Royal Government of Bhutan
Department of Energy
Ministry of Energy and Natural Resources

Multi-Criteria Assessment Framework

Prioritising Renewable Energy-Powered Lift Irrigation Sites

Contributors from the Royal Government of Bhutan
Dawa Zangmo, DoE
Dechen Dema, DoE
Rigzin Pelzang, DoE

Other Contributors
Ankit Nanda, PCC
Mewang Gyeltshen, ICIMOD
Nedup Tshering, Sangsel Eco Trade & Environmental Services
Prodyut Mukherjee, En-genuity
Ranjit Chandra Vallabhaneni, En-genuity
Sarada Tiwari, ICIMOD
Sudeshna Maitra, PCC
Zeko, Sangsel Eco Trade & Environmental Services

Lead Authors
Avishek Malla, ICIMOD
Pugazenthi Dhananjayan, ICIMOD
Deepshikha Sharma, PCC

Publication Team
Editing: ICIMOD and PopulationCouncil Consulting Private Limited (PCC)
Design and Layout: PCC (India) and 129 Degrees Design Studio
Photo Credits: Alex Treadway and Choling

Citation
DoE, 2025. *Multi-Criteria Assessment Framework: Prioritising Renewable Energy-Powered Lift Irrigation Sites.* Royal Government of Bhutan, Department of Energy, Ministry of Energy and Natural Resources.

ISBN 978-99936-703-4-6

Supported by

ICIMOD

The International Centre for Integrated Mountain Development (ICIMOD)'s Renewable Energy Intervention under the *Women's Empowerment through Renewable Energy-Powered Decentralized Lift Irrigation Systems in Bhutan (WERELIS – Bhutan) project,* funded by the International Development Research Centre (IDRC), Canada.

Funded by

IDRC · CRDI
International Development Research Centre
Centre de recherches pour le développement international

Canada

This work was carried out with the aid of a grant from the International Development Research Centre, Ottawa, Canada. The views expressed herein do not necessarily represent those of or its Board of Governors.

Multi-Criteria Assessment Framework

Prioritising Renewable Energy-Powered Lift Irrigation Sites

June 2025

Royal Government of Bhutan
Department of Energy
Ministry of Energy and Natural Resources

ནུས་ཤུགས་ལས་ཁུངས།
ནུས་ཤུགས་དང་རང་བཞིན་ཐོན་སྐྱེད་ལྷན་ཁག།
DEPARTMENT OF ENERGY
MINISTRY OF ENERGY AND NATURAL RESOURCES
THIMPHU: BHUTAN

BHUTAN
Believe

Foreword

Bhutan's commitment to sustainable development and environmental conservation is deeply embedded in our national policies and vision for the future. Agriculture remains the backbone of our rural economy, and ensuring reliable irrigation is essential for enhancing agricultural productivity, improving livelihoods, and strengthening food security. However, given the challenging topography and climate variability, conventional irrigation systems are often inadequate, requiring innovative and sustainable solutions. Renewable energy (RE)-powered irrigation systems can play a key role in addressing these challenges.

This Multi-Criteria Assessment (MCA) Framework has been developed to support the prioritisation and evaluation of RE-powered and conventional lift irrigation projects in Bhutan. It provides a structured, holistic, and evidence-based approach to evaluating and selecting sites based on technical feasibility, financial and economic viability, social inclusion, and environmental sustainability. The framework will serve as a critical decision-making tool for policymakers, planners, and project implementers, ensuring that irrigation projects are not only efficient and effective but also gender-equitable and socially inclusive (GESI).

The development of this framework has been a collaborative effort led by the Department of Energy, Ministry of Energy and Natural Resources, with support from the International Centre for Integrated Mountain Development (ICIMOD). We also extend our sincere thanks to the International Development Research Centre (IDRC) for their generous funding support, which made this work possible. Additionally, we acknowledge the valuable technical contributions of experts and all other key stakeholders who played a pivotal role in this initiative.

We extend our sincere appreciation to all the relevant stakeholders who contributed to this initiative. It is our hope that this framework will guide the successful implementation of RE-powered lift irrigation projects, contributing to rural development, climate resilience, and sustainable energy transitions in Bhutan.

Karma P Dorji
Director General

Post Box 106, Tel: +975-2-322505/323555; Fax: +975-2-335122 www.moenr.gov.bt

Preface

Sustainable access to irrigation is a critical enabler of rural livelihoods, particularly in the Himalayan region, where climate change and water scarcity pose growing threats to agricultural livelihoods. In this challenging context, renewable energy-powered lift irrigation systems emerge as a transformative solution—one that can simultaneously boost agricultural productivity, reduce fossil fuel dependency, and advance inclusive development.

This framework supports decision-makers in assessing and prioritising irrigation projects that are not just technically viable, but also gender-responsive, socially equitable and environmentally sustainable, thereby delivering maximum impact where it is needed most. The framework's emphasis on gender-responsive design is particularly crucial, as it recognises (a) the pivotal role women play in agriculture as they represent the major workforce and (b) the systemic barriers they often face in accessing resources.

This publication is the product of exceptional collaboration. ICIMOD is privileged to have worked alongside the Department of Energy under the Ministry of Energy and Natural Resources, as well as key experts and stakeholders. The framework benefits from diverse perspectives—policymakers, technical and gender experts, private sector representatives, and most importantly, the local communities.

This framework is developed as a part of the Women's Empowerment through Renewable Energy-Powered Decentralized Lift Irrigation Systems in Bhutan (WERELIS-Bhutan) project, with support from the International Development Research Centre (IDRC). We extend our deepest gratitude to IDRC for their support in advancing renewable energy and gender equality in the region. Our sincere appreciation goes to all the relevant stakeholders whose insights and experiences have shaped this work.

As Bhutan and other Hindu Kush Himalaya (HKH) regions strive to build climate-resilient futures, we hope this framework will serve as both a practical guide and a catalyst for change—helping to implement renewable energy-powered lift irrigation projects, thereby contributing to sustainable development and clean energy transitions in Bhutan.

Dr. Pema Gyamtsho
Director General, ICIMOD

International Centre for Integrated Mountain Development
GPO Box 3226, Kathmandu, Nepal
T +977 1 5275222 | **E** info@icimod.org
www.icimod.org

国际山地综合发展中心

अन्तर्राष्ट्रिय एकिकृत पर्वतीय विकास केन्द्र

Acknowledgement

The Department of Energy (DOE) extends its deepest appreciation to the International Centre for Integrated Mountain Development (ICIMOD) for its invaluable collaboration in developing the Multi-Criteria Assessment (MCA) Framework to prioritise renewable energy-powered lift irrigation sites in Bhutan. This work was made possible through the technical and financial support of ICIMOD under the Women's Empowerment through Renewable Energy-Powered Decentralized Lift Irrigation Systems in Bhutan (WERELIS-Bhutan) project, funded by the International Development Research Centre (IDRC), Canada. We sincerely thank IDRC for its commitment to advancing gender and socially inclusive and sustainable energy solutions.

