SUSTAINABILITY PARAMETRIC STUDY ON HYDROPOWER PROJECTS

A DISSERTATION

Submitted in partial fulfillment of the

requirement for the award of degree

of

MASTER OF TECHNOLOGY

in

ALTERNATE HYDRO ENERGY SYSTEMS

By

AYUSH SHARMA

DEPARTMENT OF HYDRO AND RENEWABLE ENERGY

INDIAN INSTITUTE OF TECHNOLOGY

ROORKEE-247667 (INDIA)

JUNE, 2019

DECLARATION

I hereby declare that the report which is being presented in this Dissertation, entitled as **"SUSTAINABILITY PARAMETRIC STUDY ON HYDROPOWER PROJECTS"** in partial fulfillment of the requirements for the award of the degree of **Master of Technology** in **Alternate Hydro Energy Systems**, submitted in **Department of Hydro and Renewable Energy, Indian Institute of Technology, Roorkee,** is an authentic record of my own work carried out under the supervision of **Dr. Arun Kumar**, **Professor, Department of Hydro and Renewable Energy, Indian Institute of Technology Roorkee.**

I have not submitted the matter embodied in this report for the award of any other degree.

Date: June, , 2019 (**AYUSH SHARMA)**

CERTIFICATE

This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

Dr. ARUN KUMAR
Professor,
Department of Hydro and Renewable Energy
Indian Institute of Technology
Roorkee -247667

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to my guide **Dr. Arun Kumar, Professor, HRED, Indian Institute of Technology, Roorkee** for his valuable guidance, support, encouragement and immense help at every stage of my dissertation work. The assistance he gave me is greatly appreaciated.

I am also grateful to all faculty members and staffs of **Department of Hydro and Renewable Energy, Indian Institute of Technology Roorkee**

I would also like to extend my heartfelt thanks to all my friends who have helped me directly or indirectly for the completion of this dissertation.

Dated: June, , 2019 **(AYUSH SHARMA)**

ABSTRACT

Sustainability development has become a worldwide concern in the Hydropower sector, due to the adverse impacts faced by the projects, both environmentally and socially. The current practices does not cover the aspects in total to label a project as sustainable. Sustainability is checked from the Early planning stage to Operational stage, leading to more positive perspective towards Hydropower generation. This work explore the systemic limitations of environmental assessment for hydropower development and to study and analyse the affect the sustainability parameters provided by international standards on hydropower projects of Tehri and Koteshwar at Uttarakhand and, hydropower projects of Baglihar, Uri-I, Lower Jhelum, Salal, Dul Hasti, Sewa at Jammu and Kashmir; with the analysis focusing on four pillars of sustainability i.e. Social, Financial, Environmental and Technical, during Operational stage. Both, quantitative and qualitative analysis has been carried out according to the weightage given to the parameters as per the cases. Normalized values of parameters have been used for analysis, so that calculation is done easily for parameters with different SI units.

The sustainability index of projects is measured on the scale of 0 to 1, in which 0.5 is taken as the benchmark point, scoring above is considered as sustainable and vice-versa. The study illustrates that the sustainability index ranges from 0.4 to 0.7. Results shows that hydropower projects of Tehri, Koteshwar, Baglihar, Salal, Dul Hasti have sustainability index greater than 0.5, indicating sustainable practices undergoing, whereas hydropower projects of Lower Jhelum, Uri-I, Sewa have sustainability index less than 0.5, indicating unsustainable practices. This report provides a set of comparison between the current EIA practices and sustainability index to understand how improvements could be made in future supported with the present scenario of the selected hydropower projects, with their strength, weakness and mitigations, besides literature reviews and report analysis in order to understand the extent of islanding data collection technique and contemporary challenges to be addressed with further researches.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS AND ACRONYMS

ABBREVIATION	FULL FORM
HPP	Hydropower Project
CEIA	Cumulative Environmental Impact Assessment
EIA	Environmental Impact Assessment
VEC	Valued Ecosystem Component
THDC	Tehri Hydropower Development Corporation
JKSPDC	J&K State Power Development Corporation
NHPC	National Hydro Power Corporation
ISED	Indicators for Sustainable Energy Development
MCDM	Multi criteria decision making model
DSS	Decision Support System
AR	Reservoir Area Indicator
LI	Livelihood Indicator
RS	Resettlement Indicator
DJ	Direct Job
BI	Biodiversity Indicator
GWP	Global Warming Potential
IPCC	Intergovernmental Panel on Climate Change
GP	Generation Potential
EAF	Equivalent Availability Factor
IT	Impact on Tourism
CNG	Contribution to National Grid
SPCB	State Pollution Control Board

CHAPTER 1

INTRODUCTION

1.1 GENERAL

The hydropower development planning has been oriented towards isolated projects occurring within a restricted spatial and temporal extent of the river basin as advancement of HPP requires vast number of approval and clearances right from the underlying conceptualization or planning stage of the project to plant commissioning or operation, which includes the clearances from environmental and forest authority. In recent years, the persistent shortage of power supply, national development goals and the emphasis on renewable energy resources to address various catastrophic activities have resulted in introduction of essential programs to harness extensive amount of hydropower potential from states which are rich in river basin such as Uttarakhand and Himachal Pradesh through private and public components to assemble and control HPPs. Such developments are considerable in view of hydrological, construction, geological and profitable risks and challenges in terms of efficient coordination, effective development and process. A sustainable HPP is promising only if proper planning is done and an arrangement with inclusive regulatory outline to manage the risks. Well planned HPP, proper knowledge between shareholders, energy planners and other stakeholders contribute to sustainable development.

In terms of installed capacity, hydropower has been the largest compared to any renewable source for generating electricity. It has witnessed commercial success but also faced criticism for its negative impact on environment and society. In 1998, World Bank and the International Union for Conservation of Nature (IUCN) established the World Commission on Dams (WCD) for effective development of hydropower by establishing comprehensive set the guidelines for the planning, design, implementation, and operations of dams and their decommissioning. It has given major recommendations to improve the performance and approach for assessment by collaborating with policy makers, stakeholders and financial institutions.

When climate change has emerged as major concern and correspondingly the demand for energy has encouraged for new hydropower locations, the issues surrounding environmental and social sustainability has become more prominent. The Sustainability protocol was developed to measure and guide the performance of hydropower projects against globally applicable criteria for environmental, social, financial, and technical sustainability and now hold as the guidance for the responsible preparation, implementation, and operation of these future projects.

1.1.1 ENVIRONMENT IMPACT ASSESSMENT

EIA is an activity designed to identify, predict and describe in appropriate terms the primary and secondary changes due to a proposed action (policies, plans, programmes and projects). For the EIA studies of any developmental project it is necessary to understand the total environment of the area under consideration. The total environment is a complex entity integrating physical, biological, geographical and social systems operating within the political economy which need to be assessed. To study the Socio-Economic Environment Comprehensive Personal Interviews and Surveys are conducted in the area and the data on demography, education, health, income, crop management, infrastructure, entertainment opportunities, opinion regarding the project is also obtained from the local residents and this data is analysed and socio-economic status of people are drawn. In India, there is an elaborate EIA process involving many steps such as Screening, Preliminary Assessment, Scoping, Main EIA including public hearing, appraisal etc.

1.1.2 CUMULATIVE ENVIRONMENTAL IMPACT ASSESSMENT

Adverse developmental activities have alarmed about the potential environmental and socio-economic impacts. To address these impacts in early planning and management phases, led to the development of Environmental Impact Assessment (EIA) process. EIA is further examined through Cumulative Environmental Assessment (CEIA), which results from collective impact of actions of past, present and future activities [1].

Cumulative Environmental Impact Assessment is the process of studying the potential risk involved during proposed development, on environment and socially driven factors over a period of time. It also suggests mitigations to avoid, reduce, or mitigate such cumulative impacts and risk to the extent possible [2].

CEIA also consider the combinations of impacts on a developmental activity due to other developmental activity. For the evaluation and mitigation of these impacts on known affected components, CEIA is done within specific spatial and temporal boundaries and is a recent concept for developing economy. CEIA has shifted the focus to component-oriented studies where multiple developments in an area might be reflecting a valued component [3].

1.2 VALUED ECOSYSTEM COMPONENT

Effects influence the characteristics assets and their valued environmental components (VECs), which are valued in terms of their cultural, aesthetic, social, historical and economical values and when these impacts go beyond the permissible limits or points of confinement of adequacy, the change become deplorable

VECs can include:

- Physical attributes, Wildlife habitats
- Ecosystem services,
- Social and economic aspects
- Cultural feature

Valued Ecosystem Components that have the potential to interact with project components should be included in the assessment of environmental effects as if altered by the project, would be of concern to regulatory agencies, Aboriginal persons, resource managers, scientists, stakeholders, and /or the general public. Some of these VECs with their Parameters and potential impacts on them are listed in Table 1.1

Table 1.1: VEC's for Hydropower Project

Environmental Component	VECs	Potential Impacts	Issues
Aquatic resources	River/lake consist considerable population of fishes	Deoxygenation, Eutrophication, Decrease water habitat	Number of water dependent species will decrease
Health	Physical and mental well being	Need of Healthcare institutions and facilities due to excessive pollution	Noise and Air pollution giving rise to various health problems
Ground Water	Water Availability in local aquifers	Drinking water availability and Ground water recharge	Access and timely availability
Landscape	Tourism related Cultural Heritage sites, Areas listed in protected list	Land and Air Pollution	Loss of cultural, aesthetic and tourism value
Vegetation	Local forests	Effects of Air and Water pollution on	Disruption of hydrological cycle,

		biodiversity and invasive species	Extinction of endangered species
Transport	Connectivity	Improvement the connectivity by construction improved roads and establish railway crossing	Less congestion and time saver
Wildlife	Endangered and Culturally valued species	Hunting, Habitat loss	Disruption in the path of migratory birds, Negative impact on Ecological process, Loss of livestock and species for cultural and tourism importance
Economic Condition	Livelihood of people	Development of local communities, infrastructure and educational institutions. Inability in coping up with new job pattern due to sudden resettlement	Job increment and personal growth with development of facilities around the community
Tourism	Tourist visiting for Cultural purpose or to seek the natural beauty around	Reservoir enhances scenic beauty, impoundment of water serves as big lake	Water tourism and scenic beauty become main attraction, increase in tourist resort which develop better livelihood
Air	Ambient air quality	Pollution,e.g. concentra tion of particulates	Respiratory Impacts, acid rain

Surface Water	Ambient water quality in local river	Reduced Volume/ changed flow regime, contamination, changes in course	Seasonal drying, low water quality, flooding
Irrigation	Availability of water for farming, Irrigated area	Reduced environmental flow leads to less availability of water downstream, submergence of irrigated area	Farming practices, harvest at the end of season

1.2.1 Flooding of Natural Habitats: Some reservoirs permanently flood extensive natural habitats causing local or even global extinctions of animal and plant species. Very large hydropower reservoirs in the tropics are especially likely to cause species extinctions, although such losses are rarely documented due to lack of scientific data. Particularly hard-hit are riverine forests and other riparian ecosystems, which naturally occur only along rivers and streams. From the perspective of biodiversity conservation, terrestrial natural habitats lost to flooding are usually much more valuable than the aquatic habitats created by the reservoir. An exception to this can be the shallow reservoirs in dry zones that can provide a permanent oasis, sometimes important for migratory waterfowl and other terrestrial and aquatic fauna [4].

1.2.2 Loss of Terrestrial Wildlife: During reservoir filling terrestrial wildlife can be lost to drowning as a consequence of flooding terrestrial natural habitats, although this is often treated as a separate impact.

1.2.3 Involuntary Displacement: Involuntary displacement of people is considered the most adverse social impact of hydropower projects. Involuntary displacement can also have important environmental implications, such as when natural habitats are converted to accommodate resettled rural populations.

1.2.4 Deterioration of Water Quality: Damming Rivers can reduce water quality due to lower oxygenation and dilution of pollutants by reservoirs that are relatively stagnant compared to fast-flowing rivers. Also, flooding of biomass (especially forests) creates underwater decay; and due to reservoir stratification water quality can decline because deeper lake waters lack oxygen.

1.2.5 Downriver Hydrological Changes: Major downriver hydrological changes can destroy riparian ecosystems dependent on periodic natural flooding, exacerbate water pollution during low-flow periods, and increase saltwater intrusion near river mouths. Reduced sediment and nutrient loads downriver of dams can increase so-called river-edge and coastal erosion, and damage the biological and economic productivity of rivers and estuaries. When the water is diverted to other portion of the river or to a different river, kills fish and other fauna and flora depending on the river; it can also damage agriculture and human water supplies.

1.2.6 Water-related Diseases: Some infectious diseases can spread around hydropower reservoirs, particularly in warm climates and densely populated areas. Some diseases are borne by water-dependent disease vectors (e.g. mosquitoes and aquatic snails); others such as dysentery, cholera, and Hepatitis A, etc. are spread by contaminated water, which frequently becomes worse in stagnant reservoirs than it was in fast flowing rivers.

1.2.7 Fish and Other Aquatic Life: Hydropower projects often have major effects on fish and other aquatic life. The effects on certain fish species and fisheries by increasing the area of available aquatic habitat of Reservoirs is positive. However, the net impacts are often negative because (a) the dam blocks upriver fish migrations, while downriver passage through turbines or over spillways is often unsuccessful; (b) changes in downriver flow patterns adversely affect many species, (c) many river-adapted fishes and other aquatic species cannot survive in artificial lakes; and (d) water quality deterioration in or below reservoirs because of low oxygen levels and due to sometime gas super-saturation, kills fish and damages aquatic habitats.

1.2.8 Floating Aquatic Vegetation: Floating aquatic vegetation can rapidly proliferate in eutrophic reservoirs, causing problems such as (a) degraded habitat for most species of fish and other aquatic life, (b)clogging of electro-mechanical equipment at dams, (c) improved breeding grounds for mosquitoes and other nuisance species and disease vectors, (d) impeded navigation and swimming, and (e) increased water loss from some reservoirs.

1.2.9 Loss of Cultural Property: Cultural property, including archaeological, historical, paleontological, and religious sites and objects, can be inundated by reservoirs or destroyed by associated quarries, borrow pits, roads, or other works.

1.2.10 Reservoir Sedimentation: Over time, reservoir sedimentation reduces live storage and power generation to a degree that could also lower the projects' long-term prospects for renewable energy over the long term.

1.2.11 Greenhouse Gases: Greenhouse gases are widely considered to be the main cause of human-induced global climate change. Many hydropower reservoirs flood forest areas or other areas containing biomass. Greenhouse gases, mainly carbon dioxide and methane, are released into the atmosphere from reservoirs that flood forests and other biomass, either slowly as flooded organic matter decomposes, or rapidly if the forest is cut and burned before reservoir filling. Moreover, most such hydro projects generate sufficient electricity to more than offset the greenhouse gases that would otherwise have been produced by burning fossil fuels in power plants as shown in Fig 1.1

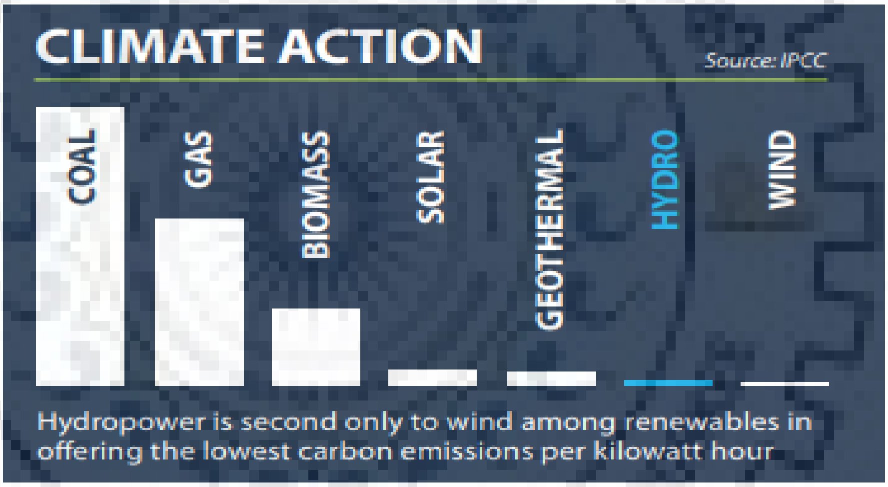


Fig 1.1 Bar graph representing Carbon Emissions [Source: IPCC]

1.3 Sustainable Hydropower Protocol

The principles in the Sustainability Hydropower Assessment Protocol, along with results of a Protocol assessment, an important framework is consulted for considering the questions about the sustainability of any particular hydropower project. There is a common view across a diversity of sectors (e.g. governments, banks, civil society, industry, NGOs) on the importance of sustainability considerations that need to be taken into account to form a view on hydropower project sustainability. The Protocol accumulate these considerations in a structured framework, and provides a platform to produce a sustainability profile for a project as shown in Fig 1.2

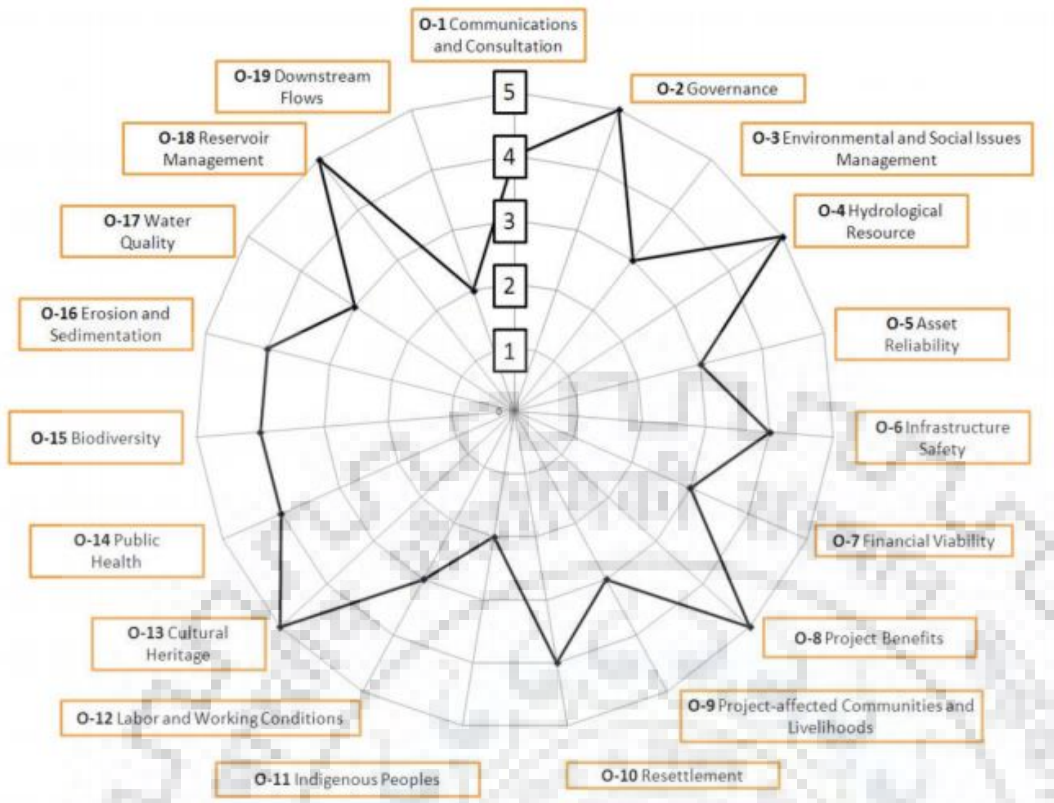


Fig 1.2 Example of a sustainability for an operations stage assessment [Source: IHA]

This Assessment Protocol is an enhanced sustainability assessment tool used to guide and measure performance of the hydropower project. It gives a framework for the assessment of the sustainability of hydropower projects [5].

