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

Landscape Assessment of **RENEWABLE ENERGY-POWERED LIFT IRRIGATION SYSTEMS IN BHUTAN**

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

Other contributors
Mewang Gyeltshen, ICIMOD
Nedup Tshering, Sangsel Eco Trade & Environmental Services
Pratha Mishra, PCC
Prodyut Mukherjee, En-genuity
Ranjit Chandra Vallabhaneni, En-genuity
Sarada Tiwari, ICIMOD
Simran Silpakar, ICIMOD
Sudeshna Maitra, PCC
Zeko, Sangsel Eco Trade & Environmental Services

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

Citation
DoE, 2025. *Landscape Assessment of Renewable Energy-Powered Lift Irrigation Systems in Bhutan.* Department of Energy, Ministry of Energy and Natural Resources, Royal Government of Bhutan.

ISBN: 978-99936-703-5-3

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

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.

Landscape Assessment of
RENEWABLE ENERGY-POWERED LIFT IRRIGATION SYSTEMS IN BHUTAN

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 energy sector plays a crucial role in driving economic growth, enhancing livelihoods, and ensuring sustainable development. As we navigate the challenges posed by climate change, water resource variability, and energy security, it is imperative to explore innovative and resilient solutions that support our national priorities, particularly in the agriculture sector.

Agriculture in Bhutan faces significant challenges, including labour shortages, water scarcity, human-wildlife conflicts, and limited market access. Despite abundant water resources, only 20% of agricultural land has irrigation access due to the country's rugged terrain, which makes water extraction difficult. Climate change exacerbates these issues, threatening livelihoods, and leaving women to manage farms under increasingly harsh conditions. To address these challenges, Bhutan is prioritising climate-resilient technologies, including renewable energy (RE)-powered lift irrigation systems such as solar PV pumping, to enhance water access and agricultural productivity. In this context, renewable energy-powered irrigation systems present a transformative opportunity to enhance agricultural productivity while reducing dependence on fossil fuels.

This landscape assessment provides a comprehensive analysis of the current state of RE-powered irrigation in Bhutan. It examines gender roles, access and capacity within the sector while identifying opportunities, and provides recommendations to promote gender-equitable and socially inclusive (GESI)-responsive RE-powered irrigation systems. The findings and recommendations in this report will serve as a valuable resource for policymakers, practitioners, and development partners in advancing sustainable energy solutions for Bhutan's agriculture sector. We are particularly grateful to the International Centre for Integrated Mountain Development (ICIMOD) for their invaluable technical expertise, regional insights, and dedication to sustainable development, which have been pivotal in shaping this report. We also extend our sincere thanks to the International Development Research Centre (IDRC) for their generous funding support, which made this work possible.

We extend our sincere gratitude to all stakeholders involved in the development of this landscape report, including government agencies, private sector actors, financial institutions, civil society organisations, communities, and end-users. We also thank the dedicated staff members of the Department of Energy (DoE), and all stakeholders associated for their input and support to this important study. Their collective expertise has been instrumental in assessing the feasibility, economic viability, and long-term sustainability of these systems in Bhutan's unique geographical and climatic context.

As we continue our journey toward a greener and more resilient future, I hope this report will inspire further collaboration and action in scaling up renewable energy-powered irrigation systems. The insights presented here will contribute to Bhutan's broader efforts in achieving a sustainable agricultural sector, strengthening rural livelihoods, and fulfilling our national and global climate commitments.

Karma P Dorji
Director General

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

ICIMOD

PREFACE

Agriculture is the backbone of Bhutan's rural communities, sustaining livelihoods and safeguarding food security for generations. Yet, as climate variability intensifies and traditional rainfed systems become increasingly unreliable, our farming communities face unprecedented challenges—declining yields, decreasing crop diversity, and unstable incomes. Renewable energy-powered lift irrigation systems emerge as a transformative solution - one that simultaneously addresses water security, climate resilience, and inclusive development while supporting Bhutan's carbon-neutrality commitments.

This Landscape Assessment of Renewable Energy-Powered Lift Irrigation Systems in Bhutan offers a multidimensional examination of the sector, providing stakeholders with:

- A comprehensive status assessment of existing systems
- Critical analysis of technical, financial, and governance barriers
- Identification of market needs and environmental considerations
- Gender Equality and Social Inclusion (GESI) perspectives
- Policy and institutional framework evaluation
- Practical and scalable recommendations for sustainable adoption

What makes this work particularly significant is its grounding in Bhutan's unique context. The nation's abundant renewable energy potential creates ideal conditions for pioneering sustainable irrigation solutions. Realising this potential requires moving beyond technology to address systemic barriers in policy, governance, finance, capacity, and gender equality and social inclusion. This report serves as a strategic roadmap for strengthening Bhutan's clean energy transition while enhancing agricultural productivity and rural resilience.