We express our sincere thanks to the teams from ICIMOD and PopulationCouncil Consulting Private Limited for their expertise and significant contribution to the development of this framework. Their specialised knowledge and technical insights have enriched the assessment methodology, ensuring its relevance and applicability in the Bhutanese context.

We are also grateful to all stakeholders, consultation and validation workshop participants, key informants, and the community and beneficiaries of the irrigation projects for their active engagement, insights, and valuable feedback. Their firsthand experiences and insights have been critical in refining the framework to meet real challenges and opportunities.

This document is a testament to the collective effort and shared vision of multiple institutions and individuals working towards sustainable, gender-inclusive, and climate-resilient irrigation solutions. We look forward to continued collaboration as we implement this framework to enhance rural livelihoods, agricultural productivity, and renewable energy adoption in Bhutan.

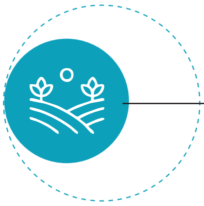
Acronyms

AHP	Analytic Hierarchy Process
BCCI	Bhutan Chamber of Commerce and Industry
CI	Consistency Index
CR	Consistency Ratio
DoE	Department of Energy
DPR	Detailed Project Report
EIRR	Economic Internal Rate of Return
GDP	Gross Domestic Product
GESI	Gender Equality and Social Inclusion
GI	Geographical Indication
IRR	Internal Rate of Return
kW	kilowatt
MCA	Multi-Criteria Assessment
MCDM	Multi-Criteria Decision-Making
NIMP	National Irrigation Master Plan
NPV	Net Present Value
RE	Renewable Energy
RGoB	Royal Government of Bhutan
RI	Random Index
WMAs	Water Management Associations

Table of Contents

List of Tables

Introduction



40%

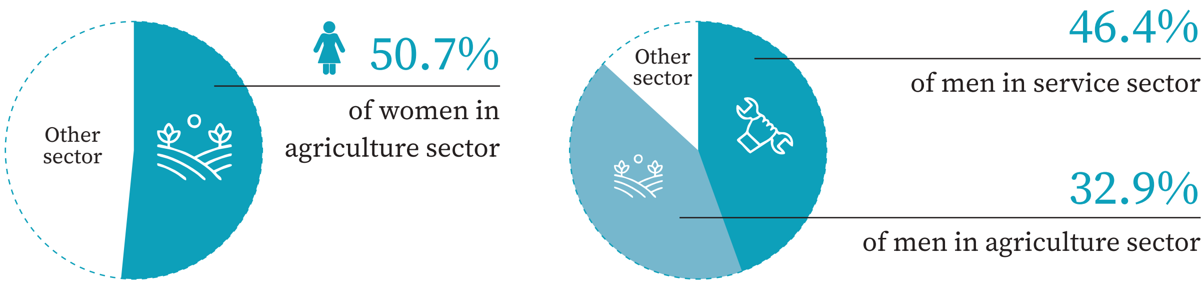
Employed in agricultural sector

Bhutan's agricultural sector, despite being a cornerstone of the nation's economy and a primary source of employment for approximately 40% of its population, has been facing significant challenges.

The primary sector's contribution to the national economy and its relative share of GDP has been steadily declining [NSB, 2022]. This trend, coupled with the potential effects of climate change on agricultural productivity, underscores an urgent need for adaptive measures to ensure food security and sustainable rural livelihoods.

The agricultural sector in Bhutan is characterised by its reliance on monsoon-fed, gravity-driven irrigation systems, which are inherently seasonal and vulnerable to climatic variability. Despite the country's abundant freshwater resources, only a small fraction is effectively utilised for irrigation. The challenges are exacerbated by Bhutan's steep, hilly terrain, where water often must be lifted from lower-altitude rivers to irrigate higher-elevation farmlands. These geographical and climatic constraints have led to declining crop yields, an increase in fallow land, and a growing dependence on food imports.

Furthermore, agriculture remains the second-largest employer, accounting for approximately 40% of the total employed population. Notably, a higher proportion of employed women work in the agriculture sector (50.7%) compared to the other sectors, whereas a higher proportion of employed men work in the service sector (46.4%) and agriculture sector (32.9%) [NSB, 2024]. The agriculture sector's declining contribution to the GDP highlights a structural vulnerability that needs to be addressed.



Given these challenges, renewable energy-powered irrigation solutions have emerged as a promising strategy. Technologies such as solar photovoltaic pumping systems offer the potential not only to enhance irrigation efficiency by providing a reliable water supply throughout the year but also to reduce the sector's reliance on fossil fuels and mitigate environmental impacts. Given its abundant renewable resources, these renewable energy solutions are particularly well-suited for Bhutan.

Recognising the critical role of irrigation in enhancing agricultural productivity, alleviating rural poverty, and fostering long-term development, the Royal Government of Bhutan (RGoB) has prioritised interventions to transform the irrigation landscape. Among these, RE-powered lift irrigation systems have gained attention as transformative solutions that address water scarcity, particularly in remote and hilly regions. These systems are envisaged to contribute to an inclusive, low-carbon energy future while promoting sustainable development and gender equity. However, the effective deployment of such systems requires a robust and systematic decision-making process that can evaluate multiple, often competing, factors.

Multi-Criteria Assessment (MCA) offers a structured methodology for evaluating and prioritising projects by considering multiple dimensions, including technical feasibility, economic viability, environmental sustainability, agricultural impact, and social inclusiveness. Although Bhutan's National Irrigation Master Plan (NIMP) is based on an MCA framework to assess irrigation projects, it needs to be reassessed and updated to address the evolving demands of modern irrigation systems and expand the scope to include renewable energy technologies in irrigation.

Limitations of the Existing Framework

The existing framework developed under the NIMP [2016] outlines five key criteria for project prioritisation: water availability, climate change and environment, level of technical difficulties, agricultural situation, and social/socio-economic. It assigns equal weights to each criterion. While this approach provides a foundational structure, it lacks responsiveness to evolving sectoral needs.

There is now a pressing need for the framework to incorporate technological advancements, promote social equity, adapt to the changing financing landscape, and support a just energy transition. By integrating these elements, the framework can remain relevant and effective in evaluating projects that are not only technologically advanced but also socially inclusive, financially sustainable, and aligned with national energy transition goals. Some of the limitations of the current MCA framework are as follows:

Water availability
This section can be further strengthened by expanding its scope to include new water sources beyond surface water, such as groundwater. It also requires incorporating an assessment of these sources' reliability, along with integrated water resource management practices. This includes ensuring protection, recharge, and sustainable management of water sources to enhance long-term availability and resilience.

