its resources. Instead of ad hoc or fragmented decision making, consensus-based acceptable solutions are important. So far, globally, limited research and publications elaborating such decision making in the hydropower sector are available but work on scheme selection is missing in the Nepalese context. In reality, hydropower appraisals and assessments following a fragmented approach to technical feasibility, economic and financial analysis, social impact analysis, environmental impact analysis, etc., are in practice. It is necessary to put all of them together into a detailed decision framework to evaluate them with due weightage. Globally, currently the project planning paradigm has shifted from earlier techno-economic to socio-environmental concerns (UNEP 2007; IHA 2014; Edenhofer et al. 2012). Further hydropower must be viewed in multidimensional ways, including irrigation, water supply, navigation, tourism, etc. (Rees et al. 2006; Ledec & Quintero 2003). For instance, hydropower integrated with irrigation could not only provide water for farming but will enhance the overall economy of the project (World Commission on Dams 2000). Worldwide project selection based on multiple criteria is gaining popularity (Foran 2010).

2.2 What is needed

As discussed regarding the problems related to hydropower development in Nepal, there are several issues which need attention vis-a-vis more plants being implemented as soon as possible to meet the energy demand. They must be developed in the most cost-effective ways, should satisfy social needs, must comply with environmental standards and the political framework, and should avoid risk and uncertainties.

Hydroelectricity planning should value the regulated water from proposed reservoirs for its multiple benefits. The business approach, interaction and social factors are unable to ensure smooth communication and need more awareness and capacity building (Sovacool et al. 2011). The country should benefit from globally practised projects / programme selections based on multi criteria decision methods (Bergner 2013; Dixit et al. 2004). The hydropower sector must be viewed in multidimensional ways and analysed with scientific tools for appraising and/or prioritizing hydropower. Although screening of projects is performed focusing on certain aspects (criteria) (MoWR 2003), several others are still either ignored or undervalued. To include diverse stakeholder interests and to fast-track hydropower development, it is important to develop a broader framework, including possible decisive (influencing) criteria in decision making.

3 Objectives and tasks

3.1 Objective of the study

As explained in the problem definition and needs in the previous chapter, the overall objective in the research is to recommend methodological improvements and to form a decision aid for the evaluation of hydropower schemes in Nepal to develop.

To achieve the main objective, a few tasks relating identification of criteria (criteria is defined as a principle or standard by which something may be judged or decided) and their weight, stakeholders and a suitable MCDM are important. These tasks are detailed in the following section.

The research verifies whether in a country like Nepal, instead of ad hoc or piecemeal, fragmented approaches to hydropower decision making, a multi criteria decision making approach is applicable. Furthermore, this research examines the effectiveness of MCDM tools in developing a decision aid for hydropower and its applicability in the field.

3.2 Tasks

One begins with identifying the relevant stakeholders in the hydropower sector in the country. The next important task of the assessment requisites is identifying and listing all possible decision criteria with their importance (weightage) for drafting a decision framework. Another important task is to identify suitable MCDMs applicable in hydropower analysis, for which we may test more than one MCDM. The final task is to verify the decision aid in the field and fine-tune it for the country context. In the following sections, the tasks are further explained.

3.2.1 Stakeholder identification

A stake holder is any individual, group, agency or organization affected by a project and/or with concern or interest in a development project and its outcomes, or having common resources impacted by a development project. Stakeholder engagement is critical for the success of hydropower development in terms of sustainability and efficiency (Mirumachi & Torriti 2012; Watkin et al. 2012). It is very necessary to identify all stakeholders likely to influence or be impacted by decisions on the hydropower development and engage them from the early stages to participate on a voluntary basis in the dialogue. A stakeholder should be treated as a ‘Partner in Development’ and not as an opponent of the project. Strengthening partnerships and mobilizing resources remain essential to achieve effective hydropower development. Therefore the sustainable development and operation of hydropower should rely on “shared vision, shared resource, shared responsibilities, shared rights & risks, shared costs & benefits” principles (BRANCHE 2015). It is important that groups need to see there is a reason for them to engage, i.e. that they can influence decisions and outcomes that would be better than if they had not participated. It is crucial to understand early in the process the stakeholder interests and the power relations between these stakeholders.

Most of them may not know or understand the perspective of the other stakeholders involved. Perspectives are a particular attitude towards or way of seeing things, for example, hydropower in this case. It is therefore important to raise awareness among them. Leadership within the community and across stakeholders is the key for success. Different viewpoints generate alternative priorities and highlight different challenges among stakeholders (BRANCHE 2015).

Among the most preferred stakeholders are the project developers/proponents and those who are most directly affected by a project, specifically those at the greatest risk who feel the impacts most intensely and could benefit the most from opportunities. The poor, landless, vulnerable and marginalized people are among these stakeholders, and it is they who are often the most difficult to get involved. Since local people will be stakeholders over most of the life of a project, their involvement and participation from the beginning is crucial to project success. The clearer the approach of public engagement and the more meaningful their involvement, the smoother and more sustainable and less conflicted the outcome will be. In every category of stakeholder engagement, gender must be considered; both women and men should be represented in activities. Prospective stakeholders include some or all of those listed below.

- Project owner, funding agencies and developers
- Affected local individuals, communities or households
- Professional experts, environmentalists, sociologists, economists
- Government agencies and their representatives at various levels (centre, district, local), from concerned ministries and departments
- Elected officials of concerned regions, municipalities, or constituencies
- Political party representatives and local parliamentarians
- Concerned business people and entrepreneurs
- Concerned Non-Governmental Organizations (NGOs), Community Based organizations (CBOs) and user groups
- Local influential people, such as informal or traditional community heads, school teachers, healers, social and religious leaders, and other notable women and men
- Health workers; social workers and marginal group workers (such associations or organizations dedicated to the upliftment of the poor, the landless, women, children and other vulnerable groups).

3.2.2 Appropriate scale of hydropower schemes in Nepal

Every category of hydropower generation scheme (see Section 2.1.2) is important and contributes to the national energy need. However it is important to review them against the immediate energy need, funding constraints, technical capacity, potential multiple benefits, etc. A very strong debate prevails on the scale issue among stakeholder in Nepal around identifying the best category hydropower generation schemes for present. While some people highlight micro- and mini-scale plants due to their contribution to energy access (Rajauriya 2012; Rijal 1999; Zahnd & Kimber 2009), others mention large schemes because of economies of scale, industrialization and revenue from the energy trade (Taylor 2008). Similarly, many of them recommend small hydro schemes because of in-country availability of expertise and readiness for execution, but many others favour medium scale as it is attractive in terms of both economies of scale and existing experience within the country. There are few people, specifically from the government bureaucracy who recommend for big schemes because of the nation's dire need for energy. Hence, with reliable information, one could review each hydropower category within a matrix of associated perspectives. Preparing such a matrix consisting of several perspectives for five hydropower scheme categories would ultimately provide us with an in-depth understanding of hydropower development in Nepal. With regard to the scale issue, a proper and balanced hydropower assessment with reliable and broader data within a multi criteria framework is necessary. Hence ranking or prioritizing those five categories of hp schemes in Nepal is important and could be seen as complementary objective of this research.

3.2.3 Development of a broader hydropower assessment procedure

Hydropower may have impacts around the project site and also could reach up to national or international (cross boarder) level. It is important to review the hydropower sector at broader way. While some interest groups benefit from hydropower projects, others may lose or be adversely impacted. Thus it is important to identify all possible stakeholders to include their voices in the broader scope of hydropower analysis. Hydropower projects can impact directly and visibly but sometimes indirectly (not visibly) as well. Hence one has to establish a mechanism or scale of measurement for impacts and also a procedure to convert all of them to a common measurement. Such a broader assessment of hydropower needs to identify all possible criteria with their importance or degree of influence. Hydropower-related information is linked with objectives, goals and measurable criteria. An objective is a specific result that is aimed to be achieved within a time frame and with available resources. They serve as the basis for creating policy, opting for strategies and evaluating performance. Similarly, goals are the main attributers through which objectives can be achieved. Goals are the results or achievements towards which effort is directed. Goals are further achieved through one or several attributers (inherent part of goal) to it and these are termed criteria or even further down sub-criteria. These criteria and sub-criteria are the starting point for evaluating the goals and objectives set in a project or plan. Economic, social and environmental goals are the most pertinent. However, one should also pay attention on the existing policy and practice in the country while reviewing hydropower. In addition country preparedness or existing policy and technical aspects of hydropower development must be included while analysing hydropower, along with all kinds of uncertainties associated with hydropower development. Goals may consist of respective sub-goals and finally measurable criteria (factors) along with their weightage (importance) for project evaluation. All this information needs to be organized together to review hydropower sector scenarios in the country and should be used for evaluation of options, ranking alternatives or working out a decision framework.

Hence at the end, a complete set of goals and criteria (contributing to respective goals) with respective weights could be organized in a matrix form. Such an evaluation matrix (a table showing relationships between two or more variables in a dataset in a grid format) could be filled with corresponding information available from all hydropower projects to be assessed. This is very useful for hydropower prioritization, as explained in the next section.

3.2.4 MCDM identification for hydropower application

Based on the data available and the type of problem one can select and verify the applicability of a tool in the particular context. Further depending upon either single or group decision making, a MCDM method and corresponding tool could be chosen. There is a need to identify an appropriate scientifically proven tool from the global practice. In this research, more than one MCDM based tool will be applied for different stages. Cross-verification of the applicability of the same MCDM for other kinds of analysis relevant to hydropower will be carried out. In addition, another MCDM method applicable to carry out a similar analysis done earlier will test the reliability of the results. This means that a type of MCDM tool applied for decision making could be test verified with another type of MCDM tool. Application of such tools to cross-verify the results could be very useful (Hämäläinen et al. 2001).

One important application of MCDM tool in this research is for the prioritizing or comparing of hydropower schemes based on data matrix obtained from the earlier analytical (evidence based) analysis. Doing so, we can test the applicability and effectiveness of MCDM in hydropower analysis. It is important to note that all these analyses are based on an evidence-based approach through secondary information sources and also expert consultations on weightage allocation to the different goals and criteria used in analysis. Furthermore, these findings can be cross-verified with an electronic (questionnaire) survey, which is another important task. In the survey, several hydropower stakeholders are consulted to collect their opinions. Respondents may be from different categories of stakeholders but should be in almost equal numbers from each category to avoid bias. Hence their response can be treated as a collective response to simplify the research analysis and avoid group wise analysis. Hence this task will lead to deliver multiple perspective views and respective positions (priorities) of scale wise hydropower schemes. Further processing will deliver scores for the alternatives to rank them. The challenge that remains is to develop a MCDM-based broader decision aid (framework). This task is further explained in the following section.

3.2.5 Developing a decision aid for sustainable hydropower development

From the earlier stage of tasks (Sections 3.2.1 to 3.2.3) all important stakeholders will be identified, all important decision criteria will be listed with their comparative importance (weight) and a probable applicable and effective MCDM will be identified (refer 3.2.4). With the help of all these important findings, a detailed draft decision framework will be developed. It is not absolute that more and more criteria are helpful to hydropower decision making (Adhikary et al. 2014). However it will be useful to begin with a detailed draft decision framework before testing its field applicability and fine-tuning. Here we develop, test and fine-tune the draft decision framework and recommend a final version of a hydropower decision framework for assessing hydropower plant development and decision making in Nepal.

To accomplish all these task so far discussed, a study plan was organized in the proper order, which is discussed in the following section.

3.3 Study plan and layout of the work

The following three tasks (stages), as shown in Figure 7, have to be executed to achieve the overall objective of elaborating an MCDM framework for the evaluation of hydropower schemes in Nepal. There are three different study blocks shown: (i) Analytical analysis of hydropower, (ii) MCDM tool applications based on secondary information and questionnaire survey on hydropower; and (iii) MCDM application for case studies. Each study includes respective activities and delivers a definite output. In sequence, the output of an earlier stage of the study is the input for the next stage. Finally a hydropower decision framework is obtained at the end as an output which is the main objective of the research.

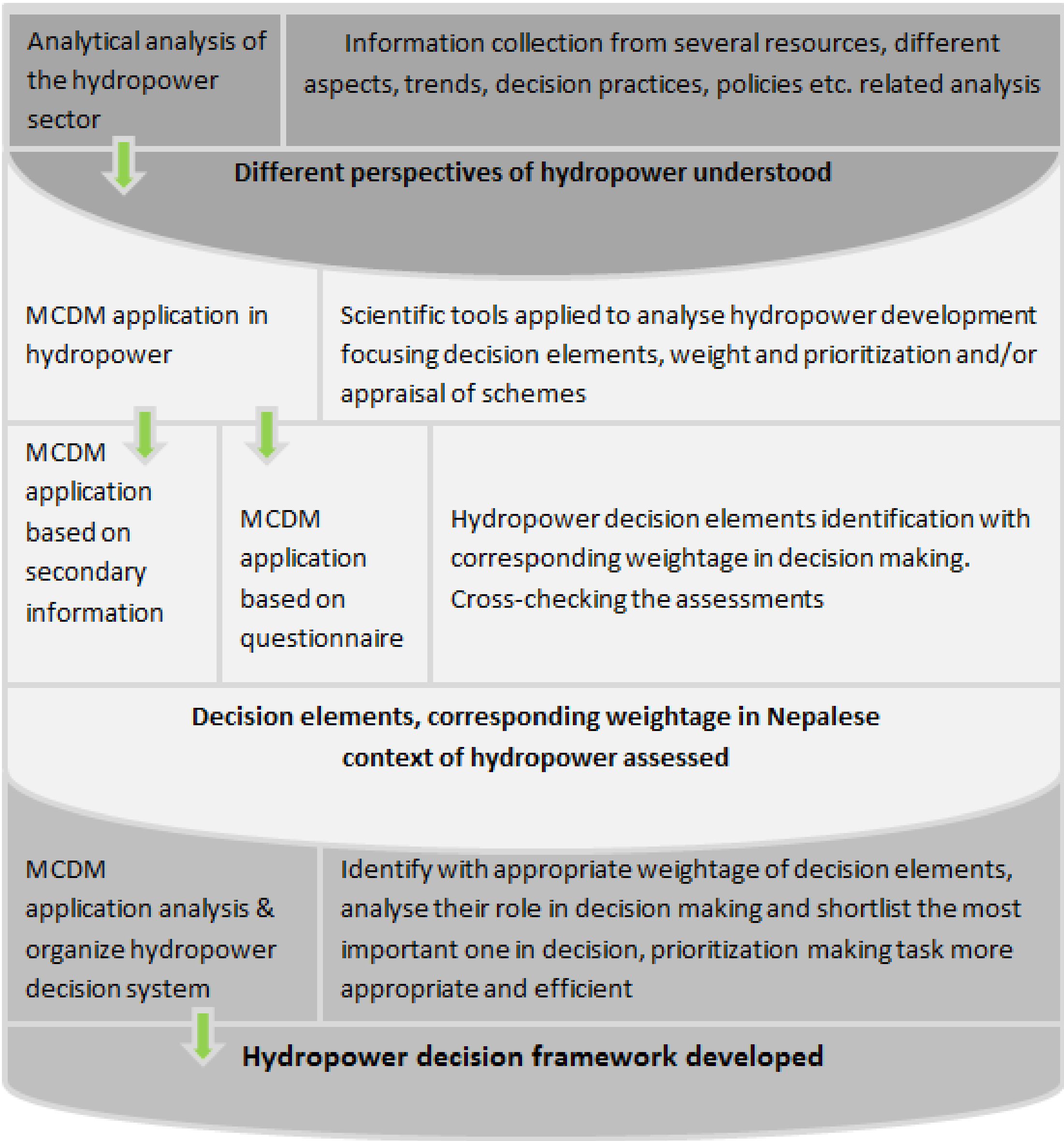


Figure 7: Schematic representation of study plan in present research

3.4 Scope of study

This research is based on two categories, evidence-based analytical analysis and MCDM applications. Both are presented with the corresponding questions to be answered as follows:

Analytical analysis

What was the hydropower sector like in the past, at present and will be likely in the near future?

What has caused hydropower development in Nepal to lag far behind the world average?

What other best practices in hydropower development could also benefit Nepal?

How decisions are made in Nepal in comparison to international hydropower projects?

MCDM applications

What, who and how much does it influences and affect hydropower decision making?

Can we identify the best alternative from a broader set of alternatives?

- MCDM applications based on secondary information:
    - Shall we test applicability of MCDM with available (secondary) information?
- MCDM applications based on questionnaire survey:
    - Are we following all the required criteria with their weightage in an appropriate way to make decisions?
- MCDM with visual aids
    - How do we develop an appropriate decision framework?
    - Which visual tool could assist in-depth comparison and analysis of alternatives?
    - Is the tool effective for handling many alternatives with a large number of decisive criteria?

The required major activities to complete the research are:

- Collect and organize by perspective detailed secondary information on hydropower development in Nepal
- Identify criteria and their influence (weightage) on hydropower decisions
- Establish a priority basis i.e. the expected direction (maximize or minimize) of decision criteria for ranking alternatives in hand
- Organize goals and criteria in the form of a decision framework
- Select and apply a decision tools for hydropower decision making in the Nepalese context (based on secondary information, questionnaire survey)
- Draft a decision framework and test its applicability in the field
- Consult national experts to cross-verify doubtful information and discuss the findings
- Recommend a final decision framework applicable for hydropower assessment or ranking of alternatives in Nepal

Here, following steps as described in earlier section 3.2, a draft decision framework will be developed. Finally such a draft tool has to be subjected to a field test and requires further refinement to obtain an efficient decision aid tool for hydropower decision making in Nepal.

One major source of data for research on hydropower decision making refers to published relevant documents. Information is collected from several sources such as government organizations and ministries dealing with energy, water resources, forests, etc.; professional organizations including engineering, geology, the environment etc.; power producers and similar others. Published scientific papers and reports are also used for this research. Information and data used in this analysis is from the past 10 years and the majority were sourced from Nepal. The expert consultation and questionnaire survey involved those stakeholders related to the hydropower sector of Nepal. Stakeholders contacted were from various groups including sociologists, economists, engineers, communities, beneficiaries and interest group representatives, planners, politicians, financiers and developers.

Finally the field visits involve project sites selected from different places in the country. These site visits survey people including beneficiaries of the projects, entrepreneurs in the region, developers of the project, public representatives and experts dealing with hydropower.

The present study scope area could represent the entire country in terms of the participation of respondents and data collection and analysis conducted. However for the final part of the research study while conducting field testing of the decision aid framework sample sites, the scope area of the study was confined to those sites (see Section 5.3).

4 Methodology

This chapter deals and describes about goals, criteria, data collections and research methodology applied. Let us start with detail methodology followed in this research first.

A complete methodology of the research was developed, as presented in Figure 8. As shown in mid-left in green colour is the comprehensive research design applied which consists of stepwise research organized (showed in blocks) from problem conception to developing the final decision framework. While the first block refers to problem conceptualization lead to perspective analysis and so on. Each research blocks consist its corresponding objectives, goals, workflow, etc. (also refer fig 1). These are further explained in the following sections.

a. Problem conceptualization

This is the initial stage of collecting relevant information about hydropower development in Nepal, the current status and related issues, planned or on-going activities and others. It is important to understand the respective views of different stakeholders such as experts, politicians, government planners and bureaucrats and civil society representatives in connection with hydropower in the country. Several discussions with professionals and academicians helped to understand the relevant problems for this research and helped to set the overall objective of the research. At this stage of study, researcher conceptualized the milestones, developed the research strategy, and developed the study plan and methodology to accomplish the research successfully.

b. Perspective analysis

Multi perspective (explained later in 5.2.3.1) analysis is analytic in nature (hence frequently referred in this research as analytic analysis) and also based on documentation and evidences (hence sometime referred as evidential reasoning). In-depth review of several perspectives of hydropower sector is extremely important to understand and analyse the sector. In this study secondary information, as the only information source at the national and regional level, was gathered from reliable sources and publications. A complete set of perspectives with corresponding weightage organized in one place would be reader friendly to understand hydropower development. A set of alternative hydropower plants could be analytically evaluated (based on evidential reasoning, refer 5.2.3.1) and assigned a score against each perspective. The score obtained for each alternative against each perspective further processed with the assigned weight against the perspectives would obtain final score of the alternative hydropower plants. This score could help to prioritize the alternatives and also provide detailed insights about the perspectives. This would certainly be useful to evaluate which perspectives are more important and could influence if changes occur in coming days, especially with the rapidly changing national context (Mainali & Silveira 2011) like enhanced social and environmental awareness, strengthened economy and built infrastructure, enhanced human capacity, etc.

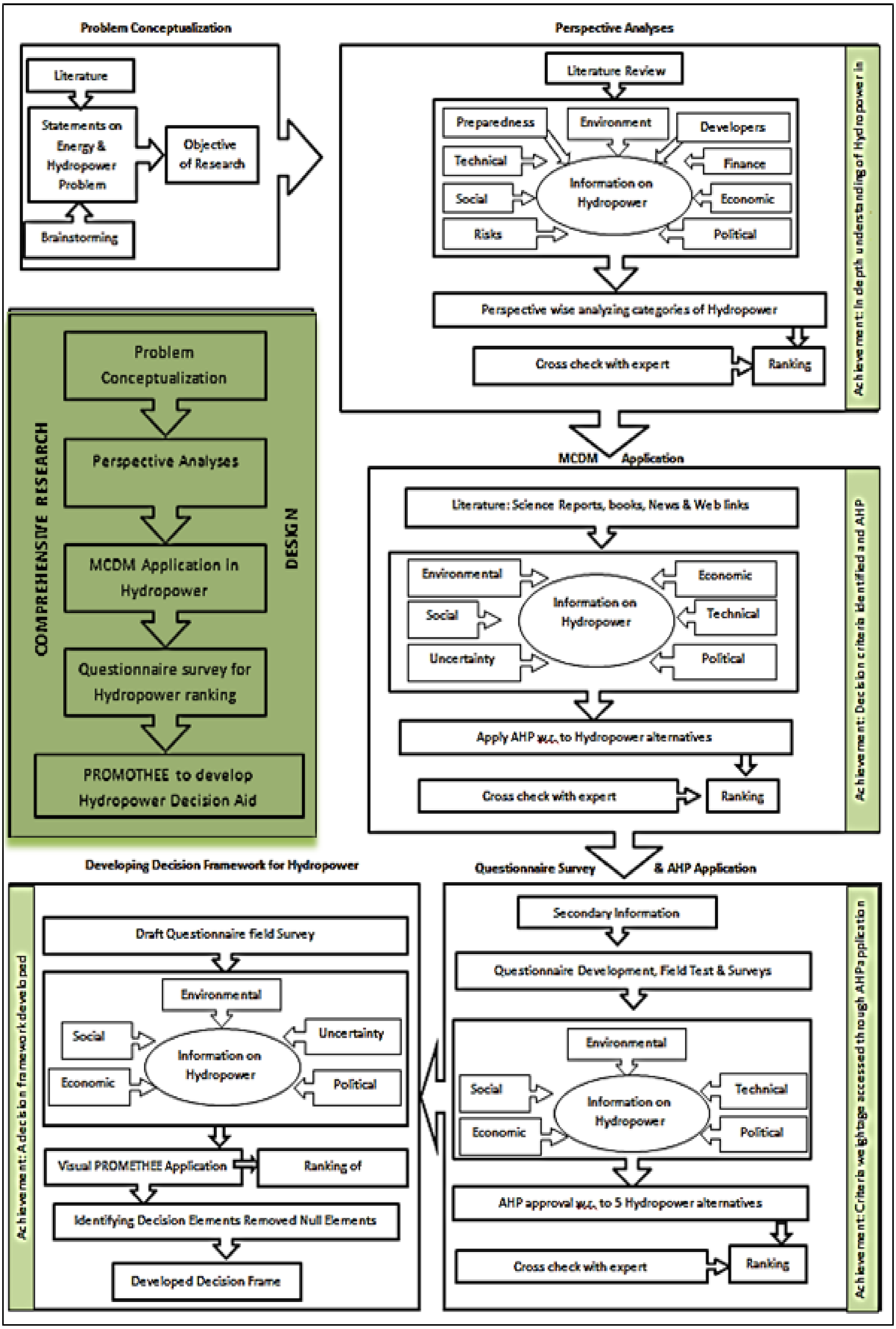


Figure 8: Details of the research methodology applied

The perspectives considered are technical, social, economic, environmental, political, financing, developers and manufacturers, country preparedness and associated risk. The alternatives considered are five different scales of hydropower generation classified in the country. A perspective analysis is applied using a suitable MCDM tool called Evidential reasoning, see Section 5.2.3.1), for scheme prioritizing (e.g. on the appropriate scale of power schemes in Nepal). The decision maker (researcher) applied a scale of 1 to 5 when evaluating each perspective against the alternatives: 5 for highest and correspondence to excellent positioning of that alternative with the corresponding perspective, 4 for good, 3 for moderate, 2 for acceptable and 1 for lowest. Thus the researcher completes the matrix and also assigns weight of criteria in consultation with experts involved in hydropower from Nepal. Finally the alternatives' scores are summarized and ranking of the alternatives is obtained.

c. MCDM application in hydropower

Data collected previously for analytical analysis are organized and used for testing the applicability of MCDMs and tools in hydropower analysis. This stage of study is an application of MCDM based on secondary sourced data of different time periods; the conclusions drawn take consideration of a good number of relevant stakeholders. Here hydropower sector secondary data obtained is synthesized (re-arranging those obtained from earlier perspectives analysis) within six headings (as goals): economic, social, environmental, technical, political and uncertainty (risk mitigation). The weight assigned to criteria from earlier studies is further verified and fine-tuned in consultation with experts. The researcher as a decision maker first familiarizes themselves with both the subject and the applied MCDM. This approach becomes even more important in a country like Nepal where most often partial or fragmented information is available. In addition, biased opinion is shared by different groups if consulted. In contrast, secondary data sources can be checked from all possible and relevant sources and cross-checked to minimize bias. In this study secondary information is processed through an MCMD.

d. Questionnaire survey and MCDM (AHP) application

Every criterion or sub-criterion in hydropower analysis may have a different weightage assigned. So far the weightage used at different stages of this research needs more verification. The decision must include all decision elements with due weightage. Here the opinion of stakeholders is collected through questionnaire survey (electronic). Further detail on this survey discussed in section 6.1.3

Questionnaire preparation is (i) mainly to assess the weightage of goals and criteria and (ii) also cross-check the applicability and trustworthiness of MCDM tools through cross-checking the ranking results obtained through earlier studies (analytical analysis and secondary information-based MCDM application). The goals, criteria and sub-criteria listed from earlier studies and expert consultations are further reorganized, following further expert consultations, under economic, social, environmental, technical and political goals. All survey responses received are tabulated into an Excel file for further processing through an appropriate MCDM tool.

The weight determination of criteria and sub-criteria is important and is based on the responses received from the survey. These weights depend upon individual perception and could differ significantly. The final weight either decided by the decision maker or averaged if groups of stakeholders involved are necessary. There are several methods to obtain weightage from stakeholders, namely weighted sum average, geometrical mean, etc. Corresponding to major criteria, received responses are synthesized for pairwise comparisons which can determine their weight (Gulmans 2013; Russo & Camanho 2015) using the geometrical mean average method (Adamcsek 2008; Mei et al. 1989). Also for sub-criteria, the collected data help to make the comparison and thus determine their weight. These data synthesized thus will be ready for further use in the AHP Expert Choice software.

e. Developing decision framework for hydropower and field test

In this step of the research, based on earlier identified criteria and assigned weight in hydropower analysis, a broader decision framework is drafted. Then a MCDM is applied to test the performance of the framework while applying case studies over a set of hydropower projects from the field. Thus the proposed multi criterion decision frame usability and capability is verified for the following:

- Evaluating several alternatives often in conflicting criteria.
- Identifying the best possible decision.
- Ranking possible decisions from best to worst.
- Comparing any set of alternatives with a specific set of criteria.
- Visualizing and identifying problems or difficulties in making good decisions.
- Making consensus decisions among several decision makers.
- Justifying or invalidating decisions based on set objectives.
- Sensitivity analysis

The very first framework is drafted based on lessons learned from various earlier stages of the research such as the evidence-based analytical analysis, MCDM applied to secondary data and MCDM applied to the questionnaire survey. Goals and criteria for the decision aid are obtained from various reviewed literature and documents such as those specific to decision making (CISMHE 2009; Goldemberg 1996; Khadka et al. 2011; JICA 2013; UNEP 2007; Catrinu 2006; Ertay et al. 2013; McCartney 2007; Nachtnebel et al. 1994), socio-political aspects (Rai 2007), sediments (Sangraula 2003; Bajracharya et al. 2011), geomantic and natural hazards (Shrestha et al. 2010), environmental and EIA guidelines (Uprety 2005; King et al. 2007; Mirchi et al. 2010), SIA guidelines (Adhikari 2011) and sustainability (Mathema et al. 2013; Kumar & Katoch 2014; Mainali & Silveira 2015; Zimny et al. 2013). At the beginning, all possible criteria are listed and reorganized under different goals in the form of a draft decision framework. A sample of alternative hydropower sites (six) chosen to cross-check the applicability of this framework and verify the nominated criteria applicability in terms of data availability, data influence and applicability. Hence decision framework performance will be tested for decision making, overall appraisal of a project, comparison of alternatives, ranking of the alternatives and / or in-depth review of the hydropower sector.

Sensitivity test of the framework thus developed is next important to perform. The assigned weight of a criterion when changed slightly may influence the ranking order of alternatives. In order to investigate whether all of these listed criteria should be evaluated to complete ranking exercise or the list could be made shorter, further analysis on the criteria sensitivity analysis is required. Some of the criteria may make a small or no contribution to the alternative ranking. In this sense they do not have discriminatory power in comparing alternatives and such criteria can be eliminated from the list to make framework concise.

For further research to continue, it is necessary understand about the requisites and assessment procedure in hydropower analysis which is explained as follows.

4.1 Requisites and assessment procedure in hydropower analysis

Hydropower by nature is closely related to several resources like forests, soil and water and also with several developmental activities. Hydropower-specific features include a broad range of impacts (environmental, social, economic), long lifetime, costly investment and renewable nature. Thus we need long term projections to assess the benefits and impacts. The very first requirement is to discuss the procedure for impact assessment.

Once a proposed hydropower project has passed preliminary technical and economic feasibility tests and attracts interest from government or funding agencies, the momentum behind the project often prevails over further assessments. Hydropower impacts, which are spread among several aspects, physical, biological, social, cultural, etc., are complex to measure. First, they could be tangible as well as intangible and hard to measure on a specific scale. Furthermore, they impact differently on different stakeholders and are perceived differently by them. Whatever complexity or challenge may be associated with such impact measurement, it is important to have standard assessments to evaluate hydropower plants. Regarding the impact domain several types of assessments (Smit & Spaling 1995) are followed, such as social impact assessment, environmental impact assessment, biodiversity impact assessment, cumulative impact assessment, etc. Several national institutions or ministries in a country might have developed required guidelines and procedural details for assessing impacts. Such national standards and guidelines provide minimum levels which have to be achieved (Jusi 2011) for a project to be approved or evaluate alternatives for comparing and ranking. There are also international agencies such as the United Nations Environment Programme (UNEP), Department of International Development (DFID), United Nations Development Programme (UNDP), International Hydropower Association (IHA), etc., who have developed such assessment guides.

As explained earlier, one has to assess different types of information. Information that is physical in nature can be assessed and measured but the complexity increases if it belongs to the biological domain and even more complex if it involves the social and cultural domains. Further involvement of human beings in assessment poses additional subjectivity to this work which may result in differing assessments. Hence it is important to assess them in an appropriate way which demands standard procedures.

There can be many procedures to measure impacts (Solomon et al. 1997) depending upon the objectives and assessed accordingly, for example by cost benefit analysis (CBA), social impact assessment (SIA), environmental impact assessment (EIA) or other evaluations. Particular guidelines for impact assessments in isolation such as those for economic, social or environmental issues may assess the impacts separately one at a time. Such an approach compartmentalizes the project into separate units and leads easily to oversimplified representation of the actual net impacts (Keskinen et al. 2012; Lamberts & Koponen 2008). Furthermore, following all of them separately and individually could make the legal context applicable to hydropower development very complex and difficult for practical application. Hence it is necessary to develop and include everything together from different guidelines, mentioned above, into a single framework for the complete impact assessment and evaluation of hydropower plants. This demands an impact assessment procedure which is much detailed than the individual guidelines and is followed strictly step by step. In general, an impact assessment procedure should be able to collect reliable information, finally convertible to common measurement and stated strategic direction (maximizing or minimizing) applicable to the goals and corresponding criteria. In this regard such assessment needs to follow certain steps:

1. Identification of the project to be assessed and scoping of area and period to be assessed
2. Identification of domains of impacts
3. Listing of the criteria / items of impacts under different domains
4. Identification of stakeholders involved
5. Development of checklist of criteria and data collection format as shown in Appendix 1
6. Detailed guidelines for data collection along with possible information sources or stakeholders as detailed in Appendix 2
7. Establishment of measurement scales, standards and strategic direction
8. Collection of data, processing for final assessment and sensitivity analysis
9. Identification of procedure to combine different impacts

Here one important requisite is selection of MCDMs tool, In general as defined by the International Society on Multiple Criteria Decision Making, MCDM is “The study of methods and procedures by which multiple and conflicting criteria can be incorporated into the decision process”(Zardari et al. 2015). Later in subsequent Chapter 5.2 multi criteria decision making (MCDM) is discussed, first in general and then specific MCDM techniques applied in this research in detail. In principle, the following will be used for selecting an MCDM technique:

- Capacity to handle many discrete alternatives with multi criteria
- Capable to use both quantitative and qualitative criteria
- Applicable for both single and as multiple decision makers (DM)
- Interactive and transparent with visual display of results

The next most important to focus is impact domains which further will be followed with goals and criteria to elaborate. Hence the possible domains of hydropower impacts are discussed in the following section.

4.2 Impact domains of hydropower

Hydropower impacts arise at all stages of the project cycle, starting from conceptualization to commissioning and even to post decommissioning. The hydropower impacts are scale-dependent (in space and time) and could reach living (human, plants, animals) or non-living (physical) entities. Details on hydropower impacts domain identification is the first requisite in the present research. Depending on whether hp plants are meant only for energy production or is affiliated with additional (multi) benefits like flood control, irrigation, navigation etc., the impact domains enlarge both in space and time. Hydropower delivers energy as an output which further links with the national developmental agenda and several domains of impacts as explained here.

4.2.1 Economic

Economic benefit is possible from hydropower development provided it is developed properly, otherwise it could impact the country in an adverse way (Dixit & Basnet 2005). Economic benefit depends upon the investment capability of the country (Shrestha 2007), financing modality (Pandey 2003), project implementation and ownership modality (Bhattarai 2006), treaty and agreement with developers (Dixit et al. 2004), country implementation and handling capability of such projects (Thut et al. 2011). Well-thought-out and planned development of hydropower could contribute significantly to strengthening the national economy, as seen in many countries such as Norway, Austria, etc. but failing to doing so may trap the nation's economy in a difficult situation, as seen in case of Laos, Ghana and Prague (Gyawali & Dixit 2001). The energy generated from such projects is input for many other developmental agendas including industrial development. Hence it has a strong correlation with national productivity, gross development product, manufacturing value addition and the overall national economy (UNIDO 2014).

4.2.2 Social

Social impact domain is closely linked with several aspects of people's lives, for example different jobs created, local resources value addition, production, household facilities, education and many similar others. With availability and sufficiency of energy, a nation can achieve energy security. This is important for people's daily energy needs for activities ranging from the household level to mobility and transportation. Safety, security and services are linked in several ways with hydropower development in the country. Here with regard to social impacts from hydropower, it is expected to maximize net (overall) social benefits at all levels. Hydropower providing social benefits and its contribution to the local communities in particular is most important and relates to upgrade the living conditions of communities at the local and regional level. In fact, hydropower as a natural resource associates both with benefits (energy availability, better living conditions, etc.) as well as threats (displacement, loss of livelihoods, etc.) (Messerschmidt 2008; Mathur 2008). Analysis is required specifically at the community level about the benefits of natural resources they possess, their distribution and also possible threats they are exposed to. Hence like in all other infra-structure projects, government interventions are important to account for the social benefits and their distribution to achieve proper social adoption of the developmental efforts (Jones & Boyd 2011).

4.2.3 Environmental

Hydropower developments in the past disregarded environmental aspects, ignoring the adverse impact caused by obstructions to the natural river flow and the physical structures developed. Hydropower is linked to water resources where one should be careful about any adverse impact because of the strong nexus among water, food and energy. Hydropower in general has broad impacts. Worldwide hydropower and dam construction has caused environmental damage due to poor assessments, vested interests, lack of knowledge, lack of enforcement of mitigation measures, lack of sufficient resources, lack of on-going monitoring or ignorance of ecosystem functions. A hydropower dam firstly changes the abiotic environment and then the biotic (Petersson 2007). Environmental concerns are at the top of the agenda for hydropower and are closely related to the location as well as the type of plant (Bhatta & Khanal 2010). Generally such concerns increase with the size of plants (Kaunda et al. 2012). Hydropower is closely linked with environmental impacts and the possible consequences of project implementation are important to understand. Environmental impacts of hydropower could range from the site (primary), for example disruption in rivers' natural flow, to neighbouring regions (secondary) for example loss of forest in a distant region to (tertiary), covering water quality and quantity. The environmental impact from hydropower is expected to result in a net positive contribution, however usually it does not. Hence hydropower impact domain is important to review.

4.3 Objectives and goals

The research objective is already explained in Chapter 3 which could be achieved through many measurable goals. Hydropower development sole objective may aiming for excellence which could be realized with many relevant and integrated goals. Goal is an observable and measurable end result to be achieved within a more or less fixed timeframe. For example, if we want the best hydropower plan from set of number of options, the hp plan with highest cumulative performing scores with economics, social, environmental and other similar goals will be selected.

Here the goals explained are many and few of them could be combined together depending upon the researcher preferences. At different level of research, starting from long list of perspectives to final decision framework developed, such goals are arranged and rearranged as per need and suggestions of experts.

The impact domain research helps to set up the hydropower development goals. These development goals are mainly reviewed through economic, social and environmental goals but there could be additional developmental goals to realize the overall objectives which solely depend upon the country context and the nature of the projects considered. Along with economic, social and environmental goals as commonly considered goals while analysing hydropower, a few additional goals are also considered by researchers: technical (World Commission on Dams 2000; Bhattarai 1997; BRANCHE 2015; Terrados et al. 2010), political (Bhattarai 1997; Bergner 2013; Terrados et al. 2010; Thompson 2008) and uncertainty or risk (Bhattarai & Fujiwara 1997; Frederick et al. 1997; Cunha & Ferreira 2014). In this regard, for hydropower development in Nepal, due to the country's circumstances, it is important to consider a few additional goals related to technical, political, uncertainty or risk issues. In the following section, more details about those developmental goals are discussed with regard to hydropower development in the Nepalese context.

4.3.1 Economic impact domain and development goal

One of the important convincing factors that most hydropower project proponents use is economic benefit and its contribution to the nation in general and local communities in particular. Thus, hydropower development is justified on the grounds of its potential ability to increase the wealth of the country, and the economic goal is one of the important to consider and analyse in every hydropower development. The economic goal largely relates to the allocation of scarce resources, principally land, labour and capital, among competing uses. This economic goal seeks generally to create the most monetary wealth possible, within the constraints of the resources available. Hydropower produces electrical energy which is a fundamental building block of modern market economies. Electricity provides light, thermal comfort and the ability to power consumer and commercial goods that modern economies rely on. But all choices come with trade-offs. Economists tend to talk about trade-offs in terms of costs and benefits. Assessing the costs and benefits of different development options can help decision makers to choose between various alternatives. The challenge for stakeholders in the country is to understand the economic implications of the various options that might play out, along with the other domains of impact and implications. Critical to this is a good understanding at a project level, since macro-economic implications are the result of the cumulative impacts of the many projects and activities in an economy. One important goal of hydropower development in a country could be maximizing economic impact at all levels (national, regional and local) which in fact is an economic goal associated with hydropower. Hence details of contributors to the economic goals need to be identified and evaluated properly. Those are the criteria used to measure overall economic goals and dealt separately section 4.4.1 in this report.

4.3.2 Social impact domain and development goal

Hydropower by nature is developed in one location but distributed over a wide range of users. Because of the different stakeholders involved in hydropower system and their diverse interests, social goal assessment involves several criteria (mainly ordinal) and could be one of the most complex goals to measure in MCDM. Hence identifying the possible list of criteria applicable is very important. Furthermore, the allocation of importance (expressed by weights) to them is another challenge. Details of the criteria are presented separately in Section 4.4.2.

4.3.3 Environmental impact domain and development goal

While developing infrastructure in a country, environmental goals are important at least to protect nature from further deterioration, if not improve it. Important environmental goals related issues such as sediment, water flow and the local ecosystem must be studied in relation to hydropower implementation and appropriate mitigation measures much be planned (Everard & Kataria 2010). Though it is difficult to mitigate all ecosystem impacts and ecosystem responses as most of them are rarely fully predictable, it is expected with minimal environmental damage and environmental conservation and upgrading to the extent possible. Hence defining environmental goal and listing related criteria is very important. In Nepal, all hydropower projects, whether small or big, have to obtain environmental clearance where a detailed account of information is collected and presented. This task is carried out in isolation and hence misses a combined approach to evaluate proposals along with other aspects (goals and criteria) simultaneously. Hence in the present study, under the environmental goal all possible applicable criteria are listed and used in a decision framework with due weightage for all criteria applied. In Section 4.4.3, further environmental criteria are discussed.

Unlike the social, environmental or economic impacts created by hydropower, there could be situation where hydropower development itself get impacted. Hence those domains are also important to consider when making hydropower decisions. Such important linking of domains relates to technical, policy and uncertainty aspects of hydropower and need to be considered in the decision framework. These are described next.

4.3.4 Technical domain and development goal

In addition, the hydropower sector being very technical in nature, this impact domain is closely related with technical issues related to both equipment and accessory production as well as maintaining the hydropower plant's healthy operations. Here the country's existing technical experience and available trained workforce plays a major role in the success of projects and hence should be considered as a separate impact domain when analysing hydropower development. Regarding the technical impacts of hydropower, the country wants to maximize capacity to maintain the hydropower sector's growth.

Hydropower from concept to post commissioning and maintaining operations for its entire lifecycle is very technical in nature. Hence the heavily embedded feature of technicality in hydropower development requires establishing technical capability as one of the major goals to achieve in project development, specifically for a country like Nepal, which has poor technical capability and huge hydro potential to explore. Several further criteria relating to accessing technical capability need to be considered under technical goals. The technical goals could be measured using criteria such as technological experience, track record, development trends, capability building with regard to hydropower. These are further discussed in a separately (refer section4.4.4).

Several hydropower decision making tools include technical goals whereas in some cases this goal is not mentioned separately but its measurable criteria are placed under other goals such as those within economic, social and environmental fields. In some cases even the technical goal is not considered in terms of the fact that decision analysis takes place once a project is found to be technically feasible. In the Nepalese context we should consider it as one of the important goals to assess because the country's technical knowledge, project exposure and experiences, availability of accessories and equipment, handling capacity and ability to tackle technical negotiations with investors are major challenges.

4.3.5 Political (policy) and development goal

Another domain of impacts could be political or policy related (Adhikary et al. 2015; Stein 2013; Beccali et al. 2003) which may have a positive or negative impact on hydropower development depending upon the existing hydropower policy framework in the country. This impact domain could benefit from more project implementation and experience to strengthen country policy and strategies to further benefit from projects to implement. Especially in Nepal, the national energy policy and energy strategy is vulnerable to political instability, and the vested interests of donors, developers and investors. These may have strong and lasting adverse impacts on project success. Hence this needs special attention and should be treated as an important impact domain of hydropower. It is the aim to see hydropower projects matching and maximizing policy conduciveness while developing.

All these domains of impact are further linked with multiple facets of hydropower development if it is developed with multiple objectives. These multi objectives of hydropower could include navigation, tourism, irrigation, flood control, water supply, etc. As mentioned earlier, these domains of impact range from the directly visible to indirectly invisible, from close to the site to wide ranging, from tangible to intangible. A broader understanding and evaluation of all impacts is complex but necessary to consider for hydropower development.

The country's political opinion and existing rules and regulations are another important goal to achieve sustainable hydropower development. Political will and a framework on hydropower development is of paramount importance. Without such will, all efforts will be useless even though they could perform excellently on all other fronts such as economic, social or environmental areas. Political acceptability of any hydropower project by the nation is extremely important (Knowles 2014) to achieve in order to initiate and complete a project to benefit the country as well as the community. The importance of such political goals is high in the Nepalese context because hydropower schemes have a long physical lifetime compared to other power systems, and huge investment is required. A long-term perspective on demand development and a stable energy pricing environment are obligatory to ensure return flows appropriately. A long-term energy strategy is also necessary for energy planning, especially in the case of high investment costs in the hydropower sector. Nepal is a poor economy and has very limited funding capacity for developing hydropower. Expected investment from the private sector or foreign investors requires a stable government and a clear policy for hydropower business in the country. In the absence of political commitments, strong policy and stable government, it is difficult to develop hydropower in a country at the desired level. Political commitment is needed for increased engagement with all stakeholders to improve their understanding of diverse issues and impacts and adequate interactions among stakeholders. Well-defined regulation governed through institutionalized organs in close cooperation is important. This will provide an enabling environment for result-oriented stakeholder engagement, and strive to include the inputs of engagement processes towards improved decision making. Hence in the

Nepalese context this aspect as a goal needs to be considered in the decision framework for assessing hydropower alternatives. Several criteria are assessed to evaluate this goal, such as the country's energy plan, preparedness, independence, regional power balances, etc., which is further briefed on later (refer section 4.4.5).

As likewise explained for the technical goal, in many instances a hydropower decision framework has to assume that the project fits into the existing policy framework of the country and hence does not use policy as a separate goal. However in Nepalese context, it should be treated as a separate goal when working on hydropower decision making.

4.3.6 Uncertainty and risk reduction goal

All infrastructure projects and commercial undertakings involve several kinds of uncertainty which may pose issues of risk and irreversibility (Mosadeghi et al. 2012; Ansar et al. 2014). Project risk assessment generally takes into account (Panthi 2007; Zhang et al. 2005; Pathak 2011) technical, economic, ecological, social and financial aspects (World Commission on Dams 2000). Lack of sufficient and reliable data, unpredictable future development in the country, limited criteria applied and other issues may result in uncertainty. Hence every goal mentioned so far is exposed to uncertainty and introduces risk of various types: physical, technical, social, environmental and financial. Here risk is among the impacts with respect to hydropower in Nepal. Because of the broader level of impacts caused by several uncertainties hydropower is prone to, earthquakes, flooding and lake outbursts, landslides, financial paucity or disturbances to on-going project implementations might cause adverse impacts on project success (Mardani et al. 2015). Hence in the context of hydropower specific to poor economies in the world, uncertainties or risk should be given adequate importance (Bonissone 2008) and must be treated as one of the goals or major criteria while planning hydropower activities. For uncertainty reduction or risk mitigation in the hydropower sector, the goal is to maximize the capability to withstand any kind of associated risk with hydropower development.

Robustness is a measure of capacity to remain unaffected by small but deliberate variation in the method parameters and provides an indication of a system reliability during normal usage. It is important concept and could be treated as a criteria for project selection which could be applied as part of risk and uncertainty or treated separately (Frederick et al. 1997). One of the goal of hydropower development is to protect the environment from any kind of loss, vulnerability or threat. Heavy upfront investment, funding scarcity, fragile geo-ecology and limited exposure or experience in the sector compels us to consider uncertainty or risk as a separate goal while analysing hydropower development (Hashimoto et al. 1982). For Nepal, a few failure or a major economic loss could put the country's economy into a vicious circle of adverse economic for many years. This issue is very important and should be treated as an important goal of project development. It helps to understand how likely a system is to fail (reliability), how quickly it recovers from failure (resiliency), and how severe the consequences of failure may be (vulnerability). Uncertainty or risk minimization as a goal could be similar to the technical, economic, etc. issues, and these are further explained in the following section 4.4.6 of this report.

4.4 Criteria to measure

As explained in the previous section on different domains and corresponding goals associated with hydropower development, it is time to measure or assess them. The main goals assessment is carried out by identifying the contributors to that specific goal: the criteria. Criteria are sometimes also called factors in MCDM systems, which basically are measurable (tangible or intangible by ordinal or cardinal measurement) and used as a basis for assessing or reasoning about something (e.g., a project) to make a judgement or decision. Within a particular goal, among the wide range of similar criteria, several can be joined together and listed as sub-goals under the main goal. Generation capacity, tangible and intangible benefits through enterprises and commercial activities, cost, employment, local resource use are some important examples of criteria to be assessed (Desai 1997). A possible list of selected criteria is briefly listed here and organized under the respective goals and sub-goals. A guide to further details about the criteria and their measurement is presented in Appendix 2.

4.4.1 Economic goal based criteria

Following the discussion (see Section 4.2.1) on importance of economics as one of the most important impact domains and the need for its evaluation, the following criteria are found to be important to evaluate.