The following are the sustainability parameters used for assessment

1. Communication and consultation
2. Governance
3. Environmental and Social Management issue
4. Hydrological resources
5. Asset reliability and efficiency
6. Infrastructure safety
7. Financial viability
8. Project benefits
9. Project Affected communities and Livelihood
10. Resettlement
11. Indigenous people
12. Labour and Working condition

13. Cultural Heritage
14. Public Health
15. Biodiversity and Invasive species
16. Erosion and Sedimentation
17. Water Quality
18. Reservoir Management
19. Downstream flow regime
20. Climate change, mitigation and resilience

CHAPTER 2

LITERATURE REVIEW

2.1 THEME: SUSTAINABILITY STUDIES

[6] Khan 2015: This paper's purpose is to explore whether SHPs in India is a sustainable industry or not. However, the author suggests that an important perspective on the development of business sustainability has not been yet subjected to empirical analysis. The study is based on the analysis of qualitative data acquired through 28 in-depth interviews with various factors that are connected to the SHP industry in India which include Independent Power Producers (IPPs), manufacturers, designers, consultants and representatives of various government organizations.

[7] Erlewein 2013: The paper aims to explore the systemic limitations of environmental assessment for hydropower development in the Indian state of Himachal Pradesh The methodology involved for qualitative analysis involves interviews with environmental experts, document reviews and field observations The study suggests that the current practice of constraining EIAs to the project level fails to address the larger effects of extensive hydropower development Furthermore, it is critically discussed as to what extent the concept of Strategic Environmental Assessment (SEA) might have the potential to overcome existing shortcomings

[8] Shrinivasan et al. 2009: This article's purpose is to explore the interlinkages between local livelihood and environmental benefits by providing energy to remote rural area through small hydropower development. The research is supported by the analysis carried out around a large development project designed for the optimum utilization of small hydropower resources in the Himalayan and sub-Himalayan regions. The project aimed to demonstrate the utility of and options for providing electricity to such villages through clean mini-hydro

The article addresses the nature of the impacts of the demonstration small hydel schemes on the local communities, to what extent they translate into environmental benefits both local and globally, and the perceptions and participation of the local communities in these small hydro schemes The study explores the impacts of the schemes on financial capital, natural capital, social capital, physical capital, human capital, and gender equity in the local communities It further provides a discussion on the links between local and global environmental benefits.

[9] Nautiyal et al. 2011: The study has been carried out to highlight the water resource and small hydropower potential in India. Utilization of small hydropower sources for sustainable development has also been presented. Among all renewable sources, small hydropower (SHP) is one of the promising sources for sustainable water and energy development. Small hydropower development is also necessary for proper utilization of available water resources.

[10] Akella et al.2009: Conventional energy sources based on oil, coal, and natural gas have proven to be highly effective drivers of economic progress, but at the same time damaging to the environment and to human health. Keeping in mind, the social, economical and environmental effects of renewable energy system have been discussed in this paper. The uses of renewable energy system, instead of, conventional energy system, to control the social, economical and environmental problems have been discussed. The results show that the trends of total emission reduction in different years, which is exponentially increasing a fter the installation of renewable energy system in remote areas.

[11] Kumar and Katoch 2014: This study intends to emphasise sustainability of run of the river (RoR) hydropower projects in hydro rich regions of India where these types of projects are being undertaken on a large scale. In addition, this study has compiled a list of sustainability Parameters which may be of use for policy makers and designers while planning RoR projects in hydro rich regions of India and similar regions throughout the world.

The sustainability Parameters suggested in the study may be helpful for policy m akersand decision takers to identify specific RoR hydropower projects towards which fo cused measures and policies may be directed. In all, these Parameters will be helpful f or sustainable development of RoR hydropower projects (large and small) in hydro rich Indian states in particular and similar regions throughout the world in general.

[12] Mishra et al. 2015: The objective of this study is to comprehensively review the current status of small hydro power development in India and develop scenarios of growth. Potential and installed capacity, technological status, policy and regulatory support to small hydro power and the whole process of developing a small hydro power plant have been comprehensively reviewed.

[13] Sachdev et al. 2015: This study aims in providing a general guidance with regards to economical design and practical realization of the main components of small hydro-power plants and their interactions. There is abundant literature which has discussed various models and control techniques used for small hydro-power plants. We envisage that summarizing such literature and coming out with a review paper would greatly help the policy/decision makers and researchers in arriving at effective solutions.

[14] Mishra et al 2011: The present review attempts to cover the benefits such as clean development mechanism (CDM), internal rate of return (IRR) for financial viability of such projects. A review on the different types of optimization techniques is also been presented to minimize the cost of the installation of SHP projects. Due to diversification in layout/configuration of small hydro plant, a number of cost equations were developed to suit the site conditions.

[15] Kamal et al. 2008: They studied the Scenario of Small Hydro Power Projects in India and its Environmental Aspect; its review provides the No. of Sites and Capacities in different States of India. Also take out critical issues facing by Investors, Stake holders, Agencies, etc. For development of the Small Hydro Power projects, Government gives Incentives/Subsidies to the Govt./Private sector. It gives the details of financial support given by Govt. of India.

[16] Purohit et al. 2007: They observed the process of clean development mechanism of Kyoto protocol. The purpose of the study is to promote sustainable development by deduction in carbon dioxide emission at lower cost. For sustainable rural development, small hydro power projects could be best to meet out the requirements of CDM as the directly displace the greenhouse gas emissions. Through supportive policies and CDM technique, the maximum utilization potential of SHP projects is more feasible.

[17] Sharma et al.2 12: They analyzed the strategies, policies and development of hydropower in India: Special emphasis on small hydro power. Paper focused on the efforts to analyze the current status, future strategies and policies of hydropower development in India with special emphasis on SHP

2.2 THEME: SUSTAINABILITY MONITORING TOOLS

[18] Afgan 2010 :The main attention of this paper is devoted to: (1) Energy efficiency as a complex problem, which has to be defined with an additive function of agglomerated economic efficiency, environment efficiency and social efficiency; (2) Information and communication technologies recognized as the tool for the development of sustainable and safe global life support systems. This comprises monitoring tools for the assessment and evaluation of potential degradation and resilience of the energy system; (3) Multi-criteria evaluation method is verified as an appropriate procedure for the Sustainability Index determination.

[19] Luthra et al. 2015: In this paper an attempt has been made to identify and rank the major barriers in the adoption of 'renewable and green' energy technologies in the Indian context. Twenty-eight barriers have been identified from an extensive literature review. These identified barriers have been categorized into seven dimensions of barriers, i.e. Economical & Financial; Market; Awareness & Information; Technical; Ecological andG eographical; Cultural & Behavioural; and Political & Government Issues.

Analytical Hierarchy Process (AHP)technique has been utilized for ranking of bar riers to adopt renewable/sustainable technologies in the Indian context. Comparisons in AHP have been made based on experts' opinions (selected from academia and industry). Sensitivity analysis has also been made to investigate the priority ranking stability of barriers to adopt renewable/sustainable technologies in the Indian context. This paper may help practitioners, regulators and academicians focus their future efforts in adoption of renewable/ sustainable energy technologies in India

[20] Carvalho et al 2002: This paper presents selection of criteria and options for the new and renewable energy technologies assessment based on the analysis and synthesis of parameters under the information deficiency method. In order to present an evaluation of the new energy technologies, a number of options featuring some of the characteristics measured by the selected sustainability Parameters are taken into consideration. For each option under consideration, the sustainability Parameters are defined in order to verify their rating under the specific constraints and to obtain the generalised index of sustainability rating of all options. The aim of this paper is to define energy Parameters used in the assessment of energy systems which meet the sustainability criterion. In this respect, the following Parameters are taken into consideration: energy resources, environment capacity, social Parameters and economic Parameters.

[21] Hovanov et al. 2000: This paper is devoted to the attempt to evaluate the sustainability of energy systems and show how it can be used in the everyday engineering practice. Obviously, this type of approach has its limitation due to the lack of data for the serious consideration of the system. But it should be anticipated that these excises might serve as guidance for eventual future applications.

[22] Ramachandran et al. 2004: Multi-Criteria Decision Making (MCDM) techniques are gaining popularity in sustainable energy management. The techniques provide solutions to the problems involving conflicting and multiple objectives. Several methods based on weighted averages, priority setting, outranking, fuzzy principles and their combinations are employed for energy planning decisions. A review of more than 9 published papers is presented here to analyze the applicability of various methods discussed. A classification on application areas and the year of application is presented to highlight the trends. It is observed that Analytical Hierarchy Process is the most popular technique followed by outranking techniques PROMETHEE and ELECTRE. Validation of results with multiple methods, development of interactive decision support systems and application of fuzzy methods to tackle uncertainties in the data is observed in the published literature.

[23] Brand et al. 2002: The paper describes the outcome of a European research project called STEEDS (Scenario-based framework to modelling Transport technology deployment: Energy–Environment Decision Support). It is an advanced Decision Support System (DSS) able to assist the policy makers in exploring the influences on market take-up of different transport technologies under various exogenous scenarios and policy options and in assessing the energy and environmental impacts of these technology mixes. To implement the decision-making analysis a newly developed evaluation methodology has been integrated into the DSS allowing decisionmakers to evaluate complex choices on the basis of enhanced access to information of different types.

[24] Liu 2014: Renewable energy is considered as a solution for mitigating climate change and environmental pollution; however, an important problem of the application of renewable energy systems (RESs) is that the evaluation of the sustainability of these systems is extremely complex. In order to assess the sustainability of renewable energy systems comprehensively, the use of sustainability Parameters (SIs) is often necessary. Since sustainability Parameters are necessary to reflect various aspects of sustainability, the development of a general sustainability parameter (GSI) including many basic sustainability Parameters (BSIs) becomes critical. In this paper, the methods of selection, quantification, evaluation and weighting of the basic Parameters as well as the methods of GSI aggregation are reviewed. The advantages and disadvantages of each method are discussed. Based on these discussions and the analysis of the uncertainties of sustainability assessment, an effective framework and its procedures of the development of GSI for renewable energy systems is presented. This GSI is not only able to evaluate all the sustainability criteria of RESs, but also can provide numerical results of sustainability assessment for different objective systems. The proposed framework in this study can be used as a guidance of the development of sustainability parameter for various renewable energy systems.

2.3 THEME: INTERNATIONAL REPORTS

[25]CAG report on small hydro power

According the CAG report on small hydro power, during 2007-12, MNRE was able to achieve its target. However, during 2012-14 there was a shortfall of around 38 *per cent*. CAG report observed delays and problems in conducting feasibility studies for identifying potential sites for setting up Small Hydro Power projects, which was a critical planning activity for development of Small Hydro Power. In Himachal Pradesh 37 consent letters were issued but the Independent Power Producers did not submit any Detailed Project Report even after five years; out of 88 Detailed Project Reports submitted by HimUrja to the Department of Energy for technical approval none had been approved and the Independent Power Producers had not submitted feasibility study reports for 78 projects allotted to them. Further, due to delays and problems in according technical approvals to Detailed Project Reports, allotment of projects, acquiring land for setting up projects and obtaining forest and environmental clearances, several projects could not be taken up and completed in time. Report also observed deficiencies in post-commissioning maintenance of the projects. Test check revealed that 60 projects in five States were shut down, under repair and maintenance or working below capacity, resulting in loss of power generation, revenue losses, unfruitful expenditure on out of order plants, wasteful expenditure on abandoned plants, etc. There were instances of non-recovery of liquidated damages, environmental dues, commitment fees, diversion of funds, excess payments to developers, non-revision of tariffs, etc. There were also deficiencies in monitoring and evaluation of projects by MNRE and State agencies.

[26] Performance Standards on Environmental and Social Sustainability's Guidance 2012: IFC has prepared a set of Guidance Notes, corresponding to the Performance Standards on Environmental and Social Sustainability. These Guidance Notes offer helpful guidance on the requirements contained in the Performance Standards, including reference materials, and on good sustainability practices to improve project performance. These Guidance Notes are not intended to establish policy by themselves; instead, they explain the requirements in the Performance Standards

[27] Policy on Environmental and Social Sustainability 2012:IFC strives for positive development outcomes in the activities it supports in developing countries. IFC believes that an important component of achieving positive development outcomes is the environmental and social sustainability of these activities, which IFC pursues and expects to achieve through the application of this Policy on Environmental and Social Sustainability (the Sustainability Policy or the Policy), and a comprehensive set of environmental and social Performance Standards. Through this Policy, IFC puts into practice its commitments to environmental and social sustainability.

[28] Hydropower Sustainability Protocol 2018: The Hydropower Sustainability Assessment Protocol is a sustainability assessment framework for hydropower development and operation. It enables the production of a sustainability profile for a project through the assessment of performance within important sustainability topics. To reflect the different stages of hydropower development, the Protocol includes four sections, which have been designed to be used as standalone documents. Through an evaluation of basic and advanced expectations, the Early Stage tool may be used for risk assessment and for dialogue prior to advancing into detailed planning. The remaining three documents, Preparation, Implementation and Operation, set out a graded spectrum of practice calibrated against statements of basic good practice and proven best practice. The graded performance within each sustainability topic also provides the opportunity to promote structured, continuous improvement. Assessments rely on objective evidence to support a score for each topic, which is factual, reproducible, objective and verifiable. The Protocol will be most effective when it is embedded into business systems and processes. Assessment results may be used to inform decisions, to prioritize future work and/or to assist in external dialogue.

2.3 GAPS IDENTIFIED

Based on Literature Review Gaps and limitations encountered are:

- Literature for sustainability is very diverse and lacks commonality. It also lacks in providing an organized and integrated approach for evaluation.
- Literature on sustainability suggests that real time data for complex scientific assessment is not available.
- To check sustainability development various methodology and guidelines are provided but interlinkage and effect of one parameter on others is not discussed. Hence, weightage on the parameters should be assigned.
- Literature on EIA suggests it mainly focuses on environmental aspects and people's economic and social conditions are not part of the process. Hence, EIA proving to be an incomplete assessment for sustainability assessment.

- Variables needed for analyses purposes are varied and differ according to various parameters and conditions

2.4 OBJECTIVES

Based on the literature review and gaps identified , following are the objective of the study:

- To study the application of Sustainability protocol to get the working of all the parameters
- To collect data from the few hydropower projects
- To analyse and carry out comparative studies based on weighted parameters and not on Valued Ecosystem Components (VEC)
- To rank the hydropower projects based on sustainability index score and highlighting their area of weakness in current practice and provide required mitigations
- Comparison between sustainability index and current EIA practice and which is better.

CHAPTER 3

METHODOLOGY

3.1 METHODOLOGY ADOPTED is shown in the Fig 3.1

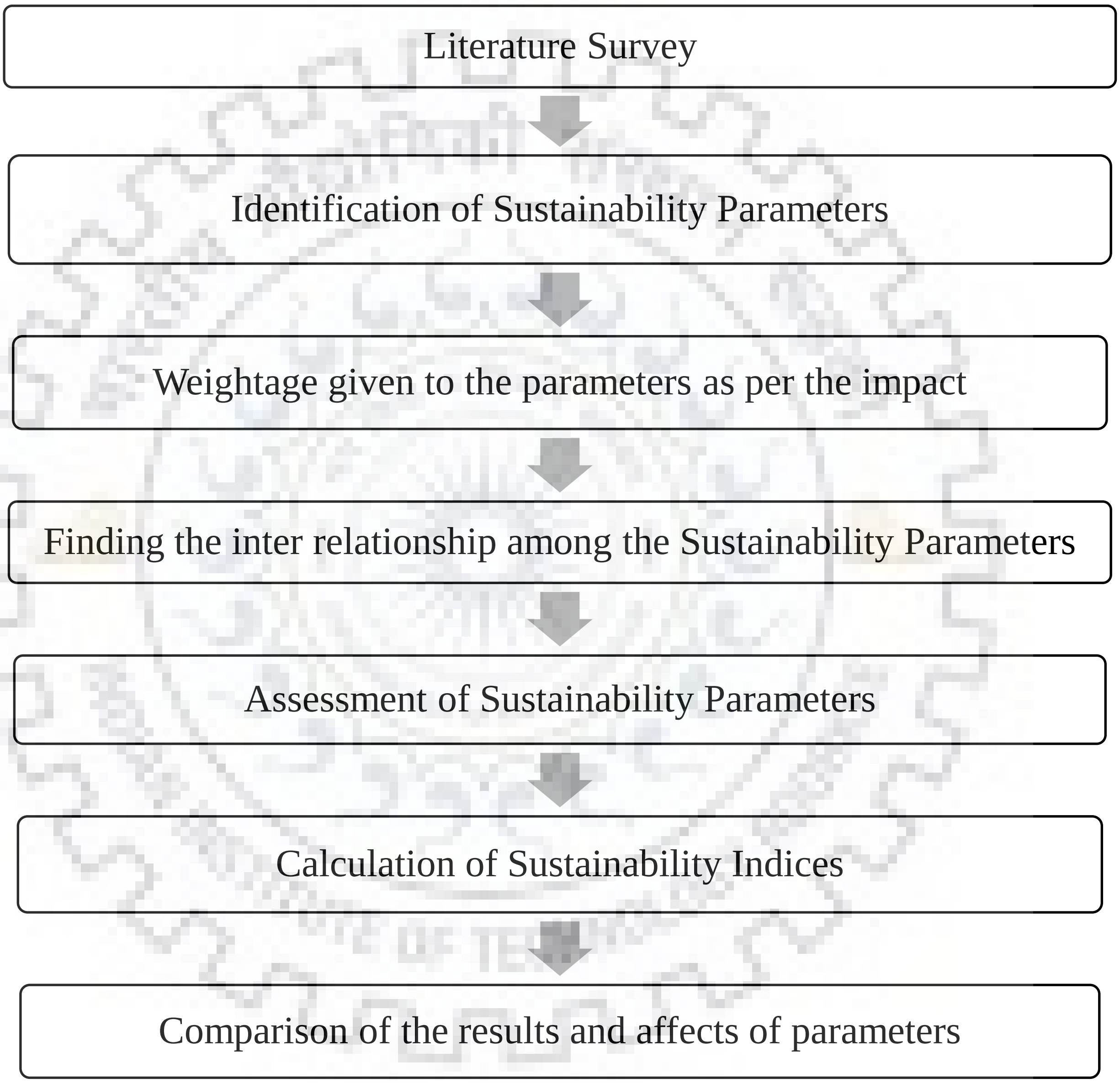


Fig 3.1 : Flow chart of Methodology adopted

3.2 STUDYING HYDRO PROJECTS

3.2.1 TEHRI

The Tehri Dam is the highest dam in India and one of the highest in the world constructed by THDC India Ltd. It is rock and earth-fill embankment dam of height 260.5 m high on the Bhagirathi River near Tehri in Uttarakhand, India as shown in Fig 3.2. Installed capacity of 1000 MW is used widely for irrigation, municipal water supply and the generation. The Normal Annual Rainfall of 1010 to 2620 mm is recorded, with recording maximum flood discharge of 3800 m^3. Probable maximum flood's value is 15540 cumecs, Full Reservoir Level (FRL) is EL 830 m, Maximum Level during design flood (MFL) is EL 835 m and at full supply level the water is 830 m. is about 42 Sq.km. The submerged forest area was 2.1 hectare and have general plant availability factor is approx. 77%, employing staff approximately of 600

Dam's length is 575 m, crest width 20 m, and base width 1,128 m. The dam creates a reservoir of 4.0 cubic kilometre with a surface area of 52 km^2. The installed hydro capacity is 1,000 MW along with an additional 1,000 MW pump storage

Design energy for 90% dependable year is 5820 MU. Energy generation target is decided by the Government and this varies every month depending on the need. July, August, September are the peak months when generation exceeds the target. Energy generation averaging 280 MU per month.