Level of technical difficulties
The present framework has the scope to expand to incorporate technological advancements in the sector, moving beyond the limitations of canal-based irrigation systems. With the emergence of new technologies such as solar and pumping systems categorised as RE-powered lift irrigation, it is crucial to integrate alternative irrigation methods, among others. The sub-criteria can be broadened to evaluate projects based on technical viability, cost-effectiveness, and functionality. Additionally, factors such as mountainous topography and site accessibility are to be included, as they significantly influence irrigation systems' technical design and implementation.

Social/socio-economic
Given that a significant proportion of the farming population is women, the current framework does not adequately address gender and socio-economic factors. To strengthen this, it is crucial to assess women's involvement in decision-making, access to resources, and capacity-building opportunities. Currently, the framework lacks specific indicators to assess women's participation in decision-making, access to resources, and capacity-building opportunities. Integrating gender and socio-economic considerations would ensure that projects actively promote equal representation, leadership roles, and access to financial and technological resources. Additionally, the framework should evaluate how irrigation projects impact local

communities' economic well-being, particularly in terms of job creation, market access, and livelihood enhancement. Additionally, the socio-economic status of both men and women influences access to economic opportunities, financial resources, and technology, which should be integrated into the framework for a more inclusive approach. The framework should ensure equal representation and active participation of women and marginalised communities by setting targets for their involvement in leadership roles, decision-making, and technical training. Promoting women's access to land, technology, and financial resources is essential to enable full participation and long-term empowerment.

Developing gender and socio-economic sensitive indicators such as women's involvement in project governance, the percentage of female beneficiaries, and their access to credit, land, and technology is critical to tracking the project's impact and ensuring equitable benefits. These indicators will help identify barriers and disparities, fostering greater gender and socio-economic equality within the farming sector and ensuring the active participation of women in the transformation process.

Economic and financial feasibility

The existing MCA framework does not include cost-benefit evaluation as part of its criteria. Incorporating this would enable developers and implementers to a project's financial and economic viability. This is crucial for strategic reasons as it sheds light on the project's sustainability—whether it can operate independently or will require ongoing subsidies or bailouts, thereby allocating public resources adequately. Projects demonstrating economic and financial feasibility are more likely to gain support from investors, lenders, and policymakers. Moreover, financially viable projects can attract private investments, which, when properly channelled and regulated, can introduce efficiency and drive long-term success.

Equal weighting

The current framework's equal weighting approach is a simplified approach that needs to be looked at based on the varying importance of factors in assessing a project's feasibility. Some criteria carry more significance than others depending on regional challenges, resource availability, and project objectives. For instance, water availability may be a critical factor in water-scarce regions which demand a higher weightage than others. To address this, an MCA framework with an Analytic Hierarchy Process (AHP) needs to be considered. AHP allows for prioritising criteria based on their relevance to the project's goals, incorporating both qualitative and quantitative data. This method enables decision-makers to assign relative weights to factors, such as giving higher weight to water availability in water-scarce regions. Integrating AHP into the MCA framework allows for more context-specific evaluations, considering project-specific conditions and factors like resource availability and technical feasibility. AHP provides a structured approach to prioritise factors by incorporating expert consultation, stakeholder input, and project-specific conditions, leading to more informed and balanced decision-making. This approach improves resource allocation, minimises suboptimal decisions, and leads to more effective and sustainable project outcomes.

The above brings forth the need to revise and enhance the MCA framework to better align with Bhutan's energy transition goals and irrigation development needs. A refined framework will ensure that irrigation projects are not only technically and financially viable but also climate-resilient, socially inclusive, and aligned with national policies. This study proposes an updated MCA framework tailored for RE-powered lift irrigation systems in Bhutan, addressing the gaps in the existing approach and improving decision-making for future projects.

By incorporating advanced decision-making techniques, such as the AHP, the proposed framework systematically quantifies the relative importance of each criterion through pairwise comparisons and stakeholder-driven weighting processes. This approach ensures a transparent, consistent, and inclusive decision-making process that aligns with the diverse priorities of Bhutanese stakeholders.

MCA encompasses a range of methodologies for evaluating and ranking alternative sub-projects and serves as an instrument to assess and order proposed sub-projects based on their merits. The process involves establishing a clearly defined hierarchy of evaluation criteria, which includes both quantifiable and qualitative factors, which have been developed through collaborative efforts with stakeholders. The outcome of MCA is a prioritised list, with the most promising projects positioned at the top. Some of the advantages of using this methodology are as follows:

1. **Comprehensive evaluation:** MCA allows for a systematic evaluation of options based on multiple criteria, ensuring that no important factors are overlooked.

2. **Transparency and objectivity:** The decision-making process becomes more transparent as the criteria and weights are clearly defined, making it less subjective.

3. **Consistency:** MCA can help maintain consistency in decision-making by applying the same criteria and weights to all options.

4. **Effective prioritisation:** By assigning weights to different criteria, MCA helps in prioritising options based on their relative importance.

5. **Decision support:** MCA provides a structured framework for decision-making, making it easier to compare and contrast options and identity the most suitable choice.

6. **Stakeholder involvement:** MCA involves multiple stakeholders in the decision-making process, ensuring their perspectives and priorities are considered.

7. **Flexibility:** MCA can be adapted to various decision-making contexts and can accommodate different types of criteria (quantitative, qualitative, or a combination).

Methodology for the Proposed MCA Framework

This section details the systematic approach used to develop the MCA framework for prioritising RE-powered lift irrigation projects in Bhutan. The process integrates qualitative stakeholder input with quantitative analytical techniques, ensuring a robust, transparent, and contextually relevant decision-support tool. The methodology comprises three main steps, namely, identification of criteria, development of a pairwise comparison matrix for scoring the criteria and stakeholder workshop for refining, scoring and validating the criteria.

Identification of Criteria and Sub-criteria

The initial step involved identifying the evaluation criteria for assessing RE-powered lift irrigation projects. A review of relevant academic literature on Multi-Criteria Decision-Making (MCDM) provided the foundation for an initial list of evaluation criteria. The NIMP [2016] is analysed to identify gaps, including the gap in renewable energy integration and insufficient emphasis on environmental and gender-related impacts. Based on the literature and initial consultations, ten criteria and their corresponding sub-criteria were proposed. These encompassed both quantitative factors (e.g., water availability, pump capacity) and qualitative aspects (e.g., stakeholder involvement, policy alignment). This process was undertaken to ensure that the MCA framework comprehensively addresses technical, environmental, economic, and social dimensions while evaluating renewable energy-powered lift irrigation projects in Bhutan. Through iterative refinement and expert feedback, the criteria were consolidated into a final set that adequately captures the multifaceted aspects of project feasibility.