This study is developed as a part of the Women's Empowerment through Renewable Energy-Powered Decentralized Lift Irrigation Systems in Bhutan (WERELIS-Bhutan) project, supported by the International Development Research Centre (IDRC). We extend our sincere gratitude to IDRC for their commitment to gender-responsive energy solutions in agriculture. We also acknowledge the invaluable contributions of the Department of Energy, under the Ministry of Energy and Natural Resources, ICIMOD's Energy Team, and all stakeholders who provided technical expertise and insights. Their work provides both the evidence base and practical pathways needed to transform Bhutan's agricultural sector through renewable energy-powered irrigation.

As part of ICIMOD's mission to promote sustainable mountain development, this report underscores the importance of cross-sectoral collaboration in energy and agriculture. I invite our international partners, policymakers, and development practitioners to consider adopting and promoting this report's recommendations. Together, we can scale these solutions to benefit not just Bhutan, but mountain communities across the Hindu Kush Himalaya region.

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

अन्तर्राष्ट्रिय एकिकृत पर्वतीय विकास केन्द्र
国际山地综合发展中心

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 Landscape Assessment of Renewable Energy-Powered Lift Irrigation Systems 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 also express our sincere gratitude to the expert teams from ICIMOD and PopulationCouncil Consulting Private Limited for their technical contributions and insights in shaping this landscape study. Their expertise has been instrumental in providing a comprehensive understanding of renewable energy-powered lift irrigation systems in Bhutan.

Our heartfelt thanks go to all relevant stakeholders, including participants in consultation and validation workshops, key informant interviewees, and the community and the beneficiaries of the irrigation projects. Their valuable inputs and experiences have enriched this report, making it a truly collaborative effort. Their participation has been instrumental in ensuring that this assessment reflects on-the-ground realities and practical solutions for the effective implementation of renewable energy-powered irrigation projects in Bhutan.

This report represents a collaborative effort aimed at enhancing rural livelihoods, strengthening food security, and advancing renewable energy adoption in Bhutan's irrigation sector. We look forward to continued partnerships in translating these findings into actionable strategies and sustainable interventions.

LIST OF ABBREVIATIONS

ADB	Asian Development Bank
AREP	Alternative Renewable Energy Policy
BAOWE	Bhutan Association of Women Entrepreneurs
BCCI	Bhutan Chamber of Commerce & Industry
BDBL	Bhutan Development Bank Limited
BoB	Bank of Bhutan
BOO	Build Own Operate
BOOT	Build Own Operate Transfer
BPC	Bhutan Power Corporation
BTFEC	Bhutan Trust Fund for Environmental Conservation
CSO	Civil Society Organisation
CST	College of Science and Technology
DDG	Decentralised Distributed Generation
DECC	Department of Environment and Climate Change
DoA	Department of Agriculture
DoE	Department of Energy
DoID	Department of Infrastructure Development
DoW	Department of Water
DRE	Department of Renewable Energy
EE	Energy Efficiency
FAO	Food and Agriculture Organization
FDI	Foreign Direct Investment
FI	Financial Institutions
FMCL	Farm Machinery Corporation Limited
FYP	Five-Year Plan
GBPL	Green Bhutan Corporation Limited
GCF	Green Climate Fund
GDP	Gross Domestic Product
GESI	Gender Equality and Social Inclusion
GIS	Geographic Information System
GLOF	Glacial Lake Outburst Flood
GPS	Global Positioning System
GVA	Gross Value Added
HP	Horsepower
ICIMOD	International Centre for Integrated Mountain Development
IDRC	International Development Research Centre
IEE	Initial Environmental Examination

ILAR	Integrated Livestock and Agriculture Report
IMP	Irrigation Master Plan
IWRM	Integrated Water Resources Management
KII	Key Informant Interviews
LG	Local Government
LULC	Land Use and Land Cover
MCA	Multi-Criteria Assessment
MoAF	Ministry of Agriculture and Forests
MoAL	Ministry of Agriculture and Livestock
MoENR	Ministry of Energy and Natural Resources
MoIT	Ministry of Infrastructure and Transport
NAS	National Agriculture Statistics
NCAM	National Commission on Agricultural Mechanization
NCHM	National Centre for Hydrology and Meteorology
NCWC	National Commission for Women and Children
NGO	Non-governmental Organisation
NIMP	National Irrigation Master Plan
NIP	National Irrigation Policy
O&M	Operation and Maintenance
PLF	Plant Load Factor
PURE	Productive Use of Renewable Energy
PM-KUSUM	Pradhan Mantri Kisan Urja Suraksha evam Utthaan Mahabhiyan
PV	Photovoltaic
R&D	Research and Development
RE	Renewable Energy
REDF	Renewable Energy Development Fund
RET	Renewable Energy Technology
RGoB	Royal Government of Bhutan
SRTM	Shuttle Radar Topography Mission
SWG	Sherchok Women's Group
UNDP	United Nations Development Programme
UNFCCC	United Nations Framework Convention on Climate Change
USGS	United States Geological Survey
WERELIS	Women's Empowerment through Renewable Energy-Powered Decentralized Lift Irrigation System
WTE	Waste-to-Energy
WUA	Water User Associations