There were 191 families identified as project affected families which were given compensation in different form by first categorising how many percentages of land and agricultural land was affected. The compensation was provided by providing land and lump sum money. Income increment is calculated for the semi skilled person, which averaged the income 15 years back, less than Rs. 25000 in the year and presently get average income of Rs. 60,000 to 70,000 in a year.

Fig. 3.2: Location Map of Tehri Dam

3.2.2 KOTESHWAR

The Koteshwar Dam is a gravity dam on the Bhagirathi River, located 22 km downstream of the Tehri Dam in Tehri District, Uttarakhand, India as shown in Fig 3.3. The dam is part of the Tehri Hydropower Complex and serves to regulate the Tehri Dam's tailrace for irrigation and create the lower reservoir of the Tehri Pumped Storage Power Station. In addition, the dam has 400 MW with 4 units of Francis turbine 100MW each. The dam is 300 m long. It has a structural volume of 560,000 m3 and its crest lies at an elevation of 618.5 m (2,029 ft) above sea level. Receiving water from Tehri Dam and collecting it from an overall 7,691 km^2 catchment area, the dam creates a reservoir with a 88,900,000 m^3 capacity, of which 35,000,000 m^3 is active. The reservoir's surface area is 29 km^2 and at full pool, it lies at an elevation of 612.5 m. It has Maximum Flood Level(MFL) of 615 m.. The height of the dam allows for a maximum 75 m (246 ft) of hydraulic head. The submerged forest area was 1.875 hectare and have general plant availability factor is approx. 66%, employing staff approximately of 250.

Design energy for 90% dependable year is 1150 MU. Energy generation target is decided by the Government and this varies every month depending on the need. July, August, September are the peak months when generation exceeds the target. Energy generation averaging 80 MU per month.

There were 73 families identified as project affected families which were given compensation in different form by first categorising how many percentages of land and agricultural land was affected. The compensation was provided by providing land and lump sum money. Income increment is calculated for the semi-skilled person, which averaged the income, less than Rs. 35000 in the year and presently get average income of Rs. 60,000 to 70,000 in a year.

.

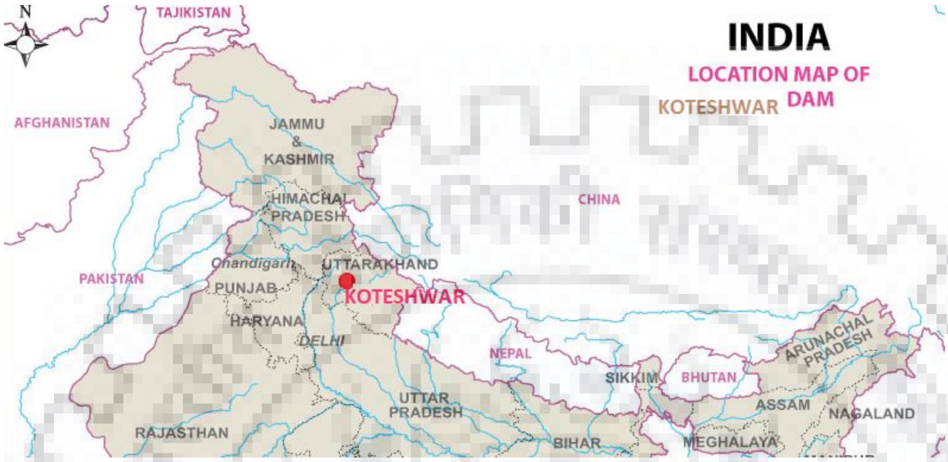


Fig 3.3: Location Map of Koteshwar Dam

3.2.3 URI

Uri Dam is a 480 MW hydropower power station on the Jhelum River near Uri in Baramulla district of the Jammu and Kashmir region as shown in Fig 3.4, administered by India. It is located very near to the Line of Control, between India and Pakistan. The station is largely built under a hill with a 10 km tunnel. Since the Indus Waters Treaty gives Pakistan the exclusive right to regulate the Jhelum River. On 4 July 2014 a 240 MW Uri-II power project which is a new project located just downstream of Uri I, was inaugurated

Uri power station is run-of-the-river scheme with an installed capacity of 480 MW (4 X 120 MW) to harnesses the Hydropower potential of river Jhelum. It is located in Baramulla district of Jammu & Kashmir. The project comprises of a 20.0 m high & 93.50 m long barrage, open channel, 8.4-meter diameter & 10.63 Km long horse shoe shaped HR, surge shaft with two 5 m diameter circular steel lined back filled pressure shaft. The underground power house with installed capacity of 480 MW houses 4 units of 120 MW capacity each designed to operate under the gross head of 262.0 m. The submerged forest area was 0.975 hectare and have general plant availability factor is approx. 76%, employing staff approximately of 250.

Design energy for 90% dependable year is 2587.38 MU. Energy generation target is decided by the Government and this varies every month depending on the need. July, August, September are the peak months when generation exceeds the target. Energy generation averaging 120 MU per month.

There were 21 families identified as project affected families which were given compensation in different form by first categorising how many percentages of land and agricultural land was affected. The compensation was provided by providing land and lump sum money. Income increment is calculated for the semi-skilled person, which averaged the income, less than Rs. 15000 in the year and presently get average income of Rs. 25,000 to 30,000 in a year.

.

Fig 3.4: Location Map of Uri Dam

3.2.4 BAGLIHAR

Baglihar Hydropower Power Project, power project on the Chenab River in the southern Doda district of the Indian state of Jammu and Kashmir as shown in Fig. 3.5. This project was conceived in 1992, approved in 1996 and construction began in 1999. It is a Gravity dam having height is 144 m, Length is 317 m, Elevation at crest is 843 m, Dam volume is 18-million-meter cube. Spillway is a chute type having capacity of 16,500 m^3/s. The power house is located on the right bank of the river below the dam and contains 6 x 150 MW Francis turbine-generators. The height of the dam allows for a maximum 130 m of hydraulic head. Total capacity of the reservoir is 395.95 million m^3, which has active capacity of 32.56 million m^3 above 836 m MSL. The surface area of the reservoir is 8.079 million m^2 and Normal elevation of 840 m The submerged forest area was 2.57 hectare and have general plant availability factor is approx. 79%, employing staff approximately of 450.

Design energy for 90% dependable year is 5174 MU. Energy generation target is decided by the Government and this varies every month depending on the need. July, August, September are the peak months when generation exceeds the target. Energy generation averaging 164 MU per month.

There were 147 families identified as project affected families which were given compensation in different form by first categorising how many percentages of land and agricultural land was affected. The compensation was provided by providing land and lump sum money. Income increment is calculated for the semi-skilled person, which averaged the income 15 years back, less than Rs. 25000 in the year and presently get average income of Rs. 40,000 to 50,000 in a year.

Fig 3.5: Location Map of Baglihar Dam

3.2.5 LOWER JHELUM

Lower Jhelum as shown in Fig 3.6, has installed capacity of 105 MW, commissioned during the year of 1978-79, have 3 Pelton turbine of 35 MW each. Presently, it has capacity of 90MW. The height of the dam allows for maximum 61.79 m. Length of water conductor is 8738.6 m, having water carrying capacity of 7700 cusec. Design discharge is 42 cumecs. Barrage's height is 10.7 m and length is 58.8m. Power channel is having length of 2.32 km and bed width of 18 m. The reservoir has Full Reservoir level of 768.5 The submerged forest area was 1.875 hectare and have general plant availability factor is approx. 66%, employing staff approximately of 250.

Design energy for 90% dependable year is 550 MU. Energy generation target is decided by the Government and this varies every month depending on the need. July, August, September are the peak months when generation exceeds the target. Energy generation averaging 28 MU per month.

There were 34 families identified as project affected families which were given compensation in different form by first categorising how many percentages of land and agricultural land was affected. The compensation was provided by providing land and lump sum money. Income increment is calculated for the semi-skilled person, which averaged the income 15 years back, less than Rs. 5000 in the year and presently get average income of Rs. 30,000 to 40,000 in a year.

Fig 3.6: Location Map of Lower Jhelum Dam

3.2.6 SALAL

Salal Hydropower Power Station, is a run-of-the-river power project on the Chenab River in the Reasi district of the Indian state of Jammu and Kashmir as shown in Fig. 3.6. The dam construction started after entering mutual agreement between India and Pakistan in 1978.The dam has Full Reservoir level: 487.68 m, Maximum water level: 494.08 m, Dead storage water level: 487.68 m, Live storage: Nil, Length of power dam: 105 m length of non-overflow dam: 125 m,

Power from the project is transmitted to the Northern Grid where it is distributed to the states of Jammu and Kashmir, Punjab, Haryana, Delhi, Himachal Pradesh, Rajasthan, and Uttar Pradesh, and the union territory of Chandigarh. The submerged forest area was 1.157

hectare and have general plant availability factor is approx. 86%, employing staff approximately of 250.

Design energy for 90% dependable year is 1080 MU. Energy generation target is decided by the Government and this varies every month depending on the need. July, August, September are the peak months when generation exceeds the target. Energy generation averaging 109 MU per month.

There were 87 families identified as project affected families which were given compensation in different form by first categorising how many percentages of land and agricultural land was affected. The compensation was provided by providing land and lump sum money. Income increment is calculated for the semi-skilled person, which averaged the income, less than Rs. 25000 in the year and presently get average income of Rs. 50,000 to 75,000 in a year.

Fig 3.7: Location Map of Salal Dam

3.2.7 DUL HASTI

Dul Hasti is a 390 MW with 3 units of 130 MW each. The location of hydropower power plant is in Kishtwar district of Jammu and Kashmir, India built by NHPC as shown in Fig 3.8. The power plant is a run-of-the-river type on Chandra River, a tributary of Chenab River, in the Kishtwar region, a rugged, mountainous section of the Himalayas, and several hundred kilometres from larger cities. It consists of a 70 m (230 ft) tall gravity dam and 186 m long, having Full Reservoir level of 1266.5 m and Maximum Discharge level of 1238.9 m which diverts water through a 9.5 km (5.9 mi) long headrace tunnel to the power station which discharges back into the Chenab.

The submerged forest area was 1.07 hectare and have general plant availability factor is approx. 68%, employing staff approximately of 300.

Design energy for 90% dependable year is 1907 MU. Energy generation target is decided by the Government and this varies every month depending on the need. July, August, September are the peak months when generation exceeds the target. Energy generation averaging 88 MU per month.

There were 88 families identified as project affected families which were given compensation in different form by first categorising how many percentages of land and agricultural land was affected. The compensation was provided by providing land and lump sum money. Income increment is calculated for the semi-skilled person, which averaged the income 15 years back, less than Rs. 35000 in the year and presently get average income of Rs. 60,000 to 70,000 in a year.

Fig 3.8: Location Map of Dul Hasti Dam

3.2.8 SEWA

Sewa-II is a hydropower power station located in the Himalayan region in Jammu and Kashmir state as shown in Fig. 3.9. It is constructed by NHPC Limited on the Sewa River, a tributary of the Ravi River. Commissioned in 2010, it has a surface power house with the capacity of 120 MW, comprising three Pelton wheel units of 40 MW each, which are fed through a 10km headrace tunnel from the Sewa II Reservoir, giving a maximum water head of 599m. The Sewa II Dam has a height of 53m. The power station generates 534 MU annually in a 90% dependable year. The submerged forest area was 0.482 hectare and have general plant availability factor is approx. 66%, employing staff approximately of 100.

Design energy for 90% dependable year is 550 MU. Energy generation target is decided by the Government and this varies every month depending on the need. July, August, September are the peak months when generation exceeds the target. Energy generation averaging 24 MU per month.

There were 54 families identified as project affected families which were given compensation in different form by first categorising how many percentages of land and agricultural land was affected. The compensation was provided by providing land and lump sum money

Income increment is calculated for the semi-skilled person, which averaged the income 15 years back, less than Rs. 20,000 in the year and presently get average income of Rs. 30,000 to 40,000 in a year.

Fig 3.9: Location Map of Sewa Dam

3.3 CRITERIA FOR PARAMETERS USED IN ENERGY SYSTEM SUSTAINABILITY ASSESSMENT

The criteria for the energy system sustainability assessment reflect four aspects, namely: resource aspect, environment aspect, social aspect and economic aspect are identified four broad important energy Parameters namely social Parameters, economic Parameters, environmental Parameters and institutional Parameters. The Hydropower Sustainability Assessment Protocol categorize Parameters under the topics social, economic, environmental and technical (IHA,2018). From the above, it is evident that sustainability assessment of energy systems should at least cover environmental, economic and social aspects. The purpose of this study, the social, economic, environmental and technical aspects of the Hydropower system will be assessed.

Economic Parameters for Sustainable Energy Development (ISED) measures how the use and production patterns of energy, as well as the quality of energy services, affect progress in economic development and how the status of the energy sector and its trends in a country might improve the chances for economic development to be sustainable in the long run.

ISED in the social dimension measures the impact that available energy services may have on social well-being. Availability of energy services has implications in terms of poverty, employment opportunities, education, community development and culture, demographic transition, indoor pollution and health, as well as gender- and age-related implications. Social ISED describes issues related to accessibility, affordability and disparity in energy supply and demand. The production, distribution and use of energy create pressures on the environment, in the household, the workplace, in the city, and at the national, regional and global levels. Therefore, energy Parameters are useful for evaluating impacts of energy systems in all these areas.

Environmental ISED measures the impact of energy systems on the overall environment, and in particular the determination of positive or negative trends in land, waters (fresh and marine), and air quality. Technical Parameters measure the technical efficiency and availability, of the energy systems for energy production and supply. The above criteria show general aspects that need to be taken into consideration in sustainability assessment.

3.4 TOOLS FOR ENERGY SYSTEM SUSTAINABILITY ASSESSMENT

Parameters and indices serve as means by measuring sustainability and ultimately assessing sustainability. Parameter selection is an important stage of sustainability assessment as identified Parameters capture essential information about the value of the system under consideration. Parameters used for assessment may be strictly specified or chosen depending on the assessment methodology or tool.

3.4.1 MCDM and Tools for Energy System Sustainability Assessment

Multiple-criteria decision-making (MCDM) or multiple-criteria decision analysis (MCDA) is a subdiscipline of operations research that explicitly evaluates multiple conflicting criteria in decision making (both in daily life and in settings such as business, government and medicine)[29]. Conflicting criteria are typical in evaluating options: cost or price is usually one of the main criteria, and some measure of quality is typically another criterion. Structuring complex problems well and considering multiple criteria explicitly leads to more informed and better decisions.

3.4.2 Decision Support System (DSS)

These are sophisticated, interactive and computer aided techniques for decisions. DSS can support complex problems that would be otherwise difficult to handle. Knowledge based DSS can support the decisionmakers in selecting criteria, alternatives and trade-offs, thus making the energy planning simple. Most DSS use MCDM methods for arriving at interim results. The applications of DSS in energy planning development include transportation energy management, electricity production alternatives[30].

3.5 PARAMETERS AND INDICES FOR ENERGY SYSTEM SUSTAINABILITY ASSESSMENT

Parameters and indices serve as means by measuring sustainability and ultimately assessing sustainability. Parameter selection is an important stage of sustainability assessment as identified Parameters capture essential information about the value of the system under consideration. Parameters used for assessment may be strictly specified or chosen depending on the assessment methodology or tool

3.5.1 Energy System

A multi-attribute, multi-dimensional, multivariate, complex system whose qualities are determined by investigating many initial indices. The energy system under consideration here is the Hydropower system namely, Tehri, Koteshwar, Baglihar, Uri-I, Salal, Lower Jhelum, Dul Hasti, Sewa.

3.5.2 Initial Indices

Specific criterion is related to qualities of the complex systems. These indices are supposedly necessary and sufficient for measuring parameters of the quality assessment of the system.

3.5.3 Criteria

Aspects of energy system that must be considered for sustainable development(sustainability) or sustainability assessment (quality assessment). The criteria for assessments are social, economic, environmental and technical.

3.5.4 Parameters (criterion)

Results obtained from the processing (to various extents) and interpretation of primary data. Parameters are parameters used to describe respective criteria aimed at sustainability assessment. The Parameter and criterion will be used interchangeably and the `attribute' will be used to mean Parameter or criterion in some general cases.

3.5.5 Normalized Parameter

A normalized Parameter is the equivalent value of the initial Parameter value on a scale (with the same unit) that allows comparison between individual Parameters. Thus, with normalization of sustainability Parameters, comparison among Parameters is achieved.

3.5.6 Aggregated Parameter

This combine, usually by an additive aggregation method, a number of components (data or Parameters) defined in the same units.