Power Generation Capacity (PG): Every hydropower scheme has a certain power generating capacity measured in kW or MW. In Nepal every power plant sells its power to the Nepal Electricity Authority (NEA) and operates for almost the same amount of time annually. Hence to avoid complexity related to data collection for annual energy generation (kWh), we assume each power plant generates its revenue proportionate to its power generation. Hence this criteria of power generation also represents the comparative position of alternative plants with regard to revenue generation. This saves much effort required for collecting detailed information on this aspect and make the decision matrix (a list of values in rows and columns that allows an analyst to systematically identify, analyse, and rate the performance of relationships between sets of values and information) brief but still effective. Hence once we select power generation capacity to evaluate alternatives, we do not need to consider revenues, otherwise this could lead to double counting. However its weightage allocation may be higher because of its relevance, with power capacity contributing to national energy need and also the amount of revenue it generates.

Benefits: Benefits from the project other than revenues are indirect in nature and of many types. They could be the following:

> Local facilities (LF): Hydropower development is accompanied by many social supports such as education and infrastructural facilities like roads and bridges (Wang 2012; Mathema et al. 2013; Shresth et al. 2016) as seen in many hydropower projects developed in the country. It also enhances transport facilities. Nepal is poor in terms of such facilities whereas hydropower development could bring them as complementary to the project itself. Hence this is one of the remarkable benefits in the Nepalese context. It is important to evaluate whether the project is benefiting the people and in what way.

Flood control (FC): Hydropower dams obstruct the river flow and the water level changes from its natural level. Hydropower could also serve (sometimes) as flood control, as in the Koshi high dam (Devkota & Gyawali 2015) but also the opposite may be true, as with the Kulekhani hydropower plant where flow construction caused huge life and property loss both upstream and downstream (Dhital 2003). It is possible to provide a flood control facility where agriculture land and residential areas may get more protection. Ambitions to control river flows for improved agriculture and industry and in particular to protect living populations and property from flooding are a fundamental aspect of water storage. The storage reservoirs regulate river flows and operate by storing varied volumes of flood waters and controlling the timing of water discharge over time. Similarly there is competition in setting reservoir rule curves that balance the drawdown levels prior to the flood season, to prevent or minimize spill, with the need to maintain a maximum hydraulic head for hydro generation. Hence it is another benefit to evaluate whether such components are incorporated in the project and whether people benefit or not.

Irrigation facility (IF): Hydropower plants could integrate additional facilities to support irrigation and enhance agriculture production. According to a 2009 report (Karen 2012), out of the country's total area of 14,718,000 ha, the cultivated area was around 2,520,000 ha (17% of the total area). Within the cultivated area, only a small percentage is provided with irrigation, whereas cultivated land still to be integrated with irrigation facilities is an estimated 2,177,800 ha. The cultivable area, which is 34% in the Terai, 8% in the Siwalik, 48% in the mountain and hill region and 10%in the high Himalayas, could benefit if hydropower could also support irrigation. Nepal being an agriculture-based economy, such a facility could benefit the farmers in the region. Hence it is important to consider whether a plant provides an irrigation facility with an adequate amount of water.

Fisheries development (FD): According to the national water plan of 2005, the Government of Nepal aimed to enhance inland fisheries and increase production to 87,000 MT per year (Samuhik Abhiyan 2012). In this perspective, hydropower projects could contribute because they create pondage, maybe of different sizes, and could provide opportunities for fisheries development. In addition to recreational fishing, some reservoirs like the Indra Sarover at the Kulekhani hydropower project support commercial fisheries. These can be in the form of fishing from boats, trapping at the dams and artificially enhancing stocks. The development of commercial fish farming (generally a by-product of a hydropower project) has recently increased in many areas. This could be a new source of income and also nutrition for local residents. However, some power plants could destroy existing fisheries facilities in the natural river flow. Hence this is an important benefit to measure when working on hydropower evaluation or decision.

Cost of Investment (CI): This is one of the important criteria (Wang et al. 2009) under economic goals used for hydropower decision making. It includes various types of hydropower plant costs (Hall et al. 2003) for construction, resettlement, environmental mitigation, etc., measured in currency per kW. Operation and maintenance is proportionate to the plant's total cost and hence is estimated accordingly.

Decommissioning is not an established practice in Nepalese context and for this research it is not applied in the decision-making analysis.

Employment is one of the important economic opportunities offered by hydropower development. It could offer different kinds of employment opportunities (Wang et al. 2010; Scott et al. 2013) as follows:

> Short-term employment (ST): Directly related to project employment opportunities during the project construction period. Employment generation near the project construction site is an important socio-economic benefit, but most of the jobs that local people work on are in the construction phase of the projects and thus are short term (Chandy et al. 2012). These jobs cease to exist once the construction phase is over. Such opportunities may enhance skills and open further job opportunities for the locals.

> Long-term employment (LT): Hydropower plants could offer long-term work opportunities directly related to the project in maintenance, operations, administration and daily labour. In comparison to the construction phase which lasts only 3-4 years, hydropower projects run for many years offering opportunities for long-term employment (Datta et al. 2012).

> Indirect benefiting employment (IB): This estimates the number of people employed because of activities linked with the energy supplied from a hydropower project (Econometrics 2013). Here indirect benefits are created due to interaction with other sectors of the economy and employment generated in SMEs, services, business, tourism, etc. Induced employment also estimate the number of people employed to provide goods and services in the project region.

4.4.2 Social goal based criteria

As described in Section 4.2.2, one of the important goals of hydropower is social and can be accessed via the following criteria.

Equity and benefits: Hydropower development is an opportunity for local communities to participate in investment through equity (shares) in the system that is developed (IFC and USAID 2017). While an individual from the local community can be interested in equity investment, buying shares in the project, local resources such as construction materials, land, rivers, etc., which belong to community should also be valued and considered as community equity invested in the project. Hydropower offers several benefits and also some adverse impacts. It is important to evaluate how the plant developers deal with them. Here we consider the following aspects:

> Equity and benefits distribution (EB): Hydropower projects generate revenues and could benefit the equity holders. A project may also provide different kinds of service such as social responsibility to the community. Fairness in benefits allocations as well as services provided from the project should be maintained (Shresth et al. 2016) and this is an important issue in Nepal. It is important to review how effectively and what degree of fairness is maintained in the cost

burden (land, forest resources, shares and investment) and benefits (jobs, fellowship, cash or social services) from projects.

Gender and mainstreaming (GM): Hydropower project sites are populated primarily by ethnic minorities (McNally et al. 2009) who are very vulnerable in achieving benefits from such project development. Women and marginalized groups (e.g., Janajati, Dalit and the ultra-poor) who have limited livelihood choices, are under-represented in the process of hydropower development across the board (in terms of stakeholder consultation, local hiring, establishing local development priorities and local governance). They are the most vulnerable to hydropower development. According to the Gender and Social Inclusion Strategy 2008, gender mainstreaming and inclusiveness of vulnerable communities is very important in modern society. Gender and affected communities blindness is no more acceptable in hydropower planning (World Commission on Dams 2000). The issue is serious in mountainous countries like Nepal, where the majority of the rural population, especially women's inclusion, voice, and access is inadequate to planning, decisions for achieving equity goals and ensuring benefits (Khadka et al. 2014). Mainstreaming of such groups should be ensured at all stages of the planning and implementation process. There should be clear consideration for the vulnerabilities that expose women to project impacts (displacement, changes in the resource base and resulting disruptions of social and economic resources and networks) and for the specific obstacles that reduce their opportunities to share benefits generated by the project.

Opportunities strengthening livelihoods (OL): Hydropower development in Nepal has proven its impact in raising the living standard of people around the country, including rural areas (Adhikari 2006). It is important to measure opportunities for strengthening livelihood activities and poverty alleviation. Comparing living standards with pre-project conditions will assist in verifying that conditions have improved. In this respect, hydropower development may include some additional activities (improved farming, hatcheries) or capacity building (vocational training) for communities which strengthens their livelihood activities and brings resource or facilities for better living conditions.

Project-induced impacts: Strong impacts from hydropower generation can be found at and around the project site (Kumar et al. 2011). In addition to directly observable impacts there could be several important but indirect impacts induced by an implemented hydropower project. According to the World Bank, hydropower projects can have important multiplier effects, creating an additional 0.4 to 1.0 of indirect (induced) benefits for every dollar of value generated (Edenhofer et al. 2012). Such indirectly induced impacts should be considered in the decision making. They include:

Movement and activities (MA): The movement and daily household activities of members of the community may be impacted by hydropower development. In the best case, it could facilitate their movement by adding facilities such as roads and bridges (Chandy et al. 2012) etc. or could cause longer distances to walk (Thoi 2015) for school, farming, grazing and other daily movement.

Law and order impact (LO): An impact on law and order and local lifestyle in general from a power plant being established (Agrawala et al. 2003) can be seen in many hydropower projects. Such hydropower might develop the site conditions and institutions develop as direct and indirect influences. Some could strengthen security (police and army) while others may impact adversely (ill-minded social elements engaged in theft). Here we wish to access the overall impact due to power plants.

Recreation opportunities (RO): The water bodies provided by many hydropower reservoirs often allow recreational uses such as fishing, sailing (canoe, kayak, water-skiing, swimming or even using small sailboats) and other activities for visitors and people living close to the reservoirs (BRANCHE 2015). Hydropower development may recreate new sites for recreation and at the same time there could be a loss of existing natural sites for recreational activities like bathing, fishing, water fetching etc. It is important to evaluate people's satisfaction with the value added by hydropower to recreational opportunities.

Health and Safety (HS): Health is a state of complete physical, mental and social well-being and not merely an absence of disease or infirmity. Hydropower is related to the health and safety issues of drinking water, sanitation, energy and nutrition. The three major routes of disease agent entry are air, water and food – very much related to hydropower, specifically due to water stagnating nearby. Hydropower projects can cause community health hazards due to pollution and water-borne diseases, especially for children and the old aged, and hence safety is a concern due to the project (Pradhan 2012). In contrast, having electricity available could extract and supply clean, uncontaminated water, fulfilling the water needs of the nearby area and suppressing water transmitted diseases (Fong & Meisen 2014). Hence hydropower health impacts are important to consider. Positive health impacts are to be enhanced and negative ones mitigated.

Displacement and resettlement (DR): Dams have displaced millions of people in many countries of the world, but such social costs of dam construction constitute a relatively new international issue with the emergence of displacement as a salient issue (Sims 2001). Displacement and resettlement of project affected families (PAF) is a major issue in Nepal (Messerschmidt 2008). "Recognition of rights is an important element in establishing the existing entitlements of adversely affected people at various locations upstream and downstream and in other affected areas" (World Commission on Dams 2000). The report also states "Regaining lost livelihood requires adequate lead time and preparation and therefore people must be fully compensated before relocation from their land, house or livelihood base "and further suggest "Mutually agreed mitigation, resettlement and development provisions should be prepared jointly with the participation of all affected people, government and the developer".

Minorities maintaining traditional lifestyle (MT): Many tribes and indigenous communities are found in hills where hydropower sites are located. Due to lack of awareness their voices are seldom heard by development planners. It is important to keep the rights and interest of indigenous and tribal peoples in the project. This include the free, prior and informed consent of indigenous and tribal peoples to developments that may affect them (Tamang 2004). The loss of traditional knowledge passing through the younger generation to the coming generation may mean they lose exposure to the traditional lifestyle. This may create difficulty for their survival and also to them losing their traditional identity (Naitthani & Kainthola 2015). Hence, the participation of indigenous and tribal peoples must become an integral part of the decision-making process and they should be ensured of their benefits including their pursuance of traditions, lifestyle and beliefs. Following appropriate negotiations conducted in good faith that lead to an agreed outcome would secure wider acceptance of development policies and projects (World Commission on Dams 2000).

Cultural heritage (CH): “Cultural heritage is the legacy of physical science artefacts and intangible attributes of a group or society that are inherited from past generations, maintained in the present and bestowed for the benefit of future generations” (Daniel et al. 2012). Cultural heritage includes tangible culture (such as buildings, monuments, landscapes, books, works of art and artefacts), intangible culture (such as folklore, traditions, language, and knowledge), and natural heritage (including culturally significant landscapes, and biodiversity)”.The natural resources associated with rivers directly support natural habitats and the livelihoods and cultural values of millions of people worldwide. While considering hydropower’s effects on cultural heritage, historical remains, earlier settlements and monuments representing their traditions and beliefs should be preserved to the greatest extent possible (Rodriguez 2012).

Community visibility (CV): Because of a planned hydropower development, a community receives more visibility in the developmental arena. Planned hydropower may enhance the community’s visibility because of environmental concerns, increased visitors and tourism (Coleoni et al. 2014). Further hydropower development may bring many other developmental activities (infrastructure like roads, bridges, schools, telephones, health posts, water supply, awareness, skill development) for the benefit of project implementation and also to the local stakeholders. Many of these developments would have taken decades if a hydropower project was not constructed (Shresth et al. 2016). Hence each hydropower project should be evaluated on its contribution in enhancing the visibility of the community in the national attention or agenda.

Transparency and governance: To produce positive and lasting outcomes, development projects should provide for greater involvement of all interested parties. A fair, informed and transparent decision-making process, based on the acknowledgement and protection of existing rights and entitlements, will give all stakeholders the opportunity to fully and actively participate in the decision-making process. This includes the following sub-criteria:

Public participation (PP): Identifying people’s rights and risks associated with a hydropower project and then recognising how they affect different parties will give planners an objective basis for identifying stakeholders (World Commission on Dams 2000). “These stakeholders must participate fully and actively in the decision-making process and be party to all negotiated agreements throughout the process, from options assessment to final implementation, operation and monitoring. Communities also need sufficient time to examine various proposals and to consult amongst themselves. Demonstrable public acceptance of all key decisions is achieved through agreements negotiated in an open and transparent process conducted in good faith and with the informed participation of all stakeholders” (World Commission on Dams 2000). Further the governance of project activities must be transparent and dealt with fairness.

Partnership in management (PM): Local communities being involved in and establishing partnerships in the management / governance of the project could enhance the success of the project. Local ownership may lead to the project becoming an arena for community collaboration and problem solving (Ahlborg & Sjöstedt 2015). Projects which act together with economic as well as social forces in the locality achieve a greater impact. Whether the project involves local existing institutions, NGOs or civil society from the beginning for project development, it is important to review its implementation and management.

4.4.3 Environmental goal based criteria

Another important impact domain and goal of hydropower project is the environment (see Section 4.2.3) which can be evaluated through the following criteria.

Degradation: There could be severe impacts on the following due to hydropower plants which could influence the decision.

Forest and biodiversity loss (FL): Conserving forests and biodiversity from losses is important. Due to hydropower plant inundation, forest loss, felling of trees, non-timber forest products (NTFP) and rare species are both affected, including in protected and non-protected forest areas.

Farmland expropriation (FE): Areas of farmland being expropriated due to roads, power houses (PH) and canal etc. is common feature of hydropower plants. Loss of commercially productive land (quantity) and loss of productivity (quality due to project water storage and regulation both upstream and downstream) should be minimized to the greatest extent possible.

Sediment balance (SB): Trapping of sediment – riverbed scouring, river bank erosion and regression of deltas is a serious concern and its control and mitigation is important for plant life and related economics.

Impacts on water resources: Water resource-related impacts are important to consider for hydropower and the following are the most relevant to evaluate.

Water quality (WQ): Hazardous chemicals for both humans (drinking) and plants (irrigation) such as lime and phosphorous loading in water could be serious concerns. In addition, the quality of water may be affected for a short duration during construction / maintenance.

Water availability (WA): Although hydropower does not directly consume water, hydro generation may be in competition with other uses, because its release schedule does not always correspond to the timing of water use by other activities but it involve river diversions negatively affecting downstream uses. Construction of hydropower across a river impacts the water level upstream (i.e. stores the water) and slows down its rate of flow. Water available for various uses (drinking, irrigation, recreation, drought mitigation and navigation) is very important and the availability of water, especially downstream, is important for comparing alternatives.

Water connectivity (WC): The impact on water's natural connectivity (for example to maintain aquatic life in rivers) and also with other streams is very important for aquatic species like fish, flora and fauna; and terrestrial species including invertebrates, fish, mammals and birds. The water continuum should be conserved to the greatest extent possible. "The flow of water links riverine ecosystems, establishing a continuum from the top of the catchment to the ocean. Upstream water resource developments cannot be separated from their downstream implications. Locally driven processes to establish the goals of environmental flows will lead to improved and sustainable outcomes for rivers, ecosystems and the riverine communities that depend on them" (World Commission on Dams 2000).

Solid waste (SW): Waste material (soil, boulders, trees) resulting from hydropower construction if not handled properly may cause catastrophes in the vicinity and demand attention (Sharma, Kuniyal, et al. 2007). Waste and noise from hydropower construction need proper handling and proper monitoring during construction as well as post construction.

Visual Impacts (VI): The community may be interested in good visual quality or preference in landscapes (Ervin & Steinitz 2003). Visual impacts on the landscape due to a project could be good or bad depending upon the site and interest from communities and the plant operator. It could also influence the decision on hydropower selection.

4.4.4 Technical goal based criteria

As discussed in Section 4.3.4, technical aspects are important in the Nepalese context and can be evaluated through following criteria.

Power reliability (PR): Power reliability and grid integration of communities is one of the benefits. A community or region may benefit due to a new hydropower plant which is integrated into the national grid. The plant ensures more reliability in supply than that of small isolated electricity supply systems (captive) suffering frequent failure. Assessing the degree of reliability in terms of continuous supply and quality (standard voltage) of power supply because of the particular hydropower plant to region / area / local communities could influence choices.

Use of local resources (UL): Hydropower developed with maximum utilization of local construction resources contributes to strengthening the local economy. It takes into account the available local resources and materials (other than infrastructure) for project development such as materials, workforce, local (community) financing, etc.

Technological knowledge (TK): Due to a hydropower project, local people get the opportunity to be trained in many ways and hence social capital is enhanced which could be used in other project replication development. In the long run, knowledge and skills acquired while developing a project in one place become national social capital to benefit the nation. It is thus important to evaluate hydropower projects in terms of knowledge and skills imparted to the local population.

Regional Balance (RB): Regional balance of power generation is good for managing grid regulation efficiently. Nepalese regional balance in terms of power generation in different regions is a highly important deciding factor in terms of T/D losses and power regularity for industry and economic activities. It is good to examine whether the plant supports the regional balance of power generation within the country.

4.4.5 Political goal based criteria

Following the discussion in Section 4.3.5 about political (policy) importance in hydropower development, the criteria which can be used to assess this goal are:

National independence (NI): National independence in energy needs is a prime criterion for the project selection. Different proposals and modalities assure different levels of energy availability for Nepalese people. While many projects are developed for supplying energy for domestic use, there are many major plants being planned for exporting energy out of the country Hence it is important to discover to what degree the project could support self-dependence in energy needs and contribute to reducing energy (electricity, fuel) imports and also improving the trade balance by reducing the import-export gap.

International conflicts (IC): Rivers flow through and shared by several communities, states (federal governments) and even countries. Project development and investor confidence are built on agreements which need to be trustable by all parties. International conflict due to project development could arise from water use rights and international rules. The question of water allocation between countries, where multipurpose demand comes from users with a wide range of needs and where human appropriation of water is reaching unsustainable levels as rivers cross borders, could be a sensitive issue. Assessing the possible conflict or issues on resource sharing and adverse impacts within existing international water and river regulations is important. It is important to cross-verify that the project is free from international river issues, tributaries, treaties, earlier contracts signed with neighbouring countries and the likes.

Sector policy (SP): The hydropower sector policy in a country needs to be followed when planning hydropower. One must evaluate the specific plant against the hydropower sector preferences set at the time in the country, such as urgency of power development, storage or run-of-river plants, centralized or decentralized plants, generation capacity of scheme and project development modalities such as public private partnerships (PPP), etc.

4.4.6 Uncertainty and risk mitigation goal based criteria

As discussed earlier (see Section 4.3.6) uncertainty and risk could be treated as a separate goal when discussing hydropower development in the Nepalese context. This goal can be measured through the following criteria.

Technical risk (TR): Assessed against the country's technical handling capability, inefficient existing electrical transmission or sub-station structure, delays in required power evacuation arrangements by the respective authorities and dependence on fast-changing international technology suppliers could adversely impact a project's technical functioning. Hence all the above could pose serious technical risk and should be accounted for when planning and evaluating hydropower plants.

Change in policy (CP) risk: Changing policy subjected to a changing political system could be a serious risk (it may be called political risk). An investor's first step is to look for a stable country policy to determine their decision. Project planning is based on existing policies and regulation but any changes made in policy can affect the expected outcome for investors and plans become vulnerable. This is a kind of political risk associated with projects and must be thought through well during decision making. Determining what an acceptable level of risk is should be undertaken through a collective political process.

Environmental risks (ER): Climate change, greenhouse gas emissions, land/rock movement, erosion and seepage and similar site-specific environmental change could cause adverse impacts on projects. Climate change may impact hydrological (flow duration curve) storage and vary the head available affecting the generation capacity of the plant. Geological stability and seismic risk affecting stability may also be life threatening for the plant. Hence environmental safety and mitigation are needed to have a healthy system in place and must be evaluated to make planning decisions.

Implementation risks: Hydropower plants take longer to complete implementation and have a longer operational life. Several types of implementation risks are present whose consideration during planning and decision making is important. They are as follows:

> Institutional risk (IR): Capable and fully responsible institutional arrangements in the country is a prerequisite for successful project implementation. This issue needs to be evaluated for each project.
>
> Social risk (SR): If disparity exists in social equity and benefit from resource use and it is not addressed properly then social risk arises. This may result in disruption of project implementation or even paralysing the functioning of the existing project by community members.
>
> Coordination risk (CR): The coordination of several activities and agencies (forest, conservation, PPA, other concessions) and infrastructural supports (roads, bridges, grid, etc.) are important for the development of hydropower projects. Lack of coordination among institutions, ministries, government agencies and local communities may cause project delays and overruns.

Market risk (MR): Change in the market in terms of demand, competing options and capital financing scenarios could adversely affect the project plan and should be considered properly. This element focuses on the marketing and financing of the project construction and possible market competition arousing associated risk.

After identifying all possible criteria in hydropower analysis, next most important is to collect them and in this research at different stages of studies different sources of data collection applied. These are explained in following section.

4.5 Data collection

In this research the triangulation method, as shown in figure 9, applied for obtaining data and verifying the results (obtained from each of three data sources. The three steps are historical research, surveys and field data as shown. In the figure 9. The work starts with evidence based information collection for analytical analysis. The data so generated used later in AHP application named secondary data based AHP. Next was to collect data from questionnaire (electronic survey) as primary data for the research. Finally the research used data collection from hydropower project sites from field. These are briefly explained in the following.

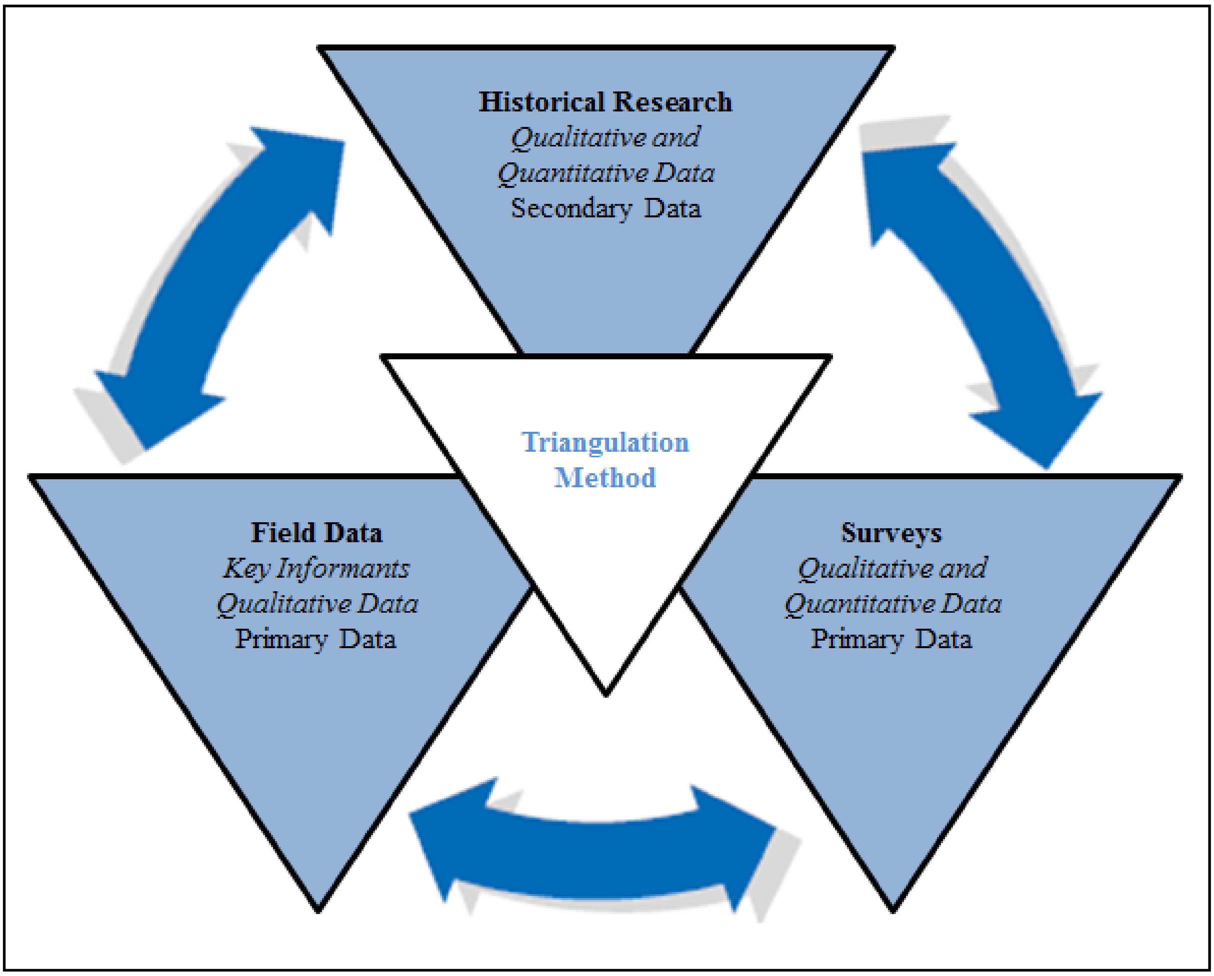


Figure 9: Triangulation method opted for data collection

Source: McDermaid & Barnstable (2001)

4.5.1 Literature and document

In this stage data is collected from literature and documents. The data is then synthesized and the process follows evidential reasoning and analytical analysis within several perspective analysis (see Section 4.b). Suitable MCDM tools applicable in hydropower analysis are researched and those found appropriate are tested with the data (secondary) available (see Section 4.c).This stage of the study will also prepare a long list of applicable criteria (Section 6.1.2) in hydropower decision analysis. Here, evidence-based analytical analysis (perspective analysis) will be applied to analyse the hydropower sector (specifically focused to prioritize hydropower schemes in Nepal) and then one MCDM will be applied to test its applicability and reliability (by comparing it with the earlier findings from the perspective analysis).

4.5.2 Questionnaire survey (electronic)

A questionnaire survey (electronic survey) is conducted to list criteria and their weightage (see Sections 3.2.4 and 6.1.3).This part of the research verifies the criteria to be used and the allocation of weights to the criteria applied (detailed in 6.1.3). At this stage, for the prioritization exercise, the same MCDM tool will be applied using similar criteria (as applied in earlier analytical study) but data obtained from the primary source (survey). This will test the data availability and applicability while applying the MCDM tools. In this way we can list the applicable and available data requirements for hydropower analysis. Further comparing results (e.g. prioritization of schemes) by applying the same MCDM tool but differently sourced data will verify its applicability and trustworthiness.

4.5.3 Site survey

Field data is sourced from the field visit of sample sites. Here based on the earlier step of the research, namely analytical study followed by two different AHP applications, a detailed hydropower decision aid tool is drafted with a full list of applicable criteria and their allocated weightage. This draft decision framework will be applied in the field to test its applicability. Furthermore, the data is processed through a MCDM tool to demonstrate the effectiveness of its decision making. In-depth analysis of the data and results are used to fine-tune the draft to make it a more robust hydropower decision framework applicable in the Nepalese context.

4.6 Summary and conclusion

Hence, as descried in this Chapter, the study will be conducted at different stages (modules), starting with analytical analysis and following with MCDMs applications till delivering a decision framework. In this process, output from one stage assist next one to begin. Required data from different sources will be obtained accordingly. In the first step of research, a large amount of information is to be organized into a data matrix (input data of a classifier arranged in row and column). This plain impact matrix (a tabular data arrangement where each force or factor is assigned a score based on its own strength and the strength of its interactions) which will consist of systems (alternatives) versus criteria with weights. Hence the data matrix will be ready to further process and use for decision analysis following MCDMs and so on. Still one important challenge is to select applicable MCDMs tools which will be elaborated in following Chapter 5.

5 Hydropower and MCDM

This chapter will present hydropower-related information and hydropower decision making. The chapter will focus more on hydropower development in Nepal and suitable MCDMs to analyse them. Multi Criteria Decision Making (MCDM) techniques in general and those applied in the present study will be elaborated. There will be more attention on certain procedure or stander to select appropriate MCDMs to apply and test. Also the projects nominated for case studies are introduced at the end of the chapter.

5.1 Hydropower development in Nepal

In Nepal, the mean annual precipitation ranges seasonally between less than 150 mm in Mustang and Dolpa region to more than 5000 mm in Kaski region with a national average of 1860 mm (Marahatta et al. 2009). Nepal with its untapped vast hydro potential is one of the world's poorest countries. Connecting the Indo-Gangatic plain with the Tibetan plateau within a span of less than 200 km and ranging height from the 8848 m of Everest to the 70 m of Kechana Kalan above sea level, the country works in a ladder-like manner, very favourable for hydropower generation as shown in Figure 10.

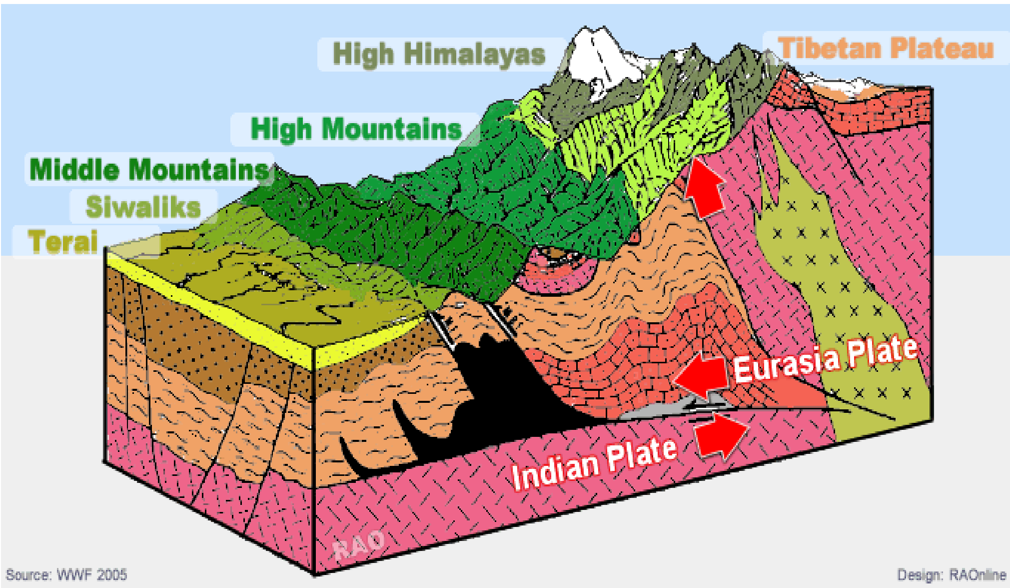


Figure 10: Geographical topography of Nepal

Source: WWF 2005

There are more than 6000 rivers and rivulets draining the country and releasing their runoff to India. Out of 17 river basins, there are three major basins as shown in Figure 11 (Koshi, Gandaki and Karnali) with three ecological zones (Terai, Hills and Mountains) dividing the country into nine hydro-ecological regions (Bhattarai 2003).

Figure 11: Major river system and catchment areas

Source: Sangraula 2003

The total estimated hydropower potential in the country is 83,000 MW (Shrestha 1966). Several researchers have analysed the hydropower potential (Jha 2010; Pradhan 2009; Bajracharya 2015) and indicate even more potential existing in the country. However to date only 727 MW of hydroelectricity has been tapped. Until now, Nepal has utilized mainly medium and small rivers for uses such as drinking water, irrigation and hydropower. The larger and perennial Himalayan Rivers, except for a few run-of-river schemes, have been virtually left untapped. Each category of hydropower plants has its own merits and challenges. Since the historical first pant was implemented in 1911, several micro and small hydro plants have been completed and several are in the pipeline. Also a few medium hydro schemes have been implemented and several are in planning. A limited number of big hydro like Kali Gandaki (144 MW) have been developed or like Upper Tamakoshi (456 MW) are in the completing stage. The country has strong experience in micro-, small- and medium-scale hydropower development while limited exposure to big-scale power generation.

The Government of Nepal's recent initiatives towards generating10,000 MW in 10 years and 25,000 MW in 20 years are under serious consideration and need careful work to avoid regrets in the future (Pun 2008b).To meet its energy needs by 2030/31, Nepal should develop an additional 2000 MW of run-of-river (ROR) type, 1200 MW of daily poundage run-of-river (PROR) type and 3700 MW of storage (reservoir) type hydropower plants (Dhungel 2014). Furthermore, to meet the energy demand by 2050, the country needs more than 11,000 MW as a minimum to sustain the present development trend to more than 32,000 MW (Rajbhandari et al. 2013) in case of the expected fast GDP growth of 8%. It is important to consider that Nepal could meet its energy demand solely through hydropower, like Norway (Morimoto 2013) and could reduce fuel import bills which are over 60% (Rai 2014) or even more (Adhikari 2012) of the country's total export earnings. With every year fuel import costs could implement 500 MW of hydropower in the country for many years to benefit. Nepal is also importing annually alternative accessories for power worth Nepali Rupees 350 billion (equivalent to US$ 350 million) which could develop 200 MW for extended benefits for many years(Arya 2007).

Along with many projects under consideration and at different developmental stages, recently the government initiated “Super 10” as nation’s priority projects of power capacity ranging from 115 to 400 MW (JICA 2013). Large schemes are still at the initial stage of identification or pre-feasibility and seem distant from realization. Although the country has a strong pool of more than 10,000 qualified professionals (NEA 2012; Mashkey & Kandel 2013), they are experienced with small- and medium-scale power plants, and extremely limited workforce is available for larger schemes. The national grid is already inefficient (IEA 2014) and power generation is regionally unbalanced (Bhattarai 2012). Mini or isolated small grids could be viable options for rural electrification (Gurung et al. 2012) but have limited generation and coverage capacity. Larger projects face problems due to land and resettlement issues (Cernea 2004). With developed infrastructure like bridges, roads, and grids in recent years, the economic viability of hydropower has been enhanced. Although larger projects could be most economic, they require huge investment. Externally financed projects are costlier and the mode of financing or contracting has a much stronger impact on project costs than economies of scale. Due to poor policies and political instability, the financing sector is hesitant to make huge investments and prefers to test business reliability in steps. Private sector participation is increasing with strong interest towards medium and bigger projects recently (DOED 2014). Environmental concerns related to hydropower bring reluctance from forest, soil, conservation and water resources related institutions and require strong inter-ministerial cooperation. Some concerns like Lake Outburst and geological instability in this Himalayan region require further consideration and investment for hydropower exploration in the country. Uncertainties and risks are important to consider (Zhang et al. 2013), specifically in the Nepalese context (Khatri 2013) of infrastructure development and particularly for hydropower (Pandey 1995). This applies at different stages of development and is of different magnitude (Panthi 2007; Shrestha 2007; Londono 2005), needing attention from the beginning of planning.

5.1.1 Hydropower decision making in Nepal

The hydropower identification, evaluation and selection procedure in Nepal is far behind the scientific decision-making procedure practised in many parts of the world. From the late 1970s onwards, foreign aid completely dominated the power sector and until recently, hydropower development was on an ad hoc basis (Pun 2008a) and influenced by donors. Furthermore, very limited research and publications are available in the Nepalese context. There is a lack of socio-economic and environmental data on different spatial-temporal scales which is of the utmost importance for sound decisions on hydropower. In Nepal, most decisions are made without considering them all together in broader perspectives. As a result of such a narrowed approach on hydropower decisions in the past, several projects have suffered, mainly due to perspectives being either ignored or undermined. Many of the implemented schemes have either exhibited a short lifetime (Thapa 2004) or suffered major environmental impacts (ICIMOD 2011; Everard & Kataria 2010; Sharma, Banjade, et al. 2007; Jha et al. 2007; Pradhan 2012). Furthermore, there is an imbalance in equitable access to and use of electricity within the country (Shah 2008). Hence it is important to review the past development trends and search for a decision-making approach based on scientific evidence and knowledge.

After the restoration of democracy in Nepal in 1990, hydropower took a new appearance. The Tenth five year periodic development plan specified eight criteria (NPC 2002) applicable for infrastructure, including hydropower, which demanded the use of Multi Criteria Decision Analysis. Water resources and hydropower could deliver quick and tangible economic benefits in a multidimensional way. An approach which encourages local participation and the use of affordable, reliable and maintainable technologies is required. Unfortunately, the hydropower decisions practised so far in Nepal have not been encouraging. Even today, Nepal is not following a consolidated method of project evaluation by putting all relevant technical, economic, financial, social and or environmental information together in a broader decision framework. Slowly people are realizing the importance of MCDM in Nepal. The application of MCDM in project analysis is increasing (Bhattarai 2014; Bhattarai & Sapkota 2013). Although MCDM application specifically in hydropower has been increasing at the global level (Rosso et al. 2014; Toloie-Eshlaghy & Homayonfar 2011), Nepal is not able to benefit from globally gained experiences on hydropower decision making. However limited MCDM studies on hydropower in the Nepalese context are available (Bhattarai & Fujiwara 1997; Panthi 2007; Shrestha 1991; S. Bhattarai 2003; Bhattarai 2006; Bergner 2013; Sapkota et al. 2012; BPI 2009; SARI/Energy 2002; Panthi & Bhattarai 2008) and these studies are important contributions to the present research.

5.2 Multi Criteria Decision Making (MCDM)

The practice of decision making is as old as man and King Solomon (1011–931 BC) was probably the first recorded example of MCDM application (Köksalan et al. 2013). The simplest form of multi criteria decision methods follow the listing of pro and cons and finding a net balance in use since the eighteenth century (MCDM 2015). Since the early 1950s, scholars have worked on non-linear programming (Kuhn & Tucker 1951) for multi objectives and then others proposed goal programming in 1961 and multi criteria negotiation in 1968. In the mid-1960s Bernard Roy developed a popular MCDM tool called ELimination and Choice Expressing Reality (ELECTRE). In this way multi criteria got more attention during the 1950s and 1960s. The more organized scientific development of MCDM began in 1971 (Zardari et al. 2015). During the 1970s focus increased on multi criteria and people started looking more consciously to make decisions considering several objectives and perspectives. The first complete exposition of MCDA was given in 1976 by Keeney and Raiffa (Eom 1999). The contribution of Prof. T.L. Saaty in MCDM with a tool called AHP also came during the 1970s and was a very valuable contribution. During the 1980s, several analysis models, supporting tools and applications were developed. After 1990, MCDM become very popular and expanded very rapidly with increasing publications as can be seen in Figure 12.

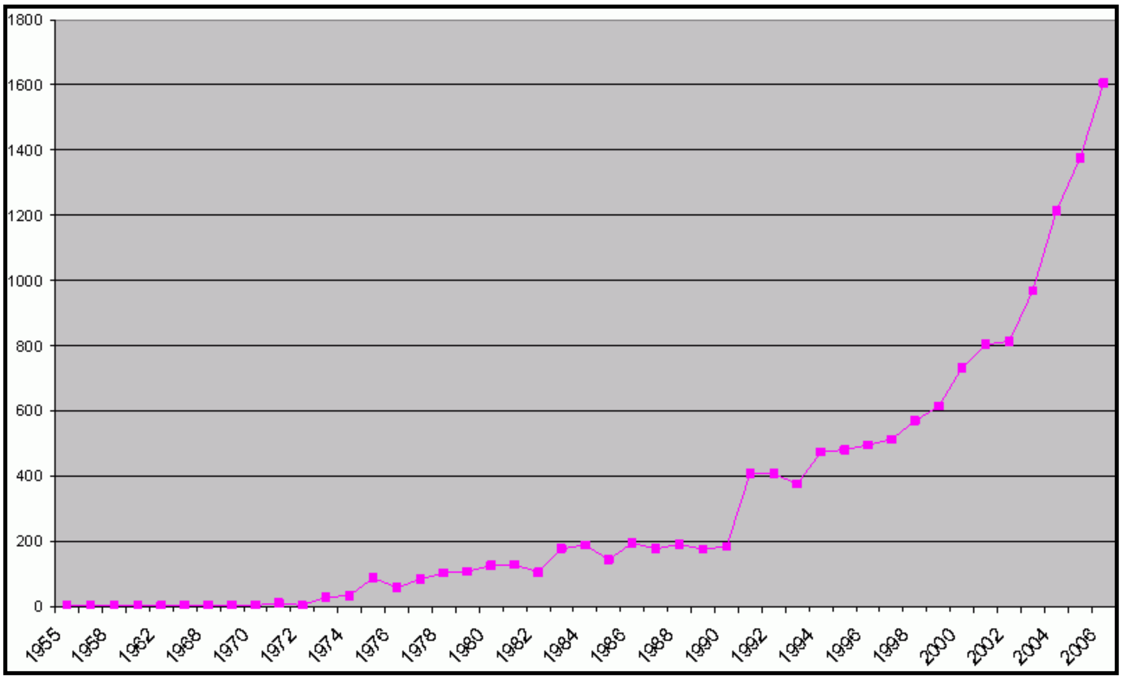


Figure 12: Yearly publication trend in the MCDM field

Source: Bragg et al. (2010)

Whatever the type of MCDM may be, they all follow a common procedure to tackle the decision-making problem and this will be explained in following section.

5.2.1 MCDM general procedure

Due to various factors and stakeholders concerned with projects in general and infrastructure projects including hydropower in particular, the projects come across controversies and conflicts. Hydropower assessment may require more qualitative rather than quantitative measurement. The major problems faced by decision makers are not technical, rather they are issues of reaching acceptable solutions within conflicting interests. Complicated by several non-tangible factors, subjective judgement is needed which is critical and requires proper comparison and evaluation of projects. The multi criteria assessment (MCA) framework ensures a robust analysis whilst permitting non-financial and distributional issues to be incorporated. This has prompted analysts to explore and apply MCA, organizing all information together and analysing it further in a scientific manner using an appropriate tool. MCDM is applied following a predefined procedure starting from problem identification and ending with final decision recommendations (Cavallaro 2009). A general approach in MCDM is depicted in Figure 13. The very first step is to discuss the problem and accordingly identify opportunity to contribute in solving the problem. Review the relevant information and imagine the trends or forecast likely to happen. Develop the plan to conduct multi criteria based approach and conduct evaluation accordingly. Evaluate all alternative solutions or options, synthesise the results and conduct sensitivity for reliability of results to confirm the final decision.

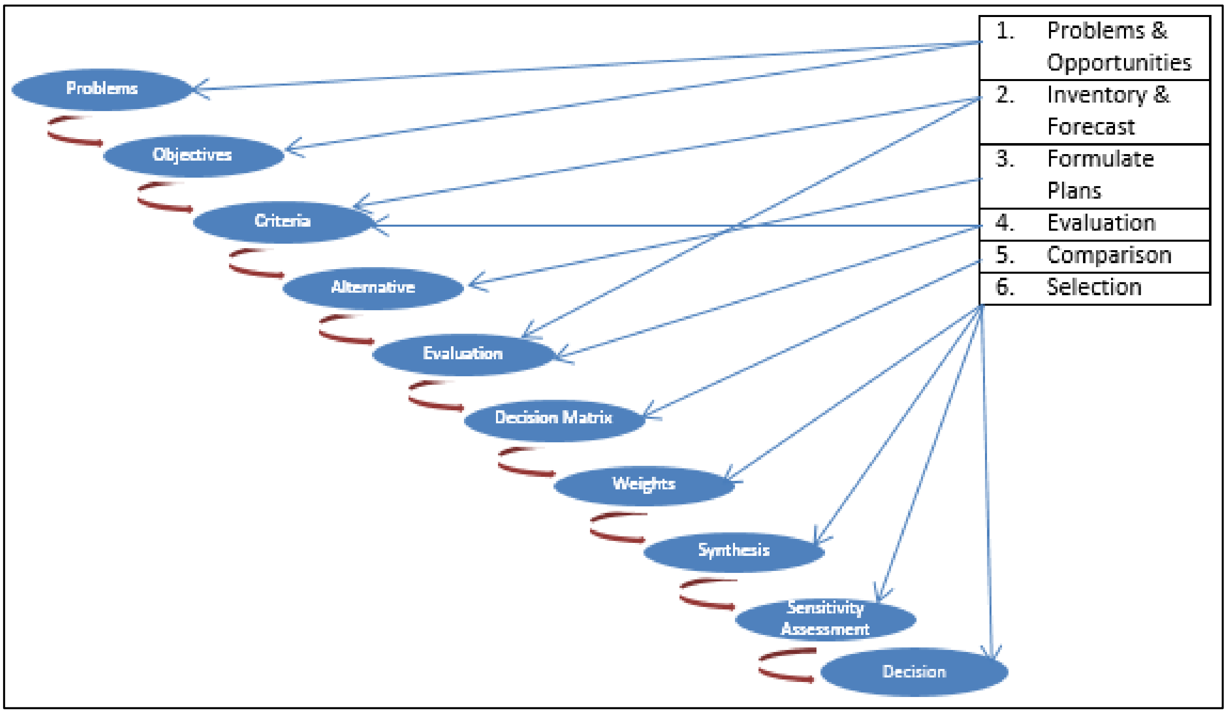


Figure 13: Relation of planning process to multi criteria decision support framework

Source: Modified from Yoe (2002)

As shown in Figure 13 and also following the MCDM procedure (George 2008) will improve

- decision outcomes by providing structured decision analysis
- decision processes by including participants and all relevant criteria and
- implementation probabilities and commitment for results to be achieved

Selecting an appropriate MCDM tool from a long list of available MCDM methods is a multi-criteria problem in itself (Abrishamchi et al. 2005; Xu & Yang 2001; Ozernoy 1997; Duckstein et al. 1989). Selecting an appropriate MCDM technique is more important than the data generation method (Park et al. 2015) There is no single MCDM method which can be considered as a superior method for all decision-making problems, the choice remaining a subjective task (Ánagnostopoulos & Pisinaras 2005). Depending upon the type of problem, the objectives, goals, criteria and alternatives determine which MCDM is appropriate.

Furthermore, it should be considered that the assessment of impacts is also related to the perspective of the analyst. A macro-economic approach may yield quite different results compared to a local impact study. In the decision-making process, subjective criteria, which are difficult to measure must be included when assessing hydropower. Subjective criteria may be more important than objective criteria in some decision situations. Issues related to decision making do not come in a sequence, rather one has to organize them in a proper sequence (Duckstein et al. 1989). Thus, decision making has always been difficult and it is hard to find a solution with all the desired benefits at the expected highest level. In reality, with understanding and compromise (trade-offs), a consensus can be reached to obtain a compromise (satisfactory) solution among the stakeholders and avoid traditional approaches of unfair decisions (Guitouni & Martel 1998). This is an approach which encourages local participation and the use of affordable, reliable and maintainable options. The decision framework should consider a net improvement of income of lower income groups of society (Gunawardena 2010; Mathur 2008). MCA is an important exercise for screening and selecting preferred options from the full range of identified alternatives. Any MCDA approach may differ subject to the project type (e.g. hydropower, forest, road), and country policy (Foran 2010).

Since the 1980s, several methods have been invented to solve decision problems (LOKEN 2007). Many of the methods have been created particularly for one specific kind of problem, and are not useful for other kinds of problem. Other methods are more generic, and many have attained popularity in various areas. The main idea in all of them is to be able to compare alternatives that have different performance levels for various criteria, to create a more formalized and better informed decision-making process. Different MCDMs may result in different recommendations (Guitouni & Martel 1998; Mahmoud & Garcia 2000) but they are unlikely to change noticeably when using different MCDM methods provided the ordinal and cardinal data are handled correctly (Hajkowicz & Higgins 2008). Studies show that when the methods are selected and used properly for decision analysis the results are mostly similar or the same (Shajari et al. 2008). To make decisions, more than one method is used to test and verify the decision results (Duckstein et al. 1994). First one has to test the stability of results (for ranking of alternatives, for example) by changing preferences and by changing the impact table (data, preferences) and then a comparison of different techniques is useful. In addition, sensitivity analysis while applying such a tool to assess the robustness of results is very important. Sensitivity is a kind of business visualization. The decision maker may obtain relevant information with regard to the economy, market situation, social and environmental aspects, associated risks and uncertainties, developmental trends and many more. Allocations of weight to the goals and corresponding criteria might give errors because of subjectivity in their assessment. In many instances due to error or uncertainty in the method or model selection, the decision maker’s preferences, context interpretation, identification of criteria, criteria weights, lack of subject knowledge and alternative selection (Mosadeghi et al. 2012) results may differ from what they really should be. By applying sensitivity analysis with the MCDM tool, one can determine how sensitive the results are to changes in the weightage of criteria used. Hence uncertainty in data and in preferences and their impact on the overall ranking and its stability must be checked through sensitivity analysis.