Developing the Pairwise Comparison Matrix

The MCA framework developed for this project is grounded in MCDM theory, specifically the AHP, which allows for the hierarchical structuring of decision problems and the quantification of relative importance through pairwise comparisons. AHP is a well-established MCDM tool that supports decision-makers in evaluating and prioritising various alternatives when faced with complex situations involving multiple criteria [Saaty, 2008]. A pairwise comparison matrix is a square matrix where each criterion is compared with every other criterion. For a set of 'n criteria', the matrix has 'n*n elements'. While constructing the pairwise comparison matrix, each criterion is compared against every other criterion to determine their relative importance. Rows in the matrix represent the criteria being evaluated, while columns represent the criteria being evaluated.

Scoring method

The scoring within the matrix is based on Saaty's fundamental 9-point scale, which facilitates the expression of subjective judgments regarding the relative importance of each criterion [Wind and Saaty, 1980; Saaty, 2008]. The scale ranges from 1 (equal importance) to 9 (extremely more important), with intermediate values (2, 4, 6, 8) for nuanced judgments.

2,4,6,8 Intermediate Values: Intermediate values between the two adjacent judgments.

1 — Equal importance: Both elements are equally important.

3 — Slight importance: One element is slightly more important that the other.

5 — Moderate importance: One element is moderately more important that the other.

7 — Strong importance: One element is significantly more important than the other.

9 — Extreme importance: One element is extremely more important than the other.

Reciprocals

For each pairwise comparison, a score is assigned to indicate how much more important each criterion is over the other, and the reciprocal score is automatically applied to the inverse comparison (e.g., if criterion A is slightly more important (value is 3) than criterion B, then the value for criterion B is 1/3 as it is slightly less important than criterion A).

Aggregation

The matrices score from multiple groups are aggregated using the geometric mean formula:

$$\textit{Combined Value} = \left(\prod_{\{i=1\}}^{n} a_{\{ij\}}\right)^{\left\{\frac{1}{n}\right\}}$$

As the pairwise comparisons in AHP represent a multiplicative relationship (e.g., how many times more important one criterion is over another), it aligns with the properties of the geometric mean which preserves these multiplicative relationships rather than the arithmetic mean which assumes an additive relationship. As it preserves the multiplicative relationships required for consistency, the geometric mean is ideal for handling reciprocal judgments in a pairwise comparison matrix. The geometric mean is also less sensitive to extreme values and helps provide a balanced aggregation of scores provided by different groups. Table 1 demonstrates that even when the sum of three variables remains constant, the geometric mean effectively captures the internal variation among the values.

Table 1. Effects of Variation in Numbers on Arithmetic, Geometric and Harmonic Mean

Variable			Sum	Mean		
A	B	C	(A+B+C)	Arithmetic	Geometric	Harmonic
1	4	10	15	5	3.4	2.2
4	5	6	15	5	4.9	4.9
0.33	6	8.67	15	5	2.6	0.9

Normalisation of the matrix

Normalisation aims to convert the matrix values into a consistent scale, allowing direct comparison between criteria. The combined pairwise comparison matrix is normalised to standardise values and calculate the weights for each criterion:

- **Column summation:** The values in each column of the aggregated matrix are summed.
- **Normalisation formula:** Each element is divided by its column sum:

$$a'_{\{ij\}} = \left\{ \frac{\{a_{\{ij\}}\}}{\{\sum_{\{j=1\}}^{n} a_{\{ij\}}\}} \right\}$$

Weight calculation

Weights are calculated for each criterion by averaging the values in each row of the normalised matrix.

$$Weight_i = \left\{ \sum_{\{j=1\}}^{n} a'_{\{ij\}} \right\} \{n\}$$

In the MCA matrix, for each row or criteria in the normalised matrix, the value of elements is added, and this sum is divided by the total number of elements for each row. The process is repeated for all the rows, and the resulting values represent the weight of the corresponding criterion. The sum of the weights of all criteria is 1 or 100%. The calculated weights provide a quantitative measure of the relative importance of each criterion, with higher weights indicating greater importance in the decision-making process. These weights rank the criteria and determine their impact on the final decision.

Consistency check

After calculating the weights, a consistency check is performed to ensure logical coherence in the pairwise comparisons. The first step in calculating the consistency ratio is to calculate the weighted sum by multiplying each element of the pairwise comparison matrix by the corresponding weight of the column criterion and then adding the results for each row.

Lambda Max (λmax) is the largest eigenvalue of the pairwise comparison matrix and is calculated by dividing each element of the weighted sum vector by the corresponding weight from the weight vector. The average of these ratios is λmax.

The Consistency Index (CI) measures the deviation from perfect consistency and is a measure of how consistent the judgments have been relative to a perfectly consistent matrix.

$$CI = \left\{ \lambda_{\{\{max\}\}} - n \right\} \{n - 1\}$$

The Consistency Ratio (CR) is the ratio of the Consistency Index (CI) to the Random Index (RI).

$$CR = \frac{\{CI\}}{\{RI\}}$$

Where RI is the Random Index for a matrix of the same size (e.g., RI = 1.32 for a 7x7 matrix). A CR < 0.10 indicates acceptable consistency. A CR of less than 0.10 is generally considered acceptable. If the CR exceeds this threshold, it indicates that the judgments in the matrix may be inconsistent, and the pairwise comparisons need to be reviewed.

Scoring projects:
Projects are scored based on the defined criteria and sub-criteria:

1. **Scoring ranges:** Defined for each sub-criterion, such as:

   Cropping intensity:
   - 1 = No change
   - 2 = Increase by 10%-25%.
   - 3 = Increase > 25%.

   Disaster risk:
   - 0 = High
   - 1 = Medium
   - 2 = Low

2. **Weighted scores:** Raw scores are multiplied by criterion weights:

$$Weighted\ score = Raw\ \ score \times Weight$$

3. **Total scores:** Weighted scores are summed to compute total scores, which are used to rank projects.

Sensitivity analysis

The robustness of project rankings is evaluated by adjusting the weights of criteria:
- **Simulating scenarios:** For example, increasing the weight of agricultural feasibility from 29% to 35%.
- **Recalculation:** Rankings are recalculated under modified weights to identify criteria with significant impacts.

Stakeholder Engagement

Stakeholder engagement played a central role in the development of the framework, ensuring that the final criteria were rooted in real-world priorities and tailored to the local context. The process began with the identification of a diverse group of stakeholders, including government agencies, the private sector, local farmers, technical experts, financial institutions, donors and representatives from industry bodies. This broad representation ensured that multiple perspectives were incorporated throughout the framework's design.