3.5.7 Composite Parameter

This combines various aspects of a given phenomenon, based on a sometimes-complex concept, into a single number with a common unit.

3.5.8 Weight Factor or Weight Coefficient Value

The weighting factor ("weight") - a non-negative number to evaluate the relevance of the individual Parameter for a summary estimate of an object.

3.5.9 Index

This generally takes the form of a single dimensionless number. Indices mostly require the transformation of data measured in different units to produce a single number. The method adopted uses weight coefficients or weighting factors and normalized Parameters to obtain an index referred to as sustainability index. Sustainability index of an energy system is demonstrated as a modern approach of sustainability assessment. Thus, a sustainability index of an energy system is a measure of its sustainability assessment[31].

3.6 PARAMETERS USED FOR ASSESSMENT

The following are the sustainability parameters recommended for assessment by IHA

1. Communication and consultation
2. Governance
3. Hydrological resources
4. Asset reliability and efficiency
5. Infrastructure safety
6. Financial viability
7. Project benefits
8. Project Affected communities and Livelihood
9. Resettlement
10. Indigenous people
11. Labour and Working condition
12. Cultural Heritage
13. Public Health
14. Biodiversity and Invasive species
15. Erosion and Sedimentation
16. Water Quality
17. Reservoir Management
18. Downstream flow regime
19. Climate change, mitigation and resilience

All the four criteria of sustainability are taken for the quantitative analysis. In which, Resettlement, Livelihood and Reservoir Area are taken as social parameters. Contribution to National Grid and Direct Job employment are taken as economic parameters. Biodiversity and Global Warming potential are taken as environmental parameters. Lastly, generation potential and Effective availability time are taken as technical parameters

Due to unavailability or un-disclosure of data on Communication and consultation, Governance, Infrastructure safety, couldn't be collected, Therefore, for calculation of sustainability index these parameters are not taken into consideration.

Whereas, Qualitative assessment of Hydrological Regime, River Morphology including Erosion and Sedimentation and Water Quality is done

Project Affected communities, Project Benefits, Resettlement, Indigenous people, Cultural Heritage and Public Health data were subjective in nature. Therefore, to reflect each parameter's contribution in the projects, Parameters namely Resettlement index and Livelihood index were chosen, which are represented in objective way.

3.7 QUA.NTITATIVE PARAMETERS FOR ASSESSMENT

3.7.1 Reservoir Area Parameter, AR (m^2/kWh)

Area Parameter (AR) was used to evaluate how many square meters of land area were used to produce a kilowatt (kWh) of energy. AR has the social implication of evaluating the value of land for power production, and can be used to ascertain whether it is worth using the area for power production.

Reservoir area per kWh was used to estimate the usefulness of the current activity taken place on the previously occupied land. Monthly reservoir area per kWh was estimated using the equation:

$$Area\ Inidcator_{monthi} = \frac{Effective\ Reservoir\ coverage_{monthi}\ (km^2)}{Energy\ generated_{monthi}\ (GWh)} \qquad (3.1)$$

3.7.2 Livelihood Parameter, LI (fraction)

Livelihood Parameter was determined by a survey conducted by the power companies to determine the general trend and to collect quantitative information of household heads income. A focus group discussion was conducted by the respective report makers to quantify present and previous income levels of fishermen and farmers who were affected directly or indirectly. All the secondary data and estimated farmers average income for a year was divided by 12 to obtain income for each month. Calculation of fishermen income scale is done by taking an average fisherman's income at peak season, average season and low fishing season. Income levels in the communities within the naturally undisturbed environment was taken as benchmark (ideal/equals 1). The percentage decrease in income was determined using the expression.

$$Income\ change = 1 - \frac{income_{present}}{income_{past}} \qquad (3.2)$$

The initial approaches to determine was differently used by both organisations but a common matrix is made to compare the effect on Livelihood of the farmers and fishermen. This approach was motivated by the fact that income scales of farmers of fishermen differ significantly. Hence a simple computation of average values and aggregation cannot be representing the situational assessment. However, the income change of farmers and fishermen expressed as deviation from unity lies within the same range as that of fishermen and hence averages could be used. In order to compute changes in monthly income, average farmers yearly income was distributed equally between the months. Fishermen seasonal income was also determined. The change in income was then computed separately and then aggregated and the mean values used.

3.7.3 Resettlement Parameter, RS (fraction)

Project affected communities are the interacting population of various kinds of individuals in the area surrounding the hydropower project who are affected either positively or negatively by the hydropower project and its associated infrastructure.

Issues that affect project affected communities may include, for example: loss or constraints on livelihoods, lowering of living standards, or economic displacement brought about due to changes associated with the project such as changes to river management and flow regimes. Specific examples could include: impacts on health or safety; impacts on cultural practices; impacts on lands, forest and riverbanks; loss of paddy lands, of home gardens, of riverbank gardens; loss of access to sacred sites, to community forest etc. In cases the impacts may result in project affected communities needing to move, but they may not be considered part of the resettlement community because the physical resettlement was a secondary impact and not a primary impact of the project [32].

Economic displacement refers to the loss of assets, access to assets, or income sources or means of livelihoods as a result of (i) acquisition of land, (ii) changes in land use or access to land, (iii) restriction on land use or access to natural resources including water resources, legally designated parks, protected areas or restricted access areas such as reservoir catchments and (iv) changes in environment leading to health concerns or impacts on livelihoods. Economic displacement applies whether such losses and restrictions are full or partial, and permanent or temporary.

On the basis of the primary and secondary data collected in respect of the project affected families a draft R&R plan was formulated in consonance with the principles enunciated in the National Resettlement and Rehabilitation Policy, 2007. Judgement is done on the basis of the work done relating to Social welfare and community development. The main objective of any Resettlement and Rehabilitation is to compensate for the acquired Agriculture land according to the Land acquired, Infrastructure facilities including water supply, sewage, drainage, electricity, streets community center, green area, park and approach path/roads at the project cost, Compensation for Houses and other immovable assets compensation for crops, fruit bearing and other trees. Table 3.1 shows the criteria for scoring

Table 3.1: Criteria for scoring

Score	State of component	Interpretation
0	Not done	No objective evidence for assessment
≤ 0.25	At most 25% complete	Very little evidence / unsatisfactory
≤ 0.50	At most 50% complete	Significant evidence / significant gaps
≤ 0.75	At most 75% complete	Significant evidence / near completion
1.00	Complete	Objective evidence on successful completion

To arrive at a score for these items, communities' score is examined by comparing with scores of Reports provided by the authorities. To do this, the we have set a standard for assessment. Judgement of an item score should is based on:

- Documented evidence and just as stated in the document. Any change during implementation is unacceptable.
- Evidence that resettlement package is addressed as stated in document.
- Evidence of effective communication, consultation and transparency at the district and local levels.
- Evidence on successful completion of a resettlement item.

A resettlement item only sores 1 after satisfying all the standards set, otherwise it scores 0.25 per standard met. score. Monthly values of resettlement Parameter is based on an observation within the reservoir during fieldwork. The observation was, there were still some settlements and farmlands in reservoir coverage area. Based on this observation it is taken that, relevance of resettlement will be most evident when the reservoir has full coverage. Average resettlement Parameter was decomposed into monthly values using the expression.

$$Monthly = \frac{Months_{rescov}}{Years\ Max_{rescov}} \times Average_{restind} \quad (3.3)$$

$Average_{restind}$ was arrived at by evaluating responses of Resettlement officer and the reports by the respected authorities.

3.7.4 Direct Job, DJ (Persons-months/GWh)

Direct labour Parameter is estimated in persons-years/GWh. For the purposes of a situational assessment, monthly value for direct job was calculated using the expression. This parameter comes under the indicator of financial viability. This is a strong parameter to present the economic strength of the power project.

$$Direct\ Job_{monthi} = \frac{Number\ of\ direct\ employees \times \frac{1}{12}\ months/year}{Energy\ generated_{monthi}} \quad (3.4)$$

3.7.5 Impact on Tourism, IT (fraction)

Monthly impact on tourism was computed as a fractional available number of visitors to the nearby national parks, periodic cultural festivals or developed tourist spot near the Hydropower project, taking into consideration pre and post inundation periods. The assessment utilizes data for the periods in which the assessment is being performed is secondary in nature and is provided as per the concerned power companies.

$$Impact\ on\ Tourism\ = \frac{Number\ of\ tourist\ pre{-}inundation}{Number\ of\ tourist\ post{-}inundation} \quad (3.5)$$

3.7.6 Contribution to National Grid, CNG (%)

Hydropower dam's monthly contribution to national electricity grid was obtained from the respective operating power companies. The percentage contribution was estimated as a fraction of total contribution into the grid.

$$Contribution\ to\ National\ Grid = \frac{Hydropower's\ Contribution\ to\ Grid}{Total\ Contribution\ to\ Regional\ Grid} \times 100 \quad (3.6)$$

3.7.7 Biodiversity Index, BI (fraction)

Biodiversity is an important parameter to estimate environmental sustainability. It takes account if protected, endangered species listed by national and local key species are affected or not. To calculate the effect on terrestrial species, Submerged forest area is taken into consideration as it is the habitat of many diverse species

For aquatic ecosystem, the river connectivity without making an obstruction for migration of local fishes is the priority with effective fish passages such as fish bypass and with devices could prevent or decrease fish from pass through turbine for Francis turbine or impulse type water turbine. Therefore, effective Restoration pool is used to calculate the indices [33]. A rough estimate of environmental impact of a hydropower plant is the ratio of its installed capacity after the submergence of biodiversity to area inundated. Monthly BI values were estimated using this relationship.

$$Biodiversity\ Index = \frac{Aquatic\ Restoration\ Area\ (km^2)}{Reservoir\ Area\ (km^2) - Submerged\ Forest\ Area (km^2)} \qquad (3.7)$$

The Biodiversity Index was considered a positive impact with a simple reasoning that the values obtained at the time of the assessment are greater than 1. The Global Warming Potential of the dam on the other hand was considered a negative environmental impact and computed as follows.

3.7.8 Global Warming Potential, GWP (kg CO_2 e/ kWh)

Global warming potential of the Hydropower plants was estimated using the IPCC methodology with default values. Annual change in carbon stock in living biomass on land converted to flooded land was estimated using

$$\Delta C_{LW\ flooded} = \left[\sum_i A_i \times (B_{after} - B_{before})\right] \times CF \qquad (3.8)$$

Where,

$C_{LW\ flooded}$ = annual change in carbon stocks in biomass on Land converted to flooded land, (tonnes)

A_i = area of land converted annually to flooded land from original land use (ha / yr)

B_{After} = biomass immediately following conversion to flooded land, (tonnes d.m./ ha) (default=0)

B_{Before} = biomass in land immediately before conversion to flooded land, (tonnes d.m/ha)

CF = carbon fraction of dry matter (default = 0.5), tonnes C (tonnes d.m)$^{-1}$

Annual CO2 emissions on Land Converted to Flooded Land, tonne CO2 /yr. was estimated using the relation

$$CO_{2\ LW\ flood} = \Delta C_{LW\ flooded_{LB}} \times \left(-\frac{44}{12}\right) \qquad (3.9)$$

The GWP was determined as the sum of the losses divided by installed capacity multiplied ny the number of hours in a year. Monthly reservoir average coverage was usd to differentiate montly GWP values

3.7.9 Generation Potential, GP (GWh/mon)

Average monthly generation potential is computed using the expression

$$GP_{monthi} = \frac{Energy\ generated_{monthi}}{Total\ energy\ generated_{period}} \times Insatlled\ Capacity \quad (3.10)$$

3.7.10 Equivalent Availability Factor, EAF (fraction)

The EAF estimates the amount of time that the dam was available for electricity production taken into account capacity available for electricity production as well as scheduled operations and maintenance. Monthly EAF was estimated as follows:

$$EAF_{monthi} = \frac{Energy\ Generated_{monthi}\ (MW)}{Peak\ capacity\ (MW) \times Time\ (\frac{hrs}{month_i})} \quad (3.11)$$

3.8 QUALITATIVE PARAMETERS FOR ASSESSMENT

These includes the parameters which were unable to be computed for the quantitative analysis. Therefore, considering the importance of these parameters, a qualitative analysis is carried out by simple scoring of High, Medium Low against the quality of performance by the parameters

3.8.1 Downstream Hydrological Regime

Ecological flow is selected as the evaluation index; with the evaluation methods as follows:

A) Dam Type Hydro Power Station:

- If the daily mean flow discharges downstream of the dam or sluice meet the requirement of ecological need based on the monitoring data of the flow, then score is **High**
- If the daily mean flow discharges downstream of the dam or sluice meet the requirements of ecological need, then score is **Medium**
- Otherwise, **Low**

B) Run of river Hydropower station with or without storage:

- If the daily mean flow discharges downstream of the dam or sluice meet the requirement of ecological need based on the monitoring data of the flow mentioned above, then score is **High**
- The automatic discharge equipment or facility without artificial control have been installed and it does not be monitored, then score is **Medium**
- Otherwise, **Low**

For the HPPs constructed on the diversion channel for irrigation or other industrial purpose, the dam or sluice refers to the dam or sluice at the beginning of the diversion channel.

The automatic discharge equipment or facility without artificial control above refer to the discharge facilities or equipment aiming to meet the ecological need downstream from the dam or sluice [33].

Here, the ecological flow refers to the regulations by authority of local government or the requirement in design documents of the hydropower station approved by authority. During any period in the evaluation period, if the discharge flow greater than the inflow upstream at the same period, this period could be regarded as abidance by the rules on ecological flow.

3.8.2 River Morphology

The disturbance of river morphology and sediment transportation are the two indices for this element. The score is done with the evaluation method follows:

i. The disturbance of river morphology:

- If the river section from the dam to the powerhouse could be maintained with curves, pools, riffles, wetland etc. under the natural conditions, then score is **High**
- If the features mentioned above are achieved by restoration and artificial measures rather than natural, then score is **Medium**
- If there could not be restored or adopted no restoration, score is **Low**

ii. Sedimentation transportation:

It should be evaluated based on the characteristics of the river sediment, sediment discharge facility and management measures of the hydropower station. The scores can vary from **Low to High**. Typical facilities and management measures are listed as follows for reference:

- Sediment discharge facility could be bottom sluice gate, flushing gallery.
- The measures for sediment discharge could be control of sedimentation through management of the water level of reservoir at the whole flood season or part of that, sediment control through management of the water level based on the different grade flow, open the gate totally to discharge the sediment regularly or not regularly.

3.8.3 Water Quality

The change of the water quality could be assessed with water quality standards as shown in Table 3.2. The method, requirement of evaluation and monitoring are as follows:

The change of water quality could be calculated by making a comparison of the difference of the water quality class on the sections of upstream and downstream. The downstream section could be selected at the suitable section near the outlet of tailrace downstream. The upstream section could be selected at the suitable section near the end of the backwater [35]. The evaluation method is as follows:

- If the change of water quality comes under Class AA and Class A which means the class of water quality does not degrades, scoring **High.**
- If the change of water quality value comes under Class B, Class C, Class D, which means the class of water quality degrade, scoring **Medium**.
- It would be regard as decrease of class of water quality if the water quality comes under Class E and get **Low** score, even when the water has been polluted by oil leakage from the pressure control devices of turbine or from the transformer as well as the wastewater discharges into the river without any treatment

Table 3.2: Water Quality Standards for River/Streams

CLASS	DESIGNATED BEST USE	CRITERIA
AA	Water supply class I; conservation of natural environment	*Total coliform organisms MPN/100mL shall be 50 or less. *pH between 6.5 and 8.5 *Dissolved oxygen 7.5 mg/l or more *Biochemical oxygen demand 1 mg/l or Less * Suspended solid 25 mg/l or less

A	Water supply class 2; fishery class I	*Total coliform organisms MPN/100ml shall be 1000 or less *pH between 6.5 and 8.5 *Dissolved oxygen 2 mg/l or more *Biochemical oxygen demand 2 mg/l or Less * Suspended solid 25 mg/l or less
B	Water supply class 3; Fishery class II	*Total coliform organisms MPN/ 100ml shall be 5000 or less *pH between 6.5 and 8.5 *Dissolved oxygen 5 mg/l or more *Biochemical oxygen demand 3 mg/l or Less
C	Fishery class III; Industrial waste water I	*pH between 6.5 and 8.5 *Dissolved oxygen 4 mg/l or more * Suspended solid 50 mg/l or less
D	Industrial water class II; Agricultural Water	*pH between 6.5 and 8.5 *Free ammonia (as N) 1.2 mg/l or less * Dissolved oxygen 2 mg/l or more * Biochemical oxygen demand 8 mg/l or Less * Suspended solid 100 mg/l or less
E	Industrial waste water III; conservation of living environment	*pH between 6.0 and 8.5 * Biochemical oxygen demand 10 mg/l or Less *Electrical conductivity less than 2250 micro mhos/cm *Sodium absorption ratio less than 26 *Boron less than 2mg/l *No Floating matter

Water supply Class I: can be treated by a simple purification process such as filtration. Water supply Class II: can be treated by conventional purification processes such as sedimentation and filtration. Water supply Class III: can be treated by advanced water purification processes with pre-treatment.

Fishery Class I: suitable for fish such as trout and bull trout inhabiting oligoprobe water, and those of fishery Class II and Class III.

Fishery Class II: suitable for fish such as the salmon family and ayu (sweet fish) inhabiting oligoprobe water and those of fishery Class III.

Fishery Class III: suitable for fish such as carp and crucian carp inhabiting β-mesosaprobic water.

Industrial water Class I: can be treated by conventional processes such as sedimentation. Industrial water Class II: can be treated by advanced purification processes with chemicals. Industrial water Class III: can be treated by special purification processes.

The requirement of evaluation and monitoring for HPPs with or without storage which could only regulate daily, the change of waste quality could be simplified as no change of water quality. For the HPPs with storage which could regulate weekly or longer, the change of water quality should be calculated based on the monitoring result at the sections mentioned above during the evaluation period.

3.9 CALCULATIONS

3.9.1 Normalized Parameter values

Normalization of a specific criterion is done on the basis of initial values of Parameters. Sustainability Parameters are not suitable for use because they have different dimensions and intervals of range, and thus cannot be compared. With the normalization of Parameters, comparison of Parameters is achieved. Normalization is achieved through mathematical expressions that use a membership function foreach Parameter. The procedure is performed for the minimum and maximum values of each Parameter in order to obtain range of values for the sustainability index. For each Parameter we,

2 Select the maximum, $\max(x_i)$, and minimum, $\min(x_i)$, for each Parameter separately for minimum and maximum values ranges.