5.2.2 MCDM types

MCDM is a vast field today with several models and tools (Figueira et al. 2005; Triantaphyllou & Shu 1998). In principle, analysis may follow either direct analysis of the performance matrix (matrix which sets out how each of the options being appraised performs on each of the criteria that form part of the analysis), multi attribute utility, linear additive model, analytical hierarchy process or outranking methods.

In the field of MCDA, a number of divergent schools of thought have emerged (Wang et al. 2009; Belto & Stewart 2002). For easy understanding, MCDM can be classified into the following broad categories (Lade et al. 2012) :

- Value measurement models (Keeney & Raiffa 1979)
- Goal, aspiration and reference level models (Romero et al. 1998)
- Outranking models (the French school) (Roy 1991)

Value Measurement Models: Popular within this category of MCDMs are multi attribute value theory (MAVT), multi attribute utility theory (MAUT) and Analytical Hierarchy Process (AHP). They follow a method in which a numerical score (or value) *V* is assigned to each alternative. A preference order of alternatives is produced by these scores, such that alternative a is preferred to b (a > b) if and only if V (a) >V (b). This approach involves giving weights *w* that represent their initial contribution to the overall score of the various criteria, based on how important this criterion is for the decision makers. The most commonly used approach refers to an additive value function MAVT (multi attribute value theory).

$$V(a) = \sum_{i=1}^{m} W_i V_i\,(a) \text{ ----------------------- (1)}$$

where $V_i\,(a)$ is a partial value function reflecting alternative *a*'s performance on criterion *i*. The partial value function must be normalized to some convenient scale (e.g. 0-100). The alternative with the highest value score is preferred. Where decision makers cooperate with the analyst, they only need to specify value functions and define weights for the criteria. The MAVT (multi attribute value theory) approach is user-friendly and simple for obtaining help with decisions.

The MAUT (multi attribute utility theory) is an extension of MAVT utility functions (Keeney & Raiffa 1979) and is used when quantitative information is known about each alternative, which can result in firmer estimates of alternative performances. The creation of utility is based on the data for each criterion and the utility function created for it. These utility functions transform an alternative raw score (e.g. dimensioned-feet, pounds, gallons-per minute, dollars) to a dimensionless utility score between 0 and 1. The utility scores are weighed by multiplying the utility score by the weight of the decision criterion and summed for each alternative to rank them. The MAUT evaluation method is suitable for complex decisions with multiple criteria and many alternatives. Additional alternatives can be readily added to MAUT analysis if data are available to determine the value of the utility. On development of the utility functions, any other alternatives can be scored against them.

The AHP (analytical hierarchy process) developed by Saaty (Saaty 2008) is similar to the multi attribute value function. AHP is based on a quantitative pairwise comparison of project alternatives. The method uses pairwise comparisons of the alternatives based on their relationship performance against the criteria. This technique is based on the fact that humans are more capable of making relative rather than absolute judgements. The analytical hierarchy process is a systematic procedure for representing the elements of any problem, hierarchically. The alternative with the highest overall ranking is preferred.

Goal, Aspiration and Reference Level Models: A popular MCDM within this category is Goal Programming (LOKEN 2007; LEE 1971; Charnes et al. 1955). The goal, aspiration and reference level models are alternatives to value measurement methods and are used to determine the closest alternative to achieve a determinant goal or aspiration level. This approximation is used as the first phase of multi criteria processes to filter out the most unsuitable alternatives. The idea in the GP methods is to solve the inequality $Zi + \delta i \geq gi$, where Zi is the attribute values, δi is the non-negative deviational variables, and gi is the goals for each criterion i. This method aims at finding a feasible solution that minimizes the vector of deviational variables. The recommended solution will be the solution at which $\delta i = 0$ for all i, which is not true in most cases and another solution must be found. The weighted sum of deviation is minimized, where W_i is the import weight and δi is the deviation of a criterion from the corresponding goal gi.

$$Zi(a) = \sum_{i=1}^{m} W_i \delta_i(a) \text{ ---------------- } (2)$$

Each alternative has a distance δ and the solution with the highest so-called 'relative closeness to the ideal solution' is the best solution.

Outranking Models: Methods based on outranking belong to the French school of thought, within which ELECTRE (Benayoun et al. 1966; Roy 1991) and PROMETHEE are the two main methods (Rangel et al. 2009) Pairwise comparison of alternatives constitute the basis of this model.

In ELECTRE, a set A(a,b,..,k) consisting of alternatives a to k is compared on all criteria. Alternative *a* outranks alternative *b* if *a* is at least as good as *b* when considering all criteria. The ELECTRE I-III methods were developed as an alternative to the utility function and value function methods. The main idea of ELECTRE is to choose preferable alternatives for most criteria, although an unfavourable alternative for any criterion should not be chosen even when it appears favourable for most other criteria. Indifferent thresholds and strict preferable thresholds are used to calculate concordance and discordance indices. The method is always suitable for finding the best alternative. ELECTRE methods uses ranking relations represented by 'S' meaning "at least as good as" while comparing actions e.g. a and b where four different situations could arise as follows:

aSb and not bSa, i.e., aP b (a is strictly preferred to b).

bSa and not aSb, i.e., bP a (b is strictly preferred to a).

aSb and bSa, i.e., aIb (a is indifferent to b).

Not aSb and not bSa, i.e., aRb (a is incomparable to b).

Electre considers the domination (how often it is better with respect to criteria) of a over b and it deficits (how strongly does it fail with respect to a criterion).

In outranking, the criteria weight is important while working out the dominant alternative. The methodology uses concordance (Cab) and discordance (dab) indices as follows (Fulop 2005; Cho 2003).

The concordance index for an ordered pair of alternatives (Aa, Ab), is the sum of all the weights for those criteria where the performance score Aa is at least as high as that of Ab, i.e.:

$Cab = \sum_{i:uia \geq \text{uib}} W_i; a, b = 1, \dots \dots, n, a \neq b$---------------------- (3)

Where $i{:}\, u_y \geq u_{ib}$ stands for the utility values for which the performance score of Aa is as high as that of Ab.

The discordance index, d_{ab} = *0 if* u_y > u_y, *i=1*,………, m i.e. the discordance index is zero if Aa outperforms Ab on all the criteria;

$dab = \max\ \ u_{ib}\ - u_{ia}\ ; a, b = 1, \dots \dots, n, a \neq b$ ---------------- (4)

i = 1,..........,m max $u_{ia} - min\ u_{ib}$

From equation (3) for each criterion where Ab outperforms Aa, the ratio is calculated relating to the difference in performance level between Ab and Aa to the maximum difference in score on the criterion concerned between any pair of alternatives. The maximum of these ratios is the discordance index. Once these indices have been established, an outranking relation S is defined (Cho, 2003):

Aa S Ab if and only if *C (Aa, Ab)* ≥ *C** and *Aa S Ab* if and only if *d (Aa, Ab)* ≤ *d**. Here *C** and *d** are thresholds set by decision maker and these thresholds are defined such that *0* < *d**<*C** < 1.

In a similar fashion, the PROMETHEE method was developed (Brans et al. 1986) based on a pairwise comparison of alternatives and is preferred to selecting a preference function for each criterion (detailed in Section 5.2.3.3). On this basis, a preferable index for a over b is determined, which is a measure of support for the hypothesis that a is preferred to b. A valued outranking relation that determines a ranking of the alternative is carried out. A well-structured procedure needs less information from the decision maker, the criteria measure is on an open scale, and it can tackle uncertainties through probability distribution, fuzzy sets and threshold values (Araz & Ozkarahan 2007).

5.2.3 MCDM application in hydropower

The broad range of the impacts of large capital projects like hydropower often leads to difficult choices between their economic benefits on the one hand and their socio-environmental costs on the other hand. In such cases, MCDM can aid the decision maker to achieve a compromise solution. While focusing more on MCDMs applicable to the hydropower context, applicable MCDMs in closely related subjects like natural resources, sustainable energy, water resources and energy planning are also distinguished.

With reference to the hydropower sector in the decision analysis, the main role of the techniques is to deal with the difficulties that human decision makers have in handling large amounts of complex information in a consistent way. Multi Criteria Assessment (MCA) techniques can be used to identify the most preferred option, to rank options, to shortlist a limited number of options for subsequent detailed appraisal, or simply to distinguish acceptable from unacceptable possibilities. As can be concluded from the literature, there are many MCA techniques and their number is still rising. A recent review of MCDM for water resource planning and management has shown that several MCDMs are mostly used for water policy strengthening, strategic planning and infrastructure selection (Hajkowicz & Collins 2006; Supriyasilp et al. 2009). With specific interest in hydropower, the most-used MCA methods are distance to ideal point, pairwise comparison and outranking methods (Strin & Groselj, 2010). Among them, widely applied in hydropower analysis are pairwise comparison and outranking methods (Hajkowicz & Collins 2006). Hence identifying those suitable from the long list is thought provoking and the criteria used in the present research for the selection of techniques (Department for Communities and Local Government 2009) are:

- applicability for single or multiple decision makers
- ability to generate the best or identify the preferred sets
- transparency
- ease of use
- data requirements not inconsistent with the importance of the issue being considered. Applicable with qualitative and quantitative data
- realistic time and workforce resource requirements for the analysis process
- ability to provide an audit trail, and
- software availability, where needed.

The most important criterion in MCDM selection could be the number of alternatives to be appraised. "Where the number of options is finite, it does not matter in principle whether this number is small or large. However, it is important to bear in mind that each alternative that has to be considered has to be appraised to determine how well it performs with respect to each criterion" (Department for Communities and Local Government 2009). Gathering and processing these data will consume resources with increased number of criteria. Selecting a simpler or detailed MCA decision support procedures could be a factor to bear in mind. In MCA problems with a finite number of alternatives, each of which is assessed in terms of a given number of criteria, the initial frame of reference is essentially the performance matrix. For each option, with respect to each criterion, this performance information needs to be collected and interpreted correctly.

Hydropower is close to water resources and is also part of natural resources. Similarly it is related to multiple uses including energy as major attributes. The rise of public awareness of environmental issues of the early 1970s put hydropower into a coexistence mode (Sternberg 2008). In Nepal such environmental concerns have been treated with due care since 1996 and so 25% of EIAs completed for total infrastructure related projects belong to the hydropower sector alone (Bhatta & Khanal 2010).

A wide range of MCDMs applied in decision making (Nachtnebel 1994; Polatidis et al. 2006) are available and many of them are preferably applied in natural resources (Mendoza & Martins 2006), sustainable energy planning (Pohekar & Ramachandran 2004; Oberschmidt et al. 2010), water resources management (Ko et al. 1994; Srdjevic et al. 2004; Abu-Taleb & Mareschal 1995; Eder et al. 1997) and hydropower assessment (Duckstein et al. 1989; Blanco et al. 2008). Further choosing the most appropriate MCDM for a specific application, one should know what conditions are supposed to be satisfied by the preferences of the decision manager. While searching possible MCDMs applicable to the hydropower sector found many tools applied are evidential reasoning, AHP, PROMETHEE, MAUT, ELECTRE etc. Here relevant literature dealing with hydropower specifically or any other subjects which apply to hydropower are considered while compiling the framework for further processing. One can see, as a commonly applied tools at the global level and also at country level are analytical analysis, AHP, PROMETHEE, ELECTRE etc. Specific to areas of applications, widely applied MCDM are AHP, ELECTRE, PROMETHEE (Toloie-Eshlaghy & Homayonfar 2011; Vučijak et al. 2013; Balali et al. 2014) for natural resources, water management and energy planning, including hydropower. One most popular and trustable tool called Analytical Hierarchy Process (AHP) is very much appropriate (Akash et al. 1999; Subramanian & Ramanathan 2012; Ahmad & Tahar 2014) for decision making on hydropower. Even in the Nepalese context, AHP is gaining popularity in decision analysis for many infrastructure developments including hydropower. Likewise PROMETHEE is very often applied in natural resources, the energy sector, renewable energy and hydropower analysis (Tavana et al. 2013; Chatzimouratidis & Pilavachi 2012; Madlener et al. 2007). PROMETHEE, as a capable tool for handling many criteria and also alternatives with flexibility of adding or removing any of them according to the analysis requirement, is chosen and applied in this research. Use of PROMETHEE in water resources and hydrology-related field is new but has been expanding very fast since 1995 (Mladineo et al. 1987; Behzadian et al. 2010). Similarly combining Graphical Analysis for Interactive Aid (GAIA) with PROMETHEE, also called Visual PROMETHEE (VP), is becoming popular (Brans et al. 1986; Saracoglu 2016), specifically after 2005 (http://www.promethee-gaia.net/assets/bibliopromethee.pdf). It is important to note that MCDA are derived as indicators of the strength of various preferences from various stakeholders and results also differ from method to method. Hence, the use of different MCDM tools in cross-verifying the results is very important (Pandey & Bajracharya 2013). It is also important to strengthen PROMETHEE with ideas obtained from AHP (Macharis et al. 2004; Corrente et al. 2013). Hence in the present research three different MCDMs are applied to reach the overall objective set. The MCDMs applied in this research are evidence-based analytical tools, AHP and PROMETHEE. PROMETHEE applications for developing decision aids can be found in several internationally published research papers (Kishor & Jagu 2011; Brans & Mareschal 1994; Tangen 1997).

For hydropower analysis, all possible criteria need to be evaluated or measured. They could be measured with respective measurement units like cost in currency unit, power in watts, impacts like high, statuses like good etc. The procedure evaluating criteria also depend upon the MCDM applied, such as simple scoring and summation, comparison on a specified scale or combination of scale and absolute value. Hence it is important to understand MCDM in general and methodological details of respective

MCDMs applicable to hydropower analysis which will be explained in the following section. Specific details about the MCDM tools used in the present research are presented in the following section.

5.2.3.1 Analytical analysis using evidential reasoning and scoring

This analysis is based on evidence and reasoning over the collected information. Sometime it is also called Evidential Reasoning (ER) MCDM. Simple scoring based on an evidential reasoning approach could be useful to analyse a finite number of alternatives (Xu et al. 2006). The fundamental steps in this analysis approach are

- Identifying problem and setting objectives
- Identifying attributes i.e. criteria and sub-criteria
- Identifying the goal (main criteria) to reach the objective
- Identifying the alternatives
- Establishing a standard of measuring for qualitative and quantitative information
- Developing an evaluation matrix and following the scoring to evaluate alternatives

Once alternatives and criteria are identified then an evaluation matrix is formed. Suppose there are M alternatives and each alternative has N attribute values then a matrix of M×N is formed whose elements xij indicate a value or an assessment of the i-th alternative of the j-th attribute.

Furthermore, an ER framework includes the concepts of

- the attribute hierarchy, from lower-level attributes to higher-level attributes
- the distributed assessment structure using degree of belief and
- the evidential reasoning approach used in aggregating degrees of belief

The most important feature of the ER framework is that it employs a degree of belief structure to represent an assessment as a distribution. The ER approach is the latest development in the MCDM area. It uses an extended decision matrix, in which each attribute of an alternative is described by a distributed assessment using a belief structure. An attribute is a property, quality or feature of an alternative. To evaluate an alternative, a criterion is set up for each of its attributes and the attribute is examined against the criterion. Because of the one-to-one correspondence between an attribute and a criterion, sometimes attributes are also referred to as criteria. In the context of MCDM, the word attributes and criteria are used interchangeably. There are two types of attribute, quantitative and qualitative. Attributes may break down further into one or more levels of sub-attributes to form a hierarchy structure. The top-level attribute of the hierarchy is normally an overall qualitative attribute. This high level attribute can be decomposed into more specific sub-attributes. The sub-attributes can be further decomposed if necessary until the bottom-level attributes can be evaluated directly.

The ER approach is used for aggregating distributed assessment results from lower-level to higher-level attributes. It employs evidential reasoning and grades are used for assessing a qualitative attribute of an alternative. A commonly used set of grades for assessing quality could be {Excellent, Good, Average, Poor, Worst} and for assessing quantitative information, like the price of the car, could be {Very Low, Low, Average, High, Very High}. It should be noted that there are no restrictions on how many grades and what grade names can be used for each attribute. Different numbers of grades can be used for different attributes. Grading is subjective to degrees of belief, which basically is the confidence level of an attribute being evaluated to a grade. For example, car engine quality could be assessed to be Excellent with 60% of belief degree and Good with 40% of belief degree. The belief degrees could be generated from a survey, group decision making or mapping evidence related to the standards of each grade. For bottom-level attributes, assessment is the process or the result of assigning grades and the associated degrees of belief to an attribute based on guidelines and evidence. For other levels of attributes, it is the process or the results of aggregating belief degrees of lower-level attributes to higher-level attributes using the evidential reasoning approach.

5.2.3.2 Analytical Hierarchy Procedure

AHP is a decision aid that assists the decision maker in choosing the best alternative (Bodin & Gass 2004) or ranking a set of alternatives. It is one of the easiest and most widely applied MCA tools (Vaidya & Kumar 2006). It contains several stages (RAC 1992), including choose decision options (alternatives), figure out evaluation criteria, obtain performance measures for the evaluation matrix, transform into commensurate units, weight the criteria, rank or score the options, perform sensitivity analysis and finally make a decision. A decision maker specifies the desired outcome as a goal. All criteria along with the associated sub-criteria corresponding to each alternative must be reviewed simultaneously (Nachtnebel 1994; Ganoulis 2008). Finally, different criteria and stakeholders' views need to be resolved within a framework of understanding and mutual compromise (Haralambopoulos & Polatidis 2003). In this regard, AHP is widely used for decision making based on several groups of decision makers (Stirn & Groselj 2010) being involved where groups have conflicts among different interests: stakeholders, owners, managers, ecologists and the public may have similar or specific goals.

Some of the fundamentals of AHP are presented here:

The MCA model is represented by an evaluation matrix x of n alternative and m criteria. The raw performance score for alternative i with respect to criterion j is denoted by $x_{i,j}$. The importance of each criterion is usually given in a one dimensional weights vector w containing m weights, where m_j denotes the weight assigned to the $_j$th 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 alternatives. The MCA algorithms will define, by some means, one or both of these functions (Meseguer et al. 2013):

$$r_i = f_1(w, x)\text{----------------------} \quad (5)$$

and

$$u_i = f_2(w, x) \text{----------------- (6)}$$

Here r_i is an ordinal number representing the rank position of alternative 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 AHP (Saaty 1987) uses pairwise comparison of alternatives. 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 preference for one criterion / option over another in each pair on a nine point scale.

The AHP is based on a set of axiomatic statements or relations (Saaty 1986) which are described below:

1. The reciprocal property that is basic in making paired comparisons. If $P_C(E_A,E_B)$ is a paired comparison of elements (an element is a defined object such as a decision variant or an evaluation criterion) A and B with respect to their parent, element C, representing how many times more the element A possesses a property than does element B, then $P_C(E_B,E_A) = 1/ P_C(E_A,E_B)$. Suppose A is 5 times larger than B, then B is one fifth as large as A.

2. The second, or homogeneity axiom, states that the elements being compared should not differ by too much, or else there will tend to be larger errors in judgement. 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, the need for arranging them within an order preserving hierarchy. Here the hierarchy means that there are functional relationships between elements as less important or, more important.

3. Dependence of a lower level on the adjacent higher level. Levels are differentiated and defined by their internal structure and functions, for example the goal is at the highest level, whereas the second level comprises the selection criteria and the base of the hierarchy comprises the alternatives. The third, synthesis axiom states that judgements about the priorities of the elements in a hierarchy do not depend on lower-level elements. This axiom is required for the principle of hierarchic composition to apply and apparently means that the importance of higher-level objectives should not depend on the priorities or weights of any lower-level factors.

4. The idea that an outcome can only reflect expectations when the latter are well represented in the hierarchy. Individuals who have reasons for their beliefs should make sure that their ideas are adequately represented for the outcome to match these expectations. This is important because the generality of AHP makes it possible to apply it in

a variety of ways and adherence to this axiom prevents applying AHP in inappropriate ways.

Consider n elements to be compared, *C1 … Cn* and denote the relative weight (or priority or significance) of *Ci* with respect to *Cj* by aij and form a square matrix *A= (aij)* of order *n* with the constraints that *aij = 1/aji*, for *i ≠ j*, and *aii = 1*, all *i*.

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

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

A perfectly consistent matrix looks as shown in Table 1 when pairwise criteria (say C1 to C4) are compared for an alternative. That is to say that, because of the reciprocal property if C2 is X times better than C1 then C1 should be 1/X times C2 and then it will be perfectly consistent.

Table 1: Sample of perfectly consistent matrix

AHP Criteria				
	C1	C2	C3	C4
C1	1	X	Y	Z
C2	1/X	1	P	Q
C3	1/Y	1/P	1	H
C4	1Z	1/Q	1/H	1

In real-life judgements, errors are unavoidable. The problem is that pairwise comparisons of elements in the AHP application, with its use of a specific scale may differ from ideal reciprocity. When the matrix size increases then comparison may result differently from a perfectly consistent matrix. This deviation is acceptable in AHP applications provided it is within an acceptable limit. Reviewing the inconsistency in data entry is important for its correction.

To check the consistency of the matrix, the first step is to obtain a normalized matrix. A matrix is normal if and only if it is unitarily similar to a diagonal matrix. Here the matrix with diagonal elements value 1 is used to calculate the normalized weight of factors (criteria).

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

$$w_i = a_{ij}/\left(\sum_{k=1}^{n} a_{kj}\right) \qquad \text{where } \forall\ i = 1, 2, ..., n \quad .\text{--------} (7)$$

The weights are consistent if they are transitive, that *is aik* = *aijajk* for all *i*, *j*, and *k*. Here we can find a vector ω of order *n* such that $A\omega = \lambda\omega$. For such a matrix, ω is said to be an Eigenvector (of order *n*) and λ is an Eigenvalue. For a consistent matrix, $\lambda = n$ but for practical reasons it is different. Hence the Eigenvalue of the matrix developed on the pairwise comparisons is an important step to work out the consistency level of the matrix and thus ensure the reliability of the result of the AHP application. There are many ways of estimating the Eigenvectors of this matrix. These Eigenvectors reflect weights of preferences. Despite the fact that we are able to evaluate the consistency of judgements, the problem of acceptable weights still remains.

The Eigenvalue method computes *w* as the principal right Eigenvalue of the matrix *A* or *w* satisfies the following system of *n* linear equations:

$$A\,w = \lambda max\; w \qquad \text{------------ } (8)$$

where λmax is the maximum Eigenvalue 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 mathematical calculation of the Eigenvector could be based on priority (principal Eigenvector) or the Geometrical Mean. Table 2 shows the important mathematics involved in the AHP application and it is further briefly explained.

Table 2: Sample of Pairwise comparison and further processing in AHP application

AHP Criteria										
	C1	C2	C3	C4	Priority	Geometrical Mean	Lambdamax	CI	RI	CR
C1	1	X	Y	Z						
C2	1/X	1	P	Q						
C3	1/Y	1/P	1	H						
C4	1/Z	1/Q	1/H	1						

C1 to C4 represent the criteria considered

Here the Priority (principal Eigenvector) column is the relative ranking of the criteria produced by dividing each element of the matrix with the sum of its column. Next, the average across the rows is computed. The sum of the priority criteria vector is one. The largest value in the priority weight is the most important criterion.

The Geometric Mean is an alternative measure of the Priority (principal Eigenvector) and is formed by taking the n-th root of the product matrix of row elements divided by the column sum of row geometric means. The Geometric Mean agrees closely with the Priority.

It is next important to determine Lambdamax, which is an Eigenvalue scalar that solves the characteristic equation of the input comparison matrix. Ideally, the Lambdamax value should equal the number of factors in the comparison for total consistency.

For matrices involving human judgement, the condition *aik* = *aijajk* does not hold as human judgements are inconsistent to a greater or lesser degree. In such a case the ω vector satisfies the equation $A\omega = \lambda max\ \omega$ and $\lambda max \geq n$. The difference, if any, between λmax and n is an indication of the inconsistency of the judgements. Following equation (6) λ value for each row is calculated and then average value of them termed $\lambda\ max$. If any of the estimates for λmax turn out to be less than n, this indicates an error in the calculation and needs a calculation cross-check.

With the help of $\lambda\ max$, the natural measure of inconsistency or deviation from consistency, called the consistency index *(CI)*, is further obtained as

$$CI = \frac{\lambda \max - n}{n-1} \qquad \text{---------- (9)}$$

The *CI* measures the degree of logical consistency among pairwise comparisons.

The consistency index of a randomly generated reciprocal matrix from scale 1 to 9, with reciprocals forced, for each size of matrix, called the random index (*RI*) is presented in Table 3. The *RI* is the average *CI* value of randomly generated comparison matrices using Saaty's preference scale sorted by the number of items being considered.

Table 3: 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 (*CR*) = *CI* / *RI*, where the *RI* value corresponds to the matrix size. *CR* indicates the amount of allowed inconsistency (0.10 or 10%). Higher numbers mean the comparisons are less consistent. Smaller numbers mean the comparisons are more consistent. *CRs* above 0.1 means the pairwise comparison should be revisited or revised.

In this way it follows from the calculations that the pairwise comparisons for the evaluation of the alternatives are consistent, because the CR for the comparison matrix is within the acceptable limit (say 10%). The next step in the AHP is to evaluate the specific alternative with respect to the criteria considered. For each criterion separately, we evaluate all the alternatives.

The calculations done so far enable us to create matrix C, whose columns are the Eigenvectors of the pairwise comparisons of the alternatives with respect to all the evaluation criteria placed above them in the hierarchy. Matrix *C* is then multiplied by the preference vector (weight) *w* for the evaluation criteria. In this way we obtain the final preference vector *x* for the alternatives under consideration.

$$x = Cw \text{ ----------- } (10)$$

The other task in the hierarchy is the synthesis of the judgements throughout the hierarchy in order to compute the overall priorities of the alternatives with respect to the goal or objectives. A pairwise comparison scale for the evaluation of the relative importance of factors used in the AHP subjective judgement in accordance with Saaty (2007) is given in Table 4.

Table 4: Scale of pairwise comparison

Intensity of Importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective.
2	Weak	
3	Moderate importance	Experience and judgement slightly favour one activity over another.
4	Moderate plus	
5	Strong importance	Experience and judgement 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 is 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)

5.2.3.3 PROMETHEE

There are a large number of possible criteria to be reviewed for several alternatives in hand in this research. This task is very challenging for the decision maker because of a person's limitation on visualising a large amount of information simultaneously. To visualise and memorise large amount of information applied to alternative comparisons or decision is very tedious. Hence some kind of difficulties (due to increase of criteria and alternatives) in AHP application could be handled by applying PROMETHEE in decision making. Some important fundamentals of PROMETHEE are described here.

PROMETHEE is applied in various fields including resource management, water resources and investment planning and project selections. It is capable of handling large-dimensioned problems. It can handle decision problems with 1000 actions, 10,000 criteria, 50 groups, 50 clusters, 10 scenarios, 10 coalitions and 100,000 evaluations (for details see http://www.promethee-gaia.net/assets/vpmanual.pdf). In PROMETHEE, the term action is used to designate either a possible decision or an item to evaluate. Visual PROMETHEE compares different actions that are evaluated on several criteria. Synonyms of actions used in this research are alternatives, options, etc. Similarly criteria here are the attributes associated to each action that makes it possible to compare the actions and to determine the best ones. Likewise, criteria group defines a sub-set of criteria that share the same outline colour within a cluster in the analysis. A cluster defines a sub-set of criteria within one or several criteria groups. This is the top level of the Visual PROMETHEE hierarchy of criteria. Each scenario contains specific evaluations and preference information. Scenarios can represent the points of view of different decision makers. A coalition is a group of decision makers. The number of evaluations is the product of the number of actions by the number of criteria by the number of scenarios

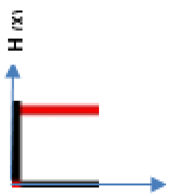
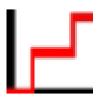
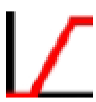
The criteria h6ierarchy in PROMETHEE has three levels: at the top are clusters (goals), intermediate are criteria groups (sometimes referred to as sub-goals) and at bottom are individual criteria or sub-criteria (decisive elements). The PROMETHEE application requires the definition of the objective of the research, the alternatives in hand which are to be prioritized or ranked, all possible criteria with sub-criteria and even elements within sub-criteria. Each element used in decision making should be marked with expected direction of preference, i.e. either to maximize or to minimize. Hereafter, depending upon the decision problem in hand, decision analysis could be based separately on each kind of stakeholder's respective scenario. For example the data processed separately for alternative ranking based on economists could be termed the Economist Scenario and a similar process could be done for sociologists, environmentalists and so on. A number of scenarios can be processed and at the end the results can be compared and even a cumulative analysis of the selected scenarios could be comprehended.

Once the objectives, goals, criteria and alternatives have been defined, the next step is selecting a preference function for each criterion which defines how pairwise evaluation differences are translated into degrees of preference. This reflects the perception of the criterion scale by the decision maker.

For two alternatives named a_i *and* a_k we evaluate their differences over a criteria (j) *represented* function f_j, with their differences represented as $f_j(a_i) - f_j(a_k)$. Usually the preference function $P_j(a_i, a_k)$ is a non-decreasing function of the difference $f_j(a_i) - f_j$

(a_k) between the evaluations of two alternatives a_i and a_k. The value of P_j (a_i, a_k) is a number between 0 and 1. It corresponds to the degree of preference that the decision maker expresses for a_i over a_k according to criterion f_j. Value 0 corresponds to no preference at all while 1 corresponds to a full preference. Six different shapes of preference functions are available in Visual PROMETHEE (Schwartz & Göthner 2009; Radojicic et al. 2013; Mareschal & De Smet 2009) to accommodate most practical situations: these are presented in Table 5. It is to note that while $x= P_j$ (a_i, a_k) values change there could be change on y axis represented as $H(x)$ axis following any of the preference functions (Brans & Vincke 1985).

Table 5: Preference functions used in PROMETHEE

S. N.	Type and shape	Description
1	Usual 	This function is very simple. This is a good choice for qualitative criteria including a small number of evaluation levels (like the often used 5-point scale ranging from very bad to very good). It does not include any threshold. It is useful provided that one feels that a one-level difference is important. In other words, "very good" is much preferred to "good" and "average" is much preferred to "bad" and so on. Here H(x)= 0 for x<0 and H(x) =1 for x>0
2	U- shape 	The U-shape preference function introduces the notion of an indifference threshold. This means up to an extent of differences in values one is not preferred over the other.
3	V-shape 	The V-shaped preference function is a special case of the linear preference function where the Q indifference threshold is equal to 0. It is thus well-suited to quantitative criteria when even small deviations should be accounted for.
4	Level 	The Level preference function is a good choice for qualitative criteria with a larger number of levels.
5	Linear 	Type V, the Linear preference function, (and Type III, V-shape, as a special case) is the best choice for most quantitative criteria. The Linear preference is the best choice for quantitative criteria when a Q indifference threshold is desired.
6	Gaussian 	The Gaussian preference function is an alternative to the Linear one. It has a smoother shape but is more difficult to set up because it relies on a single S threshold that is between the Q and P thresholds and has a less obvious interpretation. It is seldom used.

Another important step is to identify appropriate thresholds. While comparing the alternatives (actions) against a particular criterion, thresholds are applied. Three different thresholds are applied in PROMETHEE as described in Table 6. Depending on the type of preference function that has been selected, up to two thresholds have to be assessed.

Table 6: Thresholds applied in PROMETHEE

Threshold type	Description
Q - indifference	The Q indifference threshold is the largest deviation that is considered as negligible by the decision maker. This means that Q is just below that first significant value.
P- preference	The P preference threshold is the smallest deviation that is considered sufficient to generate a full preference. This means that P is slightly above this last value which the decision maker considers to make a difference in evaluation.
S - Gaussian	The S Gaussian threshold corresponds to the inflection point of the Gaussian curve (similarly to the standard deviation in statistics). It is difficult to assess and as a rule of thumb one could determine a Q and a P value and to set S equal to their average (S = (Q+P) / 2).

While S, the Gaussian threshold is not common, the P and Q thresholds are used almost in every decision making process. For Q one should start with a very small deviation (for instance a few euros) and increase it progressively until it is not felt to be negligible anymore. This means that Q is just below that first significant value. Similarly for P, one should start with a very large deviation (for instance several thousand euros) and progressively reduce it until some hesitation arises. This means that P is slightly above this last value.

The next important task in PROMETHEE is to assign weights to criteria. The weights of the criteria are essential parameters to reflect the preference of the decision maker. The weights are non-negative (> 0) numbers representing the relative importance of the criteria and depend on the priorities and perceptions of the decision maker. In PROMETHEE they are defined independently from the scale of measurement of the criteria. More important criteria have larger weights while less important ones have smaller weights. Weights are normalized automatically in PROMETHEE in such a way that their sum is equal to 1 (100%).

In mathematical terms VP is based on the following set of equations (Mareschal 2013):

The given is a finite set A of *n* alternatives *a* and f_1 to f_k, *representing k* criteria. $f_j(a)$ is the evaluation of alternative *a* on criterion f_j. Then, the task is to maximize all the individual outcomes

$$\max\{ f_1(a), f_2(a), \ldots, f_j(a), \ldots, f_k(a) | a \in A\} \qquad (11)$$

The evaluations of the alternatives on the criteria form two-way multi criteria shown in Table 7:

Table 7: Evaluation of the alternatives against criteria

Criteria →

Alternatives ↓	f_1	f_2	$\cdots$	f_j	$\cdots$	f_k
a_1	$f_1(a_1)$	$f_2(a_1)$	$\cdots$	$f_j(a_1)$	$\cdots$	$f_k(a_1)$
a_2	$f_1(a_2)$	$f_2(a_2)$	$\cdots$	$f_j(a_2)$	$\cdots$	$f_k(a_2)$
$\vdots$	$\vdots$	$\vdots$		$\vdots$		$\vdots$
a_i	$f_1(a_i)$	$f_2(a_i)$	$\cdots$	$f_j(a_i)$	$\cdots$	$f_k(a_i)$
$\vdots$	$\vdots$	$\vdots$		$\vdots$		$\vdots$
a_n	$f_1(a_n)$	$f_2(a_n)$	$\cdots$	$f_j(a_n)$	$\cdots$	$f_k(a_n)$

-- (12)

The simplest and most often used way is to compute a weighted sum (or weighted average) of the evaluations:

$$V(a) = \sum_{j=1}^{k} w_j \times f_j(a) \qquad \text{----------} \quad (13)$$

where:

- *wj* > 0 is the weight allocated to criterion *fj* (the more important *fj* the larger *wj*),
- *V*(*a*) is the resulting score of action *a*.

The next step is to enter the data corresponding to criteria and alternatives. These can be quantitative as well as qualitative. Every alternative should be evaluated, compared and positioned with a proper value or ranking corresponding to each criterion. This requires either entering the absolute value like cost, years of life, etc., or providing qualitative values like good, bad, etc., in a predefined classification. The comparison follows a similar method to the Analytical Hierarchy Process (AHP) but the difference is that number of comparisons in PROMETHEE decreases while resulting in ranking in much better ways. Pairwise comparisons of alternatives are done by computing a multi criteria preference index in the following way:

$$\pi(a,b) = \sum_{j=1}^{k} w_j \times P_j(a,b) \qquad (14)$$

where:

□□$wj > 0$ is the normalized weight allocated to criterion *fj* (the more important *fj* the larger *wj*). And also

$$P_j(a,b) = f_j(a) - f_j(b) \tag{15}$$

□□Pj (*a*,*b*) is the value of the preference function for criterion *fj* when action *a* is compared to action *b*.

With normalized weights (as discussed in Section 5.2.3.2), π (*a*,*b*) is a number between 0 and 1. It expresses the degree to which *a* is preferred to *b* taking into account all the criteria and their weights. It results that an ideal action would bear a positive flow ($\emptyset^+$) preferably equal to 1 and a negative flow ($\emptyset^-$) preferably equal to 0. Ranking of alternatives is computed based on the sum total contributions of each criterion to a specific alternative. For each alternative the preference flows are calculated as follows:

$$\emptyset^+(a) = \frac{1}{\mathrm{n}-1}\sum_{x\in A}\pi(a,x) \tag{16}$$

$$\emptyset^-(a) = \frac{1}{\mathrm{n}-1}\sum_{x\in A}\pi(x,a) \tag{17}$$

The positive preference flow $\emptyset^+$(***ai***) quantifies how a given action ***ai*** is globally preferred to all the other actions while the negative preference flow $\emptyset^-$(***ai***) expresses how a given action ***ai*** is globally preferred by all the other actions. The net contribution of those criteria is calculated as

$$\emptyset_{NET} = f(\emptyset^+) - f(\emptyset^-) \tag{18}$$

Different PROMETHEE versions have been elaborated (Behzadian et al. 2010; Oberschmidt et al. 2010). The simple approach PROMETHEE provides partial ranking, based on the computation of two preference flows ($\emptyset^+$ and $\emptyset^-$). It allows incomparability between actions when both $\emptyset^+$ and $\emptyset^-$ preference flows give conflicting rankings. Another approach called PROMETHEE II provides a complete ranking of alternatives based on net preference flow $\emptyset_{NET}$.

5.3 Case study selection

Collecting relevant data from the field arranged from the selected representative sites is discussed in this section. To test the proposed methodologies described in chapter 4 and verify the suitability of the criteria, a case study from the field is necessary. In this regard identifying the sample sites is an important task. Following aspects were considered when selecting sample sites:

(i) The research on developing a decision aid framework could better benefit from field data obtained from completed hydropower project sites.

(ii) Hydropower schemes for field visits are identified from plants completed recently so that detailed information could be obtained.
(iii) To fit the research's time and resource constraints, sites are selected which are easily accessible for information collection.
(iv) Among the five scales of hydropower generating schemes classified in Nepal (WECS 2010b), micro schemes are the largest in number followed by small and then by medium. Similarly in the total power generation contribution in the country, medium-scale schemes contribute the highest amount of power followed by large and then small. Hence the most suitable scale of schemes representing both number of schemes and contribution to power generation in the country is the small-scale generation schemes, which are thus considered for the case studies.
(v) Sample sites are selected from two of the regions (out of five politically defined development regions in Nepal, East, Mid, West, Mid-West and Far West) having more of a concentration of small-scale schemes.
(vi) The sample sites selected are from two out of three major river basins in the country.

There are almost 40 small schemes of 1 to 25 MW capacity in the country (NHA 2009). A sample size of 10 to 15% may represent the reliable data and hence a minimum of four to six site visits seems reasonable to obtain reliable results. Six already operating small-scale hydropower schemes are selected. To organize the research within the available time and resources, they are confined within two clusters from two regions, each consisting of three schemes. The clusters are from the districts of Sindhupalchowk in the mid region and Parbat in the West region of Nepal. This also represents two out of three major river basins (see Section 5.1) in the country. The sample sites selected in their two clusters are shown in Figure 14.

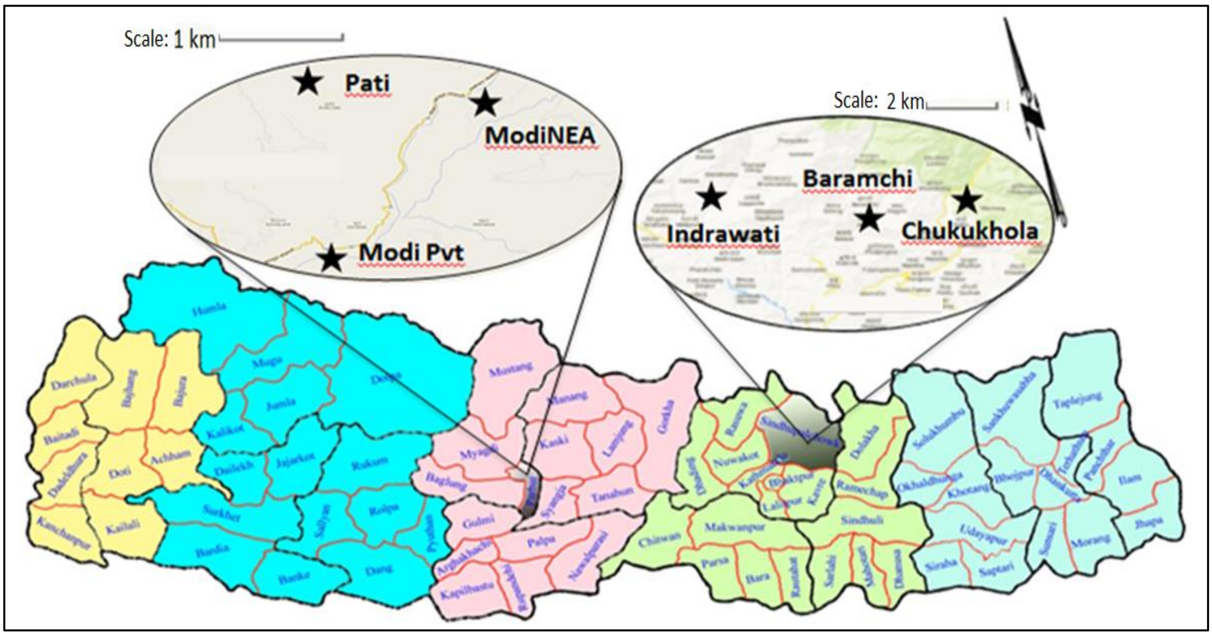


Figure 14: Location and clusters of selected hydropower schemes for field study

Table 8 summarizes information about the selected case studies. As we can see all the projects were recently completed after 2000 and all belong to the small-scale category of hydropower defined in Nepal. Further details of the case study sites are presented in the following section.

Table 8: List of projects studied

S.N.	Name of Scheme	Capacity (MW)	Location District	Owner	Year Comp.	Cost $/kW (2013)
1	Chaku Khola	1.5	Sindhupalchowk	Alliance Power Nepal, Pvt. Ltd.	2005	3452
2	Indrawati	7.5	Sindhupalchowk	National Hydropower Company	2002	3442
3	Baramchi	4.2	Sindhupalchowk	Unique / Hydro Solutions	2010	2222
4	Modi (NEA)	14.8	Parbat	Nepal Electricity Authority	2000	2734
5	Modi lower	10	Parbat	United Modi Hydropower Pvt. Ltd.	2013	2342
6	Pati	1	Parbat	Unified Hydropower Pvt. Ltd.	2006	2330

5.3.1.1 Sindhupalchowk cluster

The total area coverage of Sindhupalchowk district is 2542 km^2, of which forest covers the largest area, comprising 30.5%, followed by cultivated land 29% (DDC Sindhupalchowk 2011). The majority of the population is engaged in agriculture (78%) whereas only a small percentage are involved in business, enterprises or the service sector. A similar pattern of land use is seen in the project sites. Sindhupalchowk is very rich in water resources. Bhotekoshi, Sunkoshi, Balefi / Bramhayani, Indrawati and Melamchi are the main rivers of the district. There is a high possibility for hydropower development in the district. Currently several micro- to megawatt schemes are operational or under construction, and many schemes are under study or in the pipeline for future development (NHA 2009). As this district is close to the capital and the major load centre, developers are most interested in this region.

Three power plants are selected for the case study from this cluster: Baramchi which is also represented by short name (B), similarly Indrawati also represented by (I) and Chaku by (C). Further details about each power plant are presented in the following sub-sections.

(i) Baramchi hydropower: Chanaute (Baramchi)

The Baramchi hydropower project is situated in the Baramchi VDC of Sindhupalchowk district. The plant is a run-of-river type and was initiated with 1 MW capacity. Recently the plant capacity was upgraded to 4.2 MW. The project has one of the highest heads (615 m) in Nepal. The generated energy is evacuated via a new 18 km 33kV transmission line to the NEA sub-station at Lamosanghu. The site and surrounding region has good potential for business and enterprise growth specifically for agro-based industry, Himalayan herbs and agricultural products, mainly potatoes. The proposed Balephi–Tembathan district road passes through this region, which could further enhance future business growth in the region.

Figure 15: Baramchi hydropower plant site

Figure 16: Baramchi hydropower site location

(ii) Indrawati hydropower

The Indrawati III hydropower plant is located in the Jyamire VDC of Sindhupalchowk district. The project site is close and has good road access to the market town of Jyamiremane. The project area consists of three Village Development Committees, consisting of a population of 7500 who are mostly farmers, traders and service holders. This place is very good for agriculture and the project area has several facilities like schools, health posts, shops, rice mills, electricity, telephones, cooperatives, forest-based small industries, etc. This power plant has paved the success story of the private sector in hydropower development in the country.

Figure 17: Indrawati III powerhouse

The power plant is located at Jyamire near Melamchi at the convergence of the Indrawati and Melamchi rivers. This 7.5 megawatt privately owned run-of-river cascade scheme, located roughly 100 m downstream from the confluence with the Lapse Khola, has been operational since 2003. The project is located within the mid-hills of the mountain area at an altitude of 2000-2500 m above sea level.

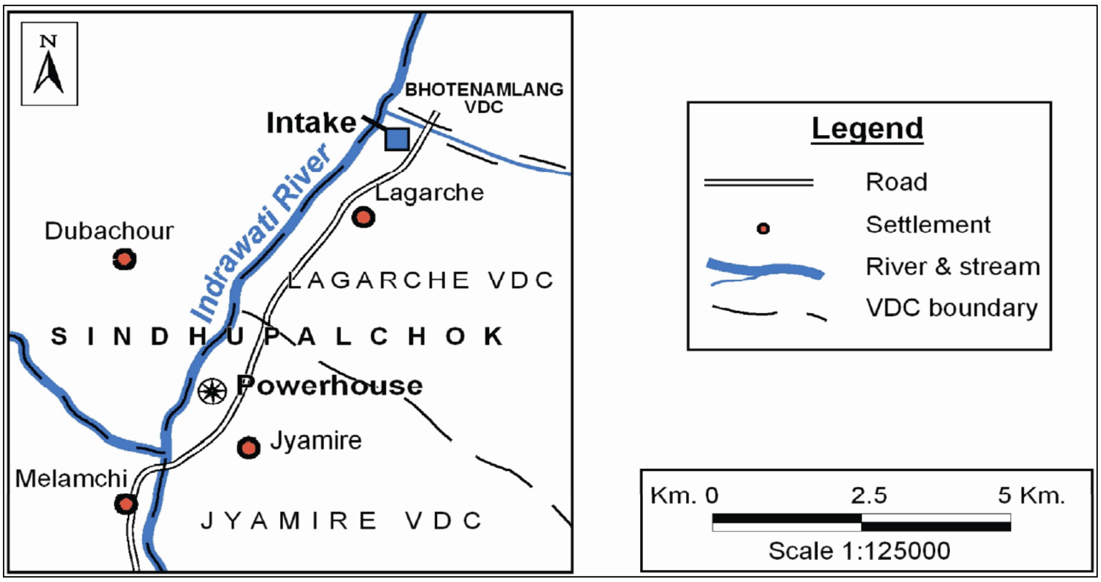


Figure 18: Location of the Indrawati river basin

Source: (Khadka et al. 2011)

Indrawati is a snow-fed river originating from the Jugal Himal range and the sedimentation in the river is quite high. The maximum flow of the Indrawati River near project area is 40.5 m3/sec on average and the minimum flow is 6.5 m3/sec recorded during February to March (Khadka et al. 2011).The scheme is allowed to divert up to 30% of the river, but field observations indicate that a much higher percentage of the flows are actually diverted in the dry season, as shown in Figure 19, leaving little for in-stream uses like fisheries.

Figure 19: Indrawati intake of power plant during dry season

Source: (Bartlett et al. 2011)

Water in the Indrawati is used for irrigation, drinking water, livestock, hydropower, water mills, and natural ecosystems. Agriculture is the main consumptive use. Due to the lack of a functional and sufficient storage infrastructure, the inter-annual fluctuations often have direct ramifications for downstream populations and basin food security.

(iii) Chaku khola hydropower: Chaku Bazzar

The Chaku khola hydropower plant is located in the Marming VDC and is a run-of-river type plant with an initial capacity of 1.5 MW. The plant was developed by the private company Alliance Power Pvt. Ltd. This power plant is one among the first few developed by the private sector in Nepal. It has worked as an eye opener as well as a confidence builder for private sector participants. Because of its remoteness and site conditions, this plant's construction cost was comparatively high. However this plant motivated many investors in the region and as a result several small plants are under construction and upgrade in the region.

Figure 20: Chaku khola hydropower

The project is close to the Araniko highway on the border of the Marming and Fulpingkatti VDCs. Nearby settlements are Gunsa, Sarpamang, School danda, Pokhari, Chandraku, Deudhunga, Jhirpa Hindi, Fulpinge and Lukusing. There are facilities like schools, health posts, agriculture/veterinary service centres, post offices, cooperatives and electricity in the project area. The majority of people are farmers but their agricultural produce is not sufficient for their needs. Hence many people from the project area work outside their village to support their family needs. Through the project installation, many people from the project area became experienced as skilled or semi-skilled labourers and are now involved in other hydropower project implementations in the region.