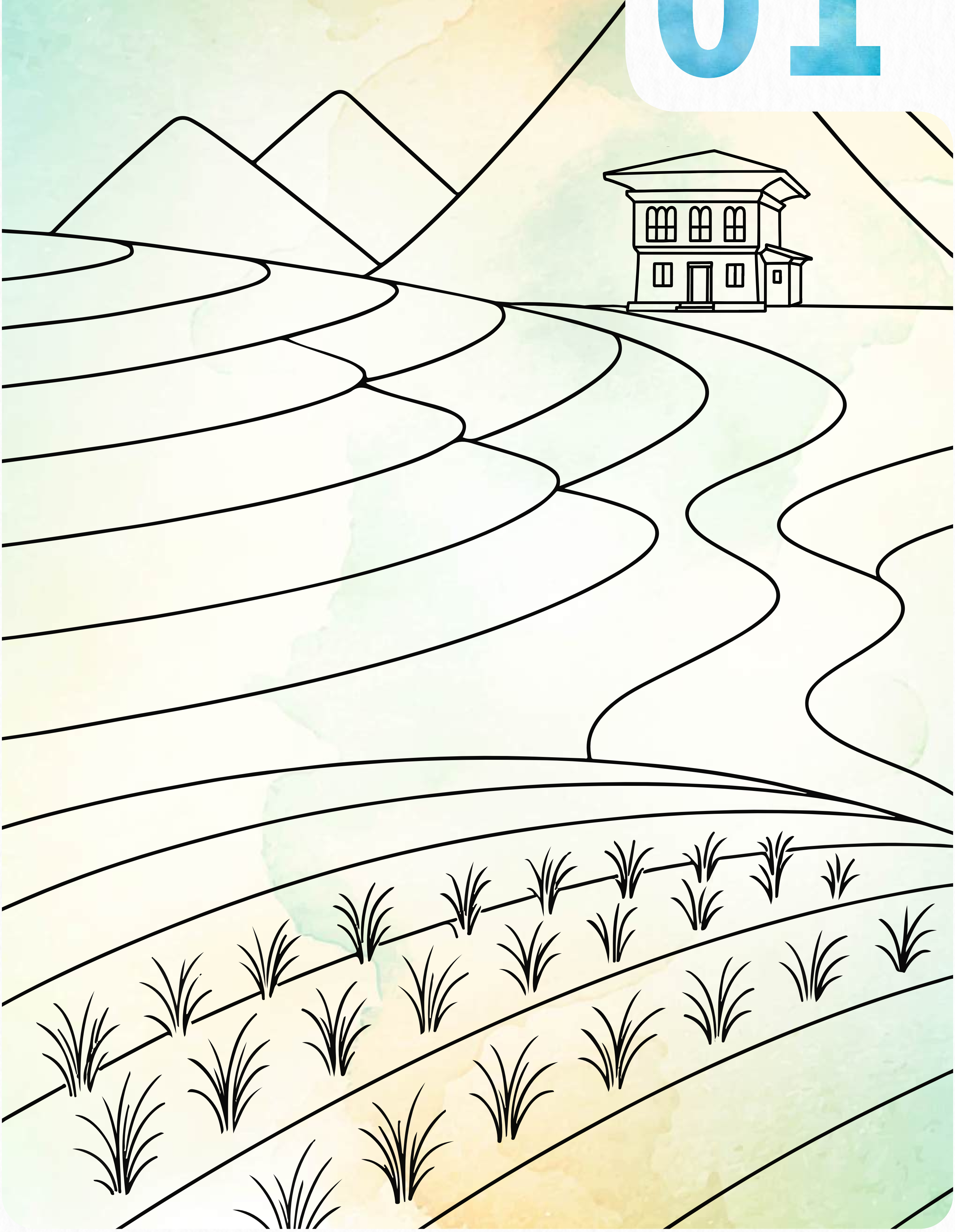
TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Introduction

01



Agriculture's contribution to Bhutan's GDP has been steadily declining, presenting significant challenges in achieving self-sufficiency in staple crops. Projections indicate a potential 4–10% decline in agricultural productivity due to climate change, underscoring the urgent need for adaptive measures. In nominal terms, the Gross Value Added (GVA) of the primary sector reached up to Nu 37 billion in 2023, an increase from Nu 33 billion in 2022, with the sector contributing 14.96% [1] to the economy. While the absolute value of the primary sector (encompassing agriculture, livestock, and forestry) has risen year-on-year, its overall share of national GDP has been on the decline [2]. Notably, the agriculture sector remains the second-largest employer in Bhutan, accounting for approximately 40% of the total workforce, while the service sector employs 43% and the industrial sector 17%.

43% employed in service sector

40% employed in agriculture sector

17% employed in industrial sector

Further, a higher proportion of employed females work in the agriculture sector (50.7%) compared to other sectors, whereas a higher proportion of employed males work in the service sector (46.4%), followed by the agriculture sector (32.9%) [3].