3 Evaluate whether the function $q(x_i)$ increases or decreases with the increase of x_i. Depending on the variation of function $q(x_i)$, select the proper expression. If membership function increases with Parameter $q(x_i)$, their relationship is expressed by:

$$q_j = q_j(a_j) = \begin{cases} 0 & if\ a_j \leq Min_j \\ \frac{a_j - Min_j}{Max_j - Min_j} & if\ Min_j < a_j \leq Max_j \\ 1 & if\ a_j > Max_j \end{cases} \tag{3.12}$$

If membership function q(xi) decreases with Parameter xi, their relationship is expressed by:

$$q_j = q_j(a_j) = \begin{cases} 0 & if\ a_j \leq Min_j \\ \frac{Max_j - a_j}{Max_j - Min_j} & if\ Min_j < a_j \leq Max_j \\ 1 & if\ a_j > Max_j \end{cases} \quad (3.13)$$

Final normalized values are calculated using the equation

$$n_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}}, \quad (3.14)$$

Table 3.3 is the matrix of initial parameters after the calculation by respective formulas.

Table 3.3: Matrix of Initial Parameters

Parameters / Projects	AR	RS	LI	CNG	DJ	IT	BI	GWP	GP	EAF
Tehri	19.50	0.87	0.93	7.40	0.36	0.47	23.81	1.832	901.8	72.33
Koteshwar	36.90	0.54	0.82	2.80	0.26	0.28	12.9	1.663	359.95	65.66
Uri-I	34.56	0.09	0.61	1.05	0.26	0.103	13.68	1.469	376.4	58.46
Lower Jhelum	118.53	0.10	0.72	1.21	0.14	0.079	12.21	1.908	86.25	75.34
Baglihar	24.62	0.71	0.90	2.25	0.24	0.11	18.67	1.815	816.23	71.67
Salal	35.77	0.60	0.79	1.97	0.205	0.16	9.41	1.63	568.45	64.36
Dul Hasti	43.91	0.34	0.69	1.58	0.28	0.19	6.10	1.975	337.3	77.98
Sewa	111.58	0.10	0.46	1.15	0.39	0.106	2.60	1.735	104.4	68.5

Area Parameter, Direct job Parameter, Livelihood Parameter and Global Warming Potential Parameter are treated as decreasing with increasing membership function $q(x_i)$. On the other hand, Resettlement Parameter, Contribution to national grid, Impact on tourism, Biodiversity

Index, Generation potential and Equivalent availability factor are considered increasing with increasing membership function $q(x_i)$. An (m x k) matrix; (4 x 10) matrix was obtained for normalized parameter values as shown in Table 3.4

Table 3.4: Matrix of Normalized Initial Parameters

Parameters / Projects	AR	RS	LI	CNG	DJ	IT	BI	GWP	GP	EAF
Tehri	0.746	0.612	0.700	0.713	0.68	0.788	0.651	0.605	0.88	0.585
Koteshwar	0.625	0.475	0.55	0.540	0.487	0.514	0.486	0.475	0.445	0.631
Uri-I	0.646	0.398	0.612	0.520	0.505	0.207	0.52	0.414	0.477	0.454
Lower Jhelum	0.237	0.501	0.465	0.411	0.305	0.276	0.383	0.640	0.387	0.506
Baglihar	0.711	0.528	0.654	0.598	0.416	0.253	0.605	0.571	0.816	0.5367
Salal	0.698	0.61	0.538	0.452	0.348	0.387	0.481	0.442	0.596	0.554
Dul Hasti	0.564	0.478	0.397	0.472	0.553	0.284	0.458	0.687	0.437	0.523
Sewa	0.288	0.423	0.388	0.465	0.700	0.326	0.405	0.528	0.393	0.5303

It is also important to mention that 0.5 is the mean sustainability index. In normalizing, each parameter was normalized within -3 and +3 standard deviations from the mean. Based on this rule each Parameter has a mean estimation of 0.5. However, in applying the rules for weight coefficient determination the actual mean value of each parameter was taken into account. This was done to bring the parameter values as close as possible and to set 0.5 pass mark for sustainability assessment. Another reason for doing that is that, it is the same energy system under consideration whose properties are most likely to be closely related. Based on the above, any sustainability index below 0.5 may be considered as “unsustainable" and any sustainability index mark above 0.5 may be considered sustainable. 0.5 is the mean sustainability index

3.10 DETERMINATION OF WEIGHT COEFFICIENT VALUES

The weight coefficient w_n (n = 1; :::;m) shows which importance is given to a particular criterion (Parameter) q_n, when the general sustainability index Q (q;w) is formed. Weight coefficient estimation is done by inputting a non-numeric weighting information, in a form of a comparative proposition (>;< or =) among Parameters. Weight coefficient estimates is given in cases. Cases 1 and 2 have none and equal weighting information respectively. Case 1 examines the data available for the work. Case 2 examines the available data application to sustainable development. Non-numeric weighting information for Cases 3 to 11 examines the situations (situational assessment) with respect parameter(s) and shows what will happen to the general sustainability index when a particular Parameter(s) is/are prioritised. Cases 3 to 10 identify which parameters are important for sustainable development of the dam. Non-numeric weighting information for case 12, is used to determine the general sustainability index of the dam. Case 11 takes into account actual weighting information for the parameters. Below is a detailed description of the cases considered and their non-numeric weighting information.

3.10.1 Case 1: No weighting information

This case is targeted at computing possible estimates for sustainability index based on information used and also the associated errors. This is done by placing no weighting information on Parameters. It is supposed that these Parameters are necessary and sufficient measuring parameters for the quality assessment of the hydropower system. In this case, it is taken that no information regarding the weight of Parameters is available. The interest is to see possible estimates of sustainability index.

3.10.2 Case 2: Equal weighting information about Parameters

In this case equal priority is given to all Parameters. The target is to achieve sustainable development by placing equal values on social, economic, environmental and technical criteria. The aim is also to eliminate uncertainties associated with estimations and separate most sustainable outcomes from least sustainable outcomes.

w(AR) = w(RS) = w(LI) = w(CNG) = w(DJ)= w(IT) = w(BI) = w(GWP) = w(GP) = w(EAP)

3.10.3 Case 3: Situational assessment: Preference to social Parameters (RS)

In this case priority is given to social Parameters. Preference is given to resettlement Parameter over livelihood and reservoir area Parameter per kWh. The non-numeric input weighting information is as follows:

w(AR) = w(LI) < w(RS); w(CNG) = w(DJ)= w(IT) = w(BI) = w(GWP) = w(GP) = w(EAP)

3.10.4 Case 4: Situational assessment: Preference to social Parameters (AR and LI)

In this case priority is given to reservoir area per kWh Parameter (AR) and livelihood parameters (LI) with all other Parameters being equal. This case is important to evaluate the value of a unit area of acquired land in energy generation. More importantly, this case might be

taken to as an advocacy of resettlement communities to help them improve their livelihoods.
The following non-numeric weighting coefficient is used.

w(AR) = w(LI) > w(RS); (CNG) = w(DJ)= w(IT) = w(BI) = w(GWP) = w(GP) = w(EAP)

3.10.5 Case 5: Situational assessment: Preference to Economic Parameters (DJ and CNG)

This case seeks to model the main economic impact of the hydropower project compared to previous economic value of the project area. To model the main economic impact of the dam, the following weighting information is used:

w(CNG) = w(DJ) > w(IT); w(AR) = w(RS)= w(LI) = w(BI) = w(GWP) = w(GP) = w(EAF)

3.10.6 Case 6: Situational assessment: Preference to Economic Parameters (IT)

This case seeks to model the main economic impact of the previous activity (tourism) of the National Park or any Lake side event compared the current existing activity (hydropower generation). To model economic impact of the Tourism, the following weighting information is used.

w(CNG) = w(DJ) < w(IT); w(AR) = w(RS)= w(LI) = w(BI) = w(GWP) = w(GP) = w(EAF)

3.10.7 Case 7: Situational assessment: Preference to Environmental Parameters (GWP)

In this case preference is given to GWP compared to BI. To do this, the following weighting information is used.

w(BI) < w(GWP); w(AR) = w(RS) = w(LI)= w(CNG) = w(DJ) = w(IT) = w(GP) = w(EAF)

3.10.8 Case 8: Situational assessment: Preference to Environmental Parameters (BI)

In this case preference is given to BI which is considered a positive Parameter relative to global warming potential (GWP) which is considered a negative Parameter. To do this the following weighting information is used.

w(BI) > w(GWP); w(AR) = w(RS) = w(LI)= w(CNG) = w(DJ) = w(IT) = w(GP) = w(EAF)

3.10.9 Case 9: Situational assessment: Preference to Technical criteria (GP)

In this case priority is given to generation potential (GP) compared to the equivalent availability factor (EAF). To do this, the non-numeric weighting information used is:

w(GP) > w(EAF); w(AR) = w(RS) = w(LI)= w(CNG) = w(DJ) = w(IT) = w(BI) = w(GWP)

3.10.10 Case 10: Situational assessment: Preference to technical criteria (GP and EAF)

This case gives equal preference to GP and EAF. This will imply that the plant is available at maximum amount of time in the year. This is a necessary condition to judge the long-term capability of the dam. The weighting information used in this case is:

w(GP) = w(EAF);>w(AR) = w(RS) = w(LI)= w(CNG) = w(DJ) = w(IT) = w(BI) = w(GWP)

3.10.11 Case 11: General sustainability index of the hydropower project

This case builds general sustainability indices for the dam project. The general sustainability indices are representative of the quality of the dam project. Non-numeric weighting coefficient used is based on the normalized mean values of initial Parameter values. The following non-numeric input weighting information and aggregated preference weighting information is used.

w(GWP) = w(GP) = w(IT) > w(EAF) = w(RS)= w(LI) = w(AR) = w(CNG) = w(GP) = w(AR)

The aggregated preference index weighting information is formed based on preference indicated by data used (case 1).

3.11 Determination of Single Preference Index

For each of the above cases, the sustainability index of a specific criterion q_n, having a weight factor w_n is given by

$$q_n(q_n; wn) = w_n q_n$$

3.12 Determination of Sustainability Indices of Specific Criteria

The sustainability index of a specific criteria Qn, having n number of q_n criterion each with weight factor w_n is given by

$$Q = \sum_{n=1}^{n=k} w_n q_n$$

Where, n = 1 to 3 for social criteria, n = 1to 3 for economic criteria,

n = 1 to 2 for environmental criteria and n = 1 to 2 for technical criteria.

3.13 Determination of the General Sustainability Index

The general sustainability index Q is given by the sum of all criterion (Parameter)q_n, multiplied by their relative weight w_n. Thus

$$Q = \sum_{n=1}^{n=k} w_n q_n$$

In this thesis, n=1,...,10.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Equal Weighting Information about Parameters

This case examines the data for sustainable development. This is done by placing equal priority on all Parameters. The case eliminates uncertainties and gives precise results. When equal weighting information is input, the weight coefficient estimation of all Parameters is equal to 0.1. Numeric estimates of the general sustainability index is shown in Table 4.1

Table 4.1: Sustainability calculation for Equal weightage

Project	***Numeric estimate to calculate Sustainability Index***		***Sustainability Index***
	Minimum	***Maximum***	
Tehri	0.031	0.088	0.666
Koteshwar	0.037	0.063	0.512
Uri-I	0.020	0.064	0.495
Lower Jhelum	0.023	0.064	0.411
Baglihar	0.025	0.081	0.548
Salal	0.034	0.069	0.510
Dul Hasti	0.028	0.068	0.505
Sewa	0.028	0.070	0.444

This case evaluates the impact of resettlement on the general sustainability index. Since the sustainability index of Uri-I, Lower Jhelum, and Sewa are less than 0.5, it means that resettlement package delivered so far is not a strong Parameter of sustainability. The sustainability index range precisely from 0.41 to 0.67 as shown in table. This case shows that if equal priority is given to all Parameters, the sustainability index of the seasons is in the decreasing order of

Tehri >Baglihar>Koteshwar>Salal>Dul Hasti> Uri-I >Sewa>Lower Jhelum

This is not absolutely the case at the planning and implementation stages of the dam. However, at the operation phase as in this dissertation, a lot of factors come into play which affect the prioritization of Parameters. For example, an environmental damage cannot be repaired, neither is the cost of restoration easy to be attained. This case may be considered as set target for sustainable development. This is because weighting is inherent to systems and when not explicitly defined all criteria are given equal weight. The next cases explore the situations of giving preference to single criteria over others (social, economic, environmental and technical), which is objective one of this dissertation.

4.2 Situational Assessment: Preference to Social Parameters: Resettlement (RS)

When resettlement Parameter (RS) is given higher priority than area (AR) and livelihood (LI) Parameters with all other remaining Parameters having equal weight the weight coefficient estimate for resettlement is 0.4936 and that of area and livelihood Parameters is 0.1117. All other Parameters have a weight coefficient estimation of 0.0404. Numeric estimates of the general sustainability index is shown in Table 4.2

Table 4.2: Sustainability calculation for Social Parameters (RS)

Project	***Numeric estimate to calculate Sustainability Index***		***Sustainability Index***
	Minimum	***Maximum***	
Tehri	0.023	0.302	0.662
Koteshwar	0.017	0.234	0.510
Uri-I	0.008	0.196	0.462
Lower Jhelum	0.011	0.247	0.443
Baglihar	0.010	0.260	0.566
Salal	0.014	0.301	0.570
Dul Hasti	0.011	0.235	0.481
Sewa	0.013	0.208	0.419

This case evaluates the impact of resettlement on the general sustainability index. Since the sustainability index of Uri-I, Lower Jhelum, Dul Hasti and Sewa are less than 0.5, it means that resettlement package delivered so far is not a strong Parameter of sustainability. Accordingly, the rank as per the Resettlement Parameter is as follows:

Tehri >Salal>Baglihar>Koteshwar>Dul Hasti> Uri-I> Lower Jhelum >Sewa

4.3 Situational Assessment: Preference to Social Parameters: Reservoir Area and Livelihood Parameter (AR and LI)

When priority is given to area per kWh Parameter (AR) and livelihood Parameter (LI) over, resettlement Parameter (RS) with all other Parameters being equal, the weight coefficient estimation for AR and LI is 0.3054 and that of RS is 0.1076. All other Parameters have weight coefficient values of 0.0402. Numeric estimates of the general sustainability index is shown in Table 4.3

Table 4.3: Sustainability calculation for Social Parameters (AR and LI)

Project	***Numeric estimate to calculate Sustainability Index***		***Sustainability Index***
	Minimum	***Maximum***	
Tehri	0.023	0.227	0.704
Koteshwar	0.017	0.167	0.553
Uri-I	0.008	0.186	0.551
Lower Jhelum	0.011	0.142	0.385
Baglihar	0.010	0.217	0.626
Salal	0.013	0.213	0.574
Dul Hasti	0.011	0.172	0.482
Sewa	0.013	0.118	0.386

The result shown used only the reservoir coverage area at the time of the assessment to estimate the value of land used in energy generation.

Accordingly, the rank as per the Area and Livelihood Parameter is as follows

Tehri >Baglihar>Salal>Koteshwar>Uri-I>Dul Hasti>Sewa> Lower Jhelum

4.4 Situational Assessment: Preference to Economic Parameters (CNG and DJ)

When preference is given to Contribution to National Grid (CNG) and Direct Job (DJ) than Impact on Tourism (IT) and all other Parameters have equal priority, the weight coefficient estimation of CNG and DJ is 0.3054. Weight coefficient estimation of IT is 0.1076. All other Parameters have weight coefficient estimations of 0.0402. Numeric estimates of the general sustainability index is shown in Table 4.4

Table 4.4: Sustainability calculation for Economic Parameters (CNG and DJ)

Project	***Numeric estimate to calculate Sustainability Index***		***Sustainability Index***
	Minimum	***Maximum***	
Tehri	0.023	0.217	0.702
Koteshwar	0.017	0.164	0.517
Uri-I	0.015	0.158	0.476
Lower Jhelum	0.009	0.125	0.373
Baglihar	0.021	0.182	0.514
Salal	0.017	0.138	0.443
Dul Hasti	0.015	0.168	0.486
Sewa	0.011	0.213	0.509

Accordingly, the rank as per the Area and Livelihood Parameter is as follows

Tehri>Koteshwar>Baglihar>Sewa>Dul Hasti>Uri-I>Salal> Lower Jhelum

4.5 Situational Assessment: Preference to Economic Parameter (IT)

When preference is given to Impact on Tourism (IT) than Contribution to National Grid (CNG) and Direct Job (DJ) and all other Parameter have equal priority, the weight coefficient estimation of IT is 0.4936. Weight coefficient estimation of CNG and DJ is 0.1117. All other Parameters have weight coefficient estimations of 0.0404. Numeric estimates of the general sustainability index is shown in Table 4.5

Table 4.5: Sustainability calculation for Economic Parameters (IT)

Project	***Numeric estimate to calculate Sustainability Index***		***Sustainability Index***
	Minimum	***Maximum***	
Tehri	0.023	0.388	0.737
Koteshwar	0.017	0.253	0.517
Uri-I	0.016	0.102	0.358
Lower Jhelum	0.009	0.136	0.342

Baglihar	0.021	0.124	0.416
Salal	0.017	0.191	0.438
Dul Hasti	0.016	0.140	0.397
Sewa	0.011	0.160	0.410

Accordingly the rank as per the Economic Parameter is as follows

Tehri >Koteshwar>Salal>Baglihar>Sewa>Dul Hasti>Uri-I> Lower Jhelum

4.6 Situational Assessment: Preference to Environmental Parameters (GWP)

When preference is given to Global Warming Potential (GWP) Parameter relative to Biodiversity Index (BI) with all other Parameters having equal weight, the weight coefficient estimation of GWP and BI is 0.5625 and 0.1708 respectively. All other Parameters have weight coefficient estimations of 0.0333. Numeric estimates of the general sustainability index is shown in Table 4.6

Table 4.6: Sustainability calculation for Environmental Parameters (GWP)

Project	***Numeric estimate to calculate Sustainability Index***		***Sustainability Index***
	Minimum	***Maximum***	
Tehri	0.019	0.340	0.641
Koteshwar	0.014	0.267	0.492
Uri-I	0.006	0.232	0.448
Lower Jhelum	0.007	0.360	0.528
Baglihar	0.008	0.321	0.574
Salal	0.011	0.248	0.470
Dul Hasti	0.009	0.386	0.588
Sewa	0.009	0.297	0.483

Accordingly, the rank as per the Environmental is as follows

Tehri>Dul Hasti>Baglihar> Lower Jhelum >Koteshwar>Sewa>Salal>Uri-I

4.7 Situational Assessment: Preference to Environmental Parameter (BI)

When preference is given to Biodiversity Index (BI) Parameter relative to Global Warming Potential (GWP) Parameter, with all other Parameters having equal weight, the weight coefficient estimation of BI and GWP is 0.5625 and 0.1708 respectively. All other Parameters have weight coefficient estimations of 0.0333. Numeric estimates of the general sustainability index is shown in Table 4.7