Figure 21: Interacting with project stakeholders at the tail race of power plant

5.3.1.2 Parbat cluster

The Parbat district is located in the west of Pokhara and connected by the Pokhara Baglung road. This district is full of hydropower potential. Several projects are under construction in addition to a few that already exist. Many private investors both from Nepal and from abroad are interested in this region for hydropower development. Due to the existing national grid, road infrastructure and power demanded by industries and also tourism, this region is very attractive for hydropower development.

As in many other parts of Nepal, the majority of people in the region are engaged in agriculture. Also due to good tourism in the vicinity, many people are engaged in the tourism sector, cottage industries and the like. In this region, economic conditions are comparatively better and there are plenty of livelihood opportunities. Because of the well-off population in the region, hydropower development with private sector interest could expand fast in the region. This region is so far developing several small and medium-range power plants and is one of the most promising regions for private investors. Road access reaching near to the plants and proximity to the national grid also favour new hydropower development in this region.

Figure 22: Modi River and area

Three power plants are selected for the case study from this cluster: the Modi scheme developed by Nepal Electricity Authority represented by short name (**MN**), Modi private represented by name (**Modi**) and Pati by short name (**P**). Further details about each power plant are presented in the following sub-sections.

(i) Modi (NEA) hydropower

The Modi khola hydropower plant developed by the NEA was the first hydropower plant in this region. It has successfully attracted many developers to the vicinity. Through excellent project implementation and successful demonstration, the project has created the infrastructural support required for new power plants like grid, sub-stations, access roads, skilled labour and awareness of the benefits of hydropower to the country, etc. The Modi khola hydropower is a peaking run-of-river type power plant with an installed capacity of 14.8 MW. It is located in Dimuwa in the Parbat district. Toad access to the site is easy and it is close to the highway connecting Pokhara and Baglung. The plant was funded through the Government of Nepal, the Nepal Electricity Authority and Korea. It was completed in 2000 and is one of the reliable power contributors to the national grid. With a total of 510 km^2 of catchment, this plant was constructed with a 67 m head and 27.5 m^3/s of discharge.

Figure 23: Modi hydropower project developed by NEA

Near to the plant are many enterprises and people are happy with the plant owner (NEA) for bringing development to the region. Activities relating to social awareness and gender empowerment can easily be seen in the project area.

Figure 24: Interacting with entrepreneurs in the project region

(ii) Modi (private) hydropower

Lower Modi is a hydropower plants studied, designed and developed by Nepali professionals. This plant is on the Modi River, a perennial water source that however contains a lot of sediment along its flow. This 10 MW capacity plant was completed in 2013. Everything except the electromechanical equipment and accessories used in this plant are from within the country. It is on a river where one plant (Modi NEA, 14.8 MW) is already in operation and several others are under construction and/or in the preparatory stages. Water discharged from one project becomes intake for another project and thus reduces much civil work on intake canals and river training for the next cascaded hydropower plant development.

Figure 25: Modi (private 10 MW) intake

This plant is very cost-effective because of the already existing support infrastructure of access roads, power grid etc. and also works like awareness, river training, procedures and systems established for participation completed by earlier hydropower plants. Similarly the information, experience available and facilities created in the region have benefited the project in several ways.

Figure 26: Interacting with project officials

(iii) Pati hydropower

The Pati Khola hydropower project is located in the Parbat district close to the other two projects in this cluster. It is on a stream contributing to the Modi River and the project site is also named Pati Khola. This area is covered with forest and agriculture is the main earning source for livelihoods. A small stretch of earthen road connects this village to the national highway, which made this project investment attractive in comparison with other sites which usually demand investment in support infrastructure. This project could be one example to demonstrate how villages can benefit from small streams existing in the village which could be turned into commercial entities like hydro resources for the country. The site location is presented in Figure 27.

Figure 27: Site location of Pati Hydropower project

The generation capacity of this plant is nearly 1 MW (996 kW) and it was developed by a private company. The generated power is hooked to the national grid. This plant is one among several developed after a policy was formed to include plants up to 1 MW under micro-scale schemes, making them eligible for subsidies. Many such scaled plants are these days under operation and many are in the developmental phase. Such projects are a showcase for rural villages to benefit from available small streams feasible for generating power.

Figure 28: Interacting with beneficiaries in the project region

5.4 Summary and conclusion

Three ways proposed to analyse the hydropower in Nepal are analytical analysis followed by two different applications of AHP and finally PROMETHEE. To finalize the decision draft and test the field applicability of PROMETHEE, a set of six sample hydropower sites nominated following a certain procedure. The selected hp sites generation capacity ranges from 1 to 15 MW and hence falling in small scale hydropower schemes. In the next Chapter those MCDMs will be applied and further results will be presented.

6 Applications

This chapter describes the application of the selected methodological tools explained in Chapters 4 and 5. They are broadly divided into two types of applications, based on general available information and MCDM applications and another MCDM application for the case studies. The different applications of MCDM are based on (i) general assessment of hydropower at the national level based on secondary data and expert opinion, and (ii) comparative assessment of case studies to field test the effectiveness of MCDM tools and the reliability of the decision framework proposed. Further details are presented in the following sections.

6.1 General available information and MCDM for hydropower in Nepal

Hydropower-related information is of various types and available via different sources. The requirement here is to collect the maximum relevant information and arrange it categorically. The easiest source for collecting such information is through secondary sources. These are analysed applying different MCDM methodologies to obtain some useful information to continue further research or analysis. Each methodological application delivers certain outputs which serve as inputs for the next MCDM application. Here the MCDMs are applied in three steps: (i) perspectives analysis, (ii) AHP applications based on secondary data obtained from perspectives analysis and (iii) AHP application based on the electronic questionnaire survey of experts. Each of them is discussed separately in the following sections.

6.1.1 Perspectives analysis

This analysis is basically an assessment of different scales of hydropower schemes based on their generation capacity. To identify the best scale of generating schemes (as an objective), various information is gathered from various secondary sources. Furthermore, the information is organized and analysed under nine different perspectives of hydropower and thus the analysis is given the name perspectives analysis. Each piece of information under the corresponding perspectives is reviewed minutely and described separately.

Sources used for information collection are published scientific articles, reports, books and manuals, news and media coverage and web links related to hydropower development in the Nepalese context. The majority of the reviewed documents are national and regional documents, not available via the Internet, sometimes not in English. Hydropower-related scientific journals published from Nepal like Hydro vision, Vidyut and Urja are good sources of information. Project reports and web links for important institutions such as the Department of Electricity Development (DOED), Nepal Electricity Authority (NEA), Water and Energy Commission Secretariat (WECS), Nepal Rastra Bank (NRB), Ministry of Environment, Science and Technology (MOEST), Alternative Energy Promotion Center (AEPC), Ministry of Water Resources (MOWR), Ministry of Energy (MOE) and others are very useful sources of information. News and daily media updates on related subjects are reviewed for the last 3-4 years.

Technical perspective

Some important technical components to be considered are country status in hydropower equipment and accessories, engineering studies and design, project implementation and operation and transmission and distribution.

Hydropower equipment and accessories are mainly of two types, electrical (generator, control and switch gear, transformer and cables/wires) and mechanical (turbine, penstock, gates and valves, manifolds, frame and support structures, poles and towers) and civil (diversion dams or weirs, powerhouse, river training, canals). The in-country capability regarding equipment and accessories is available for micro-scale hydropower except generators (Chhetri et al. 2009). Similarly for small-scale hydropower, the country is capable of managing the required equipment and accessories except turbines and generators. Medium-scale hydropower heavily depends upon imports of generators, turbines and switch gear and this will also be the case for big and large hydropower.

Hydropower project study and preparation mainly consists of survey and design (site survey, river training, dams, powerhouses, tail races, E/M systems, power evacuation, transmission and distribution), documentation, approvals, tendering and award of contracts. Within this scope of work, the country has established good capacity for all hydropower schemes from the micro to medium scale. So far for big schemes, Nepalese professionals have gained partial experience working with international experts (e.g. Kali Gandaki 144 MW and Upper Tamakoshi 456 MW) and thus we could expect big hydropower implementation solely by Nepalese experts in near future. However as of today, for big hydropower, the country needs the partial support of international expertise. Regarding large hydropower of more than 1000 MW capacity, Nepal has extremely limited workforce in terms of both quantity and quality. Hence for large hydropower country has not yet shown any capability to manage this scope of work.

The next important technical matter is country capability in project implementation and operation. In this regard, the country's capability is well established for micro and small hydropower schemes. It is also important to note that while the country has partial capability for medium hydropower implementation, support from neighbouring China and India is readily available (Tong 2008). Some Nepalese developers are entering into medium-scale hydropower development with support from external partners. Regarding big schemes, Nepal is still learning and building confidence through the implemented hydropower plant at Kaligandaki (144 MW), the on-going hydropower plant at Upper Tamakoshi (456MW) and a few others.

The power generation and operation of hydropower is another technical aspect. While the country has already proven its capability to operate and manage hydropower operations up to the small scale satisfactorily, it still depends upon outside support for the repair and maintenance of medium and big-scale hydropower (and this applies to large hydropower projects in the future). This factor increases dependency and may hinder the reliability of power availability.

The power generated needs a grid for its transmission and distribution and this is an important aspect while reviewing the technical perspective. The existing power system is important for the cost-effective accommodation of new generating plants. The existing power grid is already suffering high technical (mainly of power dissipation in electricity system components) and non-technical (mainly caused by theft, meter tampering and commercial system inefficiencies) losses (Nepal & Jamasb 2012) although a noticeable improvement in loss reduction has been reported more recently (Chaudhari 2013). Immediate transmission expansion (World Bank 2001) and a power-balanced grid system is urgently required for selecting the portfolio of candidate projects. While new micro or small-scale hydropower plants could easily be integrated at many places of existing national power grid, medium-scale hydropower could only be accommodated at limited places. It is basically conditions caused for power flow in the grid which make the losses high. In this regard, micro- and small-scale hydropower schemes have the advantage, as do medium schemes to an extent, but big or large hydropower schemes need investment and time to increase grid capacity. From the grid balance and requirement point of view, large-scale schemes are a distant dream but big-scale schemes seem feasible. Based on the technical perspective alone, smaller schemes are better fitting followed by medium and micro schemes.

Social perspective

Hydropower development is meant for people and must be seen within the social perspective. Social perspectives of hydropower may cover access, reliability, social benefits (empowerment) or threats, resettlements, involvement, inclusion, etc.

The majority of the population (nearly 80% of total population) of Nepal resides in villages (CBS 2014) and many of them are far from existing national power grid. Micro-scale schemes are popular in rural or remote from electrification areas where grid access is expensive and would take many years to arrive. The majority of the population living in rural villages has access to electrical energy generated by hydropower through decentralized or mini grids as a viable solution. More than thousands of such systems (AEPC 2011) are in operation and strong social capital has already been built in the country. It may be wise to pursue micro-hydroelectric development as an entry to bring electricity to remote areas and this concept has been appreciated globally (Saghir 2009). One of the drawbacks of micro- and small-range generation is limited power generation through local rural grids. Several institutions and experts recommend decentralized generation, which is mostly accomplished by run-of-river schemes requiring no land for reservoirs.

Although micro schemes are popular in the country, an increasing number of developers and contractors are developing small-scale schemes, especially since the restoration of democracy. Several such hydropower plants are already in operation and many (at least hundred sites) of various size are under construction or planning as can be seen from DOED web (www.doed.gov.np). This is because of government facilitation with strong policies on private sector and community participation. This builds trust because of the close interaction between the benefiting communities and developers, especially if they are from in-country. This trust leads to resolving any arising conflict and particularly land issues which they can manage with cooperation and understanding at the community level. The advantage of such a scale of hydropower is that it produces a significant amount of power and is connected with the national power grid, hence provides a more reliable electricity supply for a wider range of the population and meets the energy needed for services, industries and enterprises.

Recently a few Nepalese developers and contractors have been involved in medium-scale hydropower development (see Figure 5). Experience from the Chilime hydropower station with a capacity of 20 MW (though belonging to small hydropower schemes) developed in 2003 where community participation and support were exemplary (Bhattarai 2005; Dixit & Basnet 2005) can be replicated elsewhere in the country. Medium-range hydropower may require significant land acquisition. This could be critical to arrange but manageable because of community involvement in many cases. It produces a good amount of power and through the national grid serves the wider population and hence is understood as better than big or large plants which may have an energy export objective. This scale of hydropower ensures more power with more reliability and all sorts of social benefits and is treated as the best in the social perspective. Developing this range of power plants could be a stepping stone for marching towards big-scale hydropower in the coming years.

For big-scale projects, land acquisition from the government is a complex issue and so is displacement or resettlement of affected people. Hence such plants promise opportunities, benefits, social capital formation (a trained and skilled workforce for the nation's hydropower and infrastructure sector development) but are full of challenges such as rehabilitating the displaced population, providing support and skills for their livelihood, manging the transition from the old lifestyle to adapt to new conditions and others. Medium-scale hydropower plants under discussion are Budhigandaki (600 MW), Nausyalgad (400 MW) and under construction are Upper Tamakoshi (456 MW) (NEA 2013), Rasuwagadhi (111 MW) and Middle Bhotekoshi (102 MW). In some cases big projects and almost all large schemes are opposed by locals because of social issues making the project progress at risk. These schemes are instrumental in building confidence and expertise to replicate in the future and thus will be a strong contributor to social capital building. However such big-scale schemes are targeted with external support and for energy export purposes. This reduces the potential social benefits from this scale of hydropower for Nepalese people and a serious issue among the experts in the country.

From a social perspective, large schemes are the least preferred option at this point of time in the Nepalese context. Large schemes are mainly for energy export to neighbouring countries and hence have no significant social benefits or contribution to electrification coverage within the country. Micro schemes are readily accepted but due to the small amount of power generation, they provide limited electrification coverage and social benefits. Small hydro schemes seem promising because they enhance social capital offer a significant amount of power contribution. With more power generation and better coverage capacity, medium-scale schemes look most appropriate from a social perspective.

Economic perspective

Economics related issues of a project are reviewed both specific to local context as well as national context. The economics of the project evaluated in terms of all kinds of investment in it and every possible benefit from it. At the same time, somehow projects need investment and thus investors wish to review the plant with financial details to ensure their expected benefits from the project. Another important point is the developers involved who borrows from financers and work complying with national regulations and must evaluate the project in their own perspectives regarding what they can manage and how far they can reach in their objectives of benefit in monetary terms or any other opportunities. Hence an economic perspective is further elaborated in following sections as the general economics perspective, financing perspective and project developer perspective.

General Economic perspective

Economic benefits could already be generated from the start of project implementation by utilizing local resources which in turn strengthen the local economy. Several required construction materials like cement, concrete/pebbles, sand, etc., are available and are of good quality and quantity. Infrastructure like bridges, roads and the grid developed in recent years enhances the economic viability of hydropower. Micro-, small- and medium-scale plants which are comparatively easy to implement could best benefit from local resources and existing infrastructure. In the case of big- and large-scale plants, some imports of materials like cement and steel are necessary. Also investment for developing major support infrastructure of roads, bridges, the grid and hydromechanics is required. Investment mobilized with due diligence is most important to ensure economic return from the project and hence especially the big or large schemes where very high funding is required may be risky for existing Nepalese capacity. However, larger-scale projects could better benefit from economies of scale and could contribute significantly to strengthening the national economy. Specifically, when one third of the country's population is unemployed youth, many working as poorly paid labourers outside the country (CBS 2012), big- and large-scale projects could be the best choice to create more opportunities for economic activities. Hence the necessary preparation and in-depth evaluation of project economics must be undertaken to facilitate large-scale projects in the long run (Bergner 2013).

With regard to the immediate energy need for strengthening the country's economy, potential primary (revenues and power availability) and secondary economic benefits (e.g. Services, enterprises and indirect employment created) and resources available are most important to review. In this respect, it is big schemes which suit the country best. Large schemes could be preferred in the long run (MOP 2014) but presently they receive low preference because of their energy export-oriented approach which debars the nation from the best possible economic benefits. Medium and small hydropower are attractive and preferred correspondingly. Micro schemes have limited contribution due to their low power generation at a comparatively higher cost.

Financing perspective

Government investments and public budgets have proved insufficient to expand access to electricity (Sovacool 2013). Recently, micro schemes with near to 1000 kW generation capacity are increasingly financed by the private sector. These micro schemes are eligible to receive subsidies and licensing and approval are also easy. Projects near to the existing grid are attractive for investors as they can connect to the national grid for electricity sales. The increasing size of hydropower projects requires more investment and this makes Nepalese investors stumble. The implementations of several hydropower schemes, even on a small scale, have been halted due to funding paucity. However there seems to be a great deal of funding available within the country. Money deposits in the banks total Nrs 1109392 million (NRB 2013) and a certain percentage of this could be used to fund a few hundred MW. Similarly, remittances in Nepal exceed Nrs 500 billion per year (World Bank 2011) and prospects of direct foreign investment are also bright provided the government works out the appropriate mechanism (Adhikari 2013). With empowering settings, mobilizing soft loans and grants, equity investment and local investment could meet the funding need for several small to big schemes. In addition, an annual allocation of 15 to 20% (Nrs 25,000,000,000 equivalent of US$ 300 million approx. at the exchange rate of Nrs 85 for 1 US4) of the national budget for the coming 4 to 5 years could provide the funding for generating the required power to bridge the demand/supply gap (Jha 2012).

The risk of investment in hydropower is relatively high due to the indispensable technical preciseness, the need for huge funds and the longer gestation and repayment periods. Hence financers are hesitant to make huge investments; they prefer entering gradually by taking small exposure and share risks amongst various banks and consortium financing. So far, the financing sector has preferred small-scale hydropower development, but following the recent success stories of a few small and medium hydropower projects, the sector's confidence has been developed for medium and bigger schemes.   One such example is Upper Tamakoshi scheme (456 MW).

Financial resources available within the country could meet significant funding requirements provided appropriate financial exploration is carried out. With available resources and willingness of financing partners, medium-scale schemes seem most feasible, followed by small-scale schemes. Large schemes are not feasible on the basis of national financing and are the lowest priority for now. For small hydropower schemes, many private sectors are already involved and getting more interested in medium-scale schemes to benefit from economies of scale, but are still afraid to invest in big schemes. Micro schemes are not attractive for private investors (UNDP 2007) mainly because of the low load factor (WELink/Neha 2003; Urmee et al. 2009; Yang 2006), high upfront cost and connecting poor consumers unable to pay revenues (Gurung et al. 2013) and lacking appropriate linkage with livelihoods (Bastakoti 2006; Mahat 2004), although the government is providing strong support in terms of grants and subsidies. Such subsidies are funded by donors and these projects' sustainability could be at risk if donor support stops(Pokharel 2003).

Project developer perspective

Project developers are the one (could be individual or group) who owns and manages the project. The project developer of hydropower views the sector within his own perspectives and interest, whereas economic perspectives examine the project in terms of total economics (ranging from local level to national level economics of project) and financial perspectives mainly review the financers or financing institutions' point of view. In the hydropower sector, either a developer develops a project with organized finance from different sources and mobilizes everything required for project implementation or may invest partly. Hence their views are very important to understand the hydropower sector. In Nepal there are more than hundred groups of power project developers and they are well-institutionalized. There are two important associations: the Independent power producers (IPPP) and International Independent power producers (IIPPP).

Earlier interest of developers in small and medium plants has strongly changed towards big-scale projects (see Figure 5). Comparing licence numbers and cumulative generation issued as per the NHA 2009 report and DOED website retrieved on July 2014 confirms that cumulative generation from small schemes is decreasing, that from medium and big schemes is increasing but large schemes remain at the lowest. Micro schemes are increasing in generation but the number of licence requests is decreasing.

Because of falling prices of electromechanical equipment, confidence built, and with the improving political situation in recent years, developers' interest is shifting towards medium- and large-scale projects. Still the majority of developers are afraid of cost or time overruns (Sovacool et al. 2014), which limits their interest in the small and medium range. Huge upfront costs, long gestation periods and uncertainties prevent developers from investing in big- and large-scale schemes. Due to several constraints compounded with lack of experience, Nepalese developers are highly interested in small followed by medium schemes. Recently, big schemes of a few hundred MW are also attracting some developers. Micro schemes are not interesting for developers whereas large schemes are beyond their consideration.

Environmental perspective

Environmental concerns are gaining more attention today in Nepal and it is a priority agenda for water resources and hydropower development (WECS 2005). They are closely related to the site, type and size of power plants. Sediments in rivers are a very common and serious problem in Nepalese rivers. This can be understood through the fact that thousands of hectares of productive agricultural land has already been damaged in the country due to sedimentation (LRMP 1986). Nepalese rivers carry around 336 million tons of soil per year (Brown 1981), causing river bed aggradation at a rate of 35-45 cm annually (Dent 1984) increasing incidents of land slides and flooding. This can influence hydropower projects with variations in river courses, water availability (quantity), water quality, storage of reservoir and several other ways. Hence one must consider these factors while planning hydropower development. Sediment can significantly reduce the performance and lifetime of turbines (Thapa 2004). In most cases sediment depositions will reduce the storage capacity and may affect the inflow to turbines. Direct physical impact on turbines adversely affects project economy. Due to sedimentation in the Kulekhani hydroelectric project, its economic lifetime reduced to 30 years from the planned 100 years and so the BC ratio dropped to 1.59 from 2.59. Big reservoir-based schemes are critical in this respect, where the sediment deposition rate is directly proportional to the magnitude of the hydropower project (Thapa et al. 2005). Reduction of sediment impact is important for the life of a hydropower plant and thus sediment management in the reservoir is a critical factor and complex task. Reducing reservoir sedimentation needs terracing, afforestation, bio engineering and flushing off, which is not only challenging but also very costly.

Climate change is a global issue and the increasing temperature reduces snow coverage in many parts of Nepal (ICIMOD 2011). Cases of outbursts of glacier lakes in the Himalayas cause increased number of flash floods which can be damaging to run-of-river plants (Agrawala et al. 2003). With regard to seismicity, inundation and river endurance, bigger size, high dam and storage type power plants need extra care, precautionary measures, high levels of expertise and strong institutional coordination to minimize the loss. We must look into issues relating impacts on biology, interruption of river continuum, change of habitats and so on. Within this context, up to the lower big scale (say up to 500 MW) of hydropower, Nepalese expertise and capability can be trusted but not for hydropower above this capacity. Further considering the fragile geology of the Nepali Himalaya, developing big or large schemes is not favoured, mainly because of huge water storage and heavy dams creating huge pressure which could be disastrous if it failed. In addition, the seismic threat disfavour such schemes. On the other side, comparatively lower-scale hydropower schemes (micro, small and medium), especially the run-of-river type, stands better in comparison with big and large schemes in respect to many of the environmental threats. Medium schemes may have small threats due to seismicity and sedimentation but still can impact the river continuum, aquatic life and riparian life adversely. Micro schemes are adversely impacted due to global lake outburst floods (GLOF) many times in the past (ITDG 1998). Comparatively small hydropower projects in Nepal seem best suited to the environmental aspects of hydropower development and next best is micro schemes. Medium schemes are preferred but only with additional precautionary measures, while big schemes are less preferred, and large plants are at the lowest preference from environmental perspectives.

Political perspective

The political environment in the country is crucial for hydropower development. Hydropower development plans are worked out at national level and executed at local level. Hence policies and executions involve several stakeholders, ministries and institutions, including local level organizations and also international organizations working in the local context. The hydropower sector suffers heavily from lack of coordination or extremely poor coordination, lack of clarity on roles and responsibilities, missing accountability or lack of established workflow. In this regard, at present decisions on micro-scale hydropower which is authorized at a local level (district and community) are easy to implement, although financial support (subsidy) decisions anchored in national level approval still make progress time-consuming. Similarly small-scale schemes which until recently had to comply with strict regulations, have recently been revised with fewer restrictions for licensing, and thus such schemes' development is progressing well. One new development for medium schemes was announced recently in 2017, where licensing for plants up to 100 MW have been fast-tracked within the authority of the DOED and definitely give these scales of plants fast development. Unfortunately, for big- or large-scale plants the existing approval policies and strategies are complex and coordination among several stakeholders is involved. This will definitely slow the progress but seems necessary for the country to ensure national benefit, sectoral long-term safety and national security. Big- and large-scale energy projects with an export earnings objective are frequently discussed at the national policy makers' level. However it is a general perception in the country that instead of making hasty decisions, these projects require careful evaluation in the best national interest.

The energy vision of the national government is to meet the demand for energy services of the people of Nepal by ensuring security, sufficiency and sustainability for poverty reduction and economic development through the efficient use of indigenous energy resources.

Within the last two decades one can observe how frequently governments have made changes in policy, strategy, priority and targets. The Hydropower Development policies of 2001 and 1992 focused on types of scheme for targeted users like micro schemes for rural energy access; small and medium schemes for urban and rural Terai; and big or large schemes for energy export. The recent Hydropower Development Strategies of 2009 and 2010 have focused on sources of funding for hydropower development from public, private and international developers. As government's top priority is energy security for all in the shortest time, many special initiatives have been undertaken, such as National Water Plans (WECS 2012; WECS 2005), Hydropower development policy, Electricity crisis mitigation work plan, 25,000 MW in 20 years and 10,000 MW in 10 years etc. In spite of all these initiatives, the power deficit (nearly 900 MW) and annual incremental power demand (90 MW) are on the increase. The situation will improve if the policies and plans are stable enough for the sector to attract more investments both in-country and internationally.

Political instability and frequent changes in the ruling national government have also led to frequent changes or revisions in hydropower policy or strategies. Hence the absence of a stable hydropower policy could be risky and already distracting many investors. Due to political instability only a small electrical generation capacity was added in the country during the ten years of conflict. Even today, hydropower project development is not appropriately programmed but is haphazardly predetermined. A weak national policy or hydropower strategy could be implicated with this example. There are many highly feasible and economic hydropower plants implementable within US$ 1,000 to 1,500 per kW generation cost (Shrestha 2012). Most of them are either small- or medium-scale schemes, and for this scale Nepalese expertise and funding resources could also be manageable, so they should be developed with the highest priority. Unfortunately this has so far not attracted government attention and respective strategies have not yet been seen.

Plans and policies should also consider seasonality and explore the best use of rain water through storage. This feature favours storage type and multipurpose medium to large hydropower plants. Recently, the government has mentioned development of the bigger projects (JICA 2013) like Upper Tamakoshi (456MW), Budhigandaki (600 MW), Nausyalgad (400 MW) etc., but no clear achievement has been seen so far. The government is also interested in and convinced about the economies of scale benefit of large schemes, but these will be a priority only in the long run. So in terms of urgent energy need and government recommendations, big schemes are most appropriate followed by medium schemes in the present context. However, in terms of political ambition, the government in reality is putting more emphasis on decentralizing energy development for access. To meet the urgent energy need, micro- and small-scale projects are definitely not appropriate solutions but policy support for micro schemes for remote areas' energy access is also the preference, ahead of small schemes. Here small and medium plants with cascade could meet the said purpose in cost-effective ways. Similarly, the country should plan long-term perspectives on developing hydropower, considering its own needs first and then the export market with clarity on time and targets. Hence to assure the national interest, sufficient work is also required on project financing models to avoid regret in the future, especially when dealing with outside investment, agreements or treaties on big- and large-scale multipurpose schemes.

Country preparedness

Hydropower development may involve activities like planning, technology transfer, fund and investors mobilizing etc. where dialogue, negotiations and legal agreements are important. Experience, in-depth knowledge and readiness will help country to maximize benefits and hence all these are analysed under country preparedness. The country preparedness or readiness for hydropower development can impact sectoral development significantly, especially if it is on a bigger scale and planned long term. Maximizing multiple benefits when planning hydropower and opting for a suitable approach to achieve cost-effectiveness needs an in-depth review of the hydropower sector. For instance multipurpose (power generation with other benefits like irrigation, sanitation, water supply, navigation, industrial water uses, tourism, flood control etc.) and basin wise hydropower development could be a good approach (WECS 2012; Shrestha & Paudyal 1992). “Basin planning approaches have developed across the world in response to shifting priorities, different crises and increasing complexity in water resources management. The aim of basin planning is to optimize and choose from a series of possible objectives those that will best contribute to a range of competing economic, social and ecological goals” (Pegram et al. 2013). Detailed studies must be conducted for each river basin (see Section 5.1) of Nepal to work out the hydropower sites and potential and also the possibilities of multiple benefits from them. The country should not be in a hurry and prone to wrong development paths, endangering the national economy. The necessary preparatory work could take longer but result in the best interests for the country. Nepal has already experienced many poor treaties and contractual agreements because of being trapped by external interests in project developments and lost opportunities for benefiting from the full potential of resources and possible multiple benefits. This has happened due to lack of country preparedness and the matter become very important as project size increases.

Government institutions, experts and the academic sector are experienced to an extent and ready for implementing micro to big hydropower schemes. However several implemented hydropower plants have either stopped functioning or are malfunctioning because of technical repair and maintenance or management issues (ITDG 1998). Several of them could be revitalized (Mishra 2011) with little effort and low investment to benefit the country. Unfortunately this issue is not being addressed properly and poses a serious question about the readiness of the country to manage the hydropower sector, especially once one considers the increased sized hydropower schemes.

There is another concern about the country’s readiness to identify the best opportunities, the so-called low hanging fruit, in the changing national context. This could be explained by the fact that the country has so far been unable to see significant benefit (both reduction in cost and time for project implementation) from the recent development of infrastructure such as the Mid-Hill Highway. Close to this road, several sites for small to big hydropower schemes could be developed to generate 2,110 MW of electricity(Kuwar 2013).

The national grid is another important aspect of country preparedness for hydropower development. The existing national grid can accommodate small to medium plants at present but the expansion on-going at the 132 kV, 220 kV and 400 kV levels could accommodate up to big-scale plants. Some of the upper big-scale and large-scale generation requires high transmission capacity and sub-station expansion which needs additional resources and time. Additional support in infrastructure development is extremely important for big- and large-scale hydropower plants. Large hydropower projects would probably require power export contract negotiations with India, for which the country still not ready, and thus such schemes are not preferred in the preparedness perspective but big schemes through proper preparation could be considered. Based on these experiences, it can be concluded that the country is at the right moment to benefit from medium and small schemes followed by micro schemes.

Uncertainty and risk in relation to hydropower development

There are several factors which may cause uncertainties in hydropower development and these uncertainties put hydropower development at risk. Thus this is one of the important perspectives to consider. Uncertainties are rooted in technical issues, the country's economy and the social, environmental and political contexts. Examples include the changing national context relating to national policies, priorities, energy market, financing, investors' interests, etc. Other uncertainties related to hydrological change or unseen disasters or calamities could impact hydropower projects. Technical risks in terms of dependency on imports of equipment, accessories or support services may increase with the capacity (Goldsmith & Hildyard 1984) of plants and also with the types of technology adopted. In developing countries, specifically for large projects, risk is very high. Socio-political and policy risks also increase with capacity. The larger the project size, the larger will be the scope area and so the different stakeholders involved. Experiences show that coordination among land, forest and water resources and others for project approval and implementation is really a bottleneck. Environmental uncertainties in climate change resulting in drought, floods, glacier outbursts, shift in peaks and uncertainties in prediction / estimates of flow may cause high risks in hydropower development. As hydropower generation is increasing in the Himalayan region, GLOF hazards have become a prominent concern. Hydrological uncertainty generated risks are higher with low capacity and especially run-of-river plants. Since there is extreme seasonal variation in water availability in Nepalese rivers, all future programmes should consider storage (Hurford et al. 2014) of water during the rainy season and its utilization during dry periods. This will enhance project economies and attract investors. Another associated risk is due to earth movements, snow avalanches, seismic threats and water quality (Agrawala et al. 2003; NSC 2012) which disfavours big and large project.

Considering all the risks arising due to uncertainties applicable to the Nepalese hydropower sector, one can conclude that the least preferred schemes will be large followed by big. Small hydropower development seems the most appropriate scheme. Micro schemes, although they have minimal risks, fall behind small-scale hydropower because of the severity of climate risk but are still better positioned than medium schemes.

6.1.1.1 Summarizing results of perspectives

So far a large amount of information has been collected relating to the five alternative scales of hydropower schemes in Nepal and arranged under nine perspectives. As described in Section 4.b, all alternatives are compared by the decision maker based on their understanding and values are assigned on a predefined scale of 5 (Excellent) to 1 (Lowest) (for detail refer to Appendix 2) following evidential reasoning (see Section 5.2.3.1). The weights against each perspective are assigned as discussed in Section 4.b. This results in Table 9 where one can easily see which alternative performs at what level against which perspective.

Table 9: Scores for alternatives corresponding to perspectives and applicable weight

Perspectives \ Alternatives	Micro	Small	Medium	Big	Large	Weight
Technical	4	5	3	2	1	0.05
Social	2	3	5	4	1	0.15
Economic	1	3	5	4	2	0.25
Environmental	4	5	3	2	1	0.05
Political	2	1	4	5	3	0.2
Financial	3	4	5	2	1	0.15
Developer's	2	5	4	3	1	0.05
Preparedness	3	4	5	2	1	0.05
Uncertainty	4	5	3	2	1	0.05

All the perspectives mentioned here have different influences when comparing alternatives. For instance, while economics is a much desired perspective many others may have a least preference. Hence the values entered for alternatives against perspectives are now evaluated considering the assigned to each of them. This will result in a table where the final calculated overall score will indicate the best (highest scoring) to worst alternatives. Thus the ranking shown here are based on perspectives valued with due weightage and this is presented in Table 10. Here medium-scale hydropower is found to be the best among the alternatives.

Table 10: Ranking of alternatives with respective perspectives

Perspectives \ Alternatives	Micro	Small	Medium	Big	Large
Technical	0.2	0.25	0.15	0.1	0.05
Social	0.3	0.45	0.75	0.6	0.15
Economic	0.25	0.75	1.25	1	0.5
Environmental	0.2	0.25	0.15	0.1	0.05
Political	0.4	0.2	0.8	1	0.6
Financial	0.45	0.6	0.75	0.3	0.15
Developer's	0.1	0.25	0.2	0.15	0.05
Preparedness	0.15	0.2	0.25	0.1	0.05
Uncertainty	0.2	0.25	0.15	0.1	0.05
Overall	**2.25**	**3.2**	**4.45**	**3.45**	**1.65**

These results are also presented in Figure 29 for easy comparison. As shown in Figure 29, the big and small alternatives are closely competing with each other. Far behind them are micro schemes as the fourth priority and large as the lowest priority. Economy, being the most important perspective for the country's hydropower development, is allocated the highest weightage. Under the economic perspective, the most preferred hydropower type is medium scheme. The government, reflecting the political perspective, is the second most important perspective and favours for big hydropower schemes. Similarly the social and financial perspectives are given the equal and third highest level of importance and under both of them medium schemes are the most preferred option. All other perspectives like technical, environmental, developers, country preparedness and uncertainties are assigned equal but low weightage.

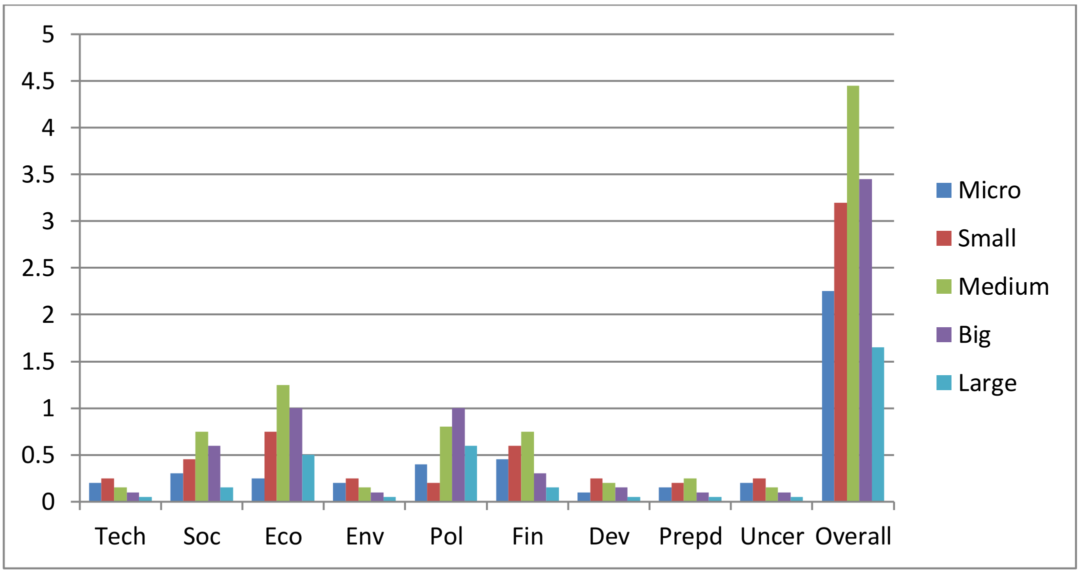


Figure 29: Overall and perspective wise ranking of alternatives

The data and results from this initial stage of research are further cross-checked by applying more scientifically approved methodologies and tools. Some important MCDM tools applied in this research are further discussed in the following sections of this chapter.

6.1.2 MCDM (AHP) application (secondary information-based)

The data obtained from the earlier study (6.1.1) is further applied through MCDM. This is necessary to test the applicability of MCDM in hydropower analysis in general and the applicability of data available while applying MCDM tools, and also to cross-check the compatibility of the MCDM results obtained with that in the earlier study based on perspective analysis (combined with evidential reasoning).

This MCDM application thus uses the secondary information from the earlier research stage (6.1.1) following the methodology described in Section 4.c. This application will fine-tune the goals and criteria used for the hydropower sector and also the weightage for the criteria used in the analysis.

The data on hydropower obtained earlier (6.1.1) under nine perspectives are now reorganized for MCDM application. The data are reorganized under six goals: technical, social, economic, environmental, political and uncertainties, and their applicable measurable criteria are given corresponding weights. This reorganizing into six goals (out of nine perspectives considered earlier) changes the weightage allocated in earlier study. Again the MCDM is applied to prioritize and rank five scales of power generation. This tests the applicability of this MCDM tool by comparing the results with the earlier results of the analytical analysis and also tests the effectiveness of the listed criteria measures. The goals and their corresponding criteria are shown in Table 11.

Table 11: Goals, criteria and their objectives (direction)

Goals (wt.)	Criteria	Objective
Technical (.15)	Experience and expertise	Maximize
	Project development dependency	Minimize
	Grid readiness for Transmission	Maximize
	System and business handling capability	Maximize
Social (.20)	Equity, benefits, induced safety and services	Maximize
	Inclusiveness and governance	Maximize
	Social capital formation	Maximize
	Energy access and reliability	Maximize
	Heritage and culture	Conserve
Economic (.25)	Generation capacity	Maximize
	Investment and operation Cost	Minimize
	Enterprise and economic activity	Maximize
	Use of local resources, infrastructure	Maximize
	Finance available	Maximize
	Developers interest	Maximize
Environmental (.10)	River morphology and riparian ecology	Conserve
	Terrestrial (land, forest) environment	Conserve
	Water quality, availability and connectivity	Maximize
	Waste and pollution	Minimize
Political (.20)	Policy & strategy support in country	Maximize
	Time to meet power development target	Minimize
	Contribution to development agenda	Maximize
	Regional balance of power system	Maximize
Uncertainties (.10)	Technological	Minimize
	Political	Minimize
	Environmental	Minimize
	Social (implementation)	Minimize
	Financing (market) risks	Minimize

The data from the earlier perspective (analytical) study (6.1.1 and table 10) is used for pairwise comparison following the rearranging them within new setup as shown in table 11. Doing so every perspectives of table 10 managed under six goals and corresponding criteria of tale 11. Analytical Hierarchy Process (AHP) using Expert Choice software (Ishizaka & Labib 2009) uses those data for further analysis. Following the standard AHP procedure, as described in Section 5.2.3.2, pairwise comparison is done using a scale of 9 to 1 (see Table 4). The researcher (single decision maker) enters relative scoring according to their subjective value judgement ranging from equal to extreme preferences. Pairwise comparisons are applied in bottom and mid-level of comparisons by the researcher whereas the weight assigned to the main goals at top level is accessed via the literature review.

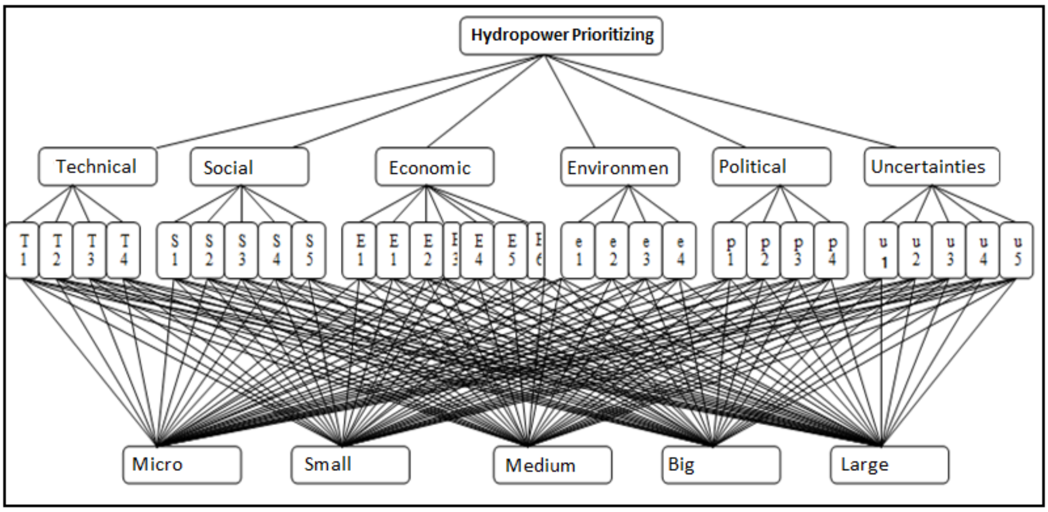


Figure 30: The AHP model applied

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

6.1.2.1 Summarizing results of MCDM (AHP) application

Important results obtained from the AHP application to prioritize scales of schemes are presented next.

<u>Goals, weights and alternative ranking</u>

Five hydropower alternatives characterized by their capacity are evaluated within the frame of six goals (table 11) and their respective criteria. Weight allocation is very important and was assessed by the decision maker with the help of documents, publications and consultations with experts working in the hydropower sector in Nepal. One could follow allocating equal weight but the decision maker decides to allocate weight differently (see table 11) to different goals according their importance. If each goal in the present study was weighted equally it would weigh on average 17% corresponding to each goal considered. 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%. The weightage for political and social goals are estimated at 20%, slightly above average. The technical goal is weighted at 15%, which is close but slightly below average weight. The environmental goal and uncertainty (for reducing associated risk) are weighted at 10%. The weights assigned to each goal and its corresponding prioritization can be viewed in Figure 31.

As shown in Figure 31, the majority of goals find medium- and big-scale schemes to be the priority, while environmental and uncertainties favour micro- and small-scale hydropower plants. One can note that big-scale hydropower development is in the interest of social, economic and political goals, whereas the technical goal prefers medium-scale plants. For both environmental and uncertainties, the preference order was from micro- towards large-scale hydropower development in Nepal. Among the goals, in terms of importance, the economic goal remains the highest (25% weightage).

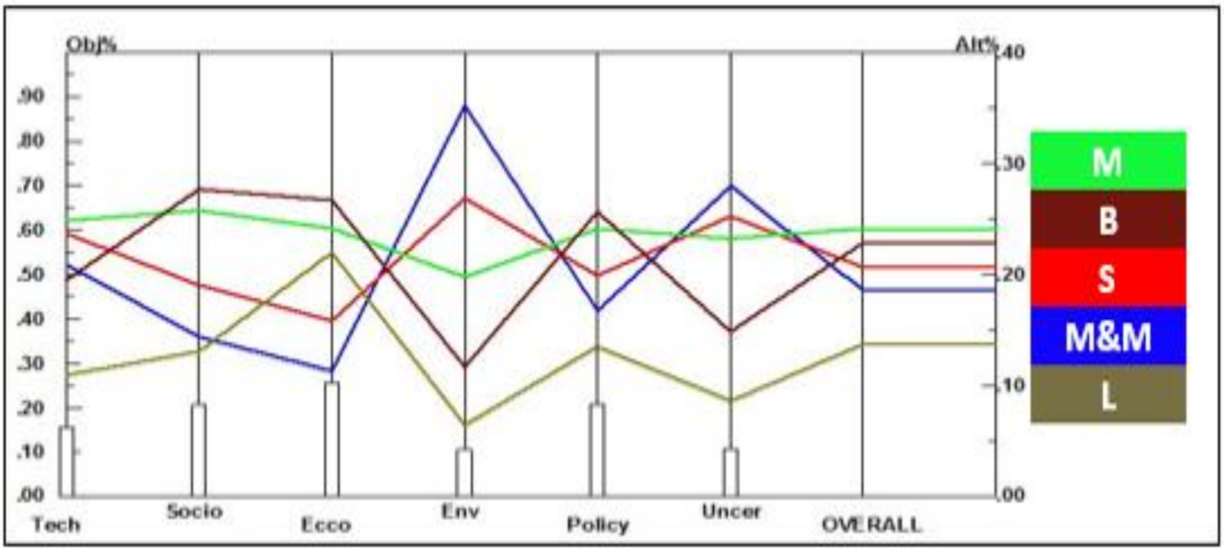


Figure 31: Prioritization with respect to various goals and weights

As shown in Figure 31 (blue line), micro schemes, although excellent in the environmental goal and uncertainties measures, are poor in the economic and social expectations. In the case of large schemes (brown line), in spite of excellent economies of scale, due to their energy export and external financing requirements, their overall contribution to the country and ranking is lowest. Future changes in priority ranking are very much dependent on the changing economic situation of the country. If such large schemes are developed for the in-country energy needs and with in-country funding resources, the priority for 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 prerequisite energy export contracts with neighbouring countries. Although big (dark red line) and small (red line) schemes are ranked second and third, they are in competition with the highest-ranked medium schemes (green).

Overall and goal wise prioritization of alternatives

In the present context, considering all goals and respective criteria, ranking of the alternatives is shown in Figure 32. It is found that medium-scale schemes in Nepal rank first, followed in decreasing priority by big, small, micro- and large-scale schemes.

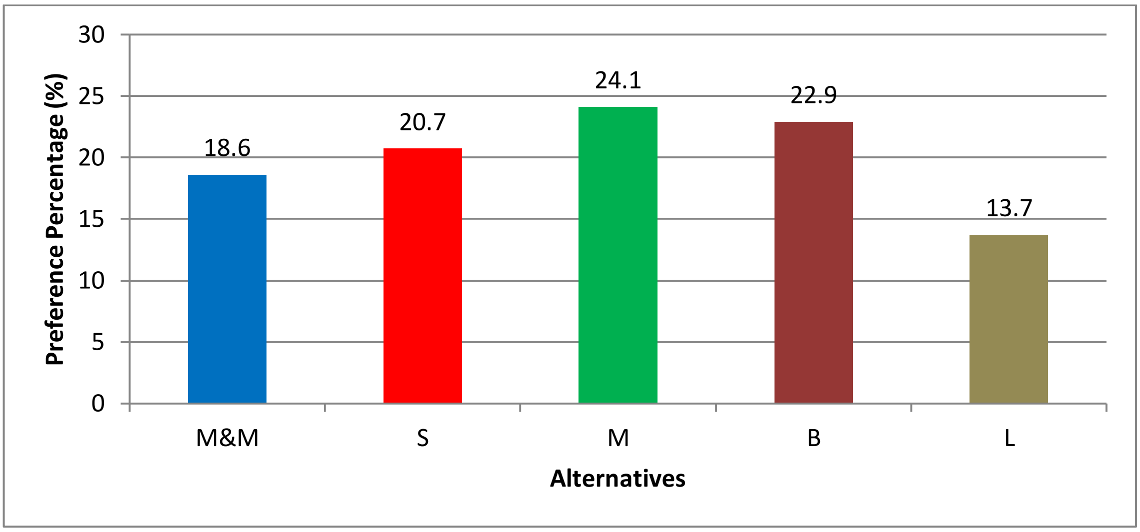


Figure 32: Final prioritization of alternatives

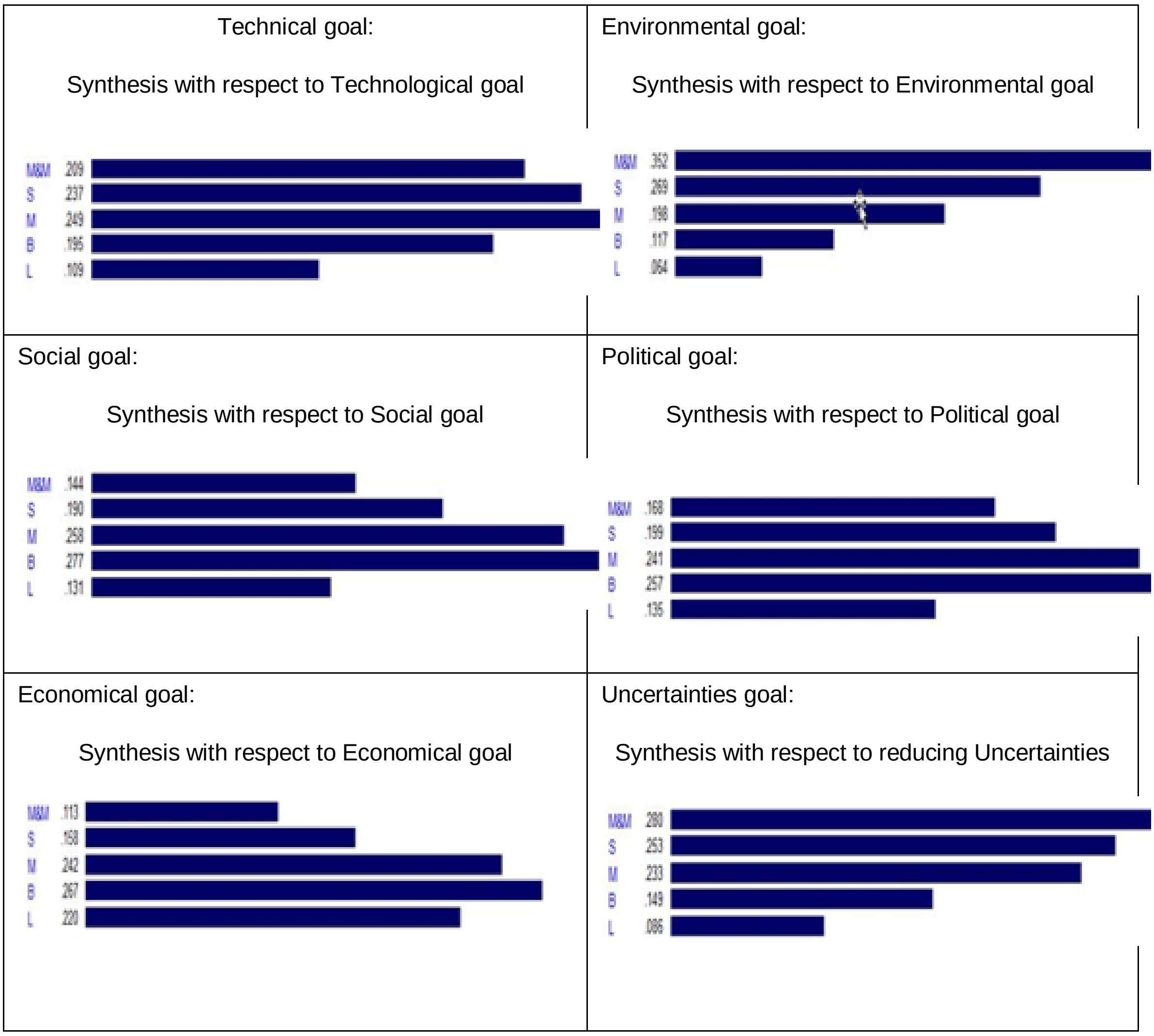


Figure 33: Prioritization with respect to various goals

According to secondary data based analysis, as can be seen here, goal wise preferences of alternatives displayed in figure 33. One can find that uncertainty and environmental goals put top priority on smaller schemes and decreases with increasing capacity of schemes. In contrast social and political goals favour big and medium schemes. Likewise technical goal put high priority for medium schemes while economic gaol favours bigger schemes.