Agriculture relies heavily on rain-fed systems and faces significant irrigation deficits. Despite its rich water resources, Bhutan effectively utilises only a small fraction of its fresh water. Currently, irrigation practices in Bhutan are predominantly gravity-fed and seasonal, relying on open-channel systems that are highly susceptible to climate variability, resulting in declining crop yields, an increase in fallow land, and a growing dependence on food imports, thereby threatening national food security. In a country characterised by steep and hilly terrain, water often needs to be lifted from lower-altitude rivers to irrigate agricultural areas at higher elevations. However, these challenges also present a unique opportunity, given Bhutan's abundant renewable energy (RE) resources [4].

RE-powered irrigation solutions, such as solar photovoltaic (PV) pumping systems, have shown great potential to address irrigation issues while advancing social and environmental objectives. These technologies are often considered gender-inclusive, as they alleviate the time and labour burden on women farmers, and enhance their health and economic conditions, strengthening not only food security but also livelihoods. 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 in this sector. Among these, RE-powered lift irrigation systems are emerging as transformative solutions to address water accessibility, particularly in remote and hilly regions [5]. These efforts will ensure long-term food security, improve gender equality, and accelerate Bhutan's transition to an inclusive, low-carbon energy future.

To support these goals, a comprehensive sector landscape assessment study has been undertaken to evaluate the status and potential of RE-powered lift irrigation systems in Bhutan. The study arises from the urgent challenges facing Bhutan's agricultural productivity, water management, and socio-economic inequalities, all exacerbated by climate change and structural limitations.

The study aims to provide actionable insights to bridge existing gaps, optimise resource use, and ensure long-term agricultural sustainability. The current state of Bhutan's agriculture, combined with its complex challenges, underscores the urgency and relevance of this research.

1.1. Objective

The specific objectives of the study are to:

1.1.1. Review and Evaluate the Current Landscape

Evaluate the current state of RE-powered lift irrigation systems across various aspects, including policy and governance structures, technical viability, capability, financial mechanisms, and gender equality and social inclusion (GESI) through a participatory research approach based on secondary and primary data.

1.1.2. Identify the Gaps and Challenges

Examine critical gaps and challenges impacting the development, implementation, and scalability of RE-powered lift irrigation systems through a multi-dimensional lens that encompasses institutional governance, policy and regulations, technical, financial, capacity, GESI, and climate and environmental aspects.

1.1.3. Develop Evidence-Based Recommendations

Develop actionable, evidence-based recommendations to assist policymakers in designing sustainable, scalable, and gender-inclusive interventions that enhance the advantages of RE-powered lift irrigation systems in Bhutan.

1.2. Approach and Methodology

This assessment report employs a participatory research approach to conduct an in-depth, multi-dimensional sectoral analysis aimed at evaluating the effectiveness of RE-powered lift irrigation systems in Bhutan. The research integrates both primary and secondary data collection methods, ensuring a comprehensive evaluation of the sector. This study provides a holistic understanding of the current status of RE-powered lift irrigation systems, including their operational challenges, performance metrics, and community involvement.

By combining desk-based policy reviews, on-site assessments, stakeholder consultations, validation workshops, and field assessments, including key informant interviews (KIIs), it ensures that the findings are comprehensive, inclusive, and actionable. The methodology prioritises inclusivity, evidence-based analysis, and sustainability as detailed below.

Inclusivity
The research incorporates a diverse range of stakeholder perspectives, including policymakers, technical experts, civil society representatives, the private sector, multi- and bilateral organisations, financial institutions, and local communities. Special emphasis is placed on GESI, ensuring that the voices of women and marginalised groups are represented throughout the study.

Evidence-Based Analysis
The study leverages existing data, reports, policy documents, case studies, and field observations to identify gaps, challenges, opportunities, and emerging trends in the implementation of RE-powered lift irrigation systems.

Sustainability and Climate Focus
The research aligns with Bhutan's climate, energy, and sustainable development goals, with a strong emphasis on environmental and financial sustainability, aiming to support the country's low-carbon development aspirations.

1.2.1. Research Design

The research employs a mixed-methods approach that combines qualitative and quantitative data collection techniques. This design ensures a thorough understanding of the current state and future potential of RE-powered lift irrigation systems in Bhutan. The key components of the research design include (1) Desk-Based Review, (2) Consultation with Stakeholders, (3) Field Visits and (4) Validation Workshop (Figure 1).

Figure 1 Overall Design and Approach of the Landscape Assessment Study

Desk-Based Review
To identify gaps in policy and implementation while establishing a multi-sectoral framework integrating irrigation, agriculture, and renewable energy systems.

Consultation with Stakeholders
To gather qualitative insights into challenges and opportunities by engaging key actors—such as government departments, farmers, NGOs, private sector representatives, and development partners—through workshops and interviews to understand their perspectives.

Field Visits
To existing renewable energy-powered lift irrigation systems will enable on-site assessments to gather primary data on technical, operational, and environmental aspects, while providing firsthand insights into system functioning and challenges.