Two participatory workshops were then organised in Thimphu, Bhutan, on 13 August and 18 October 2024. These workshops served as essential platforms for structured engagement and iterative refinement of the MCA framework. During the first session, participants critically reviewed the existing framework under NIMP, identifying its limitations and proposing enhancements. They also examined the preliminary list of evaluation criteria, contributing to its consolidation and refinement. A key exercise involved scoring a pairwise comparison matrix, which enabled the derivation of weights for each criterion.

Building on these outcomes, the second workshop addressed Bhutan-specific challenges such as site topography, water availability, and projected socio-economic impacts. In this session, stakeholders validated the final set of criteria and their assigned weightings, ensuring the framework's accuracy, contextual relevance, and practical applicability.

This inclusive and iterative engagement process not only enhanced the technical rigour of the MCA framework but also ensured it was locally grounded and aligned with the aspirations of Bhutanese stakeholders.

Multi-Criteria Assessment (MCA) Framework

The criteria for the MCA framework were identified through an iterative process, which included expert consultations, stakeholder engagements, and a review of the literature. The criteria were selected to ensure that the multi-dimensional aspects of implementing renewable energy-powered lift irrigation systems in Bhutan, particularly in the context of climate change and sustainable development, are captured. Initially, 10 criteria were identified, namely, technical feasibility, policy, infrastructure feasibility, financial viability, climate proofing and environment, agricultural feasibility, economic feasibility, social and gender impact, and project risk assessment. One of the common suggestions received during the first workshop organised in Thimphu on 13 August 2024 was to combine a few of the criteria as the stakeholders felt that they were related and should be combined. Some key inputs from the workshop included:

- 'Technical feasibility' and 'Infrastructure feasibility' criteria should be clubbed as these overlap in their functions.
- 'Financial viability' cannot be the sole criterion for rejection of a project and the comparison matrix should consider the need and urgency of the community.
- To streamline 'Financial viability' and club it with 'Economic feasibility' criteria.
- To club 'Social impact' and 'Gender impact' criteria as a single one, reflecting the Gender Equality and Social Inclusion (GESI) emphasis laid out by the RGoB.

Criteria

Based on the learnings from the first workshop and their relevance and usability to the evaluation of renewable energy-powered lift irrigation systems in Bhutan, the number of criteria were revised and a set of seven criteria were selected. Further, it was laid out that in unique cases or for special projects, the community's needs can override a project's financial viability. The seven criteria that were selected are:

Technical and infrastructure feasibility
This criterion assesses the technical feasibility of the site and best-fit technology, including access to essential infrastructure. It also emphasises the integration of new and alternative technologies, such as renewable energy-powered lift irrigation systems. Key factors considered include the availability of renewable energy sources (e.g., solar, wind, hydro) and the necessary infrastructure, such as grid access, which are critical for ensuring the project can be effectively operationalised. Additionally, the criterion evaluates the water source, its availability, recharge protection and management practices, ensuring a comprehensive assessment of the project's viability.

Policy alignment
Government policies and regulations play a significant role in determining the feasibility of RE projects. A project's alignment with national or local policies, such as renewable energy targets, subsidies, and incentives, can significantly affect its financial and regulatory viability. A project that aligns with government priorities is more likely to secure approvals, financial incentives, and institutional support.

Economic and financial feasibility
This criterion assesses the project's economic viability, ensuring that it generates sufficient financial returns while positively impacting the local economy. Financial indicators such as the Economic Internal Rate of Return (EIRR) and Net Present Value (NPV) measure the project's cost benefits. Additionally, the criterion evaluates the project's ability to create jobs, reduce energy costs, and contribute to local economic growth.

Climate proofing and environmental impact
Considering the increasing impacts of climate change, this criterion assesses the project's sustainability and its potential environmental consequences. Factors such as land use compatibility, impact on biodiversity, water quality, and soil erosion are considered to ensure that the project does not negatively affect the environment or exacerbate climate-related risks.

Agricultural feasibility
This criterion evaluates the project's potential to enhance agricultural productivity. It examines whether the proposed irrigation system will increase cropping intensity, promote crop diversification, and generate higher returns per acre for farmers.

Social and gender impact
A successful RE-powered irrigation project must promote GESI. This criterion assesses the project's potential to involve local communities, enhance livelihoods, and ensure equitable resource distribution, especially for women, disabled and marginalised groups. Gender-inclusive projects are more likely to succeed as they address the needs of all stakeholders, leading to broader community support and engagement.

Unmitigated project risk
Risk assessment is crucial to identifying and mitigating potential challenges that could undermine the project. This criterion evaluates the project's vulnerability to disasters, cultural heritage, technical risks, human-wildlife conflict, and other site-specific risks that could affect its long-term sustainability.

Further consultations with stakeholders and internal deliberations led to an understanding that a further reduction in the seven criteria was necessary due to the following reasons:

- Policy alignment was identified as an overarching criterion that applied to all project applications. Proposals that do not align with relevant policies should be excluded from consideration, effectively making this criterion a binary "go/no-go" decision point and justifying its removal from the MCA framework.
- Unmitigated project risk was deemed highly site-specific as lift irrigation systems are unique to each site. As a result, its application was deemed more appropriate during the Detailed Project Report (DPR) evaluation stage, resulting in its removal from the current criteria list.

Finally, recognising the importance of stakeholder accessibility, reducing the number of criteria was considered crucial for facilitating easier adoption and implementation of the MCA framework. Given these considerations, the MCA criteria were revised from seven to five. The final list of criteria included:

- Technical and infrastructure feasibility
- Economic and financial feasibility
- Climate proofing and environmental impact
- Agricultural feasibility
- Social and gender impact

Pairwise Comparison of Criteria and Weightage

A pairwise comparison matrix as explained in the methodology section is a tool used to compare different criteria or options against each other to determine their relative importance. For the MCA framework, it was used to compare each criterion against every other criterion to determine their relative importance.

a. Scoring the matrix

The results from the MCA workshop conducted in Thimphu on 13 August 2024 are captured in the combined pairwise comparison matrix and the calculated weightings for each criterion. During the workshop, the participants were divided into four groups, and each group was asked to discuss and score the matrix. Each pair was asked to assign a score based on how much importance needed to be assigned to the row criterion compared to the column criterion. The reciprocal value is placed in the corresponding cell for the reverse comparison. For example, if Technical and Infrastructure Feasibility is moderately more important than Agricultural Feasibility, they were asked to assign a score of 5 in the cell where the Technical Feasibility row meets the Policy Alignment column and 1/5 where the Agricultural Feasibility row meets the Technical and Infrastructure Feasibility column. In this process, the diagonal values are always scored 1, as it compares a criterion to itself. Once the four matrices (one from each group) were fully populated, geometric mean was used to combine these different perspectives into one overall matrix.