Sensitivity analysis

Since reliability of information varies considerably among various sources (e.g. publications, interviews), this may have had an impact on final results obtained in the analysis. In general, there are uncertainties in data, models (e.g. transferring data into impacts) and preferences. Furthermore, some of the information and data used may not be correctly understood, expressed or reviewed. The subjectivity of the decision maker when assessing weights for goals and criteria based on the reviewed documents and experts' suggestions is subjective and could be different from what it should be. Thus allocations of weight to the goals and corresponding criteria might have errors because of subjectivity in their assessment. All these factors could be major sources of error and thus the rankings might change. It is thus important to check the sensitivity of the ranking by variations of the weight allocated. 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 can be analysed only with a factor one level below the objective. Hence, the sensitivity analysis, another important feature of the AHP application, will verify the trustworthiness of the ranking obtained.

The economic goal whose allocated weightage is 25% (as shown in Figure 31), is now changed by +/- 5% (represented by a vertical blue line) to observe a change in ranking as shown in Figure 34 (represented by a vertical pink line). Although the ranking values slightly change, this is not enough to change the overall ranking of alternatives 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 take top priority as shown. This sensitivity test can be performed by varying the weight allocated (in Figure 31) 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 can be analysed separately to observe the influence on the ranking order of alternatives. The gradient sensitivity of each and every criterion is reviewed with a change in weightage to determine the sensitive factors as shown in the case of the economic goal in Figure 34. Here, the economic goal seems to be sensitive to a weight change if it exceeds 35% and the decision on ranking of alternatives could be influenced. However, the presently allocated weight of 25% to the economy is unlikely to change in the near future, but it could receive higher weightage with a strengthened economy in the long run. Similarly, we can vary the weightage allocated to other goals. It is found that varying the weightage +/- 5% over the allocated one does not change the ranking. Hence, the weight allocations for the goals are also stable and the ranking obtained is trusted.

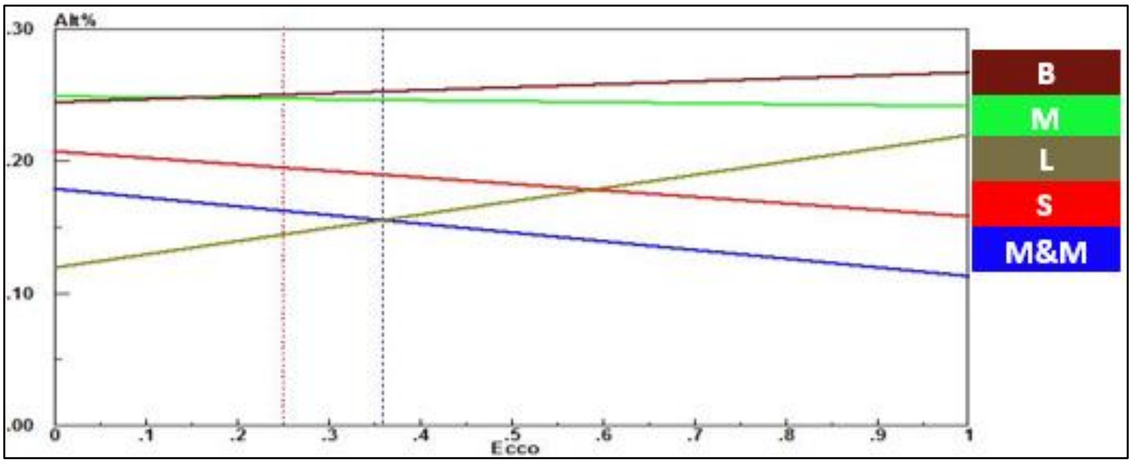


Figure 34: Sensitivity with respect to economic goal

One major issue still to be cross-checked is around the weight allocated to the criteria. This is performed through a questionnaire survey to determine the weights for all goals and criteria in addition to cross-checking the ranking results obtained earlier. This is explained in the next application of MCDM in the following section.

6.1.3 Questionnaire survey and AHP application

This part of the research work is based on a questionnaire (refer Appendix 3) survey. The main objective is to cross-verify the result for ranking hydropower schemes classified on the basis of generation capacity in Nepal. The other objective is to verify the weightage of different goals and criteria used in hydropower analysis. Focused on the research objective, a hydropower-related questionnaire is developed made up of goals, criteria and alternatives. This questionnaire consists of a total of 13 questions. Each question has five options and respondents can rank the options as per their preference on a scale of 5 (highly preferred) to 1 (least preferred). The respondent prioritizing the goals is used for determining weight allocation to the goals and allows comparison with the weights used in the earlier stages of the research (perspective analysis and secondary source-based AHP application). Each goal with contributing criteria options is also prioritized by the respondents and similar prioritizations are done for the criteria with sub-criteria.

In this analysis the goals and criteria are further fine-tuned following the discussion with experts. The earlier analysis framework (refer tale 11) with six different goals (Technical, Social, Economic, Environmental, Political and Uncertainties) and corresponding criteria is rearranged with five goals (Technical, Social, Economic, Environmental and Political) as shown in table 13. A goal uncertainties and its criteria showed in table 11 are now evaluated along with each five goals showed in table 13. Hence there may be small differences in the weightage allocated to goals from the previous research. To avoid bias, different kinds of stakeholders are involved in the survey. The important groups who influence hydropower sector development in the country are hydropower professionals, economists, sociologists, environmentalists, financers, government officials and planners, developers and contractors, entrepreneurs, beneficiaries and public representatives. These groups may have different degree of influence but their contribution in decision making is worth considering. In the present research, for simplicity, instead of group wise comparison, all of the responses obtained are treated in a single (one) group of stakeholder's response. Attention is also paid to balancing the number of respondents from each group of stakeholders to avoid any bias. To make the survey more reliable, a minimum of 70 responses were intended and accordingly double of this number (135) respondents were identified. This list was developed through reviewing experts listed in documents, expert lists in professional organizations or committees, web links for related organizations and personal communication. The availability of a name and details for a respondent through various sources was the basis to list the respondent, which avoids bias and maintains the survey within the defined boundary. Their email addresses and phone contacts were collected for further follow-up if required. In the present case, the questionnaire is sent to potential informants all within a boundary related to hydropower but belonging to several groups and at different level of professionalism. Due to outdated contact emails, many of the emails did not arrive and only 110 of potential respondents were successfully contacted. Further details on the survey are presented in Table 12.

Table 12: Overall distribution and responses to the questionnaire

Distribution and response	**Number**
Total questionnaires distributed	110
Responses received	90
Total accepted responses	85
Stakeholders' areas	
Technical and hydropower professionals	13
Sociologists	13
Economists	11
Financing (public, private, local regional, national level)	9
Environmentalists	12
Developers and suppliers	13
Planners, decision makers and Government officials	14

The obtained information was mainly organized under five different goals and 23 criteria. It was realized, after discussing with professionals involved in the hydropower sector, that general economics, financial aspects and developers' aspects of projects should be grouped under a single goal called economic. Each of these three criteria are further linked with five sub-criteria as shown in Table 13. Here criteria and sub-criteria are given short names and description.

Table 13: Goals, criteria and sub-criteria with descriptions in the questionnaire

Goal	Criteria and Sub-criteria	Descriptions
Technical	PA	Power availability (annual energy output and days per year with energy supply)
	Inf	Available supporting infrastructure: roads, bridges, power grid etc.
	Dem	Energy demand and availability to satisfy the local communities
	Cap	Country's capacity to implement, maintain and operate the project
	Lok	In-country materials, accessories, equipment and finance availability
Social	Equ	Fairness or equity in allocation of benefits and impacts to local communities
	Incl	Focus on inclusiveness, gender empowerment and vulnerability
	Imp	Project-induced impacts such as public safety, power supply reliability and displacement of people
	GVN	Transparency and governance of the project
	SCap	Technological knowhow and social capital building
Economic	Economics Pow	 Power generation capacity of plant
	Rev	Benefits from the plant, direct like revenues and indirect like services
	Cost	Cost of power generation (energy per unit generated) of the plant
	Emly	Employment generation due to power plant
	Local	Utilization of available local materials and resources to build the plant
	Finance All Nat	 Using national financing and available human resources
	PFoHi	Using partly outside financing and available human resources
	Part	Using partly outside financing and partly outside human resources
	HiCFo	Using outside financing and available human resources
	All Out	Using outside financing and outside human resources
	Developer Gov	 Government owned and operated
	IPP	National Independent Power Producers owned and operated
	IIPP	International Independent Power Producers owned and operated
	Mix	Mix of national and international joint venture JV owned and operated
	CCC	Community / Cooperative / Corporate owned and operated
Environmental	Terres	Terrestrial (land, forest) environment degradation due to hydropower project
	Mor	River morphology, riparian ecology caused by sediment, flood etc.
	Cont	Impacts on water resources (continuity, regularity, quantity and quality)
	Waste	Solid waste and pollution due to project construction and operation
	Abs	Water abstraction or damming
Political	Access	To provide energy access to remote area
	MG	To integrate with existing local (mini) grid availability nearby
	NG	To integrate with existing national grid passing nearby
	RB	To contribute to regional energy balance within country
	Exp	To supply energy for sale outside country

Starting with an objective and goals, all criteria and sub-criteria are arranged in a hierarchy (refer fig 35). The hierarchy can be identified by setting one objective at the highest level (e.g. Rank and identify the best alternative hydropower schemes) followed by goals, criteria and sub-criteria at mid-level and alternatives at the bottom level of the hierarchy to represent the decision process. As explained in 5.2.3.2 about AHP, pairwise comparison start from the sub criteria contributing to respective criteria within the context of main objective of the research. Likewise the pairwise comparison continues up to the goals and final scores for each alternatives obtained to rank them.

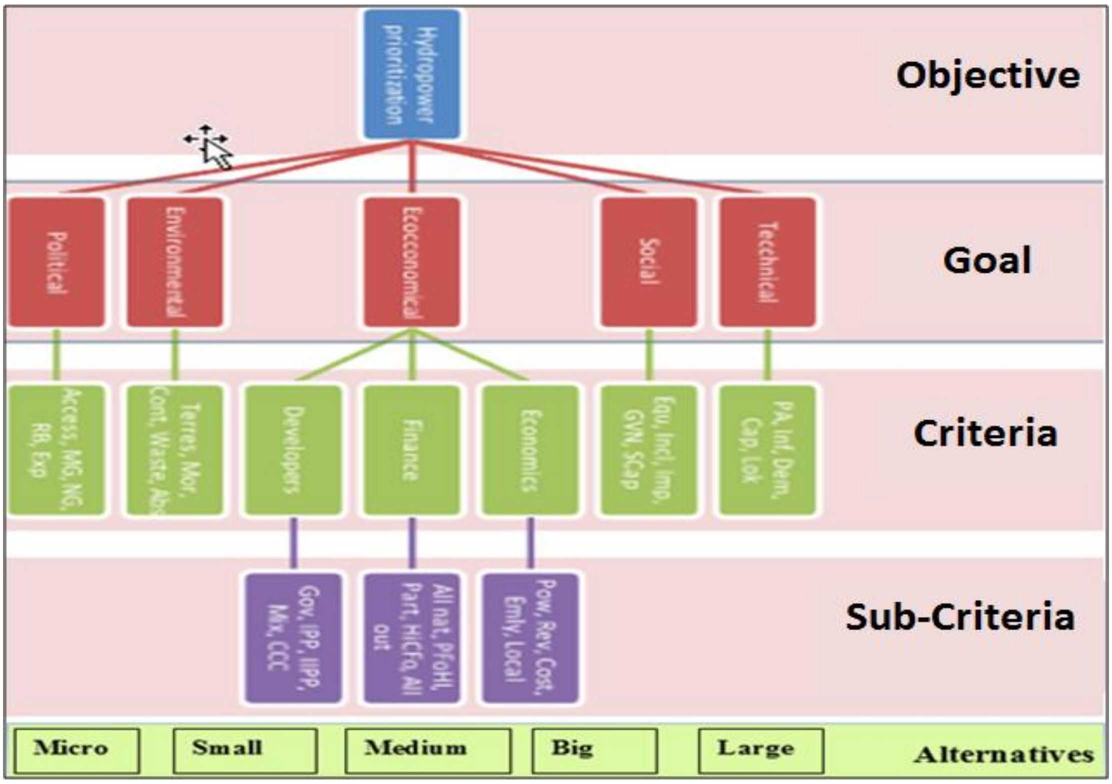


Figure 35: AHP Model applied in questionnaire survey-based hydropower analysis

The answers from the questionnaire are tabulated in excel and DM evaluated the overall responses corresponding to each question and importance obtained for each options. This made DM capable to make pairwise comparison as required in AHP. All comparison and weight allocations entered and processed through Analytical Hierarchy Process (AHP) using Expert Choice software. Here the evaluation framework is further fine-tuned to analyse the five alternatives within five goals and 23 criteria. Economics as a goal in hydropower analysis may have three criteria to evaluate and are primarily evaluated on the economics of the project from government point of view (Singh 2004), on financial aspects for investing institutions or person point of view and benefits to developer point of view. In addition they are also examined, but separately, for environmental and social perspectives. Further hydropower development needs to be examined for political compliance and technical viability. Hence the main goals considered in this analysis are technical, economic, social, environmental and political. The uncertainty related risk aspect in this analysis is considered as embedded in the goals mentioned. The results obtained from the AHP Expert Choice application are now presented.

6.1.3.1 Summarizing results of Questionnaire survey and AHP application

Goal wise prioritization of alternatives:

Synthesis of the overall judgement represents the consensus of all stakeholders. While analysing alternatives with respect to the objective of ranking hp schemes, on the criteria wise, different alternatives are prioritized differently as shown in Figure 36.

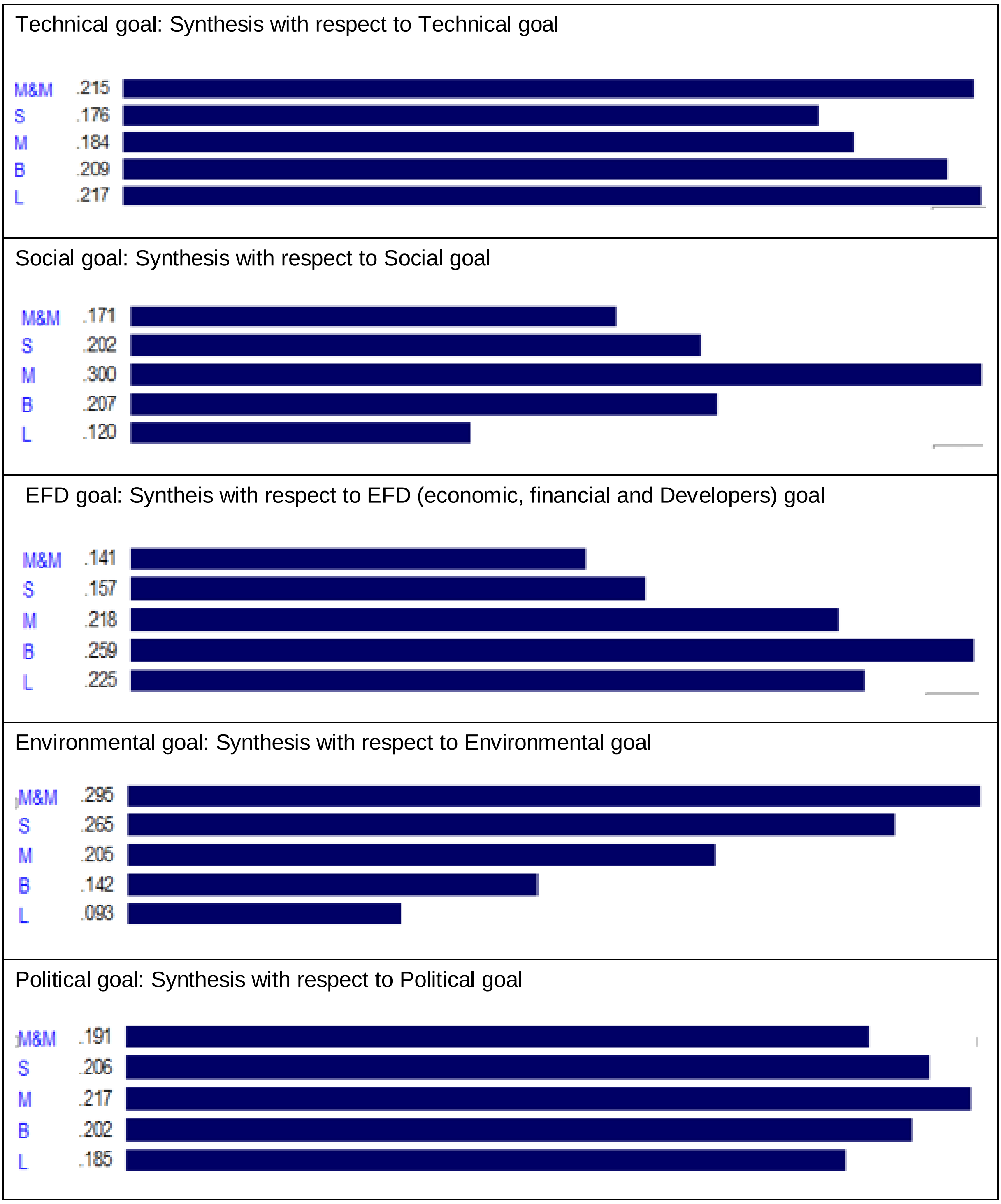


Figure 36: Priority of alternatives corresponding to main criteria

This application provided the prioritization of alternatives corresponding to five goals. We can see that for the technical goal almost all sized schemes are preferred close to each other. However large schemes are very much preferred closely followed by micro schemes and big schemes. Technically less importance is given to medium and the least to small. Similarly, on social criteria medium schemes are most preferred with a strong lead whereas large schemes are least preferred. In terms of economic criteria, big schemes are at the top priority but closely followed by large and medium schemes. For environmental criteria, the highest priority is scored by micro schemes and the priority gradually decreases with the increasing size of schemes. Although medium schemes seem better on policy, the closely competing alternatives indicate that there is no special preference or prioritization based on generation capacity.

Weight allocation to goals

Weight assigned to criteria are important in making the final ranking. For goals set at the highest hierarchy level, based on responses obtained from questionnaire survey, the highest weightage is given to economic (24.4%), followed by political (21.0%), technical (20.1%), social (18.9%) and environment (15.5%) goals, as shown in Figure 37.

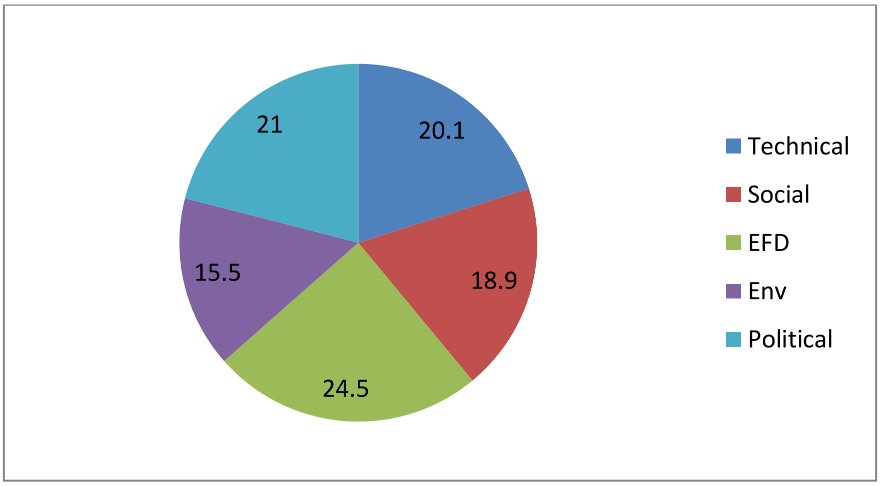


Figure 37: Weight assigned to criteria

Overall prioritization

The overall result as shown in Figure 38 finds that all alternatives are important but for the overall national interest, medium schemes seems best followed by big schemes whereas the least preferred are large schemes. Small and micro schemes are close to each other in priority. Medium schemes, which scored highest on the overall ranking, may not perform top in all criteria. They are most preferred only in the social and political criteria but third preferred in economic as well as environmental and even fourth in technical criteria (see Figure 36).

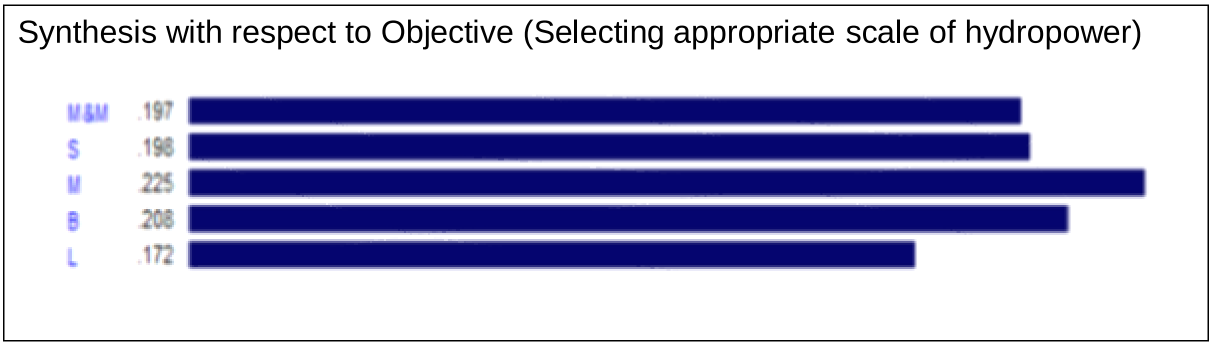


Figure 38: Overall priority of alternatives considering all criteria and sub-criteria

Alternative performance of criteria

As shown in Figure 39, all the alternatives are separately presented with the criteria used in ranking. For example, big schemes are most preferred in the economic criteria but least preferred in environmental criteria. Political and social criteria equally prefer big schemes and there is almost the same level of preference by technical criteria. The economic goal prefers schemes having a higher generation capacity, whereas the environmental goal favours those having a lower generation capacity. Medium schemes are most preferred by social criteria and large schemes least preferred.

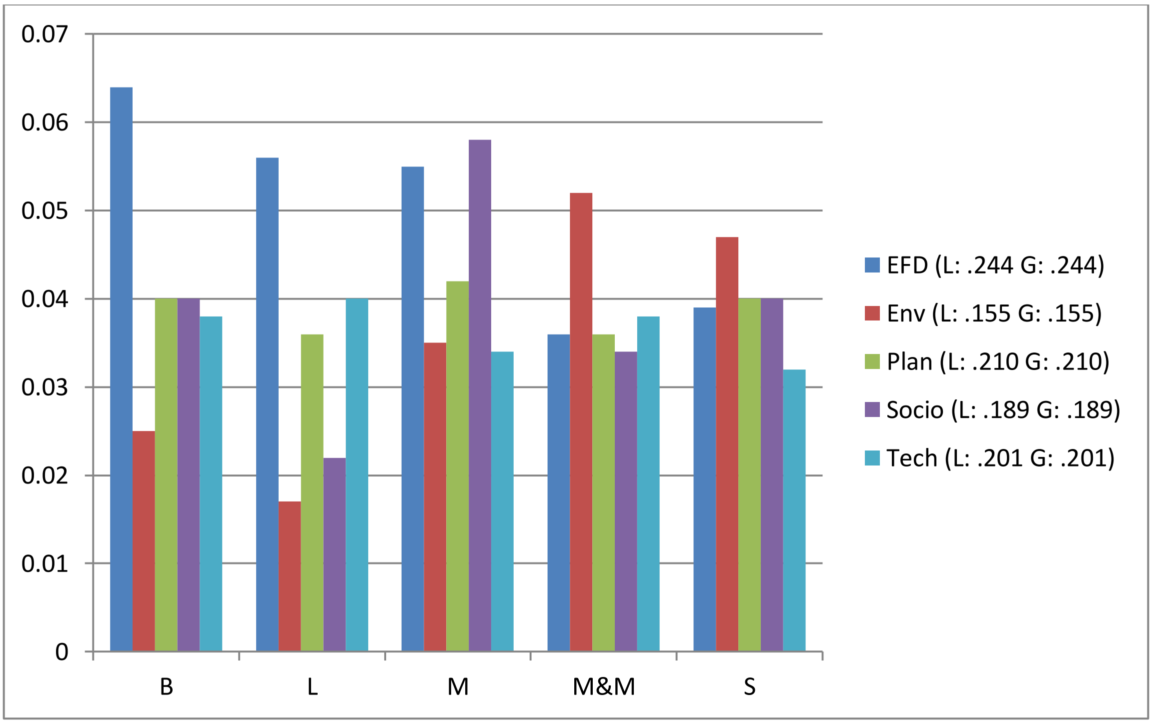


Figure 39: Weight contribution of criteria with respect to alternatives

Criteria contribution to goals analysis

Like the five goals analysed earlier, in AHP a similar analysis can be followed for criteria and sub-criteria. For example, the EFD (Economics, Finance and Developers) results are presented. Here with economics as the criterion the highest priority is assigned to big schemes closely followed by large and then medium. Similarly with financial criteria big schemes score highest but are closely followed by micro, medium and small schemes, with large schemes remaining the least priority. Against developers' perspectives as criteria the most recommended is big schemes closely followed by large and medium ones, but less preference is given to small and least to micro schemes.

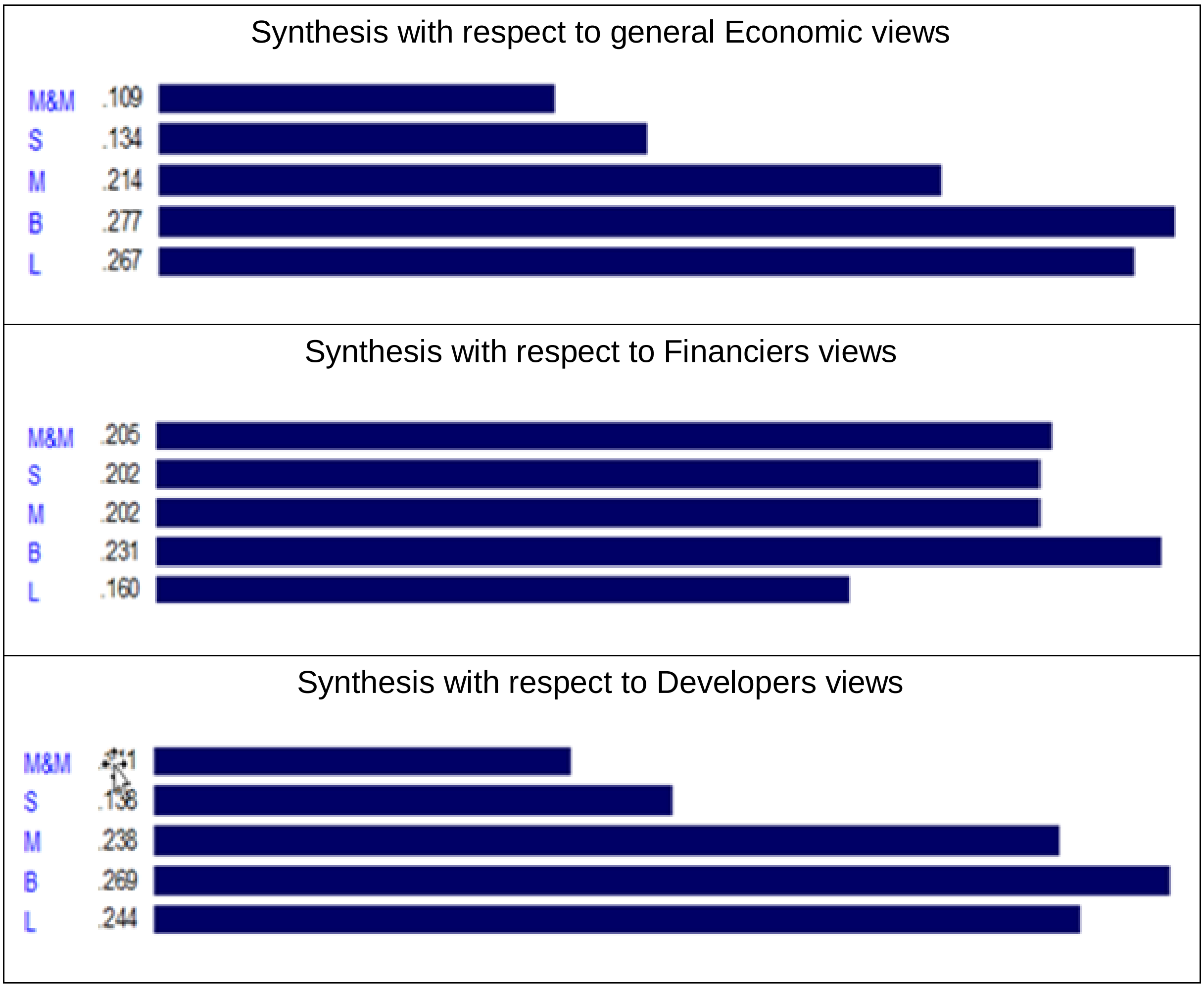


Figure 40: Contribution of criteria (Economic, Finance and Developers) to goal EFD

Sub-criteria contribution to criteria

As can be seen economic criteria receive contributions from their sub-criteria as shown in Figure 41. For example, power as a sub-criterion prefers larger schemes and similar results are seen for sub-criteria like revenues and earnings. In terms of cost criteria, high priority is assigned to big follow by medium and then large and small schemes whereas micro remains lowest. For employment sub-criteria the most preferred are big followed by large and medium with the others at a lower preference. For the local resource utilization perspective, the best alternative is micro followed by small, medium, big and large schemes.

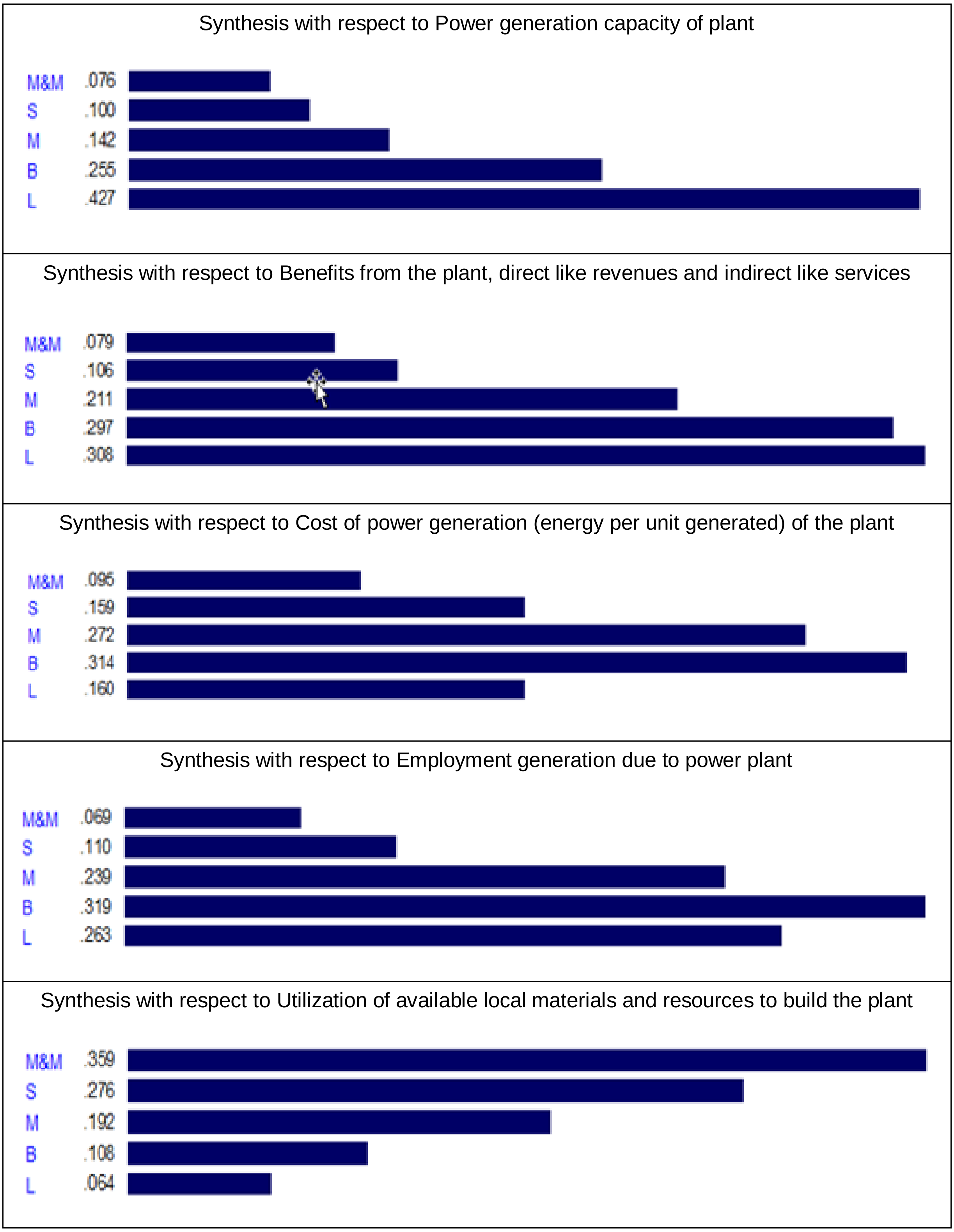


Figure 41: Contribution of sub-criteria within criteria of Economics under goal EFD

Sensitivity analysis of the results

As explained in Section 6.1.2 on sensitivity, the sensitivity analysis will verify the trustworthiness of the ranking obtained. The gradient sensitivity of each and every criterion is reviewed with a change in weightage to determine the sensitive factors as shown in the case of technical criteria in Figure 42.

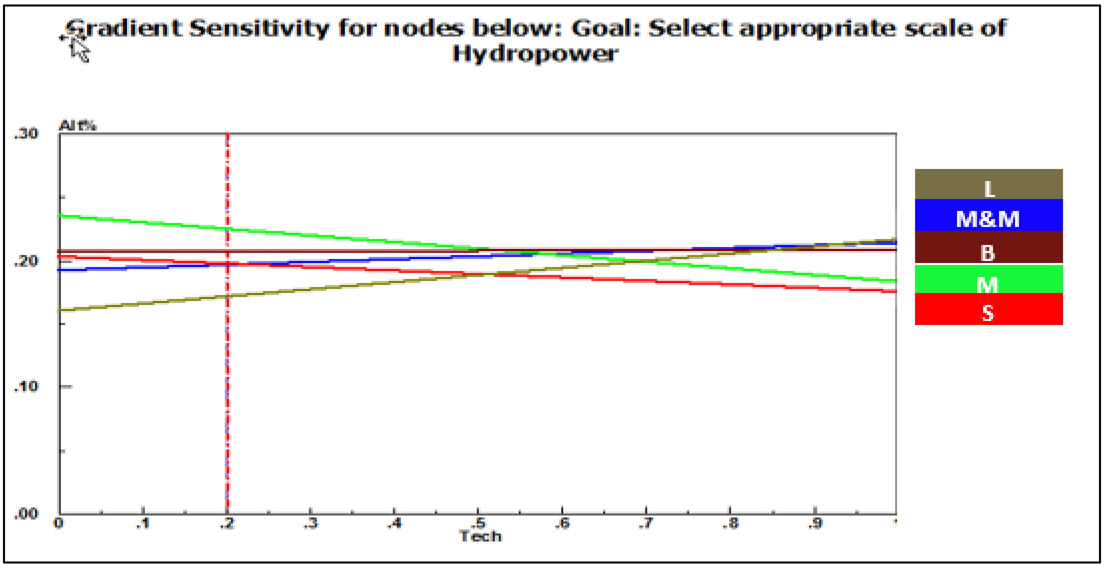


Figure 42: Gradient sensitivity of technical criteria

Here the sensitivity is illustrated for Technical goal for all five alternatives represented by horizontal lines of different colours. Along with X-axis is variation in weight allocated to Technical goal while Y-axis represent the corresponding score of alternatives. The sum total of all alternatives remain 1. Vertical red line represent the weight at this moment of Technical goal which is 0.201 By varying the vertical red line right or left we can vary the weightage of the goal (technical as per fig 42) and can see the change occurring in horizontal lines of different colours corresponding to five different alternatives. Thus sensitivity check was performed. Corresponding to the present weightage allocated to technical goal (0.201), the most preferred alternative on vertical red colour bar is medium scale hydropower schemes represented by green colour. Similarly the least preferred is large scheme. If this weightage changes to extreme left representing no weightage will put medium schemes on top rank but if weight shifted to extreme right then large scheme on top rank.

A closer review of fig. 43, all goals shows their possible change in weight, even of 10 to 20% from that assigned at present may not change the priority order except a swap of priority orders between micro and small hydropower projects. It is observed that medium schemes always remain at the top as the first priority followed by big schemes as the second priority. Similarly, large-scale schemes are the lowest priority. These alternative rankings do not change even with small variations in the weightage of the goals. Hence, the weight allocations for the goals are also stable and the ranking obtained can be trusted.

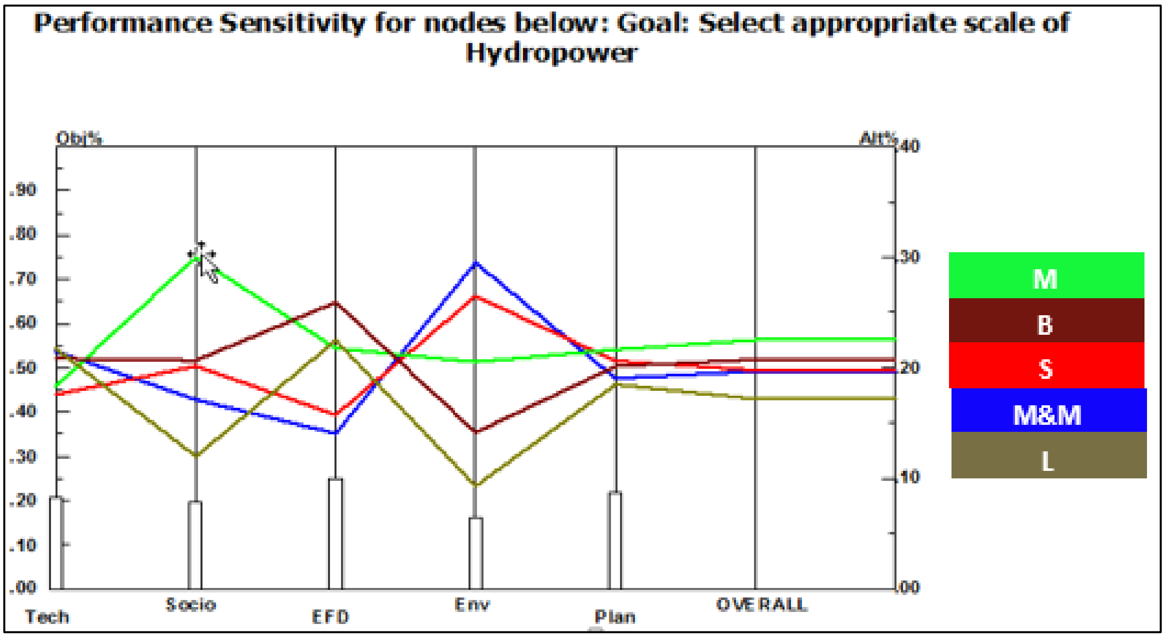


Figure 43: Overall distribution of priorities in present research (base case)

The EFD (economic, financial, developers) goal whose weight assigned is 0.244 may change along with the changing country economy and may impact the priority considerably as shown in the sensitivity graph (fig 44). Here, imagine an extreme situation when EFD weightage is 1 meaning the project selection is done solely on EFD (economics, financial and developers) basis then large schemes will be on the top priority and ranking order follows decreasing generation capacity of schemes.

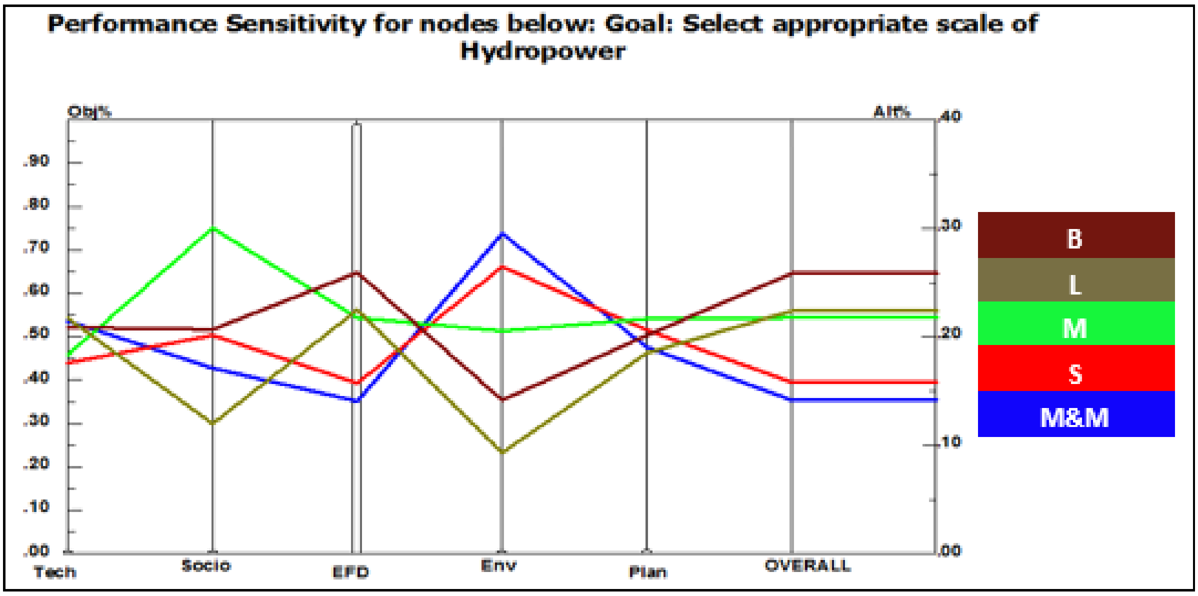


Figure 44: Change in ranking due to increased weightage of EFD

6.2 PROMETHEE application

So far the applicable goals and criteria in hydropower analysis and the applicability of MCDM in Nepalese context are verified. Hence these goals and criteria with weights could be useful for drafting a decision framework. Hence in this chapter we will first draft a decision framework. Such a decision framework should include the widest possible range of criteria applicable to the national context. The applicability of the decision framework should be field tested and finalized according to the national context.

When developing the decision framework, a MCDM tool with visual features can be highly effective to visualize the criteria contributions and various comparisons graphically. Furthermore, with the increased number of alternatives and criteria, hydropower analysis needs an appropriate MCDM tool with a visual aid to handle large matrices and comparisons. Hence a suitable MCDM is chosen accordingly as discussed in this section.

6.2.1 Drafting first decision framework

In the first step, goals, criteria and sub-criteria have to be identified to characterise the broad range of impacts of hydropower schemes related to the decision-making process under Nepalese conditions (the so-called decision aid framework). Hence a first draft decision framework is proposed as shown in Table 14. This draft is developed with the help of information available from different sources and insights gained from the different MCDM applied (see Sections 6.1.1 to 6.1.3) for analysing the hydropower sector of Nepal. The draft decision framework is set with the objective to select the best from all options available. This can be achieved via analysing hydropower with five main goals:

Economic: to enhance the country's economy

Social: to maximize social benefits

Environmental: to conserve the environment from adverse environmental impacts

Political: to enhance national status

Uncertainty: to speculate in advance and act accordingly to minimize risk and losses

While the draft decision framework accommodates all possible range of criteria and sub-criteria, avoiding double counting is important to make a trustable framework. At the very beginning there were 47 sub-criteria. After the first round of field testing of the draft framework, it is found that internal rate of return (IRR) is linked with power generation. Hence to avoid double counting in evaluation, IRR is removed from the list. Similarly repair and maintenance-related information are expressed in terms of a percent of either revenues or investment. In addition, the decommissioning required at the end of a project is not experienced in Nepalese context and hence removed from the sub-criteria listed in the decision framework.

Developing a decision framework is followed through several stages of studies and based on experiences from each stages, it is fine-tuned accordingly to improve it. While improving the framework, it is important to keep all possible criteria in the framework and doing so there could be rearrangements of goals and criteria. While developing the draft decision framework at this stage (which is final stage of study and field test), based on further consultations with expert and experiences gained from previous analytical analysis and AHP applications, the goals and corresponding criteria are rearranged as shown in table 14 which is slightly modified over table 13. While goals like economic, social, environmental and political remains same as in previous table 13. It was suggested during consultations to shift criteria under technical goal (shown earlier in table 13) to the closely linked goals in the table 14. Thus technical goal from previous decision making table has been removed. Another goal like uncertainty which was earlier shown in table 9 was found appropriate to reconsider in the decision framework as an important goal and has been included in the table 14.For decision making in hydropower, though the table 14 looks slightly different, it keeps the essence of previous decision tables (9,11 or 13) intact. Thus under five goals, all the applicable criteria and sub-criteria along with expected directions (maximizing or minimizing) are presented in Table 14.