Table 4.7: Sustainability calculation for Environmental Parameters (BI)

Project	***Numeric estimate to calculate Sustainability Index***		***Sustainability Index***
	Minimum	***Maximum***	
Tehri	0.019	0.366	0.659
Koteshwar	0.014	0.273	0.496
Uri-I	0.006	0.292	0.490
Lower Jhelum	0.007	0.215	0.427
Baglihar	0.008	0.340	0.588
Salal	0.011	0.270	0.485
Dul Hasti	0.009	0.257	0.498
Sewa	0.009	0.227	0.434

Accordingly, the rank as per the Environmental Parameter is as follows

Tehri >Baglihar>Dul Hasti>Koteshwar> Uri-I>Salal>Sewa> Lower Jhelum

4.8 Situational Assessment: Preference to Technical Parameter (GP)

When generation potential (GP) is given higher priority relative to the equivalent availability factor (EAF) with all other Parameters having equal weights, the weight coefficient estimations of GP and EAF is 0.5265 and 0.1708 respectively. All other Parameters have weight coefficient estimates of 0.0333. Numeric estimates of the general sustainability index is shown in Table 4.8

Table 4.8: Sustainability calculation for Technical Parameters (GP)

Project	***Numeric estimate to calculate Sustainability Index***		***Sustainability Index***
	Minimum	***Maximum***	
Tehri	0.020	0.495	0.777
Koteshwar	0.015	0.250	0.496
Uri-I	0.006	0.268	0.473
Lower Jhelum	0.007	0.217	0.411
Baglihar	0.008	0.459	0.695
Salal	0.011	0.335	0.561
Dul Hasti	0.009	0.245	0.464
Sewa	0.009	0.221	0.428

Accordingly, the rank as per the Technical Parameter is as follows

Tehri >Baglihar>Salal>Koteshwar> Uri-I >Dul Hasti>Sewa> Lower Jhelum

4.9 Situational Assessment: Preference to Technical Parameter (EAF)

When equivalent availability factor (EAF) is given higher priority relative to the generation potential (GP) with all other Parameters having equal weights, the weight coefficient estimations of EAF and GP is 0.5265 and 0.1708 respectively. All other Parameters have weight coefficient estimates of 0.0333. Numeric estimates of the general sustainability index is shown in Table 4.9

Table 4.9: Sustainability calculation for Technical Parameters (EAF)

Project	***Numeric estimate to calculate Sustainability Index***		***Sustainability Index***
	Minimum	***Maximum***	
Tehri	0.020	0.329	0.662
Koteshwar	0.015	0.354	0.569
Uri-I	0.006	0.255	0.464
Lower Jhelum	0.007	0.284	0.457
Baglihar	0.008	0.301	0.585
Salal	0.011	0.311	0.545

Dul Hasti	0.009	0.294	0.498
Sewa	0.009	0.298	0.482

Accordingly, the rank as per the Technical Parameter is as follows

Tehri >Baglihar>Koteshwar>Salal>Dul Hasti>Sewa>Uri-I >Lower Jhelum

4.10 SUMMARY

Objective 1 is summarized using the normalized mean values to show the characteristic weight of Parameters. From figure it can be seen that weight of Parameters is in a decreasing order of:

BI> GWP > EAF > RS > LI > AR > IT > CNG > DJ > GP

In terms of criteria it is in the order of:

Environmental > Social > Technical > Economic

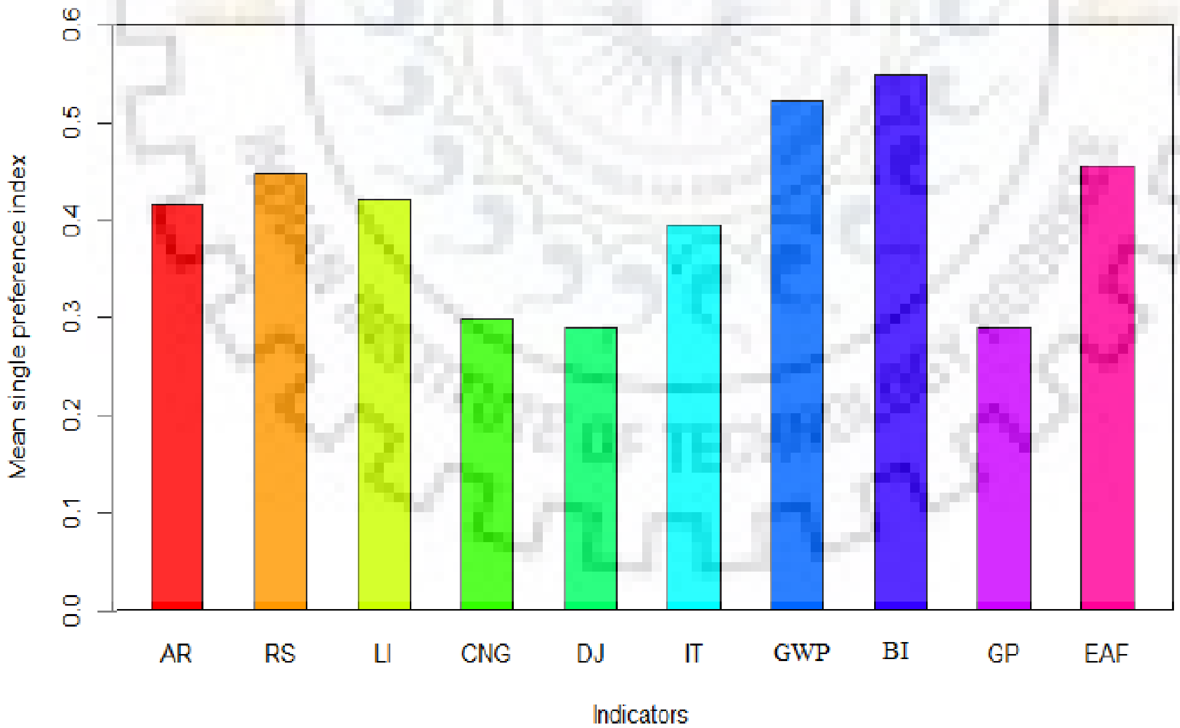


Fig 4.1: Single preference index estimation for Parameters

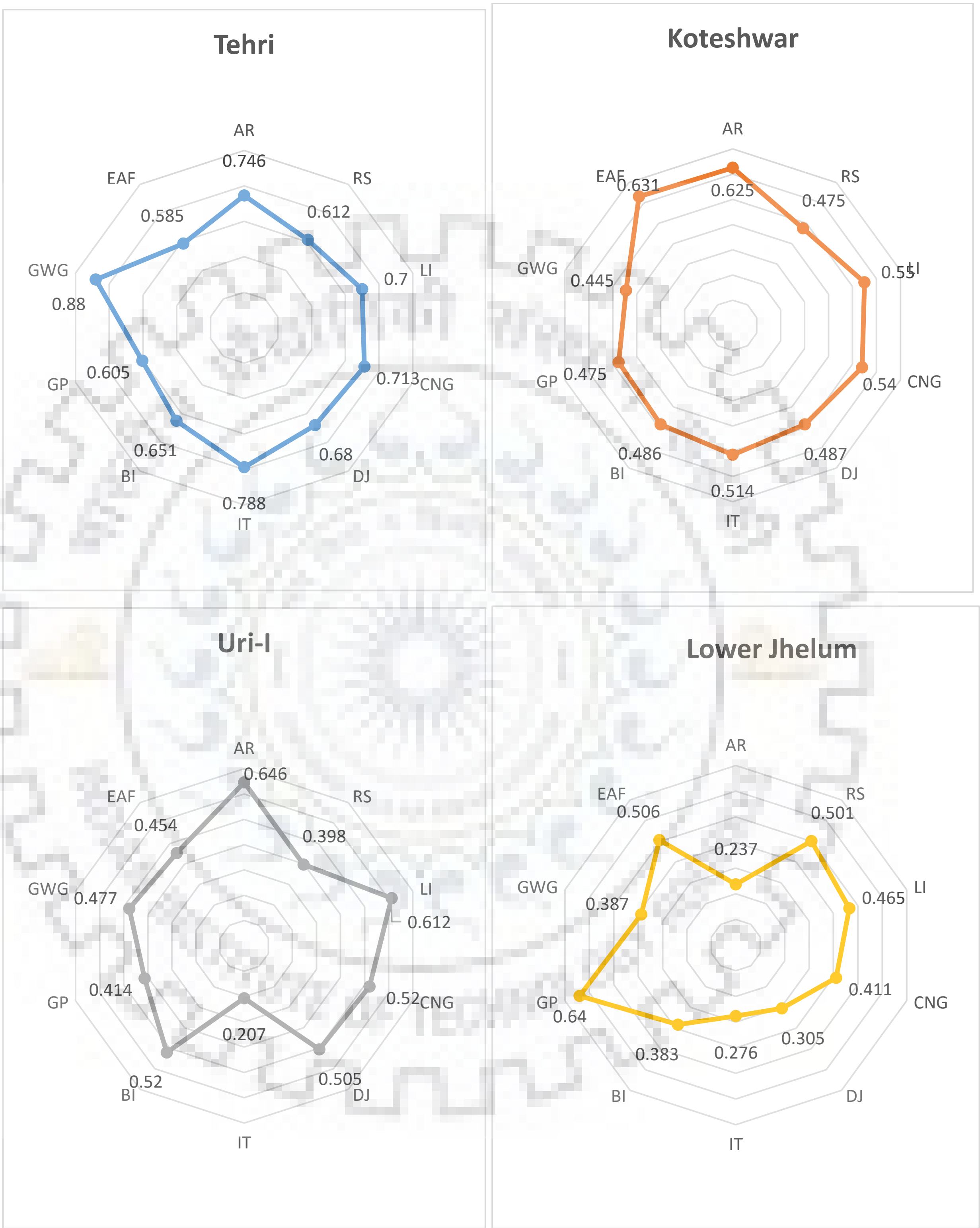
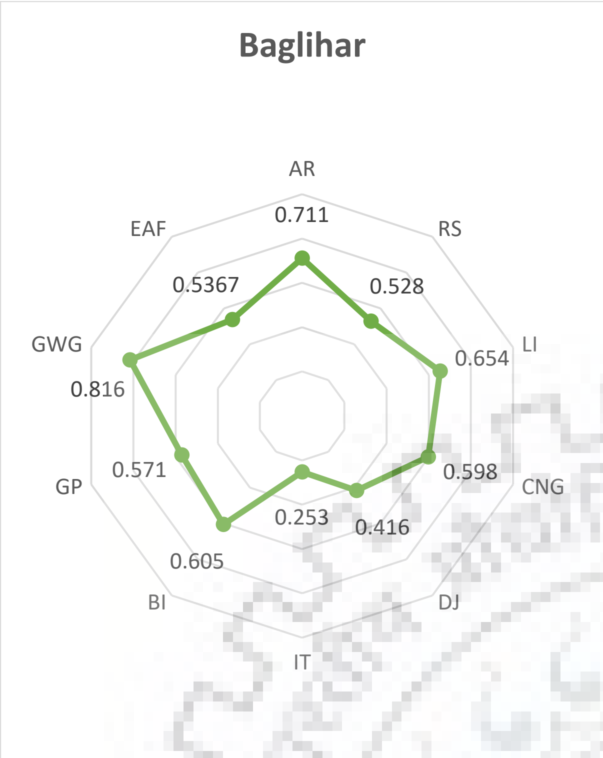
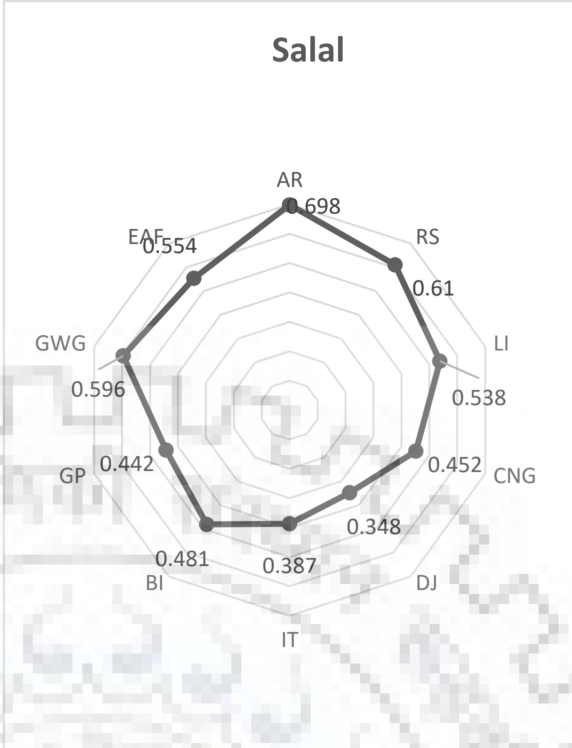
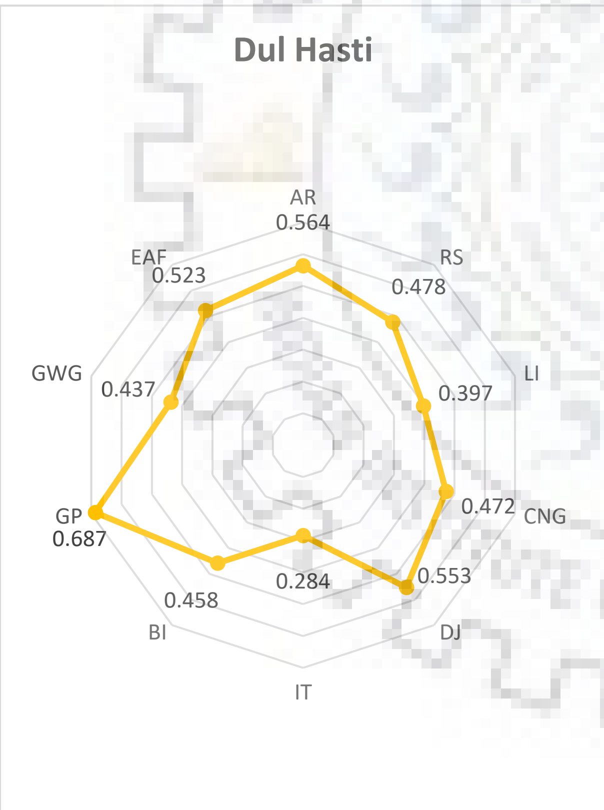
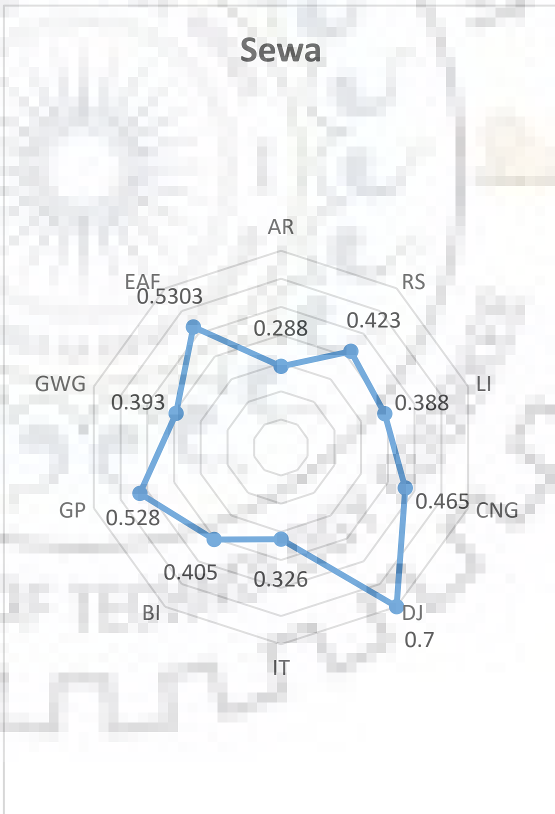


Fig 4.2: General sustainability index values when each Parameter is prioritized


Baglihar
AR
0.711
RS
0.528
LI
0.654
CNG
0.598
DJ
0.416
IT
0.253
BI
0.605
GP
0.571
GWG
0.816
EAF
0.5367


Salal
AR
0.698
RS
0.61
LI
0.538
CNG
0.452
DJ
0.348
IT
0.387
BI
0.481
GP
0.442
GWG
0.596
EAF
0.554


Dul Hasti
AR
0.564
RS
0.478
LI
0.397
CNG
0.472
DJ
0.553
IT
0.284
BI
0.458
GP
0.687
GWG
0.437
EAF
0.523


Sewa
AR
0.288
RS
0.423
LI
0.388
CNG
0.465
DJ
0.7
IT
0.326
BI
0.405
GP
0.528
GWG
0.393
EAF
0.5303

4.11 Comparative Assessment: Planning Stage vs. Operational Stage

Analysis of the events that took place before and after Hydropower development is the basis for this comparative assessment. After analysis of DPRs, EIA and EMP reports of the Hydropower projects, national issues and international issues of sustainable Hydropower development, Parameters were ranked according to how they were prioritized during the planning and implementation stages. Contribution to National Grid (CNG) was found as Parameter most prioritized and Global Warming Potential was found to be least prioritized.

The detailed order of ranking used to estimate weight coefficients for the comparative assessment is used by the equation.

w(GP) = w(CNG) = w(DJ) > w(EAF) = w(RS) > w(LI) > w(IT) = w(BI) = w(GWP) = w(AR).

Weight coefficient, normalized Parameter estimates and general sustainability index
for each parameter and criteria are shown below in Table 4.10, Table 4.11 and Table 4.12, respectively.