In the workshop, the scoring for the matrix was done on the initial list of 10 criteria: Technical feasibility; policy; infrastructure feasibility; financial viability; climate proofing and environment; agricultural feasibility; economic feasibility; social impact; gender impact; and project risk assessment. As the criteria were revised and multiple criteria were combined, the category with the higher score was taken as the new score. The combined score by group work for the five criteria is given in Table 2.

Table 2. Pairwise Comparison Scores for the Five Criteria of the MCA Framework

Criteria	Technical and infrastructure feasibility	Financial and economic feasibility	Climate proofing and environment	Agricultural feasibility	Social and gender impact
Technical and infrastructure feasibility	1.00	0.54	1.14	0.50	1.00
Financial and economic feasibility	1.85	1.00	1.50	0.92	1.32
Climate proofing and environment	0.88	0.67	1.00	0.49	0.73
Agricultural feasibility	2.01	1.09	2.06	1.00	1.77
Social and gender impact	1.00	0.76	1.37	0.57	1.00

b. Normalisation of the matrix

The pairwise scores in the matrix were normalised to convert the matrix values into a consistent scale, allowing direct comparison between criteria. After normalisation, the sum of the elements in each column equals 1. The normalised matrix reflects the relative importance of each criterion in relation to the others. The normalised score for the five criteria is given in Table 3.

Table 3. Normalised Matrix for the Five Criteria of the MCA Framework

Criteria	Technical and infrastructure feasibility	Financial and economic feasibility	Climate proofing and environment	Agricultural feasibility	Social and gender impact
Technical and infrastructure feasibility	0.148	0.133	0.161	0.143	0.172
Financial and economic feasibility	0.274	0.246	0.212	0.265	0.226
Climate proofing and environment	0.131	0.165	0.142	0.140	0.125
Agricultural feasibility	0.298	0.268	0.291	0.288	0.304
Social and gender impact	0.148	0.187	0.195	0.163	0.172
Sum	1.000	1.000	1.000	1.000	1.000

c. Final weightage

The weightage was calculated by averaging the values of each row in the normalised matrix. As delineated in Table 4, the finalised criterion weights, expressed as percentage allocations, reveal hierarchical prioritisation among stakeholders. Agricultural feasibility (29%) emerged as the highest weighted criterion, followed closely by financial and economic feasibility (24%). Social and gender impact (17%) and technical and infrastructure feasibility (15%) were also considered important criteria by the stakeholders. Climate proofing and environment (14%) received lower but significant weightage.

Table 4. Weights of the Criteria Selected for the MCA Framework

Criteria	Weight	Percentage
Technical and infrastructure feasibility	0.152	15%
Financial and economic feasibility	0.245	25%
Climate proofing and environment	0.140	14%
Agricultural feasibility	0.290	29%
Social and gender impact	0.173	17%

d. Consistency Ratio

Consistency Ratio (CR) of the final matrix was calculated to ensure the logical consistency of the pairwise comparisons. The CR for the matrix was found to be 0.004, well below the generally accepted threshold of 0.10, indicating that the judgments were consistent and reliable. According to Saaty (1990), a consistency ratio below 0.10 suggests that the pairwise comparisons are logically sound and do not need revision. This level of consistency supports the validity of the weights and rankings produced by the analysis.

Sub-criteria

Sub-criteria were developed to provide a detailed assessment of each main criterion, allowing for a more granular evaluation of specific aspects that influence the success of the project. Each sub-criterion was designed to capture a critical factor within the broader context of the main criterion. Post the first workshop, the final list of sub-criteria was developed through a combination of literature review, internal discussions and expert consultations. Sub-criteria for each criterion of the MCA are listed below and shown in Table 5.

Technical and infrastructure feasibility

- **Water resource availability** – the new/improved water source should be able to increase water availability vis-à-vis the current source and be adequate for the proposed agricultural activities by incorporating an assessment of the reliability of these sources along with integrated water resource management practices. This includes ensuring protection, recharge, and sustainable management of water sources to enhance long-term availability and resilience.
- **Best-fit technology** – selection of irrigation technology should be evaluated based on project requirements, resource availability (such as solar, wind, etc.), the levelized cost over the project's life cycle, and gender-friendly to ensure a cost-effective and sustainable solution.

- **Water transmission, storage and distribution network** – pipe/channel network (existing and new) should be able to deliver the proposed volume of the water with equitable distribution to the beneficiaries. The network should also be sustainable, i.e., economical, easy to operate, low maintenance and less prone to damage.
- **Road access and communications** – accessibility to and from the site is important for the project installation as well as the transport of agricultural produce. An all-weather road should provide access for installation and maintenance. Other types of roads can also be considered provided they ensure basic access for installation and maintenance, albeit with some difficulty. A good mobile network for communication would allow the deployment of mobile-based smart solutions, improving the monitoring, operations and maintenance of the systems.
- **Access to grid** – having access to the grid allows net metering in the future which allows additional revenue sources.

Economic and financial feasibility

- **Financial returns on the project** – financial returns can be quantified as an increase in revenue and a reduction in input costs against the project cost. Returns can be quantified in terms of net present value (NPV), internal rate of return (IRR) or payback period.
- **Economic Internal Rate of Return (EIRR)** – this considers financial returns on the project and its impact on the local economy.
- **Potential for market expansion** – the proposed project can help farmers move to high-value crops. Higher-value crops can help farmers expand their market from local to national and export markets.
- **Initial investment** – initial investment indicates the size of the project. Based on the policy priorities, initial investment can be evaluated.

Climate proofing and environmental impact

- **Water contamination** – the proposed project should not have any negative impact on local water resources, such as pollution and major diversion of the river flow.
- **Biodiversity** – the impact on biodiversity due to the proposed project should be minimal.
- **Soil erosion** – the increased water flow from the project should not increase in soil erosion.
- **Climate-proofing the infrastructure** – understanding climate patterns and designing irrigation systems that are adaptable to changing weather conditions and water availability is important for long-term viability. For example, adapting to changing climate and reducing weather-related risks such as droughts, floods, or erratic rainfall patterns.
- **Carbon emission reduction** – the proposed project should replace fossil fuel-based pumping systems with renewable energy alternatives such as solar, wind, or hydro-powered solutions. This transition should reduce greenhouse gas emissions and align with climate mitigation strategies.

Agricultural feasibility

- **Cultivable land** – assessment of the suitability of cultivation in terms of soil type, depth, slope, and relevant parameters.
- **Cropping intensity** – an increase in the number of crops in a year due to the proposed project can increase the revenue and profile of the farmers.
- **Crop diversification** – the proposed project can increase the variety of crops especially those that can help improve the soil quality.
- **Returns per acre** – returns per acre quantify the increase in profitability due to the proposed project.