Table 14: Goals, criteria and sub-criteria applicable to hydropower decision making

Goal (5)	Criteria (23)	Sub-criteria (44), symbol and description	Max / Min
Economic	Power Capacity	PG = Power Generation capacity (MW) of power plant	Max
	Benefits	LF= Impact of project implementation on infrastructure: roads, bridges, etc. Has the project brought new infrastructure or was the existing one even destroyed	Max
		FC = Flood control: community benefiting from flood control established due to project	Max
		IF= Irrigation facilitated: does the plant provide irrigation for farmers (adverse - not allocating water to them) or facilitate new irrigation systems developed by the project	Max
		FD = Fishery developed: does the plant provide new facilities for fishery growth or protection, or do fisheries activities suffer	Max
	Cost	CI = Cost of investment (including construction, resettlement, environmental mitigation, etc.) also represents cost of operation, maintenance and decommissioning	Min
	Employment	ST = Directly related to project: short-term employment (during construction)	Max
		LT = Long-term employment: directly related to project (maintenance, operation, administration and daily labour)	Max
		IB = Indirect benefits related to project: interaction with other sectors of economy creating job opportunities (SMEs, services, business, tourism, etc.) in the region	Max
	Use of local resources	UL = Takes into account the available local resources for project development such as construction materials, workforce, finance (from local communities), etc.	Max

Goal (5)	Criteria (23)	Sub-criteria (44), symbol and description	Max / Min
Social	Equity and Benefits	EB = Equity in distribution of benefits (financial, job, fellowship, cash or social services); fairness in cost burden (land, forest like resources, shares and investments)	Max
		GM = Gender mainstreaming, inclusiveness of vulnerable communities	Max
		OL = Opportunities for strengthening livelihoods and contributing to poverty reduction	Max
	Project-induced impacts	PR= Power reliability and grid integration of communities: assess the reliable power supply to region / area / local communities	Max
		MA = Mobility affected (farming, grazing etc.) adversely due to power plant developed	Min
		LO = Impact on law and order (strengthened security by police and army presence) and local lifestyle (outsiders coming into the region) due to power plant being established	Max
		RO = Recreation opportunities: new recreational sites created but at the same time there could be loss of areas for recreational activities like bathing, fishing, water fetching etc.	Max
		HS = Health and safety: measures against community health hazards due to project-caused pollution or water-borne diseases	Max
		DR = Provide support to the displaced and project affected families (PAF): project causing resettlement during implementation and also post project effects	Max
		MT = Measures taken for minorities maintaining traditional lifestyle and against project causing adverse impact on their lifestyle	Max
		CH = Conserve cultural heritage: effects on cultural heritage, earlier settlements: historical remains and cultural heritage (does it impact traditions, beliefs)	Max
		CV = Community visibility: does the project contribute to making the community visible in the national attention to receive development and recognition	Max
	Transparency and Governance	PP = Public participation in decision making: was project planning discussed and consulted in a transparent manner from the beginning	Max
		PM = Partnerships in the management of the project: does the project involve local institutions, NGOs or civil society for project development, implementation and managing	Max
	Technology knowhow and social capital	TK = Technological knowledge: due to this project, are local people trained and social capital enhanced to replicate and sustain such development	Max
	Marketing and financing risk	MR= Measures against market risk: to save adverse impact on project due to any change in market such as in demand, competition and capital financing	Max

Goal (5)	Criteria (23)	Sub-criteria (44), symbol and description	Max / Min
Environmental	Degradation due to HPP	FL = Conserve forest and biodiversity from losses: inundation, forest loss, felling of trees, NTFP and rare species affected including protected and non-protected forest areas	Max
		FE = Conserve farmland from expropriation: due to roads, pH and canals etc. Loss of commercially productive land (quantity) and productivity (quality) due to project	Max
	Sediment balance	SB = Conserve sediment balance: trapping of sediment, riverbed scouring, river bank erosion and regression of delta	Max
	Impact on water resources	WQ = Conserve water quality: hazardous chemicals both for human (drinking) and plants (irrigation) in water and quality of water affected during construction/maintenance	Max
		WA = Conserve water availability: number of weeks with low flow of water for irrigation, drinking as well as other uses, specifically downstream impact and impact on children and women	Max
		WC= Conserve water connectivity: impact of natural water connectivity (to maintain aquatic life, flora and fauna, invertebrates, fish, mammals and birds) with other streams	Max
	Solid waste and pollution	SW = Proper handling and monitoring of solid waste, noise and vibration control during construction period and during operation	Max
	Visual impact	VI = Measures taken to conserve adverse visual impacts on landscape due to project	Max
Political	Contribution to national independence	NI = To what degree the project can support national independence from other countries by utilizing national energy resources	Max
	Conflict and impact to other countries	IC = International conflict due to project: possibility of conflict on resource sharing and adverse impacts due to regulations, treaties, earlier contracts signed with other countries	Min
	Sector priority and PPP	SP = Sector priority: project should comply maximally with sector preferences set by government such as private sector participation, storage, decentralised, owner model etc.	Max
	Regional balance	RB = Regional balance: does the plant support regional balance of power generation within the country and cost-effective integration into national grid and support new industries	Max
Uncertainty	Technological risk	TR = Avoid technical risks: assessed against country technical handling capability, hydrological (flow duration curve) storage and head variation: geological stability and seismic risk	Max
	Political (regulatory) risk	CP = Stability against change in policy is important to safeguard project from adverse effects	Max
	Environmental risk	ER = Mitigation measures against environmental risks: climate change, greenhouse gas emissions, land/rock movement, erosion, seepage, etc., could cause adverse impact of project	Max
	Implementation risk	IR= Institutional risk: are institutions in place, capable and fully responsible for successful project implementation	Max
		SR= Managing against social risk: project implementation disrupted by community due to social issues	Max
		CR= Manage coordination risk: effective and smooth coordination among institutions, ministries, government agencies and local communities is a must to avoid any delay and overrun of project	Max

The proposed decision framework needs to be verified from the field where selected sample projects and stakeholders are consulted for first-hand information. This requires a complete set of survey documents with detailed guidelines on data collection and site selection as discussed, which is presented in Appendixes 1 and 2.

Developing a survey form to obtain the required data from the field is an important task. A well-structured format adhering to the goal, criteria and sub--criteria is designed to elicit relevant information. As this kind of research is being done for the first time in the Nepalese context of hydropower, extensive work is necessary to include a wide range of possible criteria and sub-criteria in the decision framework. The survey form developed is further explained with a survey guide where each of the goals, criteria and sub-criteria are explained in detail for easy understanding. It is necessary for clarity to be provided through a survey guide to maintain response entry, measurements and homogeneity while interacting with respondents. Finally a detailed checklist is prepared to ensure a complete and acceptable survey. Two surveyors are nominated to assist the survey, one with an economics background, the other as a team leader with a technical background. The decision maker (researcher) and surveyors involved had very detailed discussion on all aspects of the field survey for further clarity. The discussion was focused on understanding the objectives of the research, avoiding bias and collecting and entering field data (responses). The survey format thus developed was pilot tested in the field at a site to test the compliance of the survey format and its ability to elicit the required information. Following this field test, fine-tuning of the survey format and guide was done accordingly. Details of the survey format are presented in Appendix 1 and the guidelines in Appendix 2.

6.2.2 PROMETHEE model applied

A draft decision framework is now field tested to evaluate and prioritize the identified set of alternatives i.e. six hydropower sites. In order to collect field data to describe the physical features and the impacts of these six alternatives, a survey format is developed (see Appendix 1). Each required data point from the sites is entered according to the survey guide (see Appendix 2). At each project site the respondents surveyed in groups were (i) project owners and staff, (ii) local residents, (iii) entrepreneurs, politicians, activists and officials; and (iv) professional experts related to the projects. While many of the survey questions are responded to by several groups, certain questions are responded to only by a few of them. At the end, based on the surveyor’s perception, the surveyor evaluates the responses presented as overall judgements as consensus of all stakeholders. In total for all six sites, almost 150 persons participated in this survey. Among them, almost 25 were hydropower project professionals. For each site surveyed, the individual group responses are assessed and combined by the surveyor to make a final score with respect to each criterion. The data so obtained are first tabulated into an Excel table and then entered into a powerful multi criteria decision analysis (MCDA) tool, Visual PROMETHEE (VP). A schematic diagram of organizing the data entry is shown in Figure 45.

As shown in the fig. 45, on the top is objective of the research and at the bottom consists alternatives in hand. In the mid five goals which is attained through 22 criteria and further through 44 sub-criteria. Corresponding to each criteria, numbers shown in brackets represent the applicable number of criteria. For e.g. Eco (5) means under economics goal there are 5 criteria. Similarly correspond to each goal total number of sub-criteria is shown. For e.g. in sub criteria Eco (10) means that under economics goal there are 10 sub criteria.

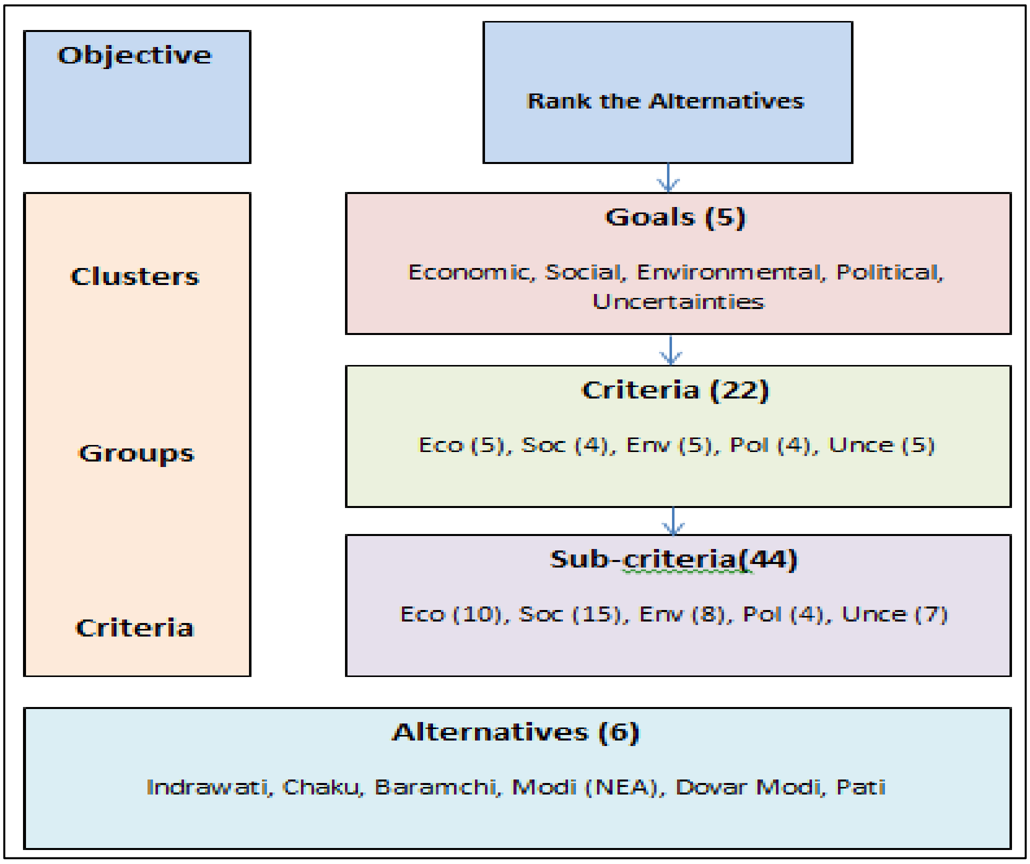


Figure 45: Functioning hierarchy in Visual PROMETHEE

According to PROMETHEE manual, when goals criteria and sub-criteria arranged in mid as shown in figure, it is also termed as Cluster, groups and criteria. VP allows to structure the criteria into clusters which in fact are goals (for instance economic, social etc. as shown on right against it in the figure. Similarly groups (shown as number in brackets against each goals), for instances are power capacity, benefits, cost, employment and use of local resources under economic goal. These groups may consists set of criteria to be measured. In the figure above, right against the criteria shows economic goal with 10 number in bracket means there are all together 10 criteria to measure and if we add all criteria involved then it is 44 altogether.

6.2.2.1 Developing impact table

Data synthesizing is an important and sensitive task before entering it into VP. For each site, both qualitative and quantitative data are analysed. While quantitative data like power generation, costs, etc., are entered in numeric values all qualitative responses are assigned ordinal numeric values (based on performance levels described in detail in the questionnaire guidelines) for example 5 for excellent, 4 for very good, 3 for good, 2 for acceptable and 1 for poor. For all other than quantified data, subjective value judgements are entered based on the survey responses understood by the researcher, as shown in table 15.

Table 15: Impact table based on information from field study and allocated weights

Goals & weight	Sub- goals	Criteria	Weight (%)	Alternatives					
				Pati	Modi	MN	B	I	C
ECONOMIC (0.35)	Power Capacity (MW)	PG	8	0.996	10	14.8	4.2	7.5	1.5
	Indirect Benefits	LF	3	3	4	4	4	4	3
		FC	1	2	2	3	3	3	2
		IF	3	2	3	1	3	3	2
		FD	2	1	1	1	1	3	1
	Cost (US$/kW)	CI	7	2330	2342	2734	2222	3442	3452
	Employment	ST	3	3	4	4	1	2	3
		LT	4	3	3	4	3	3	2
		IB	3	2	2	3	1	3	3
	Use of local resources	UL	1	3	3	4	3	3	3
SOCIAL (0.25)	Equity	EB	3	4	4	4	4	4	3
		GM	2	3	3	3	2	2	2
		OL	1	2	3	3	5	3	3
	Project-induced impacts	PR	2	4	4	4	4	5	4
		MA	2	3	3	3	2	3	1
		LO	2	4	4	4	4	4	3
		RO	2	3	3	3	3	3	4
		HS	1	4	3	4	3	4	3
		DR	1	4	4	3	5	5	5
		MT	1	3	4	4	4	4	4
		CH	1	3	3	4	4	4	4
		CV	1	3	3	3	4	3	3
	Transparency and Governance	PP	2	4	4	4	3	3	3
		PM	2	2	2	1	3	3	2
	Technology-knowhow	TK	2	1	2	4	3	3	3
ENVIRONMENTAL (0.10)	Degradation due to HPP	FL	1.5	4	4	3	1	3	5
		FE	1	3	2	2	4	2	4
	Sediment balance	SB	1.5	3	3	2	4	3	4
	Impact on water resources	WQ	1.5	4	4	3	4	4	3
		WA	1	5	5	5	5	5	5
		WC	1.5	3	3	2	3	3	2
	Solid waste and pollution	SW	1	4	4	3	4	4	3
	Visual impact	VI	1	3	2	3	2	4	5
POLITICAL (0.15)	National independence	NI	6	5	5	5	4	5	5
	International conflict and impacts	IC	1	5	5	5	5	5	5
	Sector priority and PPP	SP	3	4	4	5	4	5	5
	Regional balance	RB	5	3	3	4	4	3	3
UNCERTAINTY (0.15)	Technological risk	TR	1	4	3	n/a	n/a	n/a	n/a
	Political (regulatory) risk	CP	5	4	4	3	4	4	4
	Environmental risk	ER	2	4	4	4	4	3	3
	Implementation risk	IR	1	4	4	5	4	4	4
		SR	1	5	5	5	5	3	5
		CR	1	4	5	5	5	5	5
	Marketing and financing risk	MR	4	4	4	5	4	5	5

The completed survey forms (questionnaires) are reviewed by the researcher who also discusses the score entered by the surveyor. There was some ambiguity about the cost of generation which was sorted out in consultation with project management. To eliminate any doubts on field data gathered, it is further cross-checked and verified in consultation with the project owner and experts working in the sector. In addition, a small data gap was noticed regarding technological risk. Hence a table of raw data is obtained for each sample site ready for further synthesis and processing. Thus the values assessed to the criteria and the weight assigned (following the questionnaire survey see Section 4.d and further distributed to criteria by DM based on his best understanding) for each criterion results in impact Table 15. Criteria and acronym details followed after Table 14.

6.2.2.2 Results of PROMETHEE applications

The first Excel table, although enabling comparing alternatives with respect to a particular criteria or sub-criteria is unable to give an overall assessment of the alternatives. For overall results on alternative evaluations, the Excel data is further processed through VP. The tabulated field survey data are entered into VP academic edition along with the objective direction of each criteria and sub-criteria (maximize or minimize), preference functions, Q, the indifference function, and P, the preference and weight. Once all the data required is entered in the VP software, it process them to display several kinds of results in both numeric and visual forms. VP can present these results in more informative ways, such as PROMETHEE ranking, PROMETHEE table, PROMETHEE rainbow and walking weights. PROMETHEE ranking will show the best possible choice(s), and PROMETHEE table displays the Phi, Phi+ and Phi- scores of the alternatives for ranking purposes. PROMETHEE rainbow presents disaggregated (expanded) view of the criteria's contribution to the alternatives and the walking weights window allows the weights of criteria to be changed and the impact on the VP analysis seen (for details refer http://www.promethee-gaia.net/assets/vpmanual.pdf). It also help to identify the sensitivity associated with any of the decision criteria. The sensitivity feature of this tool is very useful for decision analysis. Further results obtained are discussed in more detail.

The VP application upon data entry is shown in Figure 46. The researcher can read and cross-check different information that has been entered. VP allows particular alternatives of interest to be selected to include in the analysis while keeping all others inactive in the analysis by clicking the boxes against the alternatives in the bottom left corner. Similarly criteria or sub-criteria can be included or excluded in the analysis by clicking the boxes on the top horizontal bar. All other information to be entered can be seen on the screen. VP analyses the entered data and displays the results in various ways: one of them along with data in the background is shown in Figure 46 as an illustration.

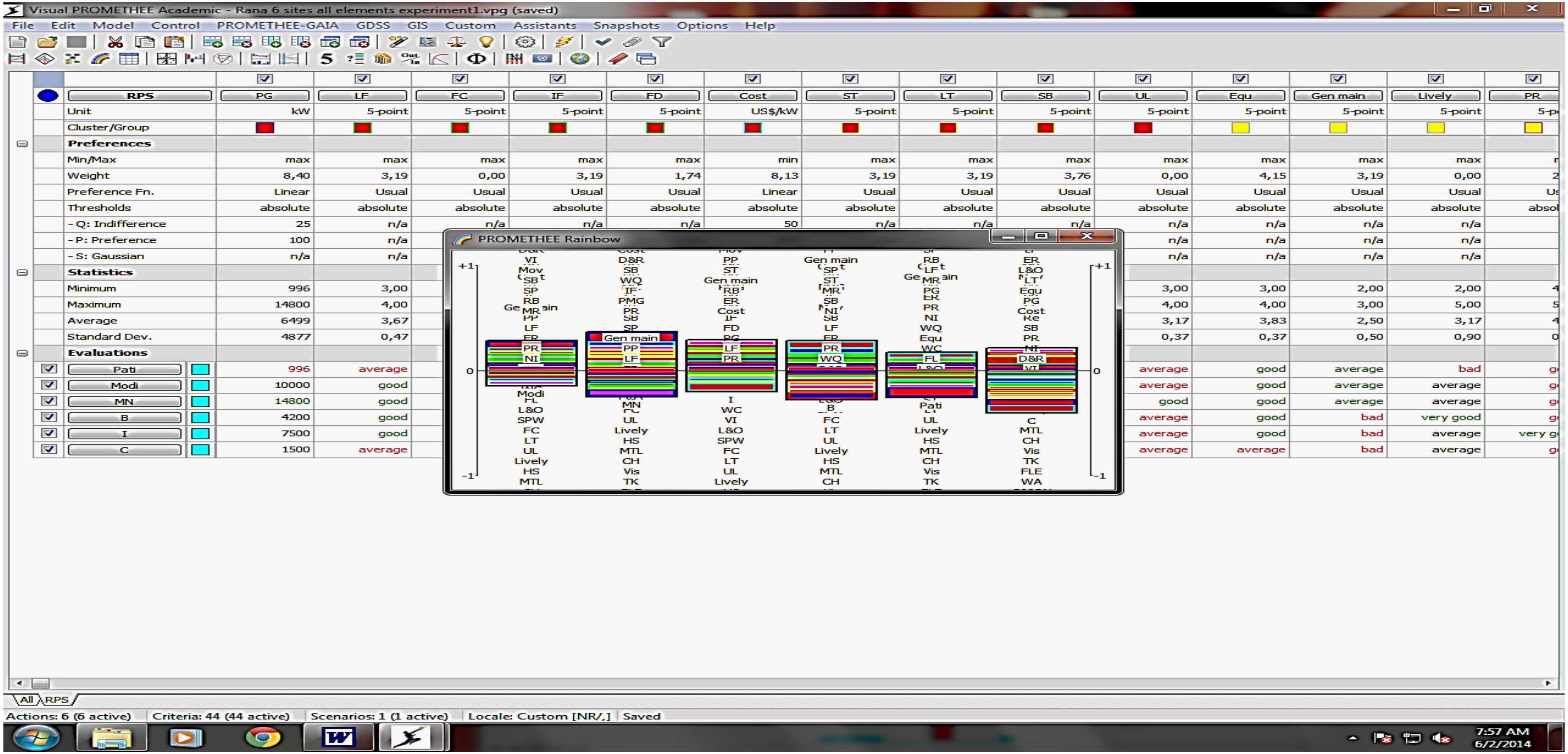


Figure 46: Screen shot showing all 44 criteria used in VP to rank actions

One important task is to allocate weights (as shown in table 15) to all goals and then to each criterion or sub-criterion. As discussed in Section 4.d, AHP application can effectively determine weight allocation (Gulmans, 2013) from the previous questionnaire survey verified with the available secondary information. The values assigned here are trustable because they were derived from the survey responses of a large number of experts working in the hydropower sector of Nepal (see Section 6.1.3). A screen shot displaying the entering of weights is shown in Figure 47.

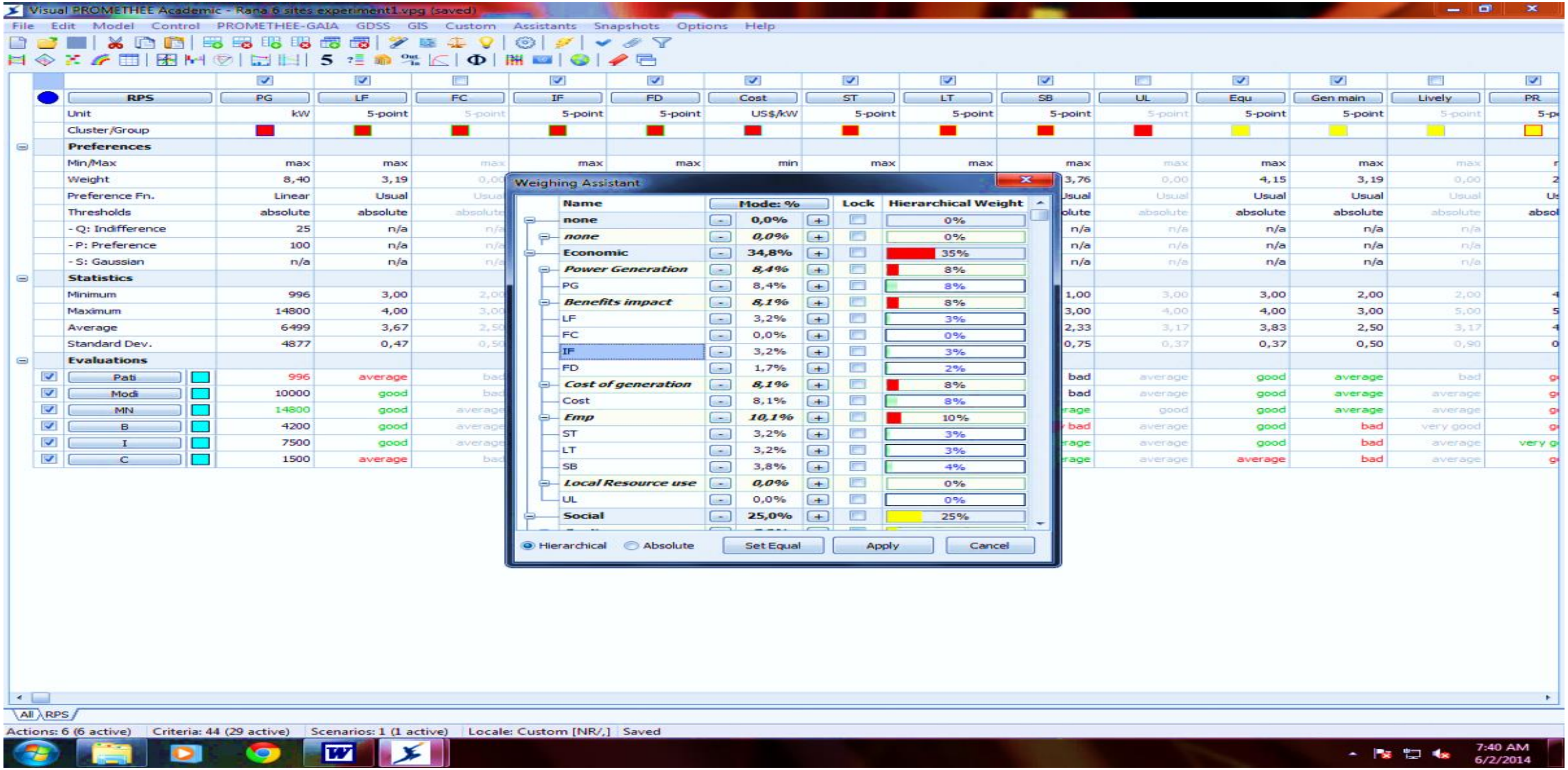


Figure 47: Screen shot of weightage allocated to criteria in ranking actions

The results of the VP application are now presented and discussed. Different ways to rank the alternations with visual as well as numeric values are discussed here. These results are based on the field data from six sample hydropower and processing through the decision framework with 29 criteria. A separate section 6.2.2.3 with heading sensitivity analysis explains how criteria reduced from 44 to 29 and finalized the decision framework.

PROMETHEE I provides partial ranking while PROMETHEE II provides complete ranking, as described in Section 5.2.3.3, taking into account all contributing criteria. Although partial ranking helps to compare alternatives' performances separately on positive and negative preference flows, complete ranking ranks alternatives on the total sum (both positive and negative together) of preference flows. The values π (a,b) expressing how much a is preferred to b (equation 14) taking into account all the criteria and their weights are computed for each pair of alternatives a, b∈A. In this way, a complete and valued outranking relation is constructed on A. The ranking analysis obtained earlier (with the full set of 44 criteria) is compared with revised decision framework (without null criteria). In both cases, among the six alternatives, three are performing well and show an overall positive scoring. Baramchi (B) is almost neutral but the remaining two are not performing well and are on an overall negative scoring. In both cases the final priority in descending order for the alternatives was Modi hydropower developed by the private sector (Modi), Modi hydropower developed by the Nepal Electricity Authority (MN), Indrawati hydropower (I), Baramchi hydropower (B), Pati hydropower (P) and Chaku hydropower (C), as listed in Table 16 and Figure 49. Here, the ranking results based on the final decision framework (with a revised set of 29 criteria) remain similar to the ranking order obtained earlier with the full set of 44 criteria for the alternatives.

Table 16: Ranking table of hydropower schemes

Rank	Hydropower (hp) scheme	øNET	ø+	ø-
1	Modi hp developed by private (Modi)	0,1244	0,3217	0,1973
2	Modi hp developed by NEA (MN)	0,1058	0,3952	0,2894
3	Indrawati hp (I)	0,0772	0,3285	0,2508
4	Baramchi hp (B)	-0,0087	0,3124	0,3210
5	Pati hp (Pati)	-0,0968	0,2200	0,3168
6	Chaku hp (C)	-0,2018	0,2406	0,4425

Following the visual displays as shown in Figure 48, the positive flows, ø+ for prioritizing alternatives from high to low (MN, I, Modi, B, C and Pati) is different from that resulting from negative flows ø- (Modi, I, MN, Pati, B and C).

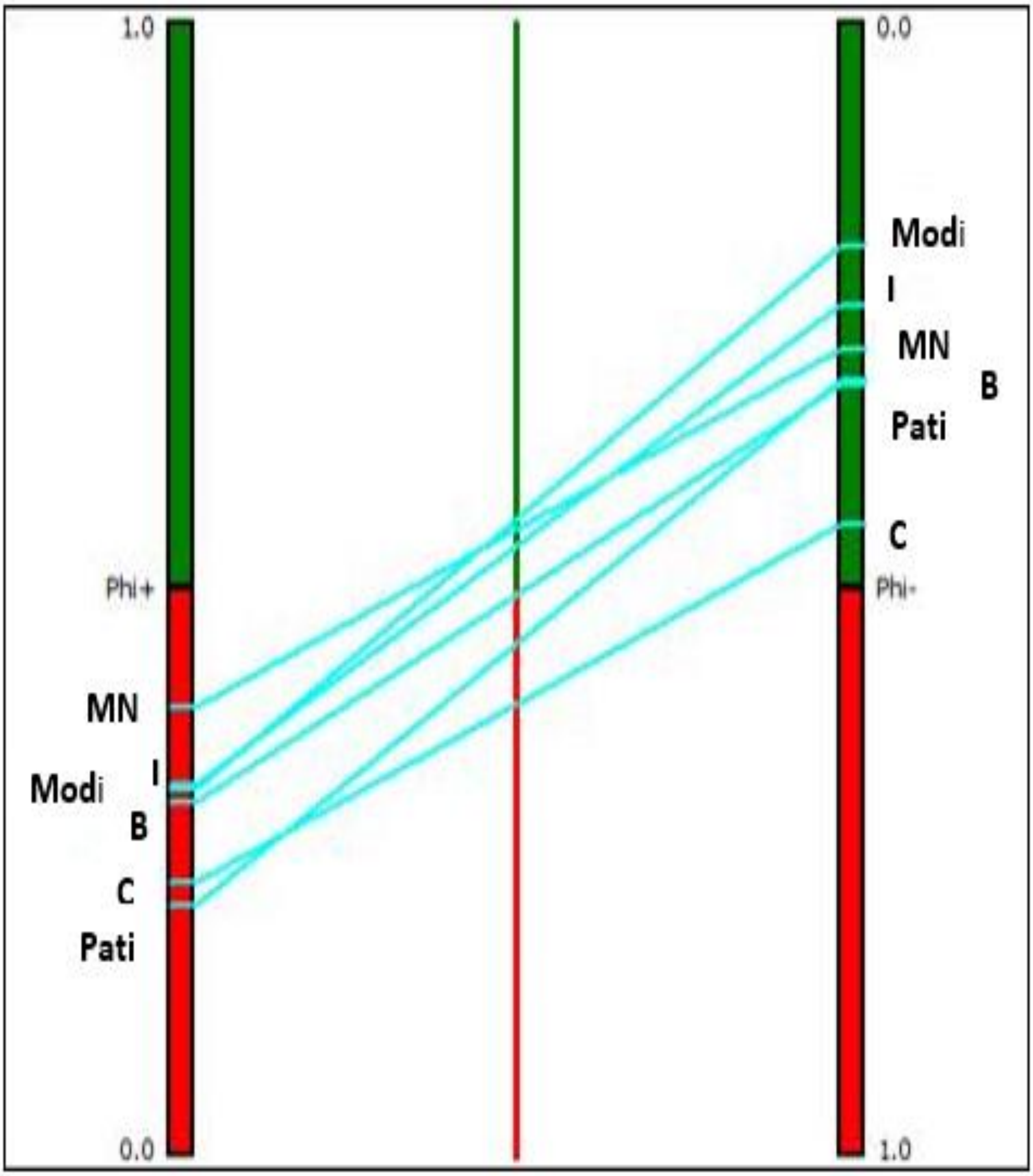


Figure 48: PROMETHEE I

Combining both positive (ø+) and negative (ø-) preference flows (shown in figure 48 and also see equation 16 - 18, refer section 5.2.3) will provide the complete ranking as shown in Figure 49. Modi NEA (MN) is best on positive attributes whereas Modi private (Modi) is best on negative attributes, but on the complete ranking, Modi private (Modi) is on top.

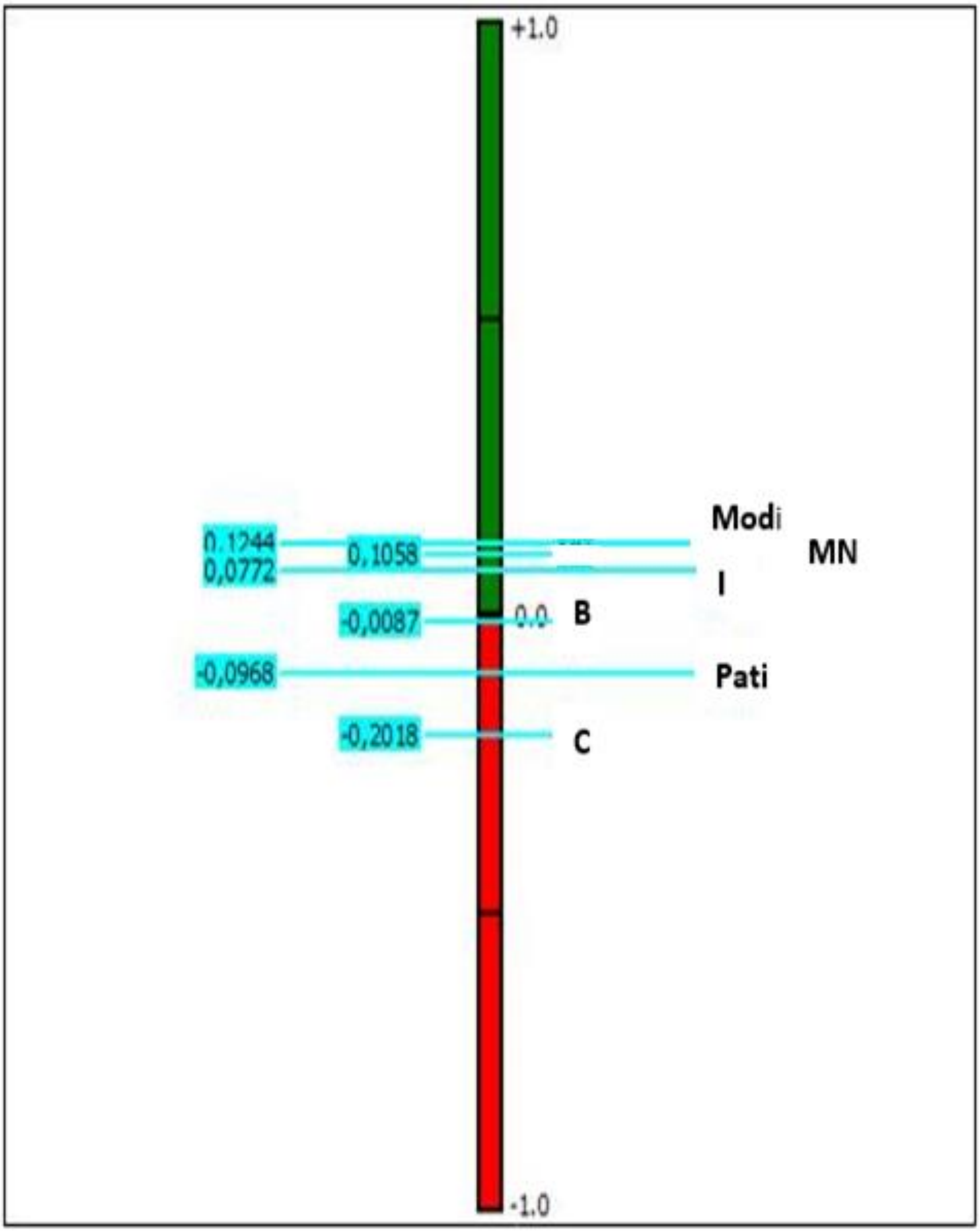


Figure 49: PROMETHEE II

PROMETHEE Diamond is an inbuilt visual feature in VP which displays the complete results which could be comparable instantly. The ranking results could be displayed as PROMETHEE Diamond as shown in Figure 50. The overall best alternative, Modi private (Modi), performs best on negative aspects on the left-hand diagonal offset. Similarly with regard to positive aspects of the same alternatives evaluated it is only the second best performer as noticed by the positive offset on the right-hand diagonal. All alternatives are also displayed the similar manner and all together. Hence alternatives performance could be easily visible and comparable once displayed on PROMETHEE Diamond.

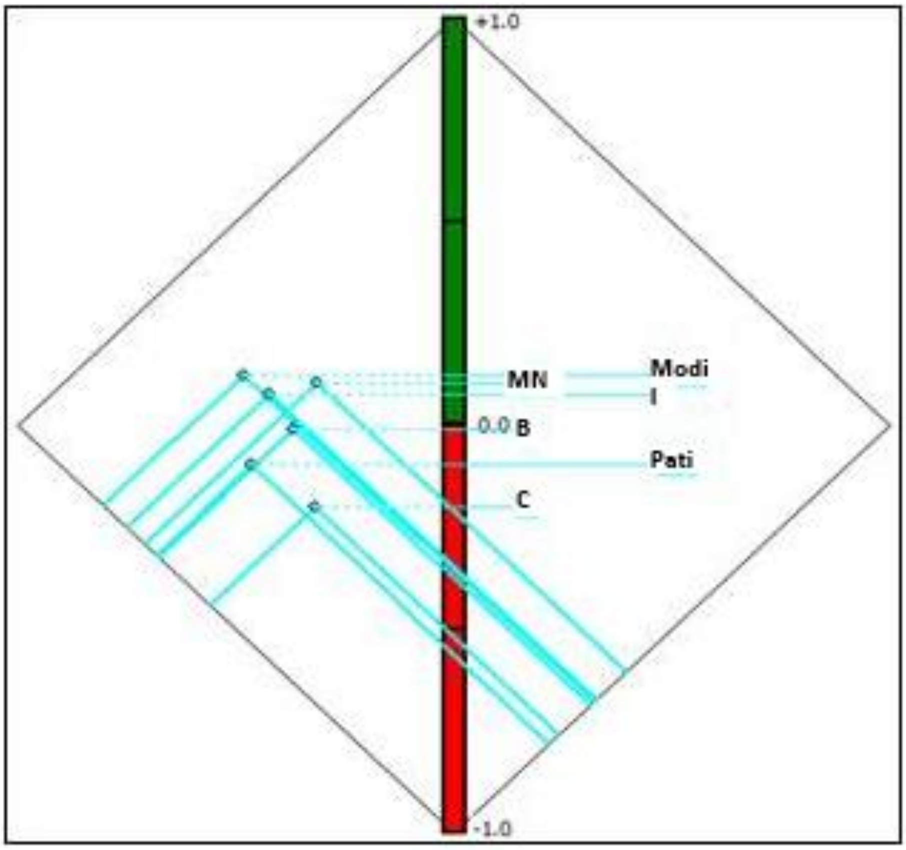


Figure 50: PROMETHEE Diamond

The ranking results from PROMETHEE diamond (which presents the net alternative positions and also shown both positive and negative flows) can also be presented in a visual network display. From the following network of alternatives, based on their overall, positive and negative score, their relative position can easily be understood. It is important to note that vertical axis is representing the offset value of alternative on right-side diagonal axis showed in figure 50 and similarly negative values of alternatives are positioned like left side diagonal axis. Their combination on vertical axis in figure determine their relative position in network. Hence the network of alternative schemes is presented with the overall ranking position (vertical axis- as shown in figure 50) and arrows indicating the dominance directions. As shown, Modi is the best performer overall and hence is vertically on top. Similarly, lowest performer on overall scoring, C is at the bottom. Likewise the arrow provides complete dominance of alternative schemes if one is better than other on both positive and negative scoring. In Figure 51 one can see that the arrows connect the alternatives with complete domination in positive as well as negative dominance, like Modi dominating Pati, Baramchi (B) and Chaku (C). There are some instances when one alternative dominates other on one type of preference flow (either positive or negative) but is dominated in another type of preference flows. This results in incomparability, as seen between Modi and MN. In such a situation, the overall ranking is based on the combination of both kinds of performance flow. To be ranked top, alternatives should perform better on both kind of preference ($\emptyset^{+}$) and $\emptyset^{-}$) and even if it fails on any one of them, it should not fail strongly. As seen here, Modi dominates MN on positive flows ($\emptyset^{+}$) but slightly fails on negative flows ($\emptyset^{-}$). Finally Modi scores more and remains top of the ranking.

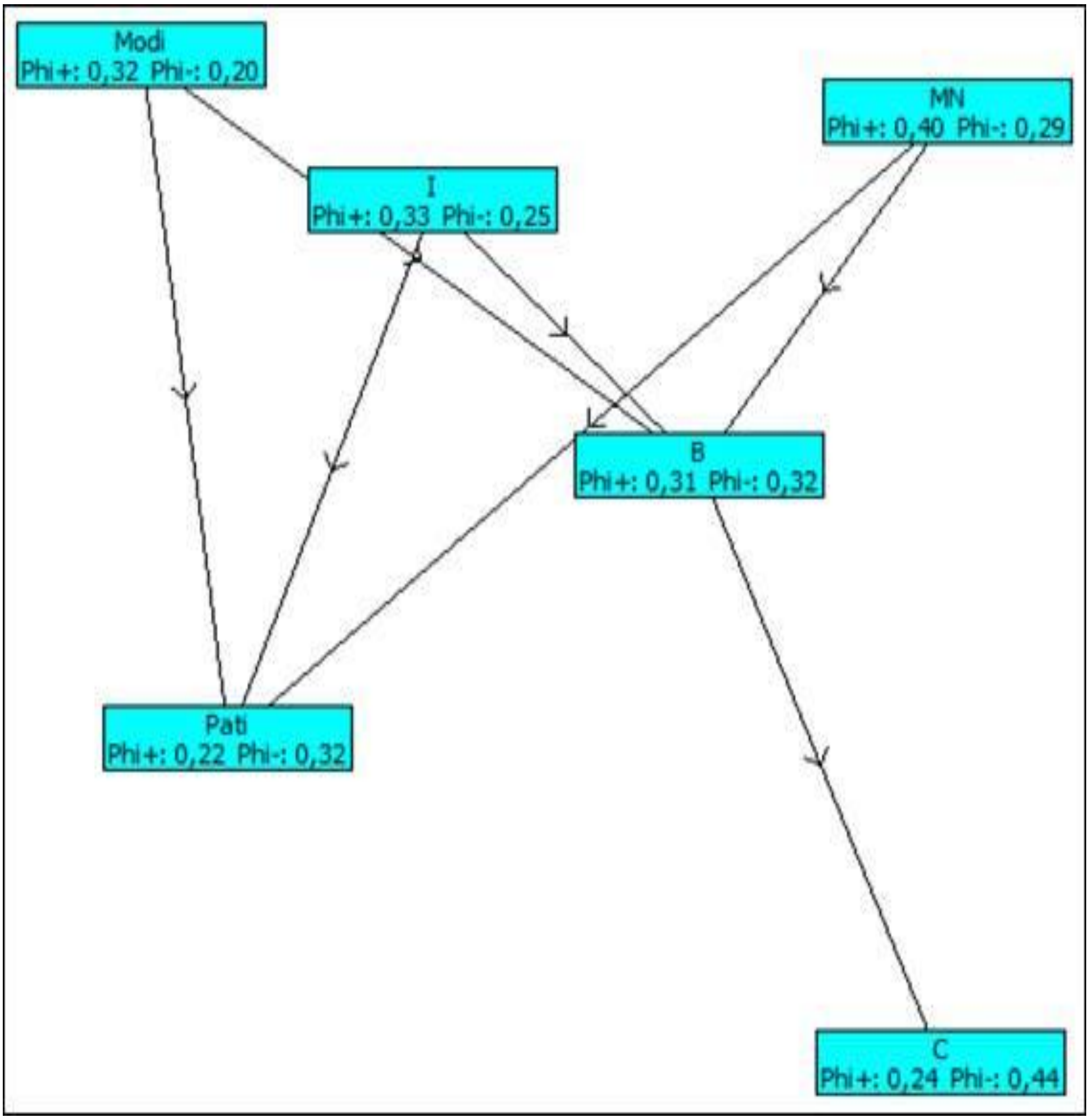


Figure 51: Network of alternatives overall ranking position and dominance directions

Further insight on each criteria contribution with respect to each alternative can be visualized from the detail Phi table in Table 17.

From the detailed Phi table shown here one can see the value assigned for all criteria. The information could be cardinal (quantitative) like PG (power generation capacity of a plant) or an ordinal (qualitative) expression like WQ (water quality). In the case of PG, with a defined preference function as well as limits, the data is evaluated and compared for all alternatives to assign the values. In this case all alternatives are assigned values from the highest +1 (highest power generation capacity of Modi NEA) to lowest -1 (lowest power generation capacity of Pati). In the case of WQ, only two different kinds of evaluation are received and assigned values accordingly.

Table 17: Phi table showing each criterion's contribution

Alternatives		Pati HP	Modi HP	Modi HP NEA	Baramchi HP	Indrawati HP	Chaku HP
	Symbol	Pati	Modi	MN	B	I	C
ECONOMIC	PG	-10,000	0,6000	10,000	-0,2000	0,2000	-0,6000
	LF	-0,8000	0,4000	0,4000	0,4000	0,4000	-0,8000
	IF	-0,4000	0,6000	-10,000	0,6000	0,6000	-0,4000
	FD	-0,2000	-0,2000	-0,2000	-0,2000	10,000	-0,2000
	CI	0,5227	0,5067	-0,2000	0,7707	-0,8000	-0,8000
	ST	0,0000	0,8000	0,8000	-10,000	-0,6000	0,0000
	LT	0,0000	0,0000	10,000	0,0000	0,0000	-10,000
	IB	-0,4000	-0,4000	0,6000	-10,000	0,6000	0,6000
SOCIAL	EB	0,2000	0,2000	0,2000	0,2000	0,2000	-10,000
	GM	0,6000	0,6000	0,6000	-0,6000	-0,6000	-0,6000
	PR	-0,2000	-0,2000	-0,2000	-0,2000	10,000	-0,2000
	MA	-0,4000	-0,4000	-0,4000	0,6000	-0,4000	10,000
	LO	0,2000	0,2000	0,2000	0,2000	0,2000	-10,000
	RO	-0,2000	-0,2000	-0,2000	-0,2000	-0,2000	10,000
	DR	-0,4000	-0,4000	-10,000	0,6000	0,6000	0,6000
	PP	0,6000	0,6000	0,6000	-0,6000	-0,6000	-0,6000
	PM	-0,2000	-0,2000	-10,000	0,8000	0,8000	-0,2000
ENVIRONMENTAL	FL	0,4000	0,4000	-0,4000	-10,000	-0,4000	10,000
	SB	-0,2000	-0,2000	-10,000	0,8000	-0,2000	0,8000
	WQ	0,4000	0,4000	-0,8000	0,4000	0,4000	-0,8000
	WC	0,4000	0,4000	-0,8000	0,4000	0,4000	-0,8000
	SW	0,4000	0,4000	-0,8000	0,4000	0,4000	-0,8000
	VI	0,0000	-0,8000	0,0000	-0,8000	0,6000	10,000
POLITICAL	NI	0,2000	0,2000	0,2000	-10,000	0,2000	0,2000
	SP	-0,6000	-0,6000	0,6000	-0,6000	0,6000	0,6000
	RB	-0,4000	-0,4000	0,8000	0,8000	-0,4000	-0,4000
UNCERTAINTY	CP	0,2000	0,2000	-10,000	0,2000	0,2000	0,2000
	ER	0,4000	0,4000	0,4000	0,4000	-0,8000	-0,8000
	MR	-0,6000	-0,6000	0,6000	-0,6000	0,6000	0,6000

To obtain the contributions of each criteria, PROMETHEE rainbow is a strong feature of VP as shown in Figure 52. Here, the rainbow profile, as the name suggests, is a combination of all positively and negatively contributing criteria presented in different colours. Each of criteria is represented by a thin rectangle of a colour and the thickness of each rectangle depends upon its contribution. If the criterion contributes positively then it will be above the horizontal line and if amount of contribution is more then it will be represented with thicker rectangle. The middle horizontal line represents a neutral value, above this line is positively contributing criteria whereas those below are contributing negatively. One can find that though Modi NEA (MN) has comparatively many more positively contributing criteria than Modi on positive aspects, at the same time several of its negatively contributing criteria are pulling the overall ranking to second for Modi private (Modi).

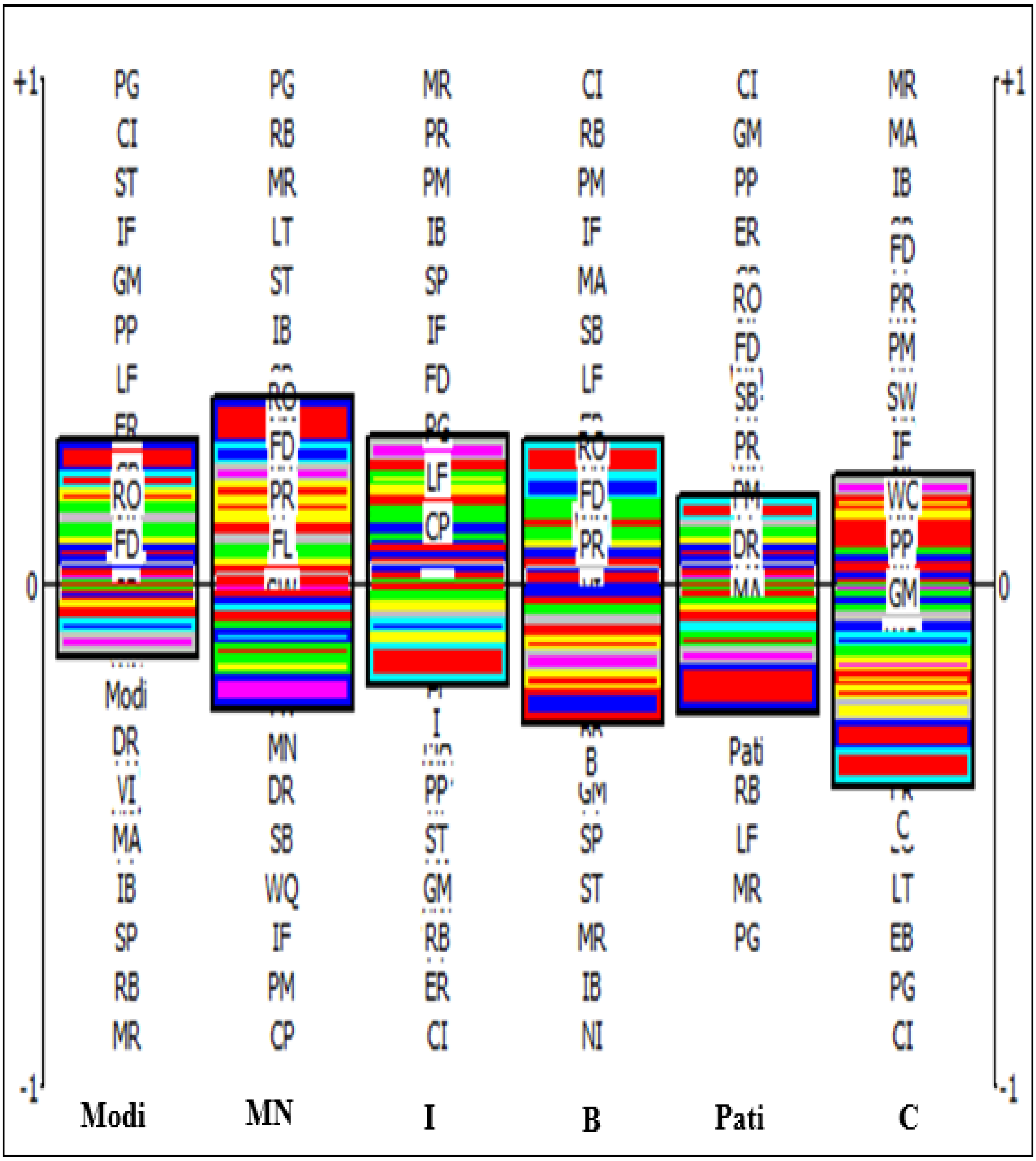


Figure 52: PROMETHEE Rainbow

For easy understanding, the summation of the criteria contributions reflects the ranking of alternatives and is shown in Figure 53. The total criteria contribution of each alternative is shown in the blue square boxes. Above the horizontal (zero line) is net positive contributions from criteria and the higher this positive value is, the better performing is the alternative. Similarly below this horizontal line is net negative value and the more this negative is, the poorer performing the alternative. Here one can find the best action is Modi followed by Modi NEA (MN) and Indrawati (I). Also putting together both positive as well as negative contributions of decision criteria places Baramchi in fourth place with an almost neutralized (nil resultant) contribution. Pati has a net negative contribution and the most negative contribution is of Chaku (C), putting it at the lowest ranking among alternatives.