Table 4.10: Weight coefficient estimation for Parameters

	Social			Economic			Environment		Technical	
Parameters	AR	RS	LI	CNG	DJ	IT	BI	GWP	GP	EAF
Weightage	0.0063	0.125	0.0813	0.1937	0.1937	0.0375	0.0375	0.0063	0.1937	0.125

Table 4.11: Normalized Parameters value

	SOCIAL			ECONOMIC			ENVIRONMENTAL		TECHNICAL	
Parameters / Projects	AR	RS	LI	CNG	DJ	IT	BI	GWP	GP	EAF
Tehri	0.746	0.612	0.7	0.713	0.68	0.788	0.651	0.605	0.88	0.585
Koteshwar	0.625	0.475	0.55	0.54	0.487	0.514	0.486	0.475	0.445	0.631
Uri-I	0.646	0.398	0.612	0.52	0.505	0.207	0.52	0.414	0.477	0.454
Lower Jhelum	0.237	0.501	0.465	0.411	0.305	0.276	0.383	0.64	0.387	0.506
Baglihar	0.711	0.528	0.654	0.598	0.416	0.253	0.605	0.571	0.816	0.5367
Salal	0.698	0.61	0.538	0.452	0.348	0.387	0.481	0.442	0.596	0.554
Dul Hasti	0.564	0.478	0.397	0.472	0.553	0.284	0.458	0.687	0.437	0.523
Sewa	0.288	0.423	0.388	0.465	0.7	0.326	0.405	0.528	0.393	0.5303

Table 4.12: Sustainability Indices for Parameters

	SOCIAL			ECONOMIC			ENVIRONMENT		TECHNICAL	
Parameters / Projects	AR	RS	LI	CNG	DJ	IT	BI	GWP	GP	EAF
Tehri	0.0047	0.0765	0.0569	0.1381	0.1317	0.029	0.024	0.0038	0.1705	0.0731
Koteshwar	0.0039	0.0594	0.0447	0.1046	0.0943	0.0192	0.0182	0.0029	0.0862	0.0788
Uri-I	0.0041	0.0498	0.0497	0.1007	0.0978	0.0078	0.0195	0.0026	0.0924	0.0576
Lower Jhelum	0.0015	0.0626	0.0378	0.0796	0.0591	0.0103	0.0144	0.0040	0.0750	0.0633
Baglihar	0.0044	0.066	0.0532	0.1158	0.0806	0.0095	0.0227	0.0036	0.1581	0.0671
Salal	0.698	0.0763	0.0437	0.0876	0.0674	0.0145	0.0180	0.0028	0.1155	0.0693
Dul Hasti	0.0036	0.0597	0.0323	0.0914	0.1071	0.0106	0.0172	0.0043	0.0847	0.0654
Sewa	0.0018	0.0529	0.0315	0.0901	0.1356	0.0122	0.0152	0.0033	0.0761	0.0663

The percentage contribution of each Parameter and criteria to the general sustainability index are determined and used as basis for comparative assessment in this work after analysis of DPRs, EIA and EMP reports of the Hydropower projects as shown in Table 4.13 and Table 4.14

Table 4.13: Percentage (%) contribution of Parameters to general sustainability

	SOCIAL			ECONOMIC			ENVIRONMENT		TECHNICAL	
Parameters / Projects	AR	RS	LI	CNG	DJ	IT	BI	GWP	GP	EAF
Tehri	0.66	10.79	8.02	19.47	18.57	4.16	3.44	0.54	24.03	10.31
Koteshwar	0.77	11.58	8.72	20.41	18.41	3.76	3.56	0.58	16.82	15.39
Uri-I	0.85	10.34	10.3	20.94	20.33	1.61	4.053	0.54	19.20	11.8
Lower Jhelum	0.37	15.36	9.27	19.53	14.49	2.54	3.52	0.989	18.39	15.52

Baglihar	0.77	11.36	9.15	19.94	13.87	1.63	3.91	0.62	27.20	11.55
Salal	0.88	15.27	8.76	17.53	13.5	2.91	3.61	0.56	23.11	13.87
Dul Hasti	0.75	12.54	6.78	19.2	22.49	2.24	3.6	0.91	17.77	13.73
Sewa	0.37	10.90	6.50	18.57	27.96	2.52	3.13	0.68	15.7	13.67

Table4.14:Percentage (%) contribution by criteria to general sustainability index

Parameters / Projects	SOCIAL	ECONOMIC	ENVIRONMENTAL	TECHNICAL
Tehri	19.47	42.20	3.97	34.34
Koteshwar	21.07	42.57	4.4	32.20
Uri-I	21.52	42.88	4.59	31.00
Lower Jhelum	25.00	36.56	4.51	33.90
Baglihar	21.28	35.43	4.52	38.75
Salal	24.90	33.93	4.16	36.98
Dul Hasti	20.06	43.92	4.51	31.49
Sewa	17.78	49.04	3.81	29.36
Average	21.39	40.82	4.28	33.50

It can be seen from table that in the planning and implementation of the Hydropower project priority was given to technical (33.5%) and economic (40.82%). Thus, about 75 % priority was given to techno-economic sustainability analysis. Priority to social and environmental Parameters are 21.39 % and 4.28 % respectively as shown in Fig 4.3

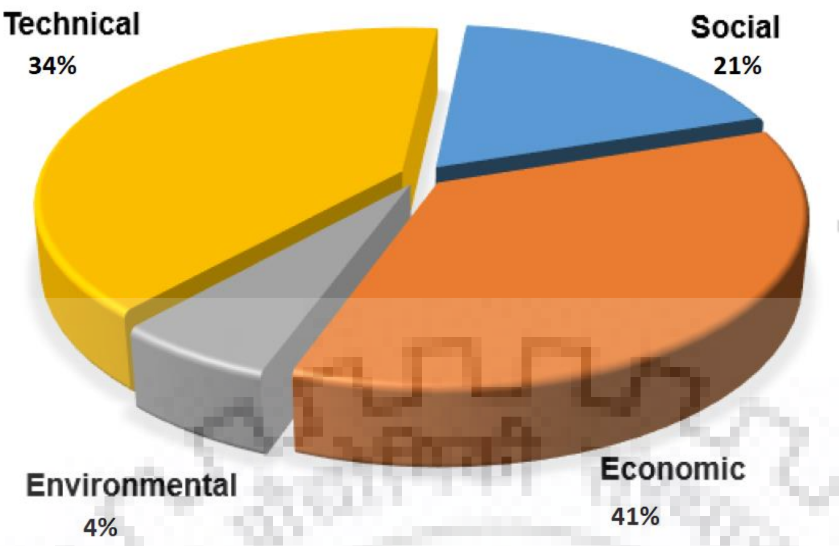


Figure 4.3: Percentage contribution by criteria to general sustainability index

However, this does not imply that technical and economic aspects of the Hydropower projects have been perfectly addressed. However, this is usually the case in the planning and implementation of dam projects. Even though environmental and social impact assessments are conducted, they are only treated as part of the process per the requirement to meet national and international standards. The long-term impact of dams on the local affected population is completely neglected during the planning and implementation stages. In some cases, national and international environmentalists and human right activists opposed the dam project, in view of potential negative environmental, health and social impacts of the project on the local population. They argued that the perceived positive benefits were overstated, and that the potential negative effects (such as displacement of communities, dispossession of land, disruption of traditional values and impoverishment of the dam affected people) were deliberately underestimated by the dam advocates to make the dam project more attractive to sponsors and stakeholders. Thus, the long term social and environmental impacts have not been considered in detail at the planning and implementation stages of the dams.

4.12 General Sustainability Index of the Hydropower Projects

The general sustainability index represents the quality of the Hydropower projects. The sustainability index formed in this case is based on the true weight of the Parameters. That is, Parameters are ranked according to a hierarchy of equivalent and decreasing order of weight. As the general sustainability index is a linear aggregation function, weights are deduced from the normalized mean values of the Parameters.

The detailed order of ranking used to estimate weight coefficients for this case is shown is

w(GWP) = w(GP) = w(IT) > w(EAF) = w(RS) = w(LI) = w(AR) = w(CNG) = w(GP) = w(AR)

The weighting coefficient and the general sustainability index is shown in the Table 4.15 and Table 4.16 respectively.

Table 4.15: Numeric Weight coefficient

	Social			Economic			Environment		Technical	
Parameters	AR	RS	LI	CNG	DJ	IT	BI	GWP	GP	EAF
Weightage	0.1	0.05	0.05	0.05	0.05	0.1	0.15	0.15	0.15	0.15

Table 4.16: Numeric estimate to calculate Sustainability Index

Project	***Numeric estimate to calculate Sustainability Index***		***Sustainability Index***
	Minimum	***Maximum***	
Tehri	0.031	0.132	0.697
Koteshwar	0.024	0.095	0.522
Uri-I	0.019	0.078	0.467
Lower Jhelum	0.015	0.096	0.423
Baglihar	0.021	0.122	0.586
Salal	0.017	0.089	0.517
Dul Hasti	0.020	0.103	0.495
Sewa	0.019	0.080	0.439

From table, it can be seen that the sustainability index of the Hydropower projects which is a measure of its quality, lies approximately within the range 0.4to 0.7.

Accordingly, the rank as per the overall General Sustainability Parameter is as follows

Tehri >Baglihar>Koteshwar>Salal>Dul Hasti> Uri-I >Sewa>Lower Jhelum

4.13 Qualitative Parametric Ranking

As per the criteria for the qualitative assessment, hydrological regime, river morphology and water quality's assessment is shown in Table 4.17, Table 4.18, Table 4.19 respectively.

Table 4.17: Qualitative Assessment of Downstream Hydrological Regime

Name of Projects	Ecological Flow	Quality Score
Tehri	HPP with storage; monitoring	High
Koteshwar	Run of River; with storage	High
Uri-I	Run of River; without storage	Medium
Lower Jhelum	Run of River; with storage	Medium
Baglihar	Run of River; with storage	High
Salal	Run of River; without storage	Medium
Dul Hasti	Run of River; without storage	High
Sewa	HPP with storage; monitoring	Medium

Table 4.18: Qualitative Assessment of River Morphology

Name	Influence of Hydro morphology	Quality Scoring	Sediment Transport	Quality Scoring
Tehri	Artificial measure	Medium	Significant Impact but acceptable	Medium
Koteshwar	Artificial measure	Medium	Significant Impact but acceptable	Medium
Uri-I	Natural measure	High	Significant Impact but acceptable	Medium
Lower Jhelum	Natural measure	High	High Impact	Low
Baglihar	Artificial measure	Medium	High Impact	Low
Salal	Artificial measure	Medium	High Impact	Low

Dul Hasti	Artificial measure	Medium	Significant Impact but acceptable	Medium
Sewa	Natural measure	High	High Impact	Low

Table 4.19: Qualitative Assessment of Water Quality

Name	Class of Water Quality	Quality Scoring
Tehri	Class D	Medium
Koteshwar	Class D	Medium
Uri-I	Class E	Low
Lower Jhelum	Class D	Medium
Baglihar	Class C	Medium
Salal	Class B	Medium
Dul Hasti	Class D	Medium
Sewa	Class E	Low

4.14 Scenario based analysis of Hydropower Projects

4.14.1Tehri

Strength: The highest dam in India is the jewel for the Indian Engineers, which proved to be the frontrunner in every aspect among the sustainability indices. Tehri has significantly improved the Livelihood index (scoring 0.7 out of 1) for the displaced and affected people, providing them with incentives and establishing infrastructure for advance education, healthcare and for societal advancement. Employment generation (scoring 0.7 out of 1) has been the major achievement, employing more than 2000 work force directly or indirectly, giving the Economic situation a major upgrade than before. Tehri itself is a big contributor to DISCOM, contributing 15% to Uttarakhand’s electricity alone which indicates very high Biodiversity Index (scoring 0.66 out of 1), Generating Potential (scoring 0.77out of 1) and efficient plant’s equivalent availability factor (scoring 0.68 out of 1). THDC has addressed the RAP with very efficient policy, scoring 0.65 out of 1, indicates the positive affect the project had in displaced and local peoples. The performance in tourism is decent compare to the other Hydropower projects (scoring 0.73 out of 1), which includes famous Tehri Lake Festival which attracts high number of water sports enthusiasts and tourists, but this festival is conducted once in a year.

Weakness: THDC was successful in implementing RAP policy, but the resettlement and submergent of the cultural heritage, still affects the displaced people as the next generation won't recognise the culture they inherit. This cultural submergent was followed by submergence of huge biomass having areas of 1.78 hectares forest, which makes this site as a Global Warming potential site. The houses developed within the RAP scheme, has developed collateral losses resulting in geological resettlement of the houses. Moreover, the site has huge potential for Tourism purpose which is only opened for 3 days in a year.

Mitigation: Tourism has a huge potential and it should be promoted to become an attractive mode of income. Collateral losses should be taken care by installing water resistant material. Lastly, cultural programs should be promoted to make the new generation aware of the submerged culture

4.14.2 Koteshwar

Strength: Along with Tehri, Koteshwar has also significantly improved the Livelihood index (scoring 0.55 out 1) for the displaced and affected people, providing them better job opportunity (scoring 0.52 out of 1) with incentives and establishing infrastructure for advance education, healthcare and for societal advancement.: The resettlement and submergent of the cultural heritage loss is not a major factor compared to Tehri's case, though Resettlement (scoring 0.51 out of 1) at the tailrace of Tehri has occurred and completely secluded the area from the present main city. Employment generation (scoring 0.52 out of 1) has been the major achievement, employing more than 2000 work force directly or indirectly, giving the Economic situation a major upgrade than before. Koteshwar itself is a big contributor in electricity by contributing 7% to Uttarakhand's electricity alone and to many parts of India which indicates highly efficient plant's equivalent availability factor (scoring 0.58 out of 1). Tourism is also a contributing factor (scoring 0.51 out of 1), it shares the equal contribution for Tehri Lake festival, but the secluded nature of Koteshwar from New Teri city, troubles the tourist for easy connectivity

Weakness: The cultural submergent was followed by submergence of huge biomass in form of trees, which makes this site as a Global Warming potential site (scoring 0.49 out of 1) which also indicates slightly low Biodiversity Index (scoring 0.49 out of 1). Due to the fluctuating demand of electricity, generating potential of Koteshwar is lightly lacking to meet the sustainability criteria (scoring 0.496). The houses developed within the RAP scheme, has developed collateral losses resulting in geological resettlement of the houses.

Mitigation: Tourism has a huge potential and it should be promoted to become an attractive mode of income. Collateral losses should be taken care by installing water resistant material. Lastly, cultural programs should be promoted to make the new generation aware.To meet the generation potential, plant should setup the minimum electricity requirement with the Government of Uttarakhand

4.14.3 Lower Jhelum

Strength: Lower Jhelum is a very old project which was commissioned in the year 1978-79 has only performed well in Environmental factor , giving us a good alternative against Fossil fuel based plants (scoring 0.53 out of 1), and after standing against the tides of time Lower Jhelum is still capable to produce sustainable Biodiversity Index (scoring 0.49 out to 1) to generate electricity and gives its contribution to the state.

Weakness: It has underperformed in most of the Parameters, then RAP wasn't as effective as today's policy. Resettlement Parameter (scoring 0.44 to 1) shows poor displacement pattern of people and unsatisfied incentives offered. Being located at the isolated area, this has become a major reason for the less employment generation (scoring 0.37 out of 1) which also leads to low standards of livelihood index comparatively (scoring 0.39 out of 1). The secluded location of project has also impacted the tourism index (scoring 0.34 out of 1) to most extent. Though the project produce sustainable Biodiversity Index, but the lower of Generation potential (scoring 0.41 out of 1) and lower Effective Availability Factor (scoring 0.45 out of 1) of plant may affect the future production of the plant.

Mitigation : Looking to the age, the project need rejuvenated measures and replacement of old parts in order to increase the sustainability of the project for the long term or constructing a new unit will boost the various sustainability

4.14.4 Baglihar

Strength: The highest dam in J&K, which proved to be the frontrunner in every aspect among the sustainability indices. Baglihar has been a major contributor for improving the Livelihood index (scoring 0.63 out of 1) for the displaced and affected local people, providing them with incentives and establishing infrastructure for advance education, healthcare and for societal advancement around the project. Employment generation (scoring 0.51 out of 1) has been the achievement, due to the National importance of this project due to Indus Water Treaty, has increased the significance of the project, employing more than 1000 work force directly or indirectly, giving the Economic situation a major upgrade than before. Baglihar itself is a big contributor to Electricity generation (scoring 0.5 out of 1), contributing 10% to J&K's electricity alone along with Punjab, Haryana etc. which indicates very high Biodiversity Index (scoring 0.58 out of 1) , high Generation Potential (scoring 0.695 out of 1) and efficient plant's equivalent availability factor (scoring 0.585 out of 1). The project has high amount of Fossil substitution effect (scoring 0.574 out of 1). Regarding the Social aspects, JKSPDC has addressed the RAP with very efficient policy, scoring 0.56 out of 1, indicates the positive affect the project had in displaced and local peoples.

Weakness: The resettlement and submergent of the cultural heritage, still affects the displaced people after the project got National importance. It is always under scrutiny as it has become controversial because of the discharge water to Pakistan under Indus water treaty. This has affected the Tourism (scoring 0.416 out of 1) near the project due to National security reasons. Moreover, the site has huge potential for Tourism purpose which lacks right now due the strategic importance of the dam. This cultural submergent was followed by submergence of huge biomass in form of trees, which makes this site as a Global Warming potential site

Mitigation: This is a new project with very less weakness, the only area for improvement is Tourism which has a huge potential and it should be promoted for the locals to become an attractive model of income.

4.14.5 Uri-I

Strength: Located near the LOC, Uri is one of the most isolated hydropower projects in India. Undoubtedly, it has given a major boost to the Livelihood index (scoring 0.55 out of 1) of the local people providing them by establishing infrastructure for betterment of the society around the project. It has produced a decent Job generation index (scoring 0.49 out of 1), considering the rough life around the terrain. This project is under scrutiny because of the Indus water treaty. As it is a run of river project, this help the Environmental indictors to have a sustainable future, fossil substitution effect and Biodiversity Index is close to have a sustainable value of 0.5.

Weakness: Due to the remote location of project, tourism (scoring 0.36 out of 1) around the project does not form a sustainable nature. Due to the restricted regulation due to Indus water treaty, generation potential (scoring 0.473 out of 1) has not fulfilled the potential which also affects and restrict plant's availability factor (scoring 0.46 out of 1) to very extent. Resettlement (scoring 0.46 out of 1) was not a priority as there were less people affected in the area

Mitigation: Due to the restrictions imposed by the Indus water treaty and remoteness of the project, it is very hard to suggest mitigation

4.14.6 Salal

Strength : It is the country's first dam built on a rock pedestal, very well planned for the project affected peoples as resettlement policies were very well implemented (scoring 0.57 out of 1), which has increased the living standard index (scoring 0.57 out of 1) of the peoples around providing them proper necessities . The plant is known for high performance, having great Generation potential (scoring 0.561 out of 1) and effective availability factor (0.545 out of 1)

Weakness: The project has 33km lake, which could attract high number of tourists, becoming a potential spot for water sports, still lacks in Tourism (scoring 0.43 out of 1)
This has also affected the Job generation (scoring 0.44 out of 1) due to or because of the project. The reservoir pondage has affected the Environmental Parameters (scoring 0.47 out of 1). The project also has slightly less Biodiversity Index (scoring 0.48 out of 1), compared to high scoring generation potential and effective availability indexes.