Validation Workshop(s)
To validate findings, prioritise recommendations, and ensure alignment with local and national priorities, serving as a collaborative platform for stakeholders to refine actionable recommendations.

1.2.2. Research Framework

The framework for the study is structured around several key dimensions that provide a comprehensive evaluation of RE-powered lift irrigation systems in Bhutan, as shown in Table 1.

Table 1 Key Factors and Indicators

Key Factors		Indicators
Governance, Policy, and Regulation	Institutional structures supporting RE-powered lift irrigation. Alignment of national policies with RE and agricultural development goals, which also includes policies on gender mainstreaming. Identification of regulatory barriers and enablers that affect the implementation of RE-powered systems.	Number of GESI-responsive policies and programmes supporting RE-powered lift irrigation, and coordination mechanisms among departments, with clarity on roles and responsibilities.
Technical Feasibility	The availability and reliability of RE technologies suitable for lift irrigation. Standards and efficiency of energy solutions in supporting sustainable irrigation practices. Evaluation of technical challenges related to system implementation, scalability, and maintenance.	Technology availability, demand, standards, supply chain, scalability, and Operation and Maintenance (O&M) practices.
	Identification of operational hurdles (including gendered access to technology and technical barriers for women) affecting the sustainability and performance of RE-powered systems, such as lack of training or social/cultural obstacles. Challenges related to the long-term maintenance of lift irrigation systems powered by RE.	
Financial Mechanisms	Cost-effectiveness of RE-powered lift irrigation systems.	Financing and business models in place, and also the affordability of the system.
	Availability of financial resources, such as grants, subsidies, and innovative financial models to support farmers and implementers. Exploration of financing options and mechanisms (including impact on gender	

	equality and equity, particularly for female farmers or female-led farming households) that ensure the scalability and sustainability of RE-powered systems.	
Gender Equality and Social Inclusion	The inclusivity of women and marginalised communities in the planning, implementation, and management of RE-powered lift irrigation systems. Ensuring equitable access to irrigation technologies for all community members, focusing on empowering women in agriculture.	Women's participation in planning and decision-making, impact on women's workload, equitable benefit distribution and participation.
Capacity and Capability	Assessing the technical expertise available within the implementing agencies, along with gender representation. Identifying capacity-building needs for government departments, local stakeholders, and other national entities involved in implementing RE-powered systems.	Technical skills available; technical and skill development programme with areas of strengthening, along with an implementation plan.
Climate and Environmental Aspects	Evaluating the impact of RE-powered systems on reducing greenhouse gas emissions and contributing to climate resilience. Assessing the adaptability of lift irrigation systems to varying climatic conditions and their role in strengthening agricultural systems against climate change.	Reduction in carbon emissions, ecosystem impacts, risk mitigation plans.
	Assessing the impact on women's vulnerability to climate change, especially in rural areas.	

This integrated approach provides a comprehensive understanding of RE-powered lift irrigation systems, identifying sustainable solutions tailored to Bhutan's unique GESI, economic, and environmental context. By employing this comprehensive approach, the research evaluated the technical and economic dimensions and connected irrigation access to enhance agricultural productivity, social inclusion, and gender equity. This provides a well-rounded understanding of the role of RE-powered lift irrigation in Bhutan's rural development.

1.2.3. Data Collection

The study involves data collection of both primary and secondary data as follows:

Secondary Data Collection

The study involved a desk review of existing literature and policies, such as the National Irrigation Master Plan (NIMP, 2016), Five Year Plans, Alternative Renewable Energy Policy (AREP, 2013), National Statistics Bureau (multiple years), National Agriculture Statistics (NAS, 2023), Integrated Livestock and Agriculture Report (ILAR, 2022), FAO Food systems Report (2022) and others.

Primary Data Collection

- **Stakeholder Engagements:** Conducted 30 KIIs with diverse stakeholders, comprising 18 males and 13 females from research institutions, government departments, financial institutions, the private sector, NGOs and communities to capture diverse perspectives on the implementation of RE-powered lift irrigation systems (Refer to Annexure 1).

- **Stakeholder Consultations and Validation Workshops:** Stakeholder consultation and validation workshops encouraged active discussions and group work with breakout sessions to identify challenges, opportunities, and qualitative insights into various aspects, such as technical feasibility, on-ground management practices, governance frameworks, policy constraints, and social dynamics related to managing RE-powered lift irrigation systems. Two stakeholder workshops were conducted to discuss challenges and opportunities for managing RE-powered lift irrigation systems.

  The participatory and validation workshop was conducted in Thimphu, with 26 participants (16 male, 10 female) and 31 participants (23 male, 8 female) respectively from diverse stakeholders including government agencies, research institutions, donors, private institutions, NGOs, community groups and banks. Both workshops facilitated active discussions and provided insights into the systems' technical, social, and governance aspects (Refer to Annexure 1).

- **Site Visits:** Observations were made at nine selected lift irrigation systems to assess the performance, identify operational challenges, and understand local community aspects (Refer to Annexure 1).