Now it is important to visualize the impact of the varying weight of one criterion at a time. Criteria have their corresponding weightage in the ranking exercise which can be seen at the bottom of the central box displaying the ranking result in Figure 53. This is also shown in Figure 47 where the analyst can vary the weight of one criterion at a time to see the impact on the ranking of the alternatives. In this way the walking weight feature discriminates the powerful and sensitive criteria from the null criteria.

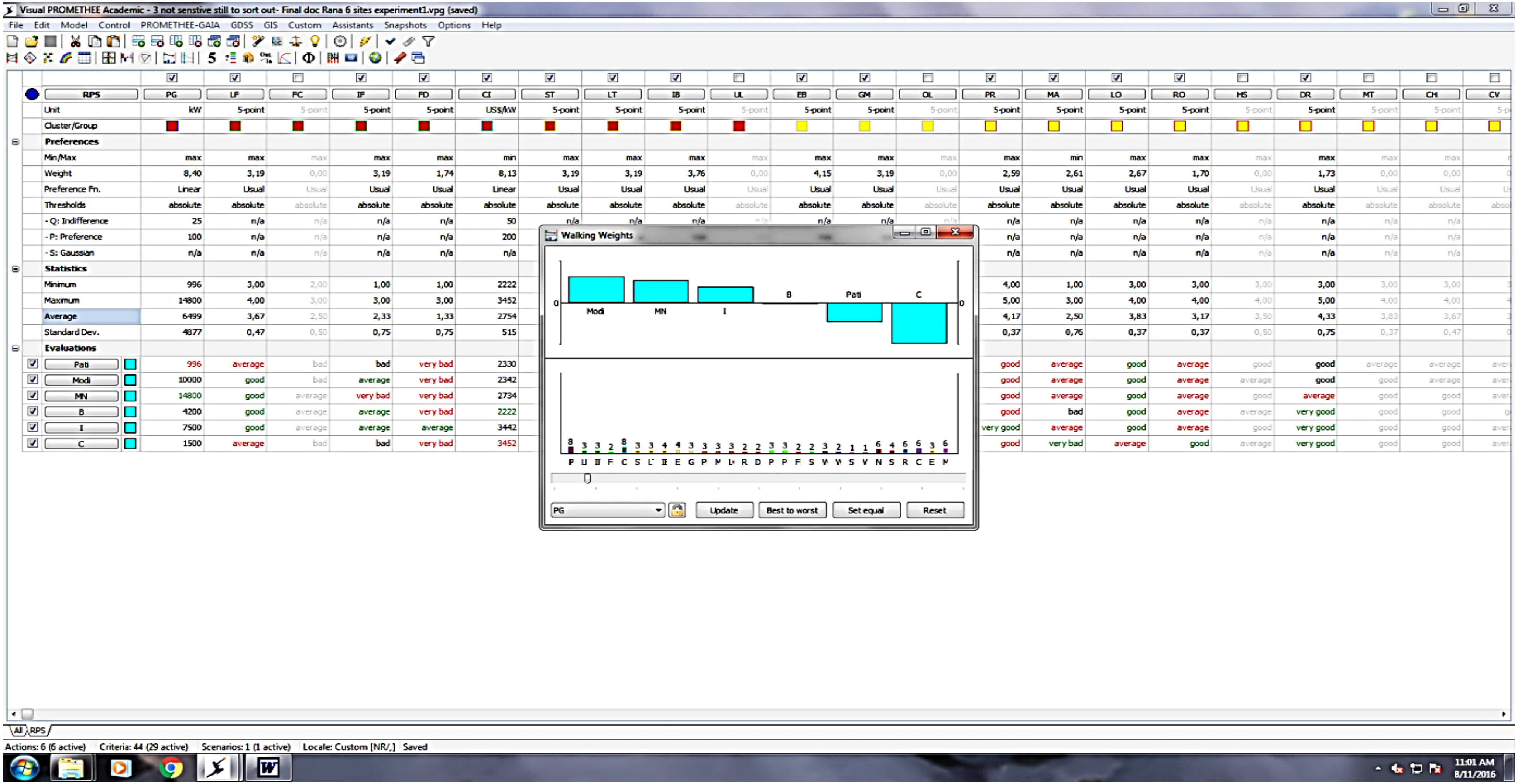
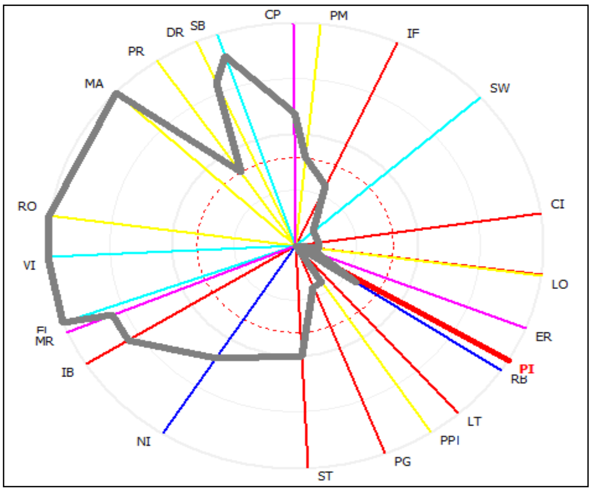
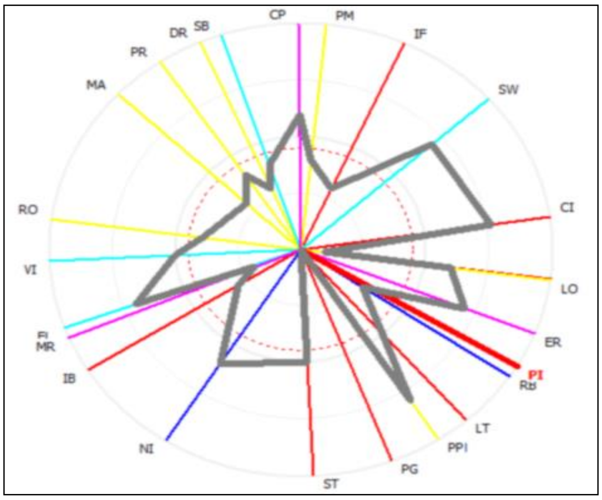


Figure 53: Overall contribution of criteria and actions ranking

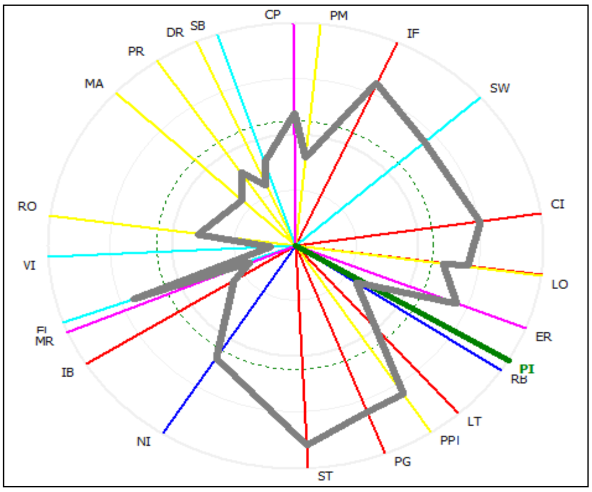
The action profile of the alternatives is another important result displayed in VP. It is helpful to see the action profiles for alternative projects (each power plant) to grasp the contribution of each element through GAIA analysis as shown in Figure 54. The action profile is shown on GAIA plane and is different from spider displays (for details see http://www.promethee-gaia.net/assets/vpmanual.pdf). In usual spider web displays the variables (criteria) are equally spaced around the center of the display but in a GAIA plane, the criteria expressing similar preferences are located close to each other and thus spacing among criteria is not uniform. Here criteria expressing similar preferences are located close to each other and the spider web shape is meaningful. The radial distance corresponds to the net flow score (-1 at the centre and +1 at the outer circle). The thick axis PI is the decision axis. The decision axis is a representation of the weighing of the criteria. If the weight of the criteria are modified, only the decision axis is modified, not the GAIA plane. The orientation of the decision axis indicate which criteria are in agreement with the PROMETHEE rankings and which are not. It is shown in red if the alternative has a net negative contribution and green if positive. This will be useful for the researcher or policy maker for planning better to reach the desired objectives. The project wise action profiles follows here.



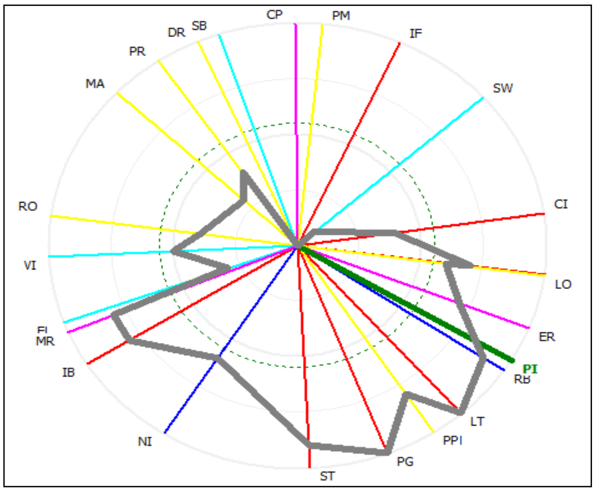
Chaku hydropower



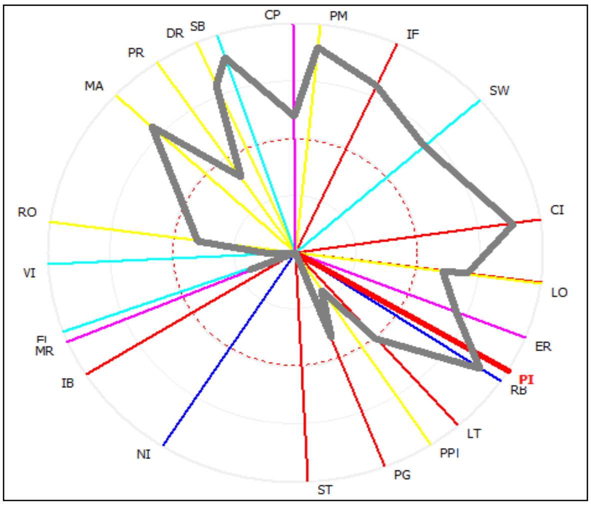
Pati hydropower



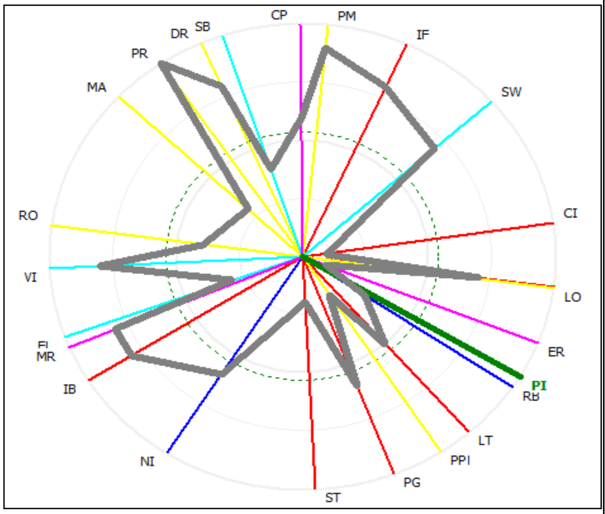
Modi (private) hydropower



Modi NEA hydropower



Baramchi hydropower



Indrawati hydropower

Figure 54: GAIA webs for hydropower plants with decision axis

6.2.2.3 Sensitivity analysis

The first draft decision framework with 44 criteria was studied with different visual results and making some changes to evaluate the strength and relevance of criteria. To understand visually, every alternatives were plotted with criteria profile. The criteria contribution profiles for each alternative is a way to display important results displayed in VP to visualize their contribution in evaluation and ranking. . An individual criterion's contribution to the ranking procedure can be evaluated by assigning a range of +1 to -1 against each criterion. Each criterion is compared among all alternatives and evaluated to a place between the most favoured (assigned +1) and least favoured (assigned -1). For each alternative, when put together, each criterion's contribution will result in a criteria profile for that alternative like shown in Figure 55 for Pati hydropower as an example.

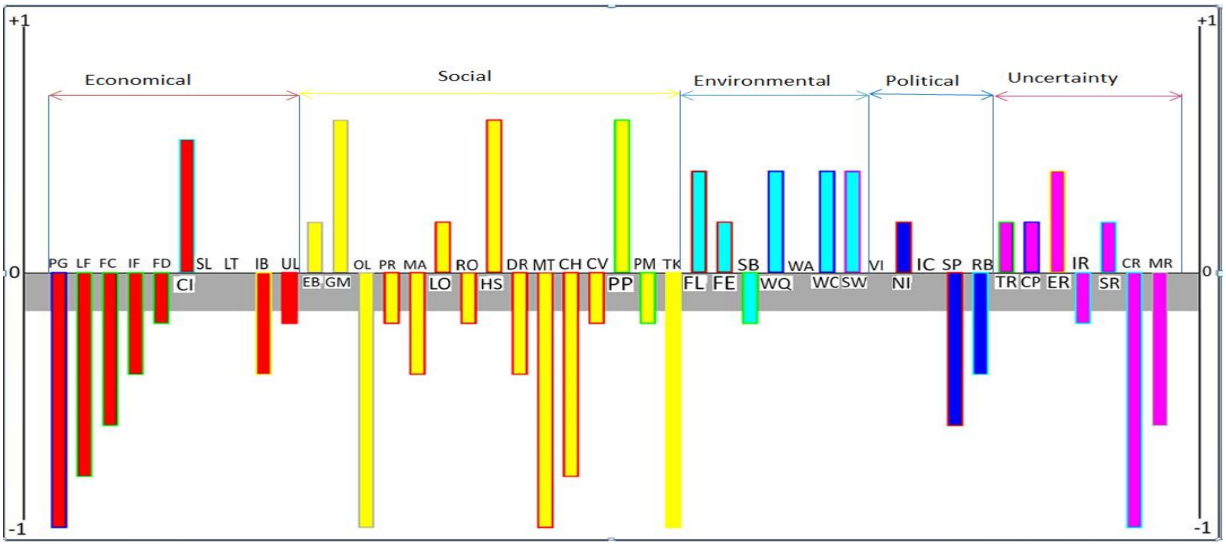


Figure 55: Criteria profile for Pati hydropower with respect to all 44 criteria applied

The colours of the columns refer to the five goals (e.g. red for economy) and also the criteria acronyms as mentioned in Table 13 are included in Figures 55 and also later on in figure 60. Here + and -1 refer to the ø values. The overall contribution of a criterion is represented by a thick brown shadow and in this case it is negative ($ø_{NET}$ =-0.0968). Thus the total sum of criteria contributions ($ø_{NET}$) obtained for each alternative can be used for compared ranking purposes (explained below). As shown here for Pati hydropower, one can see a few criteria are not contributing, some are strongly contributing while others are weakly contributing. Such criteria profiles for all alternatives will help to understand the criteria's influence on the ranking and decision exercise. To identify influencing and non-influencing criteria in decision making, sensitivity analysis is performed as explained here.

Sensitivity analysis is essential in any multi criteria decision analysis (see Section 5.2.1). In addition to common sources of errors, in Visual PROMETHEE further errors may added through poorly selected preference functions and thresholds. It is thus important to check that slight variations of the parameters do not have a large influence on the results. Visual PROMETHEE has a feature for sensitivity analysis which helps the decision maker in their task to view different outputs (results) by changing a certain input. The researcher can consider any set of alternatives to perform sensitivity analysis and can focus on any set of criteria of interest. In VP, sensitivity analysis can be performed following the walking weight of criteria and also reviewing the visual stability intervals.

As weight allocation can change with time and can also vary with the decision maker's subjectivity (Mergias et al. 2007), it could impact the outcome of analysis. Hence it is important to examine weight allocation to criteria and its possible variation (increasing or decreasing) the criteria shown at bottom of figure 56. As shown in the bottom horizontal line, each criteria weight can be varied by increasing or decreasing a criteria at a time while applying VP in computer and its impact on the ranking could be easily visualized on top horizontal blue boxes. Bigger the size of blue box above zero horizontal line is better and below is worst in terms of overall performance.

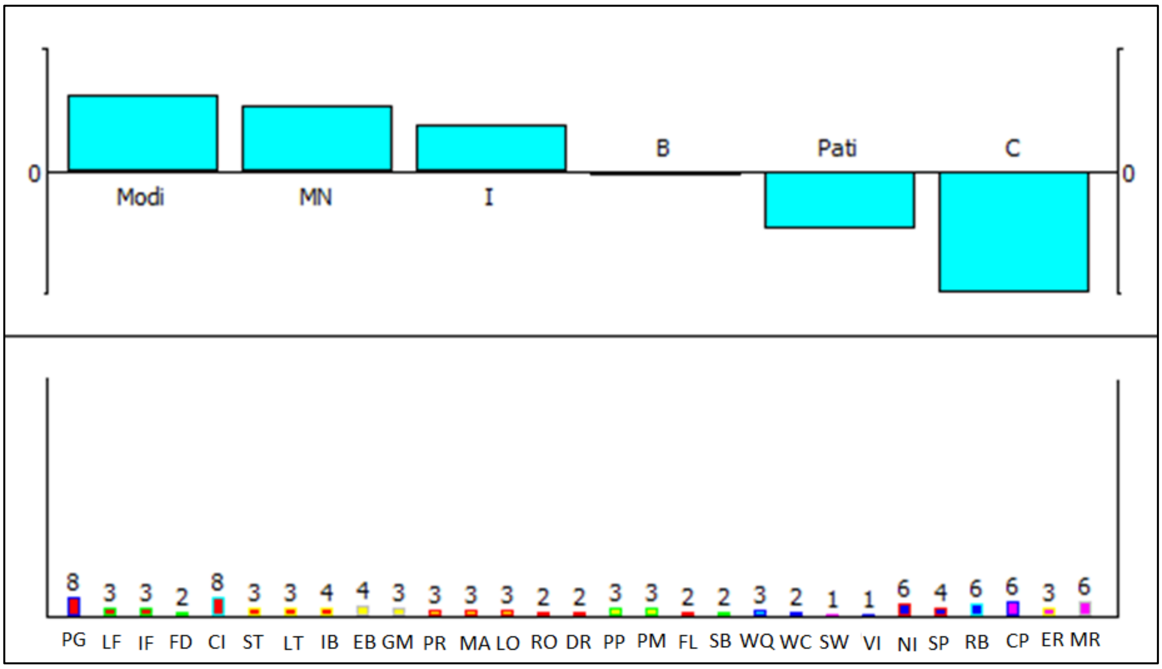
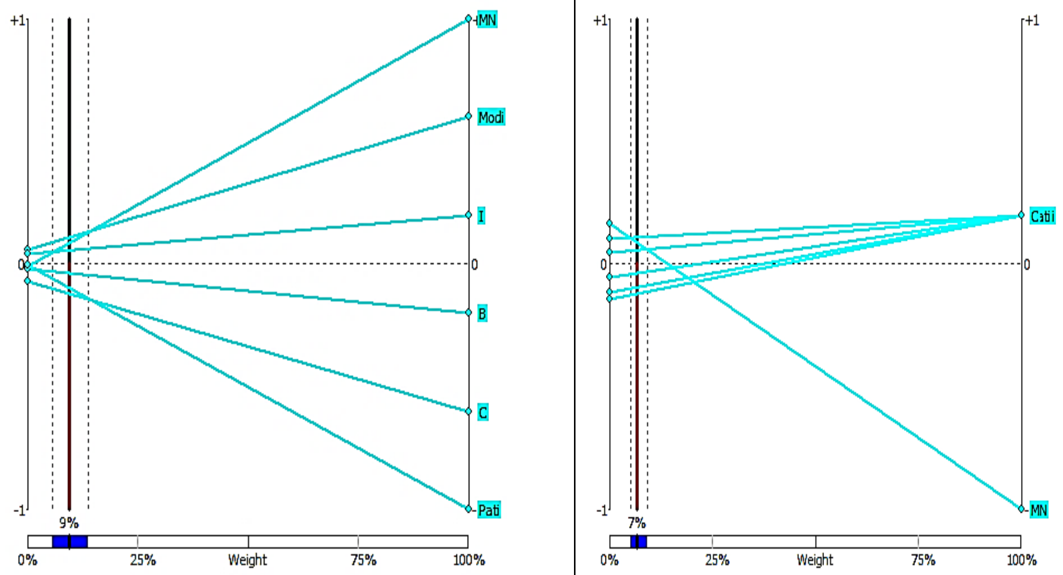


Figure 56: Flood Control (FC) criteria weight changing and impact on overall ranking

Reasonably acceptable weight allocation of criteria is a very important requirement and must be tested for the robustness of the framework. In the present research, this was tested by performing walking weights, which is simply a sensitivity test done by ranking the results by varying weights of one criterion at a time to see the impact. An example is shown in Figure 57 where the weight of criterion FC (Flood Control) is varied to observe the impact on alternative ranking. Another way to visualize the impact is by varying a criterion at a time to observe the change in positioning of all the alternatives. For illustration, two of the most important decision criteria in the present study are the power generation (PG) capacity of the plant and uncertainty on change in policy (CP) causing risk to hydropower plants. From Figure 57, it can be seen how the ranking changes with changes in their weightage. Here for power generation capacity criteria, Modi NEA (MN) is best if 100% of the decision weight is given to power generation capacity, and Pati hydropower will rank lowest. Similarly for the risk associated with change in policy, almost all other power plants reach top preference while MN drops to the lowest rank if this criterion is given 100% weightage to make decision. In this way one can visualize that the same hydropower plant, for example MN is at top priority for one criterion and lowest for another. Hence every criteria weight varied in either direction (increasing or decreasing) could impact the alternatives' ranking positions. Varying weight is useful to compare a set of chosen alternatives at a time or even evaluate a specific alternative at a time. This sensitivity analysis assists in identifying criteria exhibiting weak or strong discriminative power. In other words, when the weight of a criterion has no impact on the ranking the respective criterion could be excluded from the list.



Visual stability interval with respect to PG (Power generation)

Visual stability interval with respect to CP (change in policy risk)

Figure 57: Visual Stability of PG and CP

It is important to verify that the weight allocated to criteria in the present country context is reasonable and stable. To perform the sensitivity analysis of a criteria one can make a small change in a criteria weight (x-axis) and observe the change in the alternatives ranking profile (y-axis). As an example, shown in Figure 58 the criterion power generation capacity (PG) with weightage of 8% is used for ranking alternatives. On changing the weight of PG over a certain range (x-axis), the ranking order of the alternatives remains unchanged. Such a range is also called the stability interval which for PG in the present case ranges between 5 to 12% (between the two vertical blue lines). In other words, the broader the stability interval the less sensitive is the ranking with respect to this criterion and its weight.

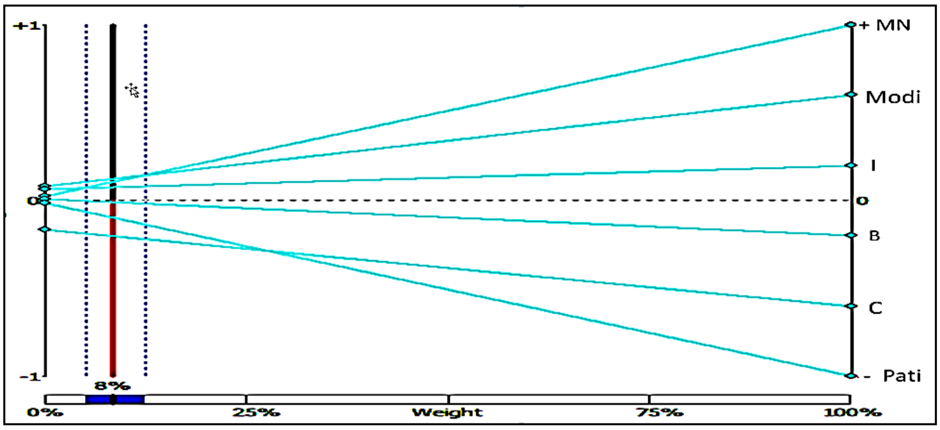


Figure 58: Sensitivity analysis of criterion Power Generation (PG) capacity of alternatives

Use of local resources (UL) is used as an example for a criterion with a low discriminative power. As shown in Figure 59, UL with weightage of 1% does not change the ranking order even if its weight changes significantly from 0 to 100%. With its wide stability interval, UL is not sensitive and can be eliminated as a null criterion.

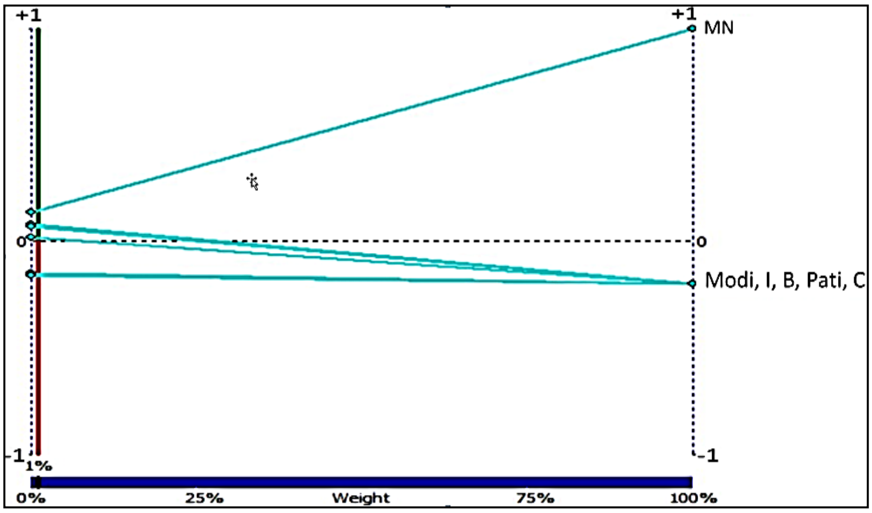


Figure 59: Sensitivity analysis of criteria Use of local resources (UL) for alternatives

Sometimes criterion weight varying over a significant range may not change the ranking and such a range is called the stability limit as presented in Table 18. If possibility of exceeding the weightage allocated beyond the stability limit for that criteria is unlikely, then the criteria weight allocated is stable and accepted. In some cases it is so wide that it has no way of changing the ranking order of the alternatives: then it is a null criterion. In the table all null criteria are highlighted in green. Such criteria can be removed from the list of active decision making criteria as they are null criteria. Some others are quite sensitive and can influence the decision just by a small variation in weightage.

Table 18: Stability details of criteria and identification of null criteria

Criteria	lower range of stability %	Weight allocated (%)	upper range of stability %
PG	2.7	5.1	6.46
LF	1.41	2.2	3.6
FC	1.4	2.2	100
IF	1.3	2.2	3.8
FD	0	1.2	3.9
CI	4.6	6.2	7.3
ST	0	2.2	3.1
LT	1.3	2.2	3.9
IB	1.2	3.2	3.8
UL	0.4	3.2	100
EB	1.4	2.2	3.6
GM	0	2.2	3.6
OL	1.3	2.2	13
PR	0	1.1	3.9
MA	0	1.1	3.4
LO	.4	1.1	2.6
RO	0	1.2	1.9
HS	0	1.2	11.7
DR	0	1.2	3.26
MT	0	1.2	100
CH	0	1.2	100
CV	0.4	1.2	10.5
PP-	0	2.2	3.6
PM	1.3	2.2	4.4
TK	1	3.2	100
FL	0	1.2	1.7
FE	0	1.2	9.3
SB	0	1.3	5.4
WQ	0	1.3	2.7
WA	0	1.3	100
WC	0	1.3	2.7
SW	0.5	1.3	2.7
VI	0.3	1.3	1.8
NI	0	6.2	6.7
IC	0	3.1	100
SP	1.7	3.1	3.9
RB	5.3	6.5	14.9
TR	0	3.1	28.8
CP	0	4.1	6.8
ER	1.4	2.2	3.6
IR	0	1.3	100
SR	0	1.2	10.5
CR	0	1.3	100
MR	2.6	4.1	4.8

As mentioned earlier (see Section 4.2.e), likewise the impact of varying weights on the overall alternative ranking and testing such variation within or outside the stability range is important. Those criteria without discriminatory power in comparing alternatives (null criteria) are eliminated from the final set of criteria used in the decision framework. Based on these final criteria in the decision framework and their allocated weights, VP is applied to analyse the alternatives.

6.3 Summary and conclusion

Results from analytical or perspective analysis determined applicable criteria and corresponding weightage estimates which was further used in secondary data based AHP application. Again the verified criteria and weightage from secondary data based AHP application helped to perform questionnaire survey for next AHP application. Also applications of different MCDMs helped to cross-check the results and applicability of MCDM tools in the hydropower context. Finally a draft decision framework developed was tested in field for its applicability and performance.

The first drafted decision framework tested in the field where it was found that all the criteria mentioned in the framework are easily obtainable and also could be used in the VP application. With sensitivity analysis and reviewing stability of each criteria, it was possible to identify criteria required for decision making and a final decision framework is developed. In other word the identification of influencing criteria and removing all those identified as null criteria (represented by green colour in table 18) the concise decision framework developed is presented in table 19 which will be effective in saving time and resources to make decision. This is what achieved in this research. The final framework thus applied following VP now can give the score against each alternatives and their ranking orders.

Table 19: Decision aids applicable for hydropower in Nepal

S.N	Goals	Criteria	Sub-criteria, symbol and description	Weight
1	**Economic**			**0.35**
		Power Capacity	PG = annual power generation	**0.09**
		Indirect Benefits		**0.08**
			LF = Local infrastructure developed due to project	0.03
			IF = Irrigation facilitated	0.03
			FD = Fishery developed	0.02
		Cost (US$/kW)	CI = Total project investment	**0.08**
		Employment		**0.10**
			ST= Directly related to project- short term 3	0.03
			LT = Directly related to project – long term 3	0.03
			IB = Indirectly related to project – secondary benefit	0.04
2	Social			**0.25**
		Equity		**0.07**
			EB = Distribution of both cost (risk) and benefits	0.04
			GM = Gender mainstreaming, inclusiveness	0.03
		Project-induced impacts		**0.12**
			PR = Power reliability and grid integration	0.03
			MA = Movement: HH activities (farming, grazing)	0.02
			LO = Impact on law and order and local life style	0.03
			RO = Recreation opportunities	0.02
			DR = Displacement and resettlement of PAF	0.02
		Transparency and Governance		**0.06**
			PP = Public participation in Decision Making	0.03
			PM = Partnerships in management/governance	0.03
3	Environmental			**0.10**
		Degradation due to HPP	FL = Forest and biodiversity loss	0.02
		Sediment balance	SB = Trapping of sediment- riverbed scouring	0.02
		Impact on water resources	WQ = Water quality	0.02
			WC = Impact of water natural connectivity	0.02
		Solid waste and pollution	SW = Solid waste, noise and vibration and proper monitoring during construction	0.01
		Visual impact	VI = On landscape due to project	0.01
4	Political			**0.15**
		National independence	NI = Project could support the independence	0.06
		Sector priority and PPP	SP = Power plant is as per the government preference	0.04
		Regional balance	RB = Supporting regional balance of power generation	0.05
5	Uncertainty			**0.15**
		Political (regulatory) risk	CP = Change in policy & priorities is political risk	0.06
		Environmental risk	ER = Climate change, greenhouse, land/rock movements	0.03
		Marketing and financing risk	MR = Change in market demand, competition and capital financing scenarios	0.06

In overall scenario, economic goal having highest weightage consists 4 criteria and 8 sub criteria, similarly social goal consists 4 criteria and 9 sub criteria (refer the final table 19) and so on. Power generation is one of the most important criteria allocated 0.09 weightage and could influence the decision significantly. Similarly cost and impacts related sub criteria are also among the most influencing. There were 15 criteria with least influence or practically no influence in decision making and are discussed later in Chapter 7.

The final decision framework thus developed is effective in hydropower analysis and could deliver all sorts of results (mentioned in section 6.2.2.2). To illustrate as one example how effective is the decision framework developed while applying VP is shown as criteria wise contribution profiles of alternatives in fig 60. Such profile may be helpful to resolve problems through appropriate action, policy or project management. Among the final list of criteria (29 listed) sometime certain criteria may not be relevant for a particular alternative while it could be prominent for another as shown in fig 60.

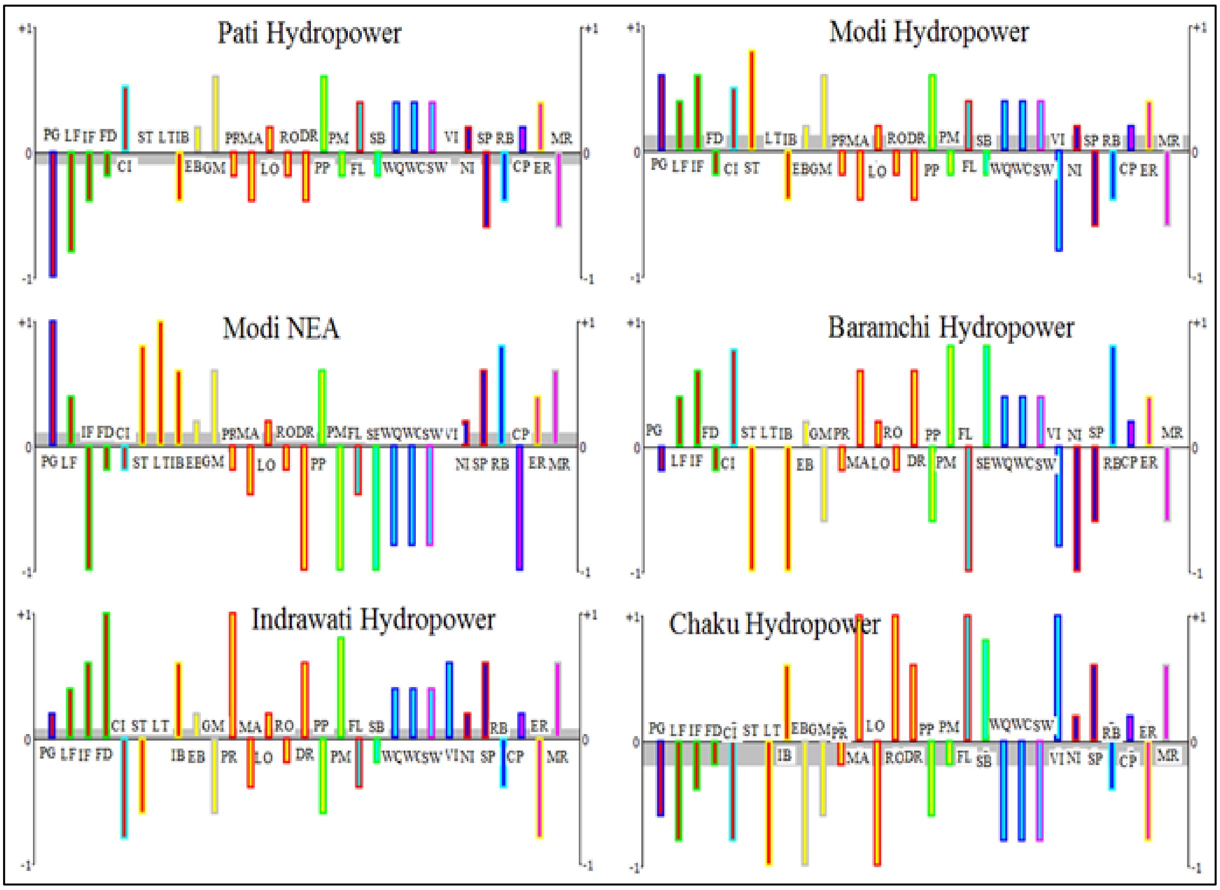


Figure 60: Decision criteria contributing to hydropower decision making in sample sites

7 Discussion of MCDMs applications and research results

The results from the research on hydropower development in Nepal with pertinent scale issues, preference, MCDM tools and decision framework are briefly discussed here. The chapter includes the results of different MCDMs applied vis-a-vis analytical analysis, AHP and VP application. For the stages of study, relevant data were obtained from various sources vis-à-vis secondary sources, questionnaire surveys, expert opinions, field visit etc. While hydropower research based on analytical analysis and AHP helped to identify applicable goals, criteria, their respective weights etc., the most important part of the study focused on VP application to develop a hydropower decision framework to evaluate and rank alternatives. While results in terms of numerical tables are helpful, visual displays are often more intuitive for comparing them. The VP application started with 44 criteria and then those with no or very low impacts (called null criteria) on rankings were eliminated. After eliminating 15 of null criteria, the final decision framework is very concise with 29 criteria. The stepwise research results up until reaching the final objective are briefly mentioned as follows:

7.1 Main objectives accomplished

Following the elaboration of existing issues of hydropower in Chapter 2, the research objective and important tasks were stated accordingly in Chapter 3. Regarding hydropower development in Nepal, two important issues were identified. The first and most important was relating with the need of appropriate hydropower decision framework, defined as main objective of the research (refer 3.1) and the second was relating with identifying the best category of hp (refer 3.2.2) among the five categories (micro, small, medium, big and large hp schemes – classified in Nepal based on generation capacity). These two issues set the main objective as well as complimentary objective of this research and are shown below respectively. Both of them were achieved successfully in this research.

- Developed decision aid to evaluated hydropower in an MCDM framework
- Prioritized or ranked the five classes of hydropower schemes in Nepal

7.2 Tasks concluded

In order to achieve the aforementioned research objectives, following were important tasks briefly summarizes here:

7.2.1 Identification of hydropower stakeholders

In order to include opinion of all possible stakeholders (refer 3.2.1) of hydropower development, it was reached to all types of stakeholders and tried to manage a balance to avoid any biasness or dominance of one kind over another. Whether it was literature or documents reviewed as evidence based analytical (perspectives) analysis; secondary data or questionnaire based AHP applications or VP applications, special attention paid to include all possible types of stakeholders to maintain a balance in analysis work.

7.2.2 Scoping domains of hydropower impacts

Details of hydropower impacts domains were analysed (refer 4.2) which includes mainly economic, social and environmental domains. While these are three main impact domains but for obtaining details views in hydropower, some other relevant domains were also reviewed under expanded headings of nine perspectives and then after rearranged in six or five goals in the research.

7.2.3 Selection of alternatives to analyse

In this research two different types of alternatives used, (i) for the first case alternatives considered were the five different scale of hydropower based on generation capacity for ranking which were used for different MCDM applications like analytical study, secondary data based AHP application and questionnaire based AHP applications and (ii) in second case, six existing hydropower sites were selected as sample projects to obtain field data to feed draft decision framework and applied VP which further fine-tuned to deliver the final decision framework.

7.2.4 Identification of goals of hydropower and their weight

The domains of hydropower impacts (refer 4.2) consists help to identify and set the goals of research. At different stages of study, these goals were chosen in more expanded form while keeping the main thrust around those three domains resulting major goals named economic, social and environmental. However for analytical study these were reviewed under nine different perspectives (goals) which allows to identify minutely over all kinds of criteria possible in hydropower. Based on those experiences and organizing many of perspectives within a goal, in secondary data based study, those were rearranged under six goals and further fine-tuned to five goals in AHP applied on data from questionnaire and also for VP field application. Regarding weights, starting from allocation of weights to different perspectives were based on literature and also consultation with experts. In similar fashion during secondary data based AHP application, earlier weights were fine-tuned following the rearranging nine perspectives under different number (six) of goals. Those weights were re-verified during questionnaire survey and hence were applied in the AHP application based on questionnaire which also provided basis (slightly refined according to goals rearranged) of weight allocation during VP application.

7.2.5 Identification of criteria and sub criteria of hydropower with their weight:

While conducting analytical analysis of hydropower through reviewing all available documentary evidences and also consulting experts, a long list of applicable criteria to analyse hydropower were evolved. Such long list of criteria were critically reviewed to avoid double counting and finally reduced to 44. Those 44 numbers of criteria or sub criteria were arranged under different nine perspectives. Accordingly criteria weights allocated in a way by DM, keeping the sum contributions of criteria weight matching with the weight of corresponding goal under which those criteria are placed. Those criteria and weights were further verified during questionnaire survey. This was very helpful to draft a decision framework with allocated weights of criteria, sub criteria and further field tested through VP applied to finalize the framework.

7.2.6 Identification of MCDMs applicable in hydropower analysis

Although MCDM application in Nepal is growing slowly, related research and application in the hydropower sector is very limited. Some suitable MCDMs applicable were identified and three of them were chosen (refer 5.2.3) to be applied in this research: analytical analysis-based evidential reasoning, AHP and PROMETHEE.

7.2.7 Collection of required (test) data

Data required were sources in this research from different sources (refer 4.4) like evidential reasoning using literature or documents while conducting analytical (perspective) analysis (refer 4.5.1) and those were also used in AHP application (named as secondary data based AHP application). For the next kind of AHP application, data were collected through questionnaire (electronic) survey (refer 4.5.2) and for VP application data were sources from field visits (4.5.3) of sample sites.

7.3 MCDMs applied and Results

In correspondence with the main objective and complimentary objective, the results are presented here along with the methods applied under respective sub-headings in following sections.

7.3.1 MCDMs applied to rank hydropower schemes based on generation capacity

The first three MCDM studies namely analytic analysis and two different AHP applications were focused to rank five alternative categories of hp in Nepal. These were helpful to identify stakeholders, goals, criteria, sub criteria and their weights. Following one round of MCDM application and verifying the results with another round or type of MCDM application verified the trustworthiness of results and MCDMs. Though details on these MCDMs presented at various section of Chapter 6, here briefly they are discussed.

7.3.1.1 Analytical (perspective) analysis

An MCDM technique was initially applied using evidence-based analytical analysis to rank five different scales of hydropower generation plants within a framework of nine goals. Commonly the hydropower sector considers economic, social and environmental goals. However in this research hydropower was reviewed in detail under several perspectives. For example, the economic goal (perspective) was further analysed under three different headings: economic benefits, financial and developers' perspectives. While project-related revenues, cost of investments and maintenance expenses are general aspects of project economics, there could be other economic factors related to project financing or financial institutions perspectives that need to be reviewed. Similarly, the economics of projects as perceived by their developers is different from general project economics or financers' point of view. Hence in hydropower while general economics is one aspect of a project, the financer or financing and developers' (owners or contractors) aspects are different. These were all given in-depth attention to include them in this analysis. In addition to these, hydropower-related perspectives in the social, environmental, technical, political, country preparedness and uncertainty areas were also analysed in depth. Based on this a simple scoring analysis was performed and found that medium-scale generation schemes best fit the present context. This simple and easy approach verified that the Nepalese context of hydropower could be analysed with the available information put together and thus an approach based on multi criteria could be effectively applied. This exercise also helped to work out the goals and decisive criteria in hydropower sector analysis in Nepal. Such evidence-based analysis gives better insights than what could be available from other approaches such as opinion surveys, workshops, expert views, groups or actors' opinions, etc.

The perspective analysis found the preference ranking among the five alternatives in reducing order of medium, big, small, micro and large. Corresponding to each perspective in the analytical analysis, the preference for alternatives was very different. While the economic, social, preparedness and finance perspectives preferred medium-scale schemes, the technical, environmental, developer and uncertainty (to reduce risk) perspectives highly favoured small-scale schemes. While the four highly weighted social, economic, political and financial perspectives gave medium schemes a high score, the remaining low-weighted perspectives could score their most preferred small schemes to place third in the ranking order. According to the perspective analysis, micro-scale schemes were not seen as the best performer by any of the perspectives even though much has been talked about them in the country. Because of their low load factor, high upfront cost and sparsely populated poor consumers, such schemes are financially unviable. Overall, micro schemes were positioned at low priority but ahead of large-scale schemes, since large-scale power development is at its very beginning stage and almost every perspective ranked them lowest except the political and economic ones.

Although the evidence-based analytic analysis was effective in understanding and prioritizing hydropower schemes, Multi Criteria Decision Analysis (MCDA) using modern scientific tools was desired to validate the results. Because of their favourable features such as ease of application, user friendliness, tool availability, capability to handle several alternatives and visual and numeric display of results, Analytical Hierarchy Process (AHP) and PROMETHEE (discussed in section 5.2.3) were the MCDMs recommended to validate and cross-check the results of the hydropower decision analysis. Hence, in addition to the evidence-based analytical study, the data and results from the analytical analysis were further used for MCDM tool applications.

7.3.1.2 AHP application based on secondary data

AHP is more suited for qualitatively expressed criteria. Here AHP application was completed in two different steps of the study.

The first was AHP application based on secondary data developed from the earlier analytical (perspectives) study. This successful application based on available data verified the applicability of the MCDM tool AHP in the hydropower sector analysis of Nepal. As in the analytical analysis, the same five alternatives (hydropower schemes based on generation capacity) were analysed. However AHP reorganized the earlier nine goals of the analytical analysis into six goals along with their corresponding criteria. It is far more informative than a workshop or survey-based approach. In addition, this approach helps to understand the relative prominence of alternatives with respect to set criteria in more detail because of the available documentary evidence and references. Through comparing earlier findings of a different methodology and verifying with the AHP application based on secondary information the research assured that AHP is an applicable tool for analysing the hydropower sector of Nepal. Use of secondary information-based AHP application in hydropower prioritization is a new approach and is a contribution to hydropower avenues.

7.3.1.3 AHP application based on questionnaire survey

AHP was once more applied to analyse hydropower based on opinions collected from experts working in the hydropower sector through a questionnaire (electronic) survey. The questionnaire was designed to collect expert preferences on previously identified and listed hydropower-related goals and criteria. This survey was very useful to determine the appropriate weights for goals and criteria. The weights of goals and criteria obtained from this survey were found to be close and comparable with the weights allocated in the two earlier applied MCDMs namely analytical (perspectives) analysis and secondary data based AHP application. In this AHP application, following experiences and advice from experts, once again the five goals and respective criteria were slightly fine-tuned to organize the analysis for the same five alternatives. During this reorganization, few criteria along with their allocated weight shifted from one goal domain to another, and changes were also made in the weights of goals accordingly. The slight change in weight allocated to the goals could be seen in the different MCDM analysis framework applied for the same set of hydropower alternatives analysis and ranking. The questionnaire-based AHP application results on alternatives ranking were compared with those obtained from the earlier MCDM applications and found to be similar. Thus, the data received from the experts through the questionnaire survey processed in AHP verified the results from the earlier studies and thus also verified the decision criteria and their weightage. The criteria wise preference analysis gave an indication that economics criteria preferred larger-scale energy generation whereas environmental criteria favoured the opposite. Although the technical criteria were not very discriminatory about alternative preferences, the social criteria highly recommended medium-scale schemes.

7.3.1.4 MCDMs results on ranking hp schemes based on generation capacity

The first three MCDMs (analytical analysis, AHP based on secondary data and AHP based on questionnaire survey) applied commonly addressed the scale issues i.e. the prioritization of five alternatives based on the generation capacity of hydropower schemes. When the MCDM tools applied (analytical and two cases of AHP) for the five alternative scales of hydropower schemes, medium-scale power generation was identified as the best option, followed by large-scale hydropower, in the present context. Small-scale hydropower was found to be the third priority followed by mini- and micro-scale projects as the fourth priority. Large hydropower with more than 1000

MW was found to be the lowest preference at present. Although big schemes are excellent at benefiting from economies of scale, government preferences and social benefits, they stand only at second priority because of the funding paucity, country preparedness, environmental concerns and associated risks. Small-scale plants, although eco-friendly contribute low quantity to the nation's energy demand. Hence they fall behind medium- and large-scale power plants in the priority preference. Micro-scale schemes, effective in energy access, receive good policy and subsidy support. These schemes are environmentally friendly and rapidly implementable with community involvement. In spite of their several good features, however, this scale of plants has limited generation and coverage capacity. Furthermore, such schemes are unable to benefit from economies of scale like other alternatives and hence are placed fourth in the ranking. Large-scale hydropower schemes are excellent at benefiting from economies of scale and seem attractive but such plants are targeted for energy export, which limits their economic contribution to national economic growth. Furthermore, they are full of uncertainties, leading to very high risks, mainly social and environmental: lack of resources and in-country capacity put this scale of power generation at the lowest priority in the present context.