Mitigation: The project has large potential for tourism and investment on this could lead to more employment and revenue generation

4.14.7 Dul Hasti

Strength: Dul Hasti is a 390 MW hydropower power plant in Kishtwar district of Jammu and Kashmir and became operational in the year 2007, the project has sustainable Biodiversity Index (scoring 0.5 out of 1) and effective plant availability factor (scoring 0.5 out of 1). The major achievement the project has done is to maintain Environmental sustainability (scoring 0.588) and effectively came out as a substitute against fossil fuels. The project has also decently contributed in increasing the livelihood index (scoring 0.49 out of 1) of the people, yet not up to the mark compared to others, making positive impact including development of roads, hospital school, parks. It was also able to generate employment around (scoring 0.49 out of 1), but due to the past agitation by the locals for the job has resulted in unstainable way for socially inclined aspect, yet still it has lot of room for improvement.

Weakness : The project location has become the main reason for less tourism (scoring 0.39 out of 1), which was also accompanied by the People have been displaced from their original native place ,and this has resulted in socio – cultural problem as it has disturbed the network of social relationships, supporting ethos and way of life . Resettlement index (scoring 0.42 out of 1) has been taken as a negative aspect for Dul Hasti, due to past agitations.

Mitigation: Past events have hindered Dul Hasti's social sustainability index but if proper support by the authority and efforts to improve tourism can definitely increase the livelihood and eradicate the negative perception of the project.

4.14.8 Sewa

Strength: Situated at the Sewa River, a tributary of the Ravi River, is a newly commissioned project which has seen high Biodiversity Index (scoring 0.534 out of 1), high Generation potential (scoring 0.52 out of 1) and effective plant availability (0.5 out of 1), to contribute towards the electricity generation.

Weakness: Located at the border of J&K and Himachal, doesn't allow proper implementation of RAP policy (scoring 0.42 out of 1) as this included two state displacement and people had their rights to choose where to migrate. The livelihood index (scoring 0.4 out of 1) is been low due to the low number of residents near the project as it became ineffective to have a sustainable impact socially, This has also affected the tourism (scoring 0.41 out of 1) nearby the project which could contribute for the development of the economic and social Parameter.

Mitigation: The project has large potential for tourism and investment on this could lead to more employment and revenue generation

CHAPTER 5
COMPARITIVE ANALYSIS

5.1 EIA: Current practice

In India, there is an elaborate EIA process involving many steps such as Screening, Preliminary Assessment, Scoping, Main EIA including public hearing, appraisal etc.

Screening

Screening is the first and simplest process in project evaluation. Screening basically screen outs the projects that don't require EIA process. But there are several issues with this. Firstly, the projects are excepted from EIA on the basis of value of investments they would be involving.The logic behind this is to keep out the small projects from tangles of the co mplex process. But, no one has proved that environment impacts are caused only bby p rojects above certain value[37]. There are many smallscale industries that contribute pollution to a great extent, and sometimes at par with large projects. Secondly, even if a project may be eligible for exception from EIA process, they might involve some technical processes which might be harmful to the environment.

Preliminary Assessment

The screening would thus clear a project or hold it for further stages. If it is held for next stage, the developer will have to take Preliminary Assessment, which involves sufficient research, review of available data and expert advice in order to identify the key impacts on the project at local environment. This study will predict the extent of the impacts and would briefly evaluate the importance for decision makers.

Scoping

Scoping is yet another stage before the main EIA process begins. The EIA study team which was organized after preliminary assessment would get engaged into discussions with developers, investors, regulatory agencies, scientific institutions, local people etc. It would study and address all issues of importance and the concerns raised by various groups. Then the team would select the primary impacts for main EIA to focus and determines detailed and comprehensive Terms of Reference for the main Environment Impact Assessment (EIA). The key issue with current scoping method in India is that it generally ignores some important issues which might appear later as conflict[38].

Main EIA

Once scoping is over, the main EIA begins. Basically, EIA would try to answer the following questions:

1. What are the potential results of the project?
2. What are the potential changes and extent of those changes? To what extent such changes matter?
3. What can be done about these changes? How the decision makers have to be informed of these changes?

Thus, the EIA becomes a cycle of asking questions, and further questions until workable solutions are reached. During this process, the key impacts on environment such as changes in air quality, noise levels, impacts on wild life, impact on biodiversity, impact on local communities, changes in settlement patterns, changes in employment stats, changes in water consumption and availability etc. are formally identified.

The answers of the questions make the so called "prediction" in the EIA process. The prediction scientifically characterises the impacts quantitatively as well as qualitatively. We note here that prediction techniques involve some degree of uncertainty.

Prediction is followed by evaluation. This part evaluates the predicted adverse impacts and determines if they can be significantly mitigated. The compensation for damaged resources, affected persons etc. are also offered here. Overall, the mitigation costs are identified and quantified. This part also involves the Cost benefit analysis of the project in terms of mitigation costs.

Once mitigation measures and costs are identified, the next part is documentation, which is called EIA report. This report has executive summary of the project, a description of the proposed development, major environment issues, impacts on environment, prediction, mitigation measures and options etc. along with gaps and uncertainties in the information; and a summary of the EIA process for general public.

Public Hearing

The SPCB conducts a public hearing at the site or in its close proximity- district wise for ascertaining concerns of local affected persons. It includes obtaining responses in writing from other concerned persons by posting on website within 7 days of receiving application. in India. Once public hearing is over, the project developer will get a NOC from SPCB and submit application to the MoEFCC secretary to get environmental clearance. In MoEFCC, the application evaluated by an Impact Assessment Agency (IAA). IAA may consult the experts and again create a team to study the project. It has full right of entry and inspection of the sites or factory premises prior to, during or after the commencement of the project [39].

5.2 Drawbacks of EIA

- There is a lack of exhaustive ecological and socio-economic indicators for impact assessment
- Public comments are not taken into account at the early stage, which often leads to conflict at the later stage of project clearance
- There is always a lack of reliable data sources because the secondary data is als o not reliable. The credibility of the primary data collected by the data collectors is also sometimes doubtful because the data collectors do not pay resp ect to the indigenous knowledge of local people.
- The detail methodology used for the prediction and evaluation of the project isn ot mentioned in the report. Limited explanations are given both to quantitativeest imation of magnitude of impact and to the assumptions and judgments used in the evaluation of impacts.
- The limited coverage of scoping is confined mainly to direct impacts. Details regarding the effectiveness and implementation of mitigation measures are oftenn ot provided.
- Emergency preparedness plans are not discussed in sufficient details and the information not disseminated to the communities
- Many EIA report are based on single season data and are not adequate to determine whether environmental clearance should be granted.

5.3 Difference in Sustainability Index and Current practice

- EIA is basically carried out to achieve sustainable development, but Environmental Impact Assessment (EIA) is only a single component of the holistic sustainable development focusing on the environmental aspects, whereas Sustainable development is a holistic term which includes social and economic in addition to environment.
- EIA often doesn’t take public comments into account at the early stage, which often leads to conflict at the later stage of project clearance. Sustainability Index gives weightage to

public opinion in all the 3 stages i.e. Early, Implementation and Operational, leading to a socially sustainable project.

- Sustainability Index try to find the best possible relationship between the parameters with multi criteria analysis modelling to highlight each parameter's effect on others.
- Sustainability Index is recommended to carry out at all 3 stages of the project unlike EIA which is carried out at only implementation stage
- In EIA, limited explanations are given both to quantitative estimation of magnitude of impact. Whereas, Sustainability index focuses more on quantitative estimation and measuring the impact of one parameter over other

5.4 Improvement over EIA

- Calculation of Sustainability Index gives weightage to each Parameters by allowing weighting of respective strengths and weaknesses before implementation of the project.
- The sustainability index's value on 0.5 in the scale from 0 to 1, indicates the sustainable practise has been carried out, presenting a simplified comparative analysis of the situation, so that mitigations can be implemented as per the need for the parameters which fails to qualify as sustainable.
- Multi-criteria analysis approach allows consideration of social, economic, environmental and technical issues via the use of parameters.

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

6.1 Conclusions

The conclusion highlights the comparative analysis of parameters used for the assessment of the strength of each parameter based on normalized mean values of parameters. The conclusion of the study are as follows:

- BI has been found the strongest parameter of sustainability, where GP is the weakest parameter of sustainability. The strength(weight) of different parameters has been found in the decreasing order as BI > GWP > EAF > RS >LI > AR > IT > CNG > DJ > GP.
- Presently, environmental parameters form the strongest parameter of sustainability and whereas technical parameters forms the weakest parameter of sustainability. The strength (weight) of parameters by criteria is in a decreasing order as environmental > social > technical > economic.
- Analysis of criterion (parameters) for the Hydropower project development in the past shows that GP, CNG and DJ were given equivalent and highest priority whilst GWP and AR were given equivalent and least priority while planning stage. Prioritization of Parameters is in the decreasing order as GP > CNG > DJ > EAF > RS > LI > IT >BI > GWP > AR.
- The general sustainability index of the hydropower project representing the quality of the project on a scale of 0 to 1, the studied hydropower projects have an index ranging between 0.4 to 0.7.
- Sewa, Lower Jhelum, Uri-I, HPPs have indices below 0.5 (the mean sustainability index) and are therefore unsustainable. Whereas, Tehri, Baglihar, Koteshwar, Salal, Dul Hasti HPPs have indices above 0.5 but less than 0.7, which indicates that Sustainable practices are carried out at their stations.
- For hydrological regime, hydropower projects of Tehri, Koteshwar, Baglihar and Dul Hasti have high quality of sustainability, whereas hydropower projects of Uri-I, Lower Jhelum, Salal and Sewa have medium quality of sustainability
- For river morphology, hydropower projects of Uri-I, Sewa and Lower Jhelum has High Quality sustainability, whereas hydropower projects of Tehri, Koteshwar, Baglihar, Salal and Dul Hasti have medium quality of sustainability

- For sediment transport, hydropower projects of Tehri, Koteshwar, Uri-I and Dul Hasti have medium quality of sustainability, whereas hydropower projects of Lower Jhelum, Baglihar, Salal and Sewa have low quality of sustainability
- For water quality, hydropower projects of Tehri, Koteshwar, Lower Jhelum, Baglihar, Salal and Dul Hasti have medium quality of sustainability, whereas hydropower projects of Uri-I and Sewa have low quality of sustainability.
- Based on the analysis, current EIA have several drawbacks and Sustainability provides a more holistic coverage of the scenario by including Economic and Social aspects .

6.2 Recommendations

Based on the study following recommendations are given :

- A multi-criteria analysis method is recommended for evaluating and prioritising energy projects. The policy makers must recognise that energy systems are complex systems whose implementation needs a consideration of not only technical and financial issues but most importantly, social and environmental aspects
- The first parameter to judge the sustainability of hydropower project should be the estimated biodiversity submergence. Any proposed hydropower project with total environment index less than 1, should be discouraged or promoted with care, as environment is strongly linked to the social and economic life of the local people.
- The rated capacity of a hydropower plant should not be used as basis for implementing a project. The available capacity, dependable capacity and equivalent availability factor should be used instead.
- It is recommended that the livelihood improvement program of the power generating companies should incorporate training in livelihood diversification with cultural training and continue a long-lasting interaction with resettlement communities and put the necessary works in place to help resettlers adapt well to the new environment.
- Resettlement communities should identify opportunities in the new environment. The new environment comes with opportunities like small-scale businesses and trading. The chiefs and opinion leaders should help their community members focus on identifying opportunities to self-improve their livelihoods. All groups affected by the project should focus on diversifying and changing livelihood for a better adaptation

6.3 Future Scope Of Work

The field of sustainability assessment is at its early stage and should be promoted in India for future hydropower projects in addition to EIA. There are numerous gaps and discrepancies in information to carry out sustainability assessment with precision.

- In present study, several parameters were untouched during the qualitative and quantitative analysis, due to lack of data availability. Hence, better assessment could be possible with the availability of missing data
- IHA has provided a reasonable balanced guideline but the procedure to carry out is not mentioned in comprehensive manner, which suggests better methodology to carry out assessment is possible.

REFERENCES

[1] Ramachandra, T.V., Charan, S. and Gururaja, K.V. 2007 Cumulative Environmental Impact Assessment, Nova Science Publisher

[2] Canter Larry,2015, Cumulative effect assessment and management, EIA Press

[3] Barrow, C.J. 1997, Environmental and Social Impact Assessment, Arnold Publisher, London

[4] Hydroelectric Power: A Guide for Developers and Investors 2012; Publisher: International Finance Corporation

[5] Hydropower Sustainability Protocol 2010; Publisher: International Hydropower Association

[6] Khan, R., 2015. Small Hydro Power in India: Is it a sustainable business?. *Applied Energy*, *152*, pp.207-216.

[7] Erlewein, A., 2013. Disappearing rivers—the limits of environmental assessment for hydropower in India. *Environmental Impact Assessment Review*, *43*, pp.135-143.

[8] Srinivasan, J.T. and Reddy, V.R., 2009. Impact of irrigation water quality on human health: A case study in India. *Ecological Economics*, *68*(11), pp.2800-2807.

[9] Nautiyal, H., 2012. Progress in renewable energy under clean development mechanism in India. *Renewable and Sustainable Energy Reviews*, *16*(5), pp.2913-2919.

[10] Akella, A.K., Saini, R.P. and Sharma, M.P., 2009. Social, economical and environmental impacts of renewable energy systems. *Renewable Energy*, *34*(2), pp.390-396.

[11] Kumar, D. and Katoch, S.S., 2014. Sustainability Parameters for run of the river (RoR) hydropower projects in hydro rich regions of India. *Renewable and Sustainable Energy Reviews*, *35*, pp.101-108.

[12] Mishra, M.K., Khare, N. and Agrawal, A.B., 2015. Small hydro power in India: Current

[13] Sachdev, H.S., Akella, A.K. and Kumar, N., 2015. Analysis and evaluation of small hydropower plants: A bibliographical survey. *Renewable and Sustainable Energy Reviews*, *51*, pp.1013-1022.

[14] Mishra, S., Singal, S.K. and Khatod, D.K., 2011. Optimal installation of small hydropower plant—A review. *Renewable and Sustainable Energy Reviews*, *15*(8), pp.3862-3869.

[15] Md. Mustafa Kamal study the Scenario of Small Hydro Power Projects in India and its Environmental Aspect *Renewable and Sustainable Energy Reviews*, *51*, pp.1018-1062.

[16] Purohit, P., 2008. Small hydro power projects under clean development mechanism in India: A preliminary assessment. Energy Policy, 36(6), pp.2000-2015.

[17] Naveen Kumar Sharma, Prashant, Kumar Tiwari and Yog Raj Sood, "A comprehensive analysis of strategies, policies and development of hydropower in India: Special emphasis on small hydro power", Renewable and Sustainable Energy Reviews, Volume 18, February 2013, Pages 460-470.

[18] Afgan, N.H., 2010. Sustainability paradigm: intelligent energy system . *Sustainability*, *2* (12), pp.3812-3830.

[19] Luthra, S., Kumar, S., Garg, D. and Haleem, A., 2015. Barriers to renewable/sustainable energy technologies adoption: Indian perspective. *Renewable and sustainable energy reviews*, *41*, pp.762-776

[20] Carvalho, M.G. and Afgan, N.H., 2002. Multi-criteria assessment of new and renewable energy power plants. *Energy*, *27*(8), pp.739-755

[21] Hovanov, N. V. and Dzyuba A., (2000). Energy system assessmentwith sustainability Parameters. Energy Policy, 28(603):612

[22] Ramachandran, M. and Pohekar, S.D., 2004. Application of multi-criteria decision making to sustainable energy planning—a review. *Renewable and sustainable energy reviews*, *8*(4), pp.365-381.

[23] Brand, C., Mattarelli, M., Moon, D. and Calvo, R.W., 2002. STEEDS: A strategic transport–energy–environment decision support. *European Journal of Operational Research*, *139*(2), pp.416-435.

[24] Liu, G., 2014. Development of a general sustainability Parameter for renewable energy systems: a review. *Renewable and sustainable energy reviews*, *31*, pp.611-621

[25] CAG Report on Small Hydro Power 2017; Publisher: Ministry of New and Renewable Energy

[26] Performance Standards on Environmental and Social Sustainability's Guidance 2012 Publisher: International Finance Corporation

[27] Policy on Environmental and Social Sustainability 2012: Publisher: International Finance Corporation

[28] Hydropower Sustainability Protocol 2018; Publisher: International Hydropower Association .

[29] Jebaraj, S. and Iniyan, S., 2006. A review of energy models. *Renewable and sustainable energy reviews*, *10*(4), pp.281-311.

[30] Mortey, E., Ofosu, E., Kolodko, D. and Kabobah, A., 2017. Sustainability Assessment of the Bui Hydropower System. Environments, 4(2), p.25

[31] Begić, F. and Afgan, N.H., 2007. Sustainability assessment tool for the decision making in selection of energy system—Bosnian case. Energy, 32(10), pp.1979-1985.

[32] Frey, G.W. and Linker, D.M., 2002. Hydropower as a renewable and sustainable energy resource meeting global energy challenges in a reasonable way. *Energy policy*, *30*(14), pp.1261-1265.

[33] Anderson, E.P., Freeman, M.C. and Pringle, C.M., 2006. Ecological consequences of hydropower development in Central America: impacts of small dams and water diversion on neotropical stream fish assemblages. *River Research and Applications*, *22*(4), pp.397-411.

[34] Tharme, R.E., 2003. A global perspective on environmental flow assessment: emerging trends in the development and application of environmental flow methodologies for rivers. *River research and applications*, *19*(5-6), pp.397-441.

[35] Shiferaw, B.A., Okello, J. and Reddy, R.V., 2009. Adoption and adaptation of natural resource management innovations in smallholder agriculture: reflections on key lessons and best practices. *Environment, development and sustainability*, *11*(3), pp.601-619.

[36] Smit, B. and Spaling, H., 1995. Methods for cumulative effects assessment. *Environmental impact assessment review*, *15*(1), pp.81-106.

[37] Kodituwakku, D. and Moonesinghe, V., 2004. The EIA Process and the Upper Kotmale Hydropower Project. SARID Journal, 1(1).

[38] Duinker, P.N. and Greig, L.A., 2007. Scenario analysis in environmental impact assessment: Improving explorations of the future. *Environmental impact assessment review*, *27*(3), pp.206-219

[38] Bonnell, S. and Storey, K., 2000. Addressing cumulative effects through strategic environmental assessment: a case study of small hydro development in Newfoundland, Canada. *Journal of Environmental Assessment Policy and Management*, *2*(04), pp.477-499

[39] Lodhi, M.S., Kuniyal, J.C. and Kanwal, K.S., 2016. Framework for Strategic Environmental Assessment in Context of Hydropower Development in the Indian Himalayan Region. International Journal Of Environmental Sciences, 5(1), pp.11-23.