1.2.4. Data Analysis

Secondary Data Analysis

This phase involved an extensive review of existing literature, policies, and frameworks to establish a fundamental understanding of RE-powered lift irrigation systems in Bhutan. The analysis prioritised critical themes such as governance, gender and social inclusion, economic viability, and technical efficiency. Insights from this review shaped the research framework and identified gaps, challenges, and potential opportunities for RE-powered lift irrigation systems.

Primary Data Analysis - Surveys

The primary data analysis used a comprehensive approach involving stakeholder engagements, field visits, and participatory workshops. KIIs were carried out with representatives from government agencies, farmers, financial institutions, NGOs, and technical experts to gather diverse insights on RE-powered irrigation systems. Field visits to nine selected locations across Bhutan provided firsthand observations of system performance, challenges, and community dynamics. These were supplemented by participatory and validation workshops, where stakeholders engaged in discussions and breakout sessions to identify gaps and fill in data. Data collection was structured to capture regional variations and ensure inclusivity, covering technical, economic, social, and environmental aspects. This integrated methodology facilitated a multi-dimensional understanding of RE-based irrigation systems in Bhutan, bridging gaps between field realities and policy considerations. The following sampling strategy was employed to strengthen the analysis.

1.2.5. Sampling Strategy

The sampling strategy for this study was carefully designed to ensure a comprehensive and representative dataset that captures the diverse perspectives of key stakeholders involved in Bhutan's RE-powered lift irrigation systems. The approach combined purposive sampling, stratified sampling, and geographical representation to include all relevant stakeholder groups while accounting for regional variations across the country.

Purposive Sampling

Purposive sampling was employed to select respondents based on their specific roles, expertise, and direct involvement in the lift irrigation systems' management, policy development, and operation. This method was critical for the KIIs, allowing the study to engage individuals with in-depth knowledge and experience in the functioning and governance of irrigation systems. Respondents were drawn from key institutions such as government agencies (e.g. Department of Water, Department of Energy), financial institutions (e.g. Bhutan Development Bank Limited, Bhutan National Bank), non-governmental organisations (NGOs) (e.g., Bhutan Trust Fund for Environmental Conservation), Civil Society Organisations, and local communities (e.g. village representatives, farmers).

Stratified Sampling

Stratified sampling was used to ensure the inclusion of diverse stakeholder groups, each playing a different role in the functioning of the lift irrigation systems. Participants were categorised into key groups, ensuring a balanced representation across the various dimensions of the study. This included government officials, farmers and local communities, academic and research institutions, private sector entities and financial institutions. By incorporating stakeholders from each of these groups, the study could comprehensively evaluate the systems across multiple dimensions, including technical performance, economic viability, social inclusion, and environmental sustainability.

Geographical Representation

To ensure that the study reflected the regional variability of Bhutan's diverse landscape, respondents were selected from multiple Dzongkhags across the country during nine site visits and KIIs. The five Dzongkhags included Thimphu, Wangdue, Punakha, Samtse, and Paro. Table 2 details the location of the nine sites covered during the study.

Table 2 Site Visit and Geographical Details

Dzongkhag	Gewog	Irrigation Scheme
Paro	Shaba	Shaba pump/lift irrigation scheme (Gangri village)
Punakha	Barp	Lobesa pump/lift irrigation scheme (Lobesa village)
	Guma	Phaduna pump/lift irrigation scheme (Lakhu village)
	Guma	Pump/lift irrigation scheme (Dochhukha_Dzomlingthang_Ritsa chiwog)
Samtse	Namgaychhoeling	Jitti pump/lift irrigation scheme
	Ugyentse	Chunpathang pump/lift irrigation scheme (Thakuri Dara village)
Wangdue	Thedtsho	National Seed Centre
	Thedtsho	Agriculture Research Centre

The following instruments (Table 3) have been developed to facilitate effective engagement and data collection from diverse target groups involved in the workshops.

1.2.6. Report Writing and Recommendations

The final phase synthesised findings from the desk-based review, research design, and field surveys into actionable insights. The analysis led to the development of strategic, evidence-based recommendations targeting both technical and social dimensions of RE-powered irrigation systems. These recommendations address identified gaps and challenges while promoting sustainability, scalability, and inclusivity in Bhutan's RE-powered lift irrigation system.