Social and gender impact

- **Community engagement** – prioritise inclusive community engagement to ensure that both women and marginalised groups contribute meaningfully to the project's design, implementation, operation and maintenance, and decision-making. Strong community engagement, including women and marginalised groups, enhances ownership and ensures that the project aligns with the local needs. Additionally, the extent of community contribution, whether in the form of financial investment, labour, or governance participation, needs to be considered. Establishing community-led water management associations (WMAs) is vital in ensuring long-term governance and maintenance of irrigation infrastructure. This could include the percentage of community members, including women, involved in the project's daily operations, maintenance, logistical support, and decision-making related to its management.
- **GESI engagement** – adopt GESI-responsive engagement in project development, design, operation and maintenance, implementation, and decision-making that ensure opportunities for women to access, manage, and benefit from the irrigation systems. Focus on fostering leadership roles for GESI and increasing their participation in decision-making processes. Sub-indicators to be included are the proportion of male, female, and marginalised people's representation in project design, operation and maintenance, implementation, management, technical roles, leadership positions, and decision-making, such as water management associations.
- **Equity** – ensure that marginalised groups have fair and equitable access to resources, tariffs, incentives, and market access, and explicitly address social and economic inequalities in access to water, technology, market, and financial resources. This includes the proportion of farmers, including small-scale and marginalised farmers, benefiting from the irrigation system and the equity of water distribution among different social groups (i.e., women, men, and marginalised farmers).
- **Impact on the Socio-economy** – the project should contribute to overall socio-economic development by creating employment and business opportunities and increasing incomes. It should contribute to a reduction in time and labour burdens, particularly for women. It should assess the number of people benefiting from the project, including small-holder farmers and marginalised groups. The potential for job creation and business opportunities, such as agribusiness development and value chain enhancements, needs to be considered. Additionally, the project should evaluate its impact on household incomes, ensuring that beneficiaries experience financial improvements. Reduction of time and labour for women, particularly in water collection and irrigation activities, allowing them to engage in other productive and income-generating tasks, is an important aspect. Additionally, nutrition and food self-sufficiency should also be assessed, ensuring that improved irrigation contributes to greater food production, household food security, and dietary diversity for farming communities.

MCA Framework with Criteria and Sub-criteria

The proposed MCA framework outlines the key criteria and sub-criteria for prioritising renewable energy-powered lift irrigation sites in Bhutan, addressing important dimensions such as GESI, agriculture, technical feasibility, and sustainable development. It reflects stakeholder priorities and ensures coherence with national development goals as well as Bhutan's unique environmental and social context. Table 5 presents the updated MCA framework, detailing the criteria, sub-criteria, and guiding questions to support the effective prioritisation of potential sites.

Table 5. Multi-Criteria Assessment Framework

Criteria: Technical and infrastructure feasibility

Weightage **15%**

Sub-criteria	Questions for sub-criteria
Water resource availability	• Is the water resource available throughout the year? • Is it adequately available during the most important season? • Is there any conflict around water in the area? • Is there an existing system or capacity for water intake, enhancing recharge, and protecting intake infrastructure?
Best-fit technology	• What is the resource availability (such as solar, wind, hydro etc.)? • Is it technically feasible? • What is the levelized cost over the project's life cycle? • Is the technology gender-friendly?
Water transmission, storage and distribution network	• Is the distribution system economic, equitable and reliable?
Road access and communications	• Is there access to the road for the transportation of men and material for execution (installation and maintenance)? • Is 'the right way' available or not? • Are communication facilities accessible at the site? • Are smart communication technologies available to ease information access to communities?
Access to grid	• Does the site have access to the grid and the quality of the grid?

Criteria: Financial and economic feasibility

Weightage **25%**

Sub-criteria	Questions for sub-criteria
Financial returns on the project	• What would be the return of the project? (NPV, IRR, Breakeven point, cost-benefit ratio and payback period)
Economic internal rate of return	• Is the project viable as per the economic internal rate of return?
Potential for market expansion	• Is there potential for (1) market expansion, e.g. crops going to farther markets, (2) niche/certifiable product, e.g. organic, geographical indication (GI) etc.?
Initial investment	• What is the total, and per kW initial investment?

Criteria: Climate proofing and environment

Weightage 14%

Sub-criteria	Questions for sub-criteria
Water contamination	• Is there a negative impact on local water resources given that intensive agriculture would now be carried out?
Biodiversity	• Has the project got clearance from the relevant department with respect to its impact on biodiversity?
Soil erosion	• Would there be adverse effects on soil like increased erosion due to increased water flow?
Climate-proofing the infrastructure	• Does the project incorporate climate-proofing infrastructure measures to withstand extreme weather events?
Carbon emission reduction	• Is there carbon emission reduction?

Criteria: Agricultural feasibility

Weightage 29%

Sub-criteria	Questions for sub-criteria
Cultivable land	• Has an assessment been conducted on the suitability of cultivation considering soil type, depth, slope, and other relevant parameters?
Cropping intensity	• What will be the increase in cropping intensity due to the project?
Crop diversification	• Will there be any new crops that will be cultivated?
Returns per acre	• What will be the increase in income generated per acre for the farmers?

Criteria: Social and gender impact

Weightage 17%

Sub-criteria	Questions for sub-criteria
Community engagement	• Is the community actively participating in the project's development and future implementation? • In what forms are they contributing — through labour, financial support, or other means?
GESI engagement	• Is there adequate representation of GESI in the project's development and future implementation — for example, in terms of the number of men, women, and marginalised people? • Are GESI groups actively participating in decision-making roles?
Equity	• Would the project ensure fair water resource distribution, tariffs, incentives, and market access among farmers and that small-scale and marginalised farmers/vulnerable groups benefit from the project?
Impact on the socio-economy	• How many people have benefitted? • Potential number of jobs and businesses that can be created? • Increase in incomes of beneficiaries? • Reduction in time and labour of women? • Does the project improve the availability and affordability of nutritious food for self-sufficiency?

Discussion

A pairwise comparison matrix as explained in the methodology section is a tool used to compare different criteria or options against each other to determine their relative importance. For the MCA framework, it was used to compare each criterion against every other criterion to determine their relative importance. The results of the MCA framework highlight the priorities of stakeholders in Bhutan when evaluating RE-powered lift irrigation systems. The high weightage given to Agricultural Feasibility (29%) suggests that stakeholders are aware of the importance of improving agricultural outcomes in rural Bhutan. The stakeholders prioritised the site's agricultural context and the project's effect on cropping intensity and agricultural productivity. Given that irrigation systems are intended to enhance crop yields and support food security, stakeholders have rightly emphasised the need to ensure these systems deliver measurable improvements in agricultural productivity. The distribution of weights is consistent with the core objectives of lift irrigation infrastructure, where the project's potential impact on agricultural productivity is identified as the primary determinant of its overall effectiveness. This is in consonance with the purpose of evaluating any lift irrigation project; that is, it should have a positive and substantial impact on the primary livelihood of the farmers.