A strong contradiction was found between governments and investors/developers in terms of their preference for the scale of schemes. The government emphasizes bigger schemes to benefit from economies of scale and also to meet the urgent energy demand of the nation, and also favours micro-scale schemes for rapid energy access in remote rural areas. Investors (funding agencies) and developers (private sector) think quite differently. They are reluctant to invest in micro-scale schemes as it is not a profitable sector for them. Big schemes are also beyond their investment capacity and not preferred. For them, medium- and small-scale schemes are the best options.

Among the considered goals in hydropower prioritization, the economic goal is of most importance and is likely to remain so in the coming years. Its importance will even increase with the strengthening national economy and increased power demand by neighbouring countries. This goal was found to be most sensitive in scheme prioritization. Changing weightage allocated to the economic goal, on both sides either decreasing or increasing, changed the priority order of the hydropower alternatives. Although this factor is currently stable for a wide variation (15%-35%), the strengthened future economy of Nepal and a strong market existing in neighbouring countries may place large and big hydropower projects at priority in the long term. Similarly for the social goal as the second most important decision goal, people are more concerned with impacts produced by the projects. Similarly the most important risks for hydropower in taking off in the country are changes in policy and market risk. It was also noticed that one of the important political goals in decision making was related to the regional balance of the power system and national independence. Environmental concerns are several and important in decision making but weighed low in comparison to other decisive factors.

The MCDM tools applied in this study verified their applicability in hydropower analysis and the available data could deliver trustable results. Moreover, the reliability of the results could be verified with sensitivity application and this was conducted for each MCDM applied in this research. Hence the results obtained are trustable.

The tools used such as evidence-based analytical analysis were very easy to understand and to achieve simple scoring. The highest score is for the best alternative.

The scoring table is very helpful for criteria wise comparison of the alternatives. It can be organized with visual displays like charts and figures for better understanding of the results. A more scientifically organized analysis is possible with the AHP application where a certain number of alternatives within a limited set of goals and criteria can be analysed. Based on pairwise comparison, a decision is obtained following a logical sequence. With the help of the concordance feature built with this analysis, the decision process follows within the right track and hence the results obtained are more trustable.

7.3.1.5 Sensitivity analysis & conclusions:

The results of the prioritization or ranking of the alternatives obtained were similar in all three MCDM applications applied for ranking five alternative schemes. Reliability of results need sensitivity analysis because the human and other errors might have occurred to differ the results from it should be otherwise. Just varying slightly the weight allocated to goals or criteria should not alter the results much and has been tested accordingly. Thus the results of AHP applications were tested through sensitivity analysis and found to be trustworthy. Hence AHP based on secondary information was found to be an easy and reliable approach to analyse and prioritize hydropower.

7.3.2 MCDM (PROMETHEE) applied to develop decision framework

So far hydropower analysis had been completed through different MCDM applications, namely evidence-based analytical analysis and two different AHP applications (secondary data obtained from the analytical analysis and data collected from experts' opinions through the questionnaire survey). These studies helped to obtain sufficient details on all possible domains of hydropower impacts (goals), measurable indicators (criteria) and their respective weights. Furthermore, these applications helped to determine an appropriate hierarchy applicable for hydropower analysis. With all this information in place, the next step was to draft, test and finalize an appropriate decision framework applicable in hydropower decision making. This is presented in following section.

7.3.2.1 Draft decision aid and data collection for VP application

Following the earlier studies, with identified criteria, goals and their weights, a draft decision framework was proposed. The draft framework thus proposed to analyse (evaluate) alternative hp sites and was configured with five goals, 23 criteria and 44 sub criteria (refer table 14). To test the effectiveness of the framework, it was tested through field application. A sample of six existing sites from two different clusters, each consisting three sites were selected (refer 5.3). All kind of field data required were possible to collect from the field following field data collection format, survey guidelines and check list. This confirms that the decision framework based on multi criteria is applicable and workable in Nepal. Further those data were entered in to VP (as explained in 6.2) along with respective weights to develop impact table (refer table 15). Once VP applied, the results were available in digital (numeric) as well as visual displays detailing all criteria and goals in many ways to show the scores, rankings of alternatives, contributions of every sub criteria, criteria or goals to achieve final score or rankings (for detail refer 6.2). This also confirms that VP could be effectively applied as MCDM tool to analyse hydropower sector and could assist in decision making.

Such a complete set of criteria measurements and evaluations could be useful in different ways, for example to obtain

1. Detailed hydropower assessment: Any hydropower project could be assessed against all of the criteria. The final summation of the scores of all criteria could be used for comparing alternatives. Even for a single alternative, a detailed assessment of criteria and their cumulative score is possible. In this kind of assessment there is no minimum requirement for the score against the criteria to ensure sustainability. Hence even if the hydropower cumulative scores are very high but it performs poorly on any one criterion this could fail the project.

2. Hydropower sustainability assessment: This kind of assessment is similar to the detailed assessment with one additional feature: an assigned critical minimum or maximum value against all criteria required for the sustainability of the plant. Plant which fail on any of the criteria can be removed and the rest that qualify further analysed based on the score obtained. This exercise also invites the collection of every kind of information related to hydropower: much is either not available (specifically in underdeveloped or developing countries) or unreliable. Hence even after a good exercise the end result may not be useful or different. Thus a further requirement is to develop an even simpler and smarter, more effective decision framework.

3 Hydropower decision aid: Here from the complete list of applicable criteria for analysing hydropower, a minimum list of criteria could be identified while all other criteria which are non-determining in the comparison analysis are removed. The proposed list of criteria in draft decision framework needs to be studied in depth with sensitivity analysis to determine those contributing significantly to the comparison analysis of options and decision making which is explained in following section.

7.3.2.2 Selection of relevant criteria

Now one more challenge remains is about verifying the effectiveness of criteria in decision making. It raises a question, do we really need all of those listed criteria which may demand more time and expense to collect data. Alternatively what we could do to make the decision framework more concise and impacting without losing quality. This need to verify once more the list of criteria proposed and hence discussed here.

In most situations, a more specific decision framework is needed to assist decision makers to compare the alternatives and recommend attractive alternatives. Although in the initial phase a wider list of criteria was applied in hydropower project appraisal, it is important to reduce the criteria list to the discriminative set that mostly contributes and finally influences the decision making, especially when there is a problem prioritizing alternatives or selecting the best alternative. With more visualization features and a large number of criteria as well as alternatives handling features, PROMETHEE was used to develop the final decision framework. The first draft of the decision framework consisted of 44 sub-criteria measures and PROMETHEE was applied to a field test of six hydropower sites as alternatives to evaluate and rank. It was found that only 29 criteria participated in the decision making. Many of the criteria listed in the draft decision framework did not influence the ranking of alternatives: they were called null criteria and could be eliminated. Some of these null criteria do not influence the ranking of alternatives over a wide range of weight variation. For example criteria like MT or CH (see Table 18) even if they varied their weight within a wide range (say 0 to 100 %) did not change the ranking order of the alternatives and were described as strong null criteria. There were many strong null criteria identified: Flood control (FC), Use of Local resources (UL), Measures Taken for minorities (MT), Conserve cultural Heritage (CH), Technology Knowledge (TK), Water Availability (WA), International conflict (IC), Institutional Risk (IR) and Coordination Risk (CR) etc. (see Table 18). Likewise there were many other null criteria whose weight variation within a considerable range around their allocated weight did not influence the ranking order and such null criteria found were impact on Law and Order (LO), Health and safety (HS), Community Visibility (CV), conserving Farmland from Expropriation (FE), Technological Risk (TR) and Social Risk (SR) (see Table 18). Altogether 15 null criteria were found which did not influence the hydropower ranking. Thus from the full list of criteria in the draft decision framework, once all null criteria were excluded and the list was consolidated the decision framework had 29 criteria for decisions on option analysis or ranking. Thus, a final decision aid was developed for hydropower with a total of 29 criteria as shown in Table 19. One important point to note is that once the null criteria were removed from the list, then their allocated weight was shared among the new setup of decision criteria. Hence it can be noticed that the weights of the criteria in the final decision framework are slightly different from those in the draft decision framework.

7.3.2.3 Results from VP application with final decision framework

VP application with the final decision framework (with 29 criteria) was applied and delivered the similar results what was obtained from the framework proposed with long list of 44 criteria. Hence application of VP and its visual displays were very instrumental to identify the null criteria to remove and obtain concise and impacting decision framework.

VP is capable to handle large number of alternatives (may be even in thousands) and evaluated with many criteria. As DM need not to remember pairwise comparison at each time, it is easy to enter required data into VP software one by one. Flexibility of choosing the selected alternatives to compare or even review with regard to specific criteria are the good features which enable DM to analyse different as and when scenarios.

Results of VP presented as PROMETHEE ranking (displaying best to worst ranking), PROMETHEE table (score on Phi, Phi+ and Phi-), PROMETHEE I (partial ranking separately on positive or negative contributions scale) and PROMETHEE II (combined to one final scale), PROMETHEE diamond (presenting all combined – partial scores both on positive or negative contributions on two diagonal scales and final net score on the vertical scale), PROMETHEE rainbow (presents disaggregated and expanded view of the criteria's contribution to the alternatives) and walking weights (allows the weights of criteria to be changed and so the VP results) (for details refer 6.2.2). The ranking results found Modi (private) hp as best option among all six alternatives analysed in this research. The final priority in descending order for the alternatives was Modi hydropower developed by the private sector (Modi), Modi hydropower developed by the Nepal Electricity Authority (MN), Indrawati hydropower (I), Baramchi hydropower (B), Pati hydropower (P) and Chaku hydropower (C).

Finally all alternatives criteria contribution profiles are displayed in VP to visualize details of each criterion contribution in scoring which help to view influencing and non-influencing criteria in decision making. Further it is analysed through sensitivity analysis explained in detail (section 6.2.2.3) and mentioned briefly here.

7.3.2.4 Sensitivity analysis and conclusion:

Sensitivity analysis is essential in any multi criteria decision analysis (see Section 5.2.1) and so is applied in VP to test the reliability of results. The sensitivity feature of this tool is very useful to identify the sensitivity associated with any of the decision criteria. In VP, sensitivity analysis can be performed following the walking weight of criteria and also reviewing the visual stability intervals. The weight of one criterion at a time was varied to see the impact on the ranking of the alternatives which helped to remove 15 null criteria from the first decision draft framework. With a sensitivity check and stability check of weights (refer table 18), it helped to develop a final decision framework. If within weight variation range the ranking order of alternatives does not change then it is called a stability interval. Variation of weights and its impact on visual stability intervals helps in understanding the robustness of weights assigned to criteria and their sensitivity if the weight varies. This way the final framework developed is robust and all criteria are important and participate in decision making.

This research on VP application identify that for better decision making in hp sector a specific decision framework is required and could be developed with the help of VP application. The framework thus developed in present case is capable of evaluating, comparing, ranking or choosing the best among the hydropower alternatives. In addition, the framework is easily understandable and applicable in the field. This development of a decision framework could be helpful in hydropower development for the coming years (up to 2030) in general and in terms of the present context (5 years from now) specifically. Sensitivity analysis helped to cross-check the robustness of the results from the VP application and was found very appropriate to apply. VP has high strength to handle many alternatives with a large number of criteria. This tool is very easy to understand and to apply since the decision maker does not need to remember things to compare. The field test of the draft decision framework applying VP found the framework effective in hydropower analysis.

8 Conclusions and recommendations

Nepal is very rich in hydro potential but so far generation lags far behind the need. Among the various reasons for the poor hydropower development, one very important is the lack of an appropriate decision framework. Even after a century long history of hydropower development in Nepal, the country still does not have a sound decision framework. Thus the main goal of this thesis was to develop a decision framework for hydropower development in Nepal. In this research, different MCDMs tested and applied successfully to deliver a decision framework. The following sections summarize the results, conclusions, recommendations and limitations of this research.

8.1 Results

With regard to developing decision aid for hydropower as main goal and ranking five categories of hydropower schemes classified in Nepal as a complimentary goal, the research used various studies based on different MCDMs. The main results are briefly mentioned here.

The first three MCDMs studies were focused on ranking of hp schemes whereas the last one VP application was to deliver decision framework of hp. During the perspective analysis which was based on evidence-based analytical analysis, different nine perspectives reviewed. Along with economics, social, environmental and political perspectives, special emphasis were given on technical, financial, developers, country preparedness and uncertainties aspects of hydropower. This approach was very helpful to collect information in detail which were later on compiled in excel to review them simultaneously. One of the most appealing observation worth mentioning here is about the country inadequate preparedness, specifically to negotiate and benefit from larger schemes. It has high associated risk at present. This study ranked alternatives priority in descending order like medium, big, small, micro and large schemes. This evidence based analytical study was instrumental to identify all the possible list of criteria and their importance (weightage) from various evidence based sources.

Information from analytical study was used as input to secondary data based AHP application. At this stage of study nine perspectives modified into six goals by rearranging criteria with weight from earlier study. While economics, social, environmental and policy (political) goals remains as like in previous application, technical and uncertainties were also included as goals. The successful application resulted the similar ranking, as of previous study, proved that globally used MCDM based tool (here AHP) could be applicable in Nepal and results are trustable.

To test the trust worthiness of earlier results and re-verify the applicability of AHP, once more a questionnaire based AHP performed. Based on earlier experiences, to obtain wider views of different stakeholders on criteria and goals related to hp, electronic questionnaire survey conducted. The survey helped to re-determine weights of goals and criteria. Here again the ranking results found similar like in previous studies. This further verified the trustworthiness of MCDMs applicability in hydropower analysis in Nepalese context.

Through the earlier studies on hp schemes ranking, all possible goals, criteria and sub criteria were identified and accordingly first hydropower decision framework was proposed. The draft decision framework was field tested in six sample hp sites. It was found easy to apply and was further processed in VP. Because of visual aid and sensitivity test, a concise decision framework with all criteria required to make healthy decision was developed. Finally the decision framework thus developed delivered hp rankings, individual score and all sort of comparison both in numeric as well as visual form. In the present study of six sampled hp, Modi (private) scheme was found the best with its highest scorer whereas that with the lowest score Chaku remained at the least priority. The decision aid thus developed performs well and could be helpful in hydropower analysis and decision making.

8.2 Conclusions

Globally, hydropower decision making involves a multi criteria approach and several scientific tools are available which could also be useful in Nepal. The conclusion of the research is mainly related to the hydropower decision aid developed for Nepal, including the applicable criteria along with their recommended weights. In addition, the research also identified and ranked hydropower schemes classified in Nepal based on the generation capacity of the plants. The findings of the research related to these are summarized here.

The main conclusion of the research was the successful development of a hydropower decision framework. It was observed that a wide range of criteria need to be measured when undertaking hydropower-related analysis. However, several of them could be important but do not have the power to make differences when considering comparing or ranking alternatives. Such null criteria were identified and removed from the initially drafted decision framework which made the framework simpler and more efficient. Through sensitivity testing during VP application, such concise and smart decision framework was developed for hydropower decision analysis. The decision framework is applicable to accomplish project decision, project appraisal, evaluation, comparison and ranking. For the present case study of six sample sites, the most preferred alternative found was the Modi (private) hydropower scheme. According to decreasing preference order it was followed by Modi NEA, Indrawati, Baramchi, Pati and Chaku. Thus the PROMETHEE VP application was found to be effective in hydropower analysis and also in developing a decision aid for hydropower.

Hydropower development spread over broad impacts domains ranging from economic to social, environmental and political. Considering that several of these domains related issues are subject to various sources of uncertainties, it is recommendable to integrate minimizing uncertainties to avoid related risk as a separate goal to evaluate, specifically within the prevailing country context like in Nepal. Thus including all of them together, within a framework based on multi criteria approach, for the evaluation of hydropower scheme is necessary. Such a framework for hydropower decision making is first and foremost important for benefiting from the abundant hydro resources in the country. VP was found to be an appropriate tool particularly because of its many good features such as its ability to handle a large number of alternatives and criteria measurements, to deal with the trade-offs among different criteria, to handle quantitatively and qualitatively expressed criteria simultaneously, and its suitability for ordinal value judgement and handling data uncertainties.

The present study has verified the effectiveness of the proposed methodology based on MCDMs such as PROMETHEE for developing a hydropower decision framework. The methodology was applied to six hydropower schemes surveyed with 150 respondents and analysed within five goals and in 44 criteria. Visual PROMETHEE was found to be an appropriate tool to appraise an individual project or to compare and rank a set of hydropower alternatives. This tool provides flexibility to analyse all decisive criteria both for an individual scheme or a set of alternatives of the analyst's choice. This feature enables decision makers to identify criteria needing more attention and may be helpful for strategy formulation for hydropower development. The decision framework developed could be applied with VP for analysing the hydropower sector under various scenarios by arbitrarily changing the parameters. This will facilitate further in-depth and strong diagnosis of the alternatives and the issues/problems associated at any level with any criteria. This may help planners to understand and identify the required action and plan better.

The proposed decision aid framework with the recommended criteria and weights is suitable for the evaluation of hydropower schemes in the present context. From the broad list of all possible 44 criteria, 15 were found to be inactive in decision making and hence removed. Thus the framework developed is concise, with 29 criteria and their assigned weights. With changing international and national contexts, the present weightage may need revision and adjustment in the future. As such change will take place slowly, the proposed decision aid will remain almost the same for the coming five to ten years.

The approach followed to develop a decision framework provides a transparent decision process involving every possible stakeholder. Moreover, it provides rapidness, being useful due to the less time required by the respondents. In a less developed country or poor economy where sufficient and reliable databases do not exist, such an easily and quickly understandable method for developing and applying a decision aid would be effective. The decision aid thus developed was found to be applicable in the Nepalese context. The visual aid further helps in promoting sound understanding and decision making.

In addition to the main research objective of developing decision framework, another complimentary objective was to rank the alternatives of five different scales of generation schemes in Nepal. Each scale of schemes could best fit in some contexts and benefit the country in different ways. For example while micro-scale projects supply rural remote communities with limited power, big- or large-scale schemes certainly can contribute significantly to the national energy need. However bigger schemes need huge funding as well as a long gestation time. In the future, if funding is organized and the modality of project development ensures more resources and benefits circulating within the country, big schemes could become a priority very soon. In contrast, small- or medium-scale power plants can be implemented conveniently and benefit to the country. From the analysis it was found that medium-scale schemes are most preferred, followed by big schemes. Small schemes were ranked as the third priority followed by micro schemes in fourth place on ranking. The two extreme scales of schemes, namely micro- and large-scale hydropower, exhibit the lowest priority. Recently few private sector investors and developers have shown interest in big-scale schemes (more than 1000 MW) and such schemes are also preferred by the government due to the huge energy need and the associated economies of scale benefit. Nepal alone is not in a position to construct large-scale hydropower plants but with limited external assistance the country could grasp up to big-scale power plants. Changes with time in experience, built-in capability, strengthened future economy, international interest and strong energy demand by neighbouring countries may place large- and big-scale hydropower plants in the priority in the long term. One can identify from the end results which alternatives should be the priority among those mutually exclusive alternatives. This will help policy makers to develop strategy and policy accordingly.

8.3 Recommendations

A hydropower strategy or road map for a country is very important and should be updated at regular intervals of time. With changing international as well as national scenarios, specifically on economics and technology, over time, the present weightage may need revision and adjustment in the framework developed today.

In addition, existing or planned infrastructure like roads, bridges, transmission lines, and security in the project areas, as well as local participation, are important criteria in selecting power projects. Using the existing infrastructural support, the development of suitable size (possibly medium-scale) storage type plants is highly recommended. It is critical for Nepal to do more preparatory work to plan large-scale hydropower development to ensure the national interest and avoid regrets in the long run. Furthermore, it is of utmost importance to comply with environmental as well as social concerns and in particular the handling of displacements of people.

8.4 Limitations

Although the obtained framework is proposed for hydropower decision making in general, the study was confined to a limited number of hydropower sites. Due to time and resource limitations, the selected sites were of small-range schemes (1 to 25 MW) located in two geographical regions. To make the framework more robust, further research is therefore highly desirable, including more sample sites from various regions and of various generation capacities.

The quality of the data sources and availability of information vary considerably at the local and state levels. Assessing reliable data on time and within the resources available was challenging and hence might have caused some discrepancies.

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Appendices

Appendix 1: List of criteria and data collection format

MCDM Master Survey form								
Name of Plant					Indrawati Hydro Power Plant			
Contact Details					Rameshwor Pd. Singh			
	Factors	Subfactors	Elements		PP & Officials	Community	Civil Society	Exp. Indv.
1	**Economic**							
		A) Power Capacity	Yearly Power generation					
		B) Benefits (economic)						
		>> Tangible Benefits ($/kWh)						
			Total revenues					
			Export - To NEA grid (Rs or kWh @)					
			Local consumption:					
			IRR - Based on project plan					
		>> Intangible Benefits						
			Through local infrastructure development					
			Flood control effect :					
			Irrigation Facilitated:					
			Fishery developed:					
		C) Cost						
			Total Investment					
			Operation and maintenance					
			Decommissioning					
		D) Employment						
			Directly related to project: **Short term**					
			Directly related to project: **Long term**					
			Indirectly related to project (**secondary benefit**):					
		E) Use of available local / in country	Available local resources and materials					
2	**Social**							
		A) Equity & benefit distribution and						
		inclusiveness of project	Distribution: Both cost (risk) and benefits					
			Gender main streaming, inclusiveness					
			Opportunities strengthening livelihood					
		B) Project induced impacts						
			Power reliability and Grid integration					
			Movement: HH activities (farming, grazing)					
			Impact on law and order and local life style					
			Recreation opportunities:					
			Heath Safety: Effect on human					
			Displacement and resettlement of PAF					
			Minorities maintaining traditional life style:					
			Effects on cultural heritage, earlier settlements					
			project to make the community visible					
		C) Transparency and Governance						
			Public participation in Decision Making:					
			partnerships in management / governance					
		D) Technology-knowhow &social ca	local people trained & social capital enhanced					
3	**Environmental**							
		A) Degradation due to HPP						
			Forest and biodiversity loss:					
			Area of farmland expropriated:					
		B) Sediment balance	Trapping of sediment – riverbed scouring,					
		C) Impact on Water Resource						
			Water quality:					
			Water availability:					
			Impact of water natural connectivity					
		D) Solid waste and Pollutions during	Solid waste, noise and vibration					
		construction period and proper handling	Also proper monitoring during construction					
		E) Visual Impacts	On landscape due to project					
4	**Political**							
		A) Contribution to National Indepenc	project could support the independency					
		B) Conflict and impact to other count	International conflict (due to project):					
		C) Sector (Hydro power developme	power plant is as per the govt. preference.					
		D) Regional balance (in power genera	supporting regional balance of generation					
5	**Uncertainty**							
		A) Technological risks	Hydrological,geological and seismic risk.					
		B) Political (regulatory) risk	Change in policy & priorities is political risk					
		C) Environmental risks	Climate change, greenhouse, land/rock--					
		D) Implementation risk						
			Institutional risk:					
			Social risk:					
			Coordination risk:					
		E) Market / financing risk	Change in market demand, competition					
			& capital financing scenarios.					

Appendix 2: Field data explanation note and collection guide

Goals	**Criteria**	**Symbol and Meaning of sub-criteria**	**Remarks**
Economic	Power Capacity	PG = Power generation capacity (MW) of the plant To make the consistency use the annual power generation based on design. e.g. Indrawati of 5 MW may be generating 100000 kWh (units) in one year. Source: Available either from the Power Plant people or project design / approval / EIA documents.	Data from Field to be collected: Enter the Annual Power Generation Capacity in units. Action after field data collected: This **rating** is entered only after collecting all the sites individual Power Capacity and need to follow as: Rate Highest as 5 and lowest as 1 after surveying all sites
	Benefits	LF = Impact of project implementation on infrastructure such as road, bridge etc. Has the project brought new infrastructure or was the existing one even destroyed Source: Power Plant people/community survey focused groups.	Data from Field to be collected: Very high to very negative (5-1) If resulted into new infrastructure (road, bridge, school, hospitals etc.) and is also for public use then 5, very minimal infrastructure developed just due to project need only and / or limited use to public then 4 No significant structure built for public, the scenario remains as it is for public benefit then 3 If the existing earlier infrastructure developed by others / govt. used by project and no other infrastructure in the community developed by the project then 2, if the existing one are used and even destroyed by the project and a kind of loss to the communities then 1.
		FC = Flood control: Community benefiting from flood control established due to project. Source: Power Plant people/community survey focused groups.	Data from Field to be collected: Very high to very negative (5-1) If PP develop safe environment in terms of protection against flooding (danger existing before the PP) constructed 5, if the people were not in danger before PP but still the PP took measure to further reduce the flood risk then 4, if there were no flood threat earlier and even after PP there is no such threat and PP has done nothing on this flood protection then 3, if there were no flooding earlier but due to PP some kind of flooding likely as per the people perception then 2 and if the flood control is not included in the PP construction and communities see the high flooding danger due to PP in place then 1
		IF = Irrigation facilitated: Does the plant provide irrigation for farmers (adverse-not allocating water to them) or facilitate	Data from Field to be collected: Existing or new irrigation developed could result into following five

		new irrigation systems developed by project. Source: Power Plant people/community survey focused groups.	scenarios and rank as Very good to very bad on scale (5-1) If the project developed irrigation facilities along with PP to benefit the communities then 5 If there were some kind of irrigation facilities and PP revived to make it more functional then 4 If no support or constraint posed on functioning of the already existing or no new facility added due to PP then 3 If no new added but the existing one is suffering due to water use constraint posed by PP then 2 If irrigation facilities from pre-project is heavily disturbed due to water shortage caused by PP then 1
		FD = Fishery developed: Does the plant provide new facilities for fishery growth or protection, or do fisheries activities even suffer.	Data from Field to be collected: Very much to not at all (5-1) If new fisheries developed after PP then 5, if little action supported 4, if no activity 3, if due to PP some earlier fishery business disturbed then 2 and if completely damaged the earlier fishery practices in the communities then 1
	Cost	CI = Cost of Investment (Cost include construction, resettlement, environmental mitigation etc.) and also represent cost on operation, maintenance and decommissioning. Add all the cost and convert at present rate in terms of per kW and then rate it. Source: Available either from the Power Plant people or project design / approval / EIA documents.	Rate Highest as 5 for the lowest per kW cost and lowest as 1 for highest per kW after surveying all sites
	Employment	ST = Directly related to project: Short term employment (during construction). Rate Highest as 5 and lowest as 1 after surveying all sites. Source: Power Plant people/community survey focused groups.	Data from Field to be collected: No. of jobs during construction Some group may respond with clear number then simply enter it and finally will compare with others to rate in between 5 to1. But where clear figure is not available then ask the group whether very good short term job (nearly each house one person almost every day) available during construction then 5, if fairly good number (nearly each house one person most of the time) then 4, not much but nearly each house one person half of the year then 3, small number and intermittent only then 2 and if they say no jobs for local offered during construction then 1

		LT = Long term employment: Directly related to project (maintenance, operation, administration and daily labour). Rate Highest as 5 and lowest as 1 after surveying all sites Source: Power Plant people/community survey focused groups.	Data from Field to be collected: No of jobs once plant started generation
		IB = Indirect benefits related to project: Interaction with other sectors of economy creating job opportunities (like SMEs, services, business, tourism etc. in the region) Rate Highest as 5 and lowest as 1 after surveying all sites. Source: Power Plant people/community survey focused groups.	Data from Field to be collected: Very high to very negative (5-1) If people / stakeholders are extremely satisfied with thousands of people benefiting (5), very much satisfied if several hundred are benefiting (4), satisfied if few- nearly 100 people are benefiting (3), acceptable if less than hundred people are benefiting (2) and not satisfied if negligible number of people are benefiting (1)
	Local resource use	UL = It takes into account the available local resources for project development like construction materials, manpower, finance (from local communities) etc. Source: Power Plant people/community survey focused groups.	Data from Field to be collected: Very much to not at all (5-1) If PP uses all local materials & manpower for construction with finance available within country without borrowing from outside then 5 If majority from within country and some elements from outside then 4 If some materials equipment and finance from outside and some from within country 3 If majority from outside and only little from within the country then 2 and If almost all (90%) in terms of total project costing from outside then 1.
Social	Equity & benefits	EB = Equity in distribution of benefits (financial, job, fellowship, cash or social services). Fairness in cost burden (land, forest like resources, share & investment). Power plant (PP) are concerned with several direct or indirect cost burden to locals (land, forest, natural resources of the communities and individuals, share, investment options etc.) and sometime community people bear those to welcome and run the project. At the same time PP are supposed to share some of the benefits (job opportunity, other opportunities to benefit like scholar ships, cash or different kinds of social services) to the communities. This aspect of inquiry is to access the fairness of such distribution (not the quantity) Source: Power Plant people/community survey focused groups.	Data from Field to be collected: Extremely, very much, fair, acceptable, fair to unfair (5-1) Very much fair distribution both benefits from project and cost due to the project then 5, if benefits distribution is fairer but cost equity little unfair then 4, if both of them are not fairly but acceptable then 3, if cost fair but benefit unfair and people have issues then 2 and if both unfair and unacceptable then 1.

		GM = Gender mainstreaming, inclusiveness of vulnerable communities Source: Power Plant people/community survey focused groups.	Data from Field to be collected: Extremely to very negative (5-1) If PP showed commitment very attentively 5, if only limited to small scale then 4, not responding for these elements then 3, rather ignoring or partial to these then 2 and if extremely going against such consideration then 1
		OL = Opportunities for strengthening livelihood and contributing in poverty reduction. Source: Power Plant people/community survey focused groups.	Data from Field to be collected: Very significant to very negative (5-1) If the PP involved or its implementation resulted in lively hood support activities to alleviate poverty at very recognition level then 5, if somehow positive but low impacting then 4, if no seen impacts then 3, if the PP presence even worsen the livelihood and economics of locals then 2 and if degraded very badly then 1.
	Project-induced impacts	PR = Power reliability and grid integration of communities: Assess the reliable power supply to region / area / local communities Source: Power Plant people/community survey focused groups.	Data from Field to be collected: Very reliable to not at all (5-1) If communities get connected to national grid, PP operates most of the time say > 95% and power availability is more than 90% of time (except load shedding issue) then 5, if national grid available and PP is very rarely failing in supplying in its operation then 4, if national grid is not available in spite the plant is implemented but power available regular then 3, if National grid is not available and also power is very frequently failing / not available then 2 and if PP is mostly failing power supply and shut down longer periods then 1.
		MA = Mobility affected (farming, grazing etc.) adversely due to power plant developed HH overall daily movement and activities (farming, grazing, social), specifically hh affected in between plant intake and tail race may suffer a lot than other people in communities. Hence this aspect needs to be considered carefully. Source: Power Plant people/community survey focused groups.	Data from Field to be collected: Very much to not at all (5-1) Due to PP (infrastructure support like bridge, road etc.) if those hh benefit to commute their daily household and farming work then 5, It may disturb their local activities but infrastructural support in between these areas by project resolved and even improve their movement issues then 4, If the project is not affecting their daily movement then 3,

			If these people has to spend more time than earlier to do their daily movement then 2 and If these people suffers mainly hours of their daily movement due to PP then 1
		LO = Impact on law and order (strengthen security by police and army presence) and local life style (out-siders commencing in the region) due to power plant established. Such PP might develop the site condition and several institutions develop as direct and indirect influences. Some of them could strengthen security (police and army) while others may impact adversely (ill-minded social elements engaged in theft and stealing). Here we wish to access over all impact due to PP. Source: Power Plant people/community survey focused groups.	Data from Field to be collected: Very positive to very negative (5-1) If situation is far better than before the PP then 5, if somehow improved then 4, if more or less similar then 3, if worsen then 2 and if very badly evolved then 1.
		RO = Recreation opportunities: New recreational sites created but at the same time there could be loss of area for recreational activities like bathing, fishing, water fetching etc. for general public. Value added due to increased scenic recreation and people satisfaction. Source: Power Plant people/community survey focused groups.	Data from Field to be collected: Very positive to very negative (5-1) If it is very much appreciated by communities with new opportunities added then 5, if it has added some opportunities then 4, if not changed at all then 3, if lost some of the previous recreational opportunities then 2 and if created a big loss of previous famous or well used facilities then 1.
		HS = Health Safety: Measures against community health hazard, due to project-caused pollution or water-borne diseases. Project can cause community health hazard, specifically for children and old aged and hence safety is concerned due to project. Source: Power Plant people/community survey focused groups.	Data from Field to be collected: Direct or indirect PP can cause health impact but at different level. Hence if it is improving hygiene and helping total safety then 5, if helping at minimal level then 4, if not affecting then 3, if affecting negatively then 2 and if seriously then 1.
		DR = Provide support to the displaced and project affected families (PAF): Project causing resettlement during	Data from Field to be collected: Enter the number HH shifted and resettled

		implementation and also post project affects. Source: Power Plant people/community survey focused groups.	Action after field data collected: Finally this will be converted on 5 to 1 scale after visiting all sites
		MT = Measures taken for minorities maintaining traditional life style and saving any against project causing adverse impact on their lifestyle. Source: Power Plant people/community survey focused groups.	Data from Field to be collected: Very significant to very negative (5-1). If they feel better helped to maintain or even upgrade their traditional life style then 5, If very much same as pre-project then 4, if some kind of change but close to former traditional life style the 3, if change and causing dissatisfaction then 2 and if causing very much change and dissatisfaction then 1.
		CH = Conserve cultural heritage: Effects on cultural heritage, earlier settlements: Historical remains and cultural heritage (Does it impacted traditions, beliefs). Source: Power Plant people/community survey focused groups.	Data from Field to be collected: Very significant to very negative (5-1) If better helped to maintain or even upgrade their cultural heritage and settlements then 5, If very much same as pre-project then 4, if some kind of change but not noticeable then 3, if change and causing dissatisfaction then 2 and if causing very much change and dissatisfaction then 1.
		CV = Community visibility: Does the project contributed to make the community visible in national attention for receiving development and recognition. Source: Power Plant people/community survey focused groups.	Data from Field to be collected: Very much to not at all (5-1) If the project made the community visible in national planning and priority then 5, if made visibility at least at region / district level due to this PP then 4, if as like earlier then 3, if village or communities are criticized due to PP intervention and created negative image then 2 and if it adversely impact the name and fame of community what they had earlier then 1.

	Transparency and Governance	PP = Public participation in Decision Making: Was project planning discussed and consulted in transparent manner from the beginning. Source: Power Plant people/community survey focused groups.	Data from Field to be collected: Very much to not at all (5-1) If the community people involved since conception and involved in project planning and decision making then 5, if only certain people or at certain time involved then 4, if not involved but shared the plan or decision then 3, if only involved at briefing before implementation then 2 and if never given chance to be involved in decision making then 1.
		PM = Partnerships in the management of the project: Does the project involve local institutions, NGOs or civil society for project development, implementation and managing. Source: Power Plant people/community survey focused groups.	Data from Field to be collected: Very much to not at all (5-1) If very much local institutions, NGOs or civil society involved from beginning then 5, If limited involvement of local institutions, NGOs or civil society involved from beginning then 4, If negligible involvement of local institutions, NGOs or civil society involved from beginning then 3, If some kind distance maintained from involving local institutions, NGOs or civil society then 2 and If restriction of involving local institutions, NGOs or civil society then 1.
	Technology / know how	TK = Technological knowledge: Due to this project, local people trained and social capital enhanced to replicate and sustain such development. Source: Power Plant people/community survey focused groups.	Data from Field to be collected: Very positive to very negative (5-1) If community people felt well trained and capable to assist other similar project then 5, if some aspect they felt capable then 4, if they can assist to replicate other projects simply as semi or unskilled manpower then 3, if simply as unskilled can support then 2 and if they could not even share labour work experience then 1.
Environmental	Degradation due to hydro power project (HPP)	FL = Conserve forest and biodiversity from losses: Inundation, forest loss, felling of trees, NTFP and rare species affected both including protected and non-protected forest area. Source: Power Plant people/community survey focused groups.	Data from Field to be collected: Very positive to very negative (5-1) Extremely unaffected (5), very good conserved(4), slightly affected but not noticeable (3), affected up to noticeable level (2) and very badly affected (1)

		FE = Conserve farmland from expropriation: Due to road, PH and canal etc. Loss of commercially productive land (quantity) and productivity (quality due to project). Source: Power Plant people/community survey focused groups.	Data from Field to be collected: Very positive to very negative (5-1) Extremely unaffected (5), very good conserved(4), not significantly affected (3), affected and noticeable (2) and very badly affected (1)
	Sediment balance	SB = Conserve Sediment balance: Trapping of sediment – riverbed scouring, river bank erosion and regression of delta. Source: Power Plant people/community survey focused groups.	Data from Field to be collected: Very positive to very negative (5-1) Extremely unaffected meaning well managed- as like pre-project time (5), very good managed no river scoring (nearly natural bed conserved) (4), not significantly affected but noticeable (3), affected, noticed very easily (2) and very badly affected (1)
	Impact on Water Resource	WQ = Conserve water quality: Hazardous Chemicals both for human (drinking) and plants (irrigation) in water and quality of water affected during construction / maintenance. Source: Power Plant people/community survey focused groups.	Data from Field to be collected: Very positive to very negative (5-1) If free of such pollution then 5, if small amount present but not causing damage to human and plant then 4, if little amount but acceptable for short period of use then3, not acceptable for human and plant then 2 and if causing very adverse results to human and plant then 1.
		WA = Conserve water availability: Number of weeks with low flow of water for irrigation, drinking as well as other uses, specifically downstream impact and impact on children and women. Source: Power Plant people/community survey focused groups.	Data from Field to be collected: Very positive to very negative (5-1) If regularly available throughout the year then 5, if some time interrupted then 4, if frequently interrupted then 3, if long gaps up to a week on availability then 2 and if supply discontinued for more than 2-3 weeks then 1
		WC = Conserve water connectivity: Impact of water natural connectivity (to maintain aquatic life, flora and fauna, invertebrates, fish, mammals and birds) with other streams. Source: Power Plant people/community survey focused groups.	Data from Field to be collected: Very positive to very negative (5-1) Natural condition as before project (5), conserved near to natural (4), conserved to acceptable (3), affected significantly (notable by people easily) (2) and very badly impacting (1)
	Solid waste and Pollutions	SW = Proper handling and monitoring on solid waste, noise and vibration	Data from Field to be collected: Very positive to very negative (5-1)

		control during construction period and during construction. Source: Power Plant people/community survey focused groups.	No pollution or managed very well (5), little pollution, not notable (4), notable pollution but managed (3), significant pollution and no proper handling management (2) and high pollution without handling which is unacceptable (1)
	Visual Impacts	VI = Measures taken to conserve adverse visual impacts on landscape due to project Source: Power Plant people/community survey focused groups.	Data from Field to be collected: Very positive to very negative (5-1) Remains as natural before project or even improved (5), slightly changed and worsened - not noticed easily (4), worsened scene but acceptable (3), significantly notable worsened (2) and very much worsened to easily notable (1)
Political	Contribution to National Independence	NI = To what degree the project could support the national independency from other countries by utilizing national energy resources. The project could support the independency on other countries based on energy (less energy import, Improve trade balance due to energy export - international business). Note: Do not focus on project financing, technology, R&M etc. - as these factors are already taken into account. Source: Power Plant people/community survey focused groups and experts opinions.	Data from Field to be collected: Very positive to very negative (5-1) Contributing significantly to save trade gap (only nation and no external party benefiting) 5, Contributing up to some level to save trade gap (majorly nation benefiting and less external party benefiting) 4, Contributing negligibly to save trade gap (less nation and majorly external party benefiting) 3, Contributing adversely to save trade gap (negligibly nation and extremely external party benefiting) 2, and Contributing extensively to widen the trade gap (no nation but only external party benefiting) 1,
	Conflict and impact to other countries.	IC = International conflict (due to project): Assess the possible conflict or issues on resource sharing and adverse impacts - How is it going to impact the relations with neighbours and even bilateral / multilaterals as per international water and river regulations. Here it is important to cross-check free from any international river issues, tributaries, treaties, earlier contract signed with neighbouring countries and alike. Source: Power Plant people/community survey focused groups and experts opinions.	Data from Field to be collected: No conflict to very strong conflict (5-1). Based on resource sharing issue if no possibility of conflict rather improving mutual cooperation then 5, if somehow possibility exits but then 4, if situation remains as it is then 3, if some possible conflicts seen then 2 and if serious conflict then 1.
	Sector priority and Public Private participation	SP = Evaluate whether the power plant is as per the government's sector (Hydro power) preference. It may consider the facts like power urgent development, storage type vs run off river priority set by government, centralized vs decentralized priority for power project development at that time when it was developed, small vs big in	Data from Field to be collected: Strongly inline to complete opposite (5-1). Strongly in line with government policy 5, if as per national hydro power but not in every respect then 4,

		capacity and government preferences in terms of PPP etc. seen by the stake holders. Source: Power Plant people/community survey focused groups and experts opinions.	if not complying on several aspects but acceptable then 3, if developed but with some critics by that time on project then 2 and if developed ignoring any priority scale on factors mentioned in this category then 1.
	Regional balance	RB = Regional Balance: Is the plant support regional balance of power generation within the country? Nepalese regional balance in terms of power generation in different regions is highly important deciding factors in terms of T/D losses and power regularity to industries and economic activities. Hence judge this power when developed in terms of regional power balance. Source: Power Plant people/community survey focused groups and experts opinions.	Data from Field to be collected: Strongly support to complete opposite (5-1). If very well-suited at that time for regional power balance then 5, if somehow justified 4, if not affected in any way 3, if not favoured any balance then 2 and if created a serious unbalance then 1.
Uncertainty	Technological risks	TR = Avoid Technical risk: Assessed against country technical handling capability, hydrological (flow duration curve) storage and head variation: geological stability and seismic risk. Source: Power Plant people/community survey focused groups.	Data from Field to be collected: Value in between 5 to 1. Proficient Engineering leading to technical reliability. No risk (5), less risk (4), moderate risk (3), high risk (2) and extreme risk (1)
	Political (regulatory) risk	CP = Change in policy: Stability against change in policy is important to safeguard project from adverse effects. Policy and priorities affect the project. It is political risk associated with project. Source: Power Plant people/community survey focused groups.	Data from Field to be collected: Value in between 5 to 1. No risk (5), less risk (4), moderate risk (3), high risk (2) and extreme risk (1)
	Environmental risks	ER = Mitigation measures against Environmental risks: Climate change, greenhouse gas emissions, land/rock movement, erosion and seepage and similar site environmental change could cause adverse impact on project. Environmental safety and mitigation needed for healthy system in place. Source: Power Plant people/community survey focused groups.	Data from Field to be collected: Value in between 5 to 1. No risk (5), less risk (4), moderate risk (3), high risk (2) and extreme risk (1)
	Implementation risk	IR = Institutional risk: Are institutions in place, capable and fully responsible for successful project implementation. A well-institutionalized system is clear in their role, responsibility and functions smoothly. Source: Power Plant people/community survey focused groups.	Data from Field to be collected: Value in between 5 to 1. If project is developed well in institutionalized manner then5, some weakness noticed but well-institutionalized then 4, institutionalized and functions acceptable level then 3, if frequent institutional weakness observed then 2 and if very bad in institutionalization aspect then 1.

		SR = Managing against social risk: disruption caused by people or community. Important to deal social equity and benefit on resource use and equally responsibility born both by project and community. If such factors are not managed then could result serious social disruption and paralyse the project. Source: Power Plant people/community survey focused groups.	Data from Field to be collected: Value in between 5 to 1 Hence if such risk are not likely due to well considered planning then 5, if some chances likely but not serious then 4, if possible and can disrupt then 3, if such disruption likely with adverse results then 2 and if very much likely and damaging then 1.
		CR = Manage Coordination risk: Several ministries coordination (forest, conservation, PPA, other concessions) and infrastructural supports (road, bridges, grid etc.) are important for the development of hydro project. In weak coordination or in its absence, it may cause time over run and adversely impact project economy. It finally relates the economic effectiveness of project. Source: Power Plant people/community survey focused groups.	Data from Field to be collected: Value in between 5 to 1 If very well coordinated then 5, if coordination is smooth 4, if coordinated with some issues 3, if frequent issues then 2 and if lot of coordination issues and adverse impacting then 1.
	Market / financing risk	MR = Measures against Market risk: Change in market in terms of demand, competing options and capital financing scenarios. This element focus on the market and financing of the project received while constructed and faced market competition and risk associated. It is market risk of project. Source: Power Plant people/community survey focused groups.	Data from Field to be collected: Value in between 5 to 1 No risk meaning nothing went wrong (5), less risk means some kind of risk but caused no harm(4), moderate risk means some financial burden came (3), high risk means significant cost implications (2) and Extreme risk means deviated very much from initial estimate and time plan (1).

Appendix 3: Questionnaire

Respondent: **Category:**

1. Prioritize the scale of Hydro Power Plant Development in Nepal at present context

( ) Micro Hydro (1 to 1000 kW)
( ) Small Hydro (1 to 25 MW)
( ) Medium Hydro (25 to 100 MW)
( ) Big Hydro (100 to 1000 MW)
( ) Large Hydro (more than 1000 MW)

2. Rank the risk most sensitive to be considered when developing Hydro power

( ) People / community participation and support
( ) Financing uncertainty and failure
( ) Political instability and policy weakness
( ) Technical weakness and failure to sustain the project
( ) Environmental challenge to affect the Hydro Power

3. Preferred ownership and development modality

( ) Government owned and operated
( ) National Independent Power producers owned and operate
( ) International Independent Power producers owned and operate
( ) Mix of National and International JV owned and operate
( ) Community / cooperative / Corporate owned and operate

4. Focus of the Hydro Power plant to provide

( ) Energy access Household
( ) Electricity for Industries and employment
( ) Energy for Export to earn cash
( ) Energy for export in exchange to import during deficit
( ) Energy through a regional grind encompassing many countries

5. What kind of Hydro power Plant should be preferred?

( ) Runoff River
( ) With at least daily pondage to meet daily peak load
( ) Small storage to meet seasonal peak demand at least
( ) Large storage to reach at least annual autonomy
( ) Extra-large storage to generate maximum power and support longer autonomy

6. New Hydro Power Plant selection should preferred

( ) To support the remote areas without electricity
( ) To integrate with existing local (mini) grind available nearby
( ) To integrate with existing national grind passing nearby
( ) To contribute in regional energy balance within country
( ) To supply energy for sale to outside country

7. Hydro Power selection should be preferred on

( ) Using national financing and available human resources
( ) Using partly outside financing and available human resources
( ) Using partly outside financing and partly outside human resources
( ) Using outside financial resources but using available human resources
( ) Using outside financial resources and outside human resources

8. To best economic interest from Hydro Power, prioritize the following sub-factors

( ) Generation (Power) Capacity of plant
( ) Benefits associated (both direct eg. revenue and indirect e.g. services) with the lant

( ) Cost of Power Generation of the plant
( ) Employment generation due to plant
( ) Utilization of available local materials and resources to build the plant

9. Prioritize the following sub factors under the social factors of Hydro power development
( ) Fairness on equity allocation of benefits and impacts
( ) Focusing on Inclusiveness, Gender Empowering and vulnerability
( ) Project induced impacts like safety, power supply reliability & displacement etc.
( ) Transparency and Governance of the project
( ) Technical knowhow and social capital building

10. Rate (importance) the following sub factors under Environment with regard to Hydro power
( ) Terrestrial (land, forest) Environment degradation due to hydro power project
( ) River morphology, riparian ecology caused (by sediment, flood etc.)
( ) Impact on water resources (continuity, regularity, quantity and quality)
( ) Solid waste and pollutions due to project construction and operation
( ) Water abstraction or damming

11. Prioritize the following sub factors while technically decide the project selection
( ) Power availability throughout the year
( ) Available support infrastructure like road, bridge, power grid etc.
( ) Energy demand and availability to satisfy the local communities
( ) Country capability to implement, maintain and operate the project
( ) In country materials, accessories, equipment and finance availability

12. Prioritize the following sub factors of Political factors as per their importance with regard to hydro power development
( ) Contribution to National Independence of energy availability
( ) Conflict with (water rights, Trans boundary and International water) and impact on economy, business deals with other countries
( ) Conducive hydro power sector policy, strategy and plan
( ) Attracting foreign investment in the sector development
( ) Regional (within country) power generation balance

13. Prioritize the Factors to be considered for developing Hydro Power in Nepal
( ) Technical
( ) Social
( ) Environmental
( ) Economical
( ) Political

Curriculum vitae

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March 1992 – Dec. 2006:	Associate Professor at Institute of Engineering, Dept. of Electrical Engineering, Pulchowk, Kathmandu, Nepal.
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