Table 3 List of Survey Instruments

	Instruments		
	Framework for Group Work - Consultative Workshop	Structured Questionnaires – Field KIIs	Structured Individual KIIs
Government Agencies	✓		✓
Research Institutions	✓		✓
Private Sector	✓		✓
Financial Institutions	✓		✓
NGOs	✓		✓
Local Government Representatives	✓	✓	✓
Farmers		✓	✓
Local Communities		✓	✓
Village Heads		✓	✓
Engineers		✓	✓
CSOs			✓

Background

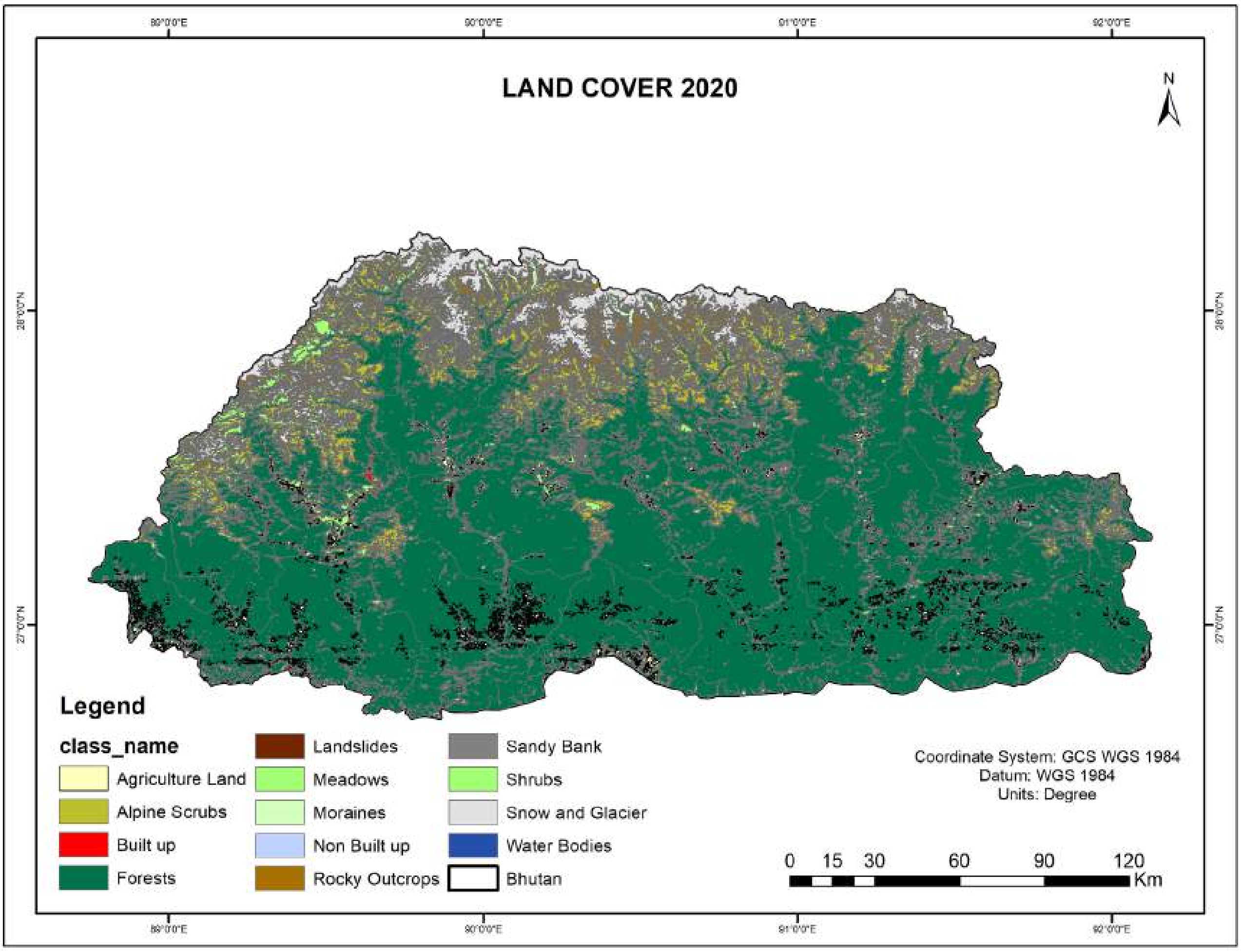
02

2.1. Country Profile

38,394 sq km

Bhutan spans roughly 38,394 square kilometres, making it one of the smallest countries in the world. Despite its size, its mountainous landscape and diverse ecosystems play a crucial role in its global importance. Bhutan's economy is primarily based on hydropower exports, agriculture, and tourism. The country has implemented strict policies to ensure that its development remains sustainable and minimises environmental impacts. With a population of around 770,276 (2023), the country upholds a deep commitment to harmonise environmental conservation, as well as the well-being of its people [6]. This steadfast dedication makes Bhutan one of the few carbon-negative nations globally.

Figure 2 Land Cover Map of Bhutan



Bhutan is administratively divided into 20 dzongkhags (districts), which serve as the primary units of governance. Each dzongkhag has its own unique identity, influenced by its geography, culture, and local traditions. For example, Thimphu Dzongkhag, which houses the capital, serves as the political and cultural centre of the country, while Paro is famous for its historical sites, such as the Taktsang Monastery. On the other hand, dzongkhags like Gasa and Lhuentse are celebrated for their unspoiled landscapes and rich cultural heritage. These districts, each led by a Dzongda, are further divided into gewogs (blocks) and thromdes (urban municipalities) to support decentralised governance and local development [6].

70%
Forest cover

7%
Permanent snow, glaciers

3%
Cultivation or agriculture

4%
Meadows and pastures

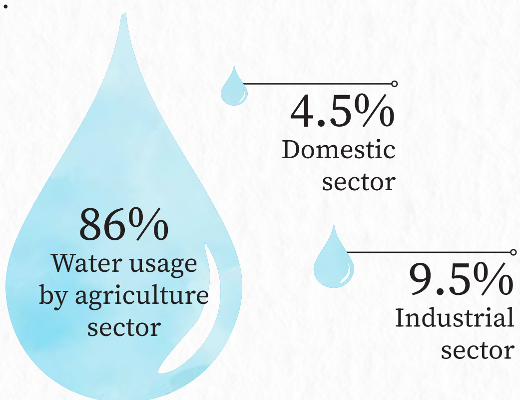
16%
Barren, rocky or covered in scrubland [7]

4.11%
Shrubs

8.89%
Alpine scrubs

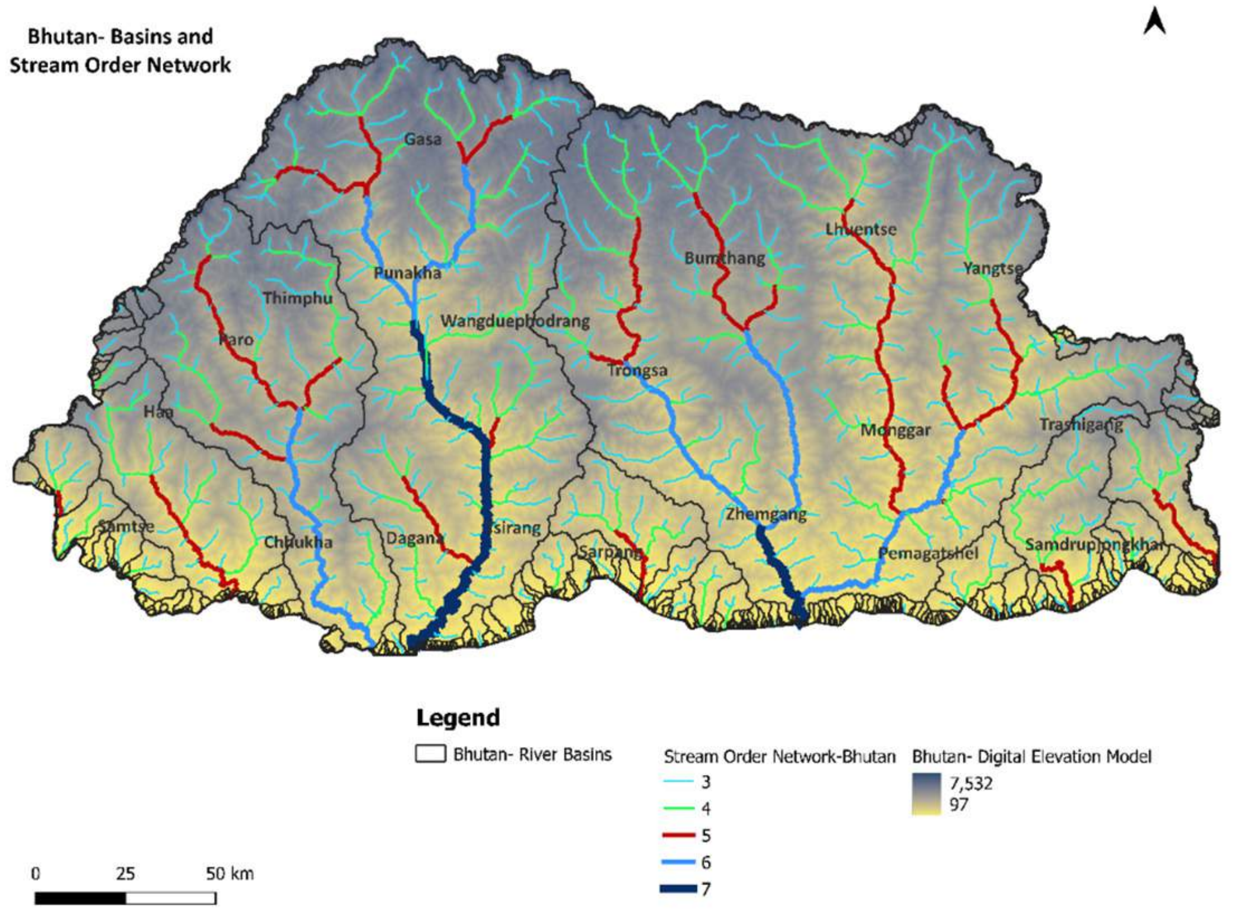
2.96%
Agricultural land equivalent to about 281,186 acres [8]

Bhutan is renowned for its abundant water resources. Despite its small size, the country boasts one of the highest per capita water availabilities in the world, with approximately 94,500 m^3 of water available annually per person. Most of Bhutan's water comes from glacial lakes, glaciers, wetlands, and monsoon-