The weightage given to 'Financial and economic feasibility' underscores the importance of ensuring the project's financial viability and its impact on the local economy. The 'Social and gender impact' is considered more critical than the 'Technical and infrastructure feasibility', as stakeholders prioritise the social and gender outcomes. Given that the RE-powered lift irrigation systems are intended to create significant positive effects on social and gender aspects, these impacts are deemed of greater importance in the project's overall evaluation. 'Technical and infrastructure feasibility' was also considered an important criterion and reflects stakeholders' acknowledgement of the need for equitable project benefits and practical infrastructure assessment. The weightage ensures that the concerns of marginalised groups, particularly women, are considered and are crucial for social equity and the long-term success of any project. The weightage of 'Climate proofing and environment' indicates stakeholders' recognition of the importance of the project's sustainability and resilience to climate change, given Bhutan's unique environmental challenges. The reduction of the criteria and the final proposed set of criteria was discussed in the Validation Workshop with stakeholders held in Thimphu on 18 October 2024.

Way Forward

A pairwise comparison matrix, as explained in the methodology section, is a tool used to compare different criteria or options against each other to determine their relative importance. For the MCA framework, it was used to compare each criterion against every other criterion to determine their relative importance. The framework will serve as a critical tool for evaluating and prioritising renewable energy-powered lift irrigation projects in Bhutan. The adoption process will include field trials to validate the methods for achieving sub-criteria indicators, sub-criteria weightage, and comprehensive training and capacity-building programmes for government officials and stakeholders involved in project evaluation. This will ensure the consistent and effective application of the MCA framework across various projects. Additionally, the framework should be designed for periodic review and updates to incorporate emerging changes, such as shifts in government policies, evolving climate risks, and technological advancements. This iterative approach will ensure that the MCA framework remains relevant, adaptive, and effective over time [Saaty 2008; Mardani et al., 2015].

References

- Mardani, A., Jusoh, A., MD Nor, K., Khalifah, Z., Zakwan, N., & Valipour, A. (2015). *Multiple criteria decision-making techniques and their applications – A review of the literature from 2000 to 2014*. Economic Research-Ekonomska Istraživanja, 28(1), 516–571. https://doi.org/10.1080/1331677X.2015.1075139
- National Environment Commission & Department of Agriculture. (2016). *National Irrigation Master Plan 2016*. Adapting to Climate Change through IWRM (Contract No. CDTA 8623-BHU, p. 187). Thimphu, Bhutan: Egis Eau, Royal Society for Protection of Nature, & Bhutan Water Partnership. Retrieved from https://www.adb.org/sites/default/files/project-documents/46463/46463-002-dpta-en_4.pdf
- National Statistics Bureau. (2022). *Integrated Agriculture and Livestock Census, Bhutan (p. 228)*. Thimphu: Royal Government of Bhutan. Retrieved from https://www.nsb.gov.bt/wp-content/uploads/dlm_uploads/2023/05/Report-re-for-web.pdf
- National Statistics Bureau. (2024). *Labour Force Survey: Fourth Quarter*. Thimphu: Royal Government of Bhutan. Retrieved from https://www.nsb.gov.bt/wp-content/uploads/dlm_uploads/2025/01/Q4-LFS-Report.pdf
- Saaty, T. L. (2008). *Decision making with the analytic hierarchy process*. International Journal of Services Sciences, 1(1), 83–98. Retrieved from https://www.rafikulislam.com/uploads/resourses/197245512559a37aadea6d.pdf.
- Wind, J., & Saaty, T. L. (1980). *Marketing applications of the analytic hierarchy process*. Management Science, 26(7), 641–658. https://doi.org/10.1287/mnsc.26.7.641

Bibliography

- Hezam, I.M., Ali, A.M., Sallam, K., Hameed, I.A., & Abdel-Basset, M. (2024). *An efficient decision-making model for evaluating irrigation systems under uncertainty: Toward integrated approaches to sustainability*. Agricultural Water Management, 303, 109034. https://doi.org/10.1016/j.agwat.2024.109034
- Jagu, D., Pugazenthi, D., Kishore, V.V.N. (2014). *Application of Multi-criteria Decision Aids for Selection of Off-Grid Renewable Energy Technology Solutions for Decentralised Electrification*. In: Bhattacharyya, S., Palit, D. (eds) Mini-Grids for Rural Electrification of Developing Countries. Green Energy and Technology. Springer, Cham. https://doi.org/10.1007/978-3-319-04816-1_11
- JICA (n.a). *Framework for Irrigation Development*. The Japan International Cooperation Agency (JICA). Retried from https://openjicareport.jica.go.jp/pdf/11705050_04.pdf
- Kumar, A., Sah, B., Singh, A.R., Deng, Y., He, X., Kumar, P., & Bansal, R.C. (2017). *A review of multi criteria decision making (MCDM) towards sustainable renewable energy development*. Renewable and Sustainable Energy Reviews, 69, 596-609. https://doi.org/10.1016/j.rser.2016.11.191
- Ministry of Works and Human Settlements (2009). *Environmental Impact Assessment & Management Plan*. Thimphu: Ministry of Works and Human Settlements, Royal Government of Bhutan. Retried from https://www.moit.gov.bt/wp-content/uploads/2010/11/3_EIA_EMP_BUDP2-Report_Nov-2009-.pdf
- National Environment Commission (2000). *Environmental Assessment Act of Bhutan 2000*. Thimphu: National Environment Commission, Royal Government of Bhutan. Retried from https://oag.gov.bt/wp-content/uploads/2010/05/Environmental-Assessment-Act-of-Bhutan-2000English-version.pdf
- National Environment Commission (2001). *Regulation for the Environmental Clearance of Projects*. Thimphu: National Environment Commission, Royal Government of Bhutan. Retried from https://oag.gov.bt/wp-content/uploads/2011/02/Regulation-for-the-Environmental-Clearance-of-Projects-2001-English.pdf
- Raza, M.A., Yousif, M., Hassan, M., Numan, M., & Kazmi, S.A.A. (2023). *Site suitability for solar and wind energy in developing countries using combination of GIS- AHP; a case study of Pakistan*. Renewable Energy, 206, 180-191. https://doi.org/10.1016/j.renene.2023.02.010
- Tiwari, D.N., Loof, R., & Paudyal, G.N. (1999). *Environmental–economic decision-making in lowland irrigated agriculture using multi-criteria analysis techniques*. Agricultural Systems, 60 (2), 99-112. https://doi.org/10.1016/S0308-521X(99)00021-9

Royal Government of Bhutan
Department of Energy
Ministry of Energy and Natural Resources

Telephone: +975 (2) 322 505 / 323 555 | Fax: +975 (2) 335 122
Website: https://www.moenr.gov.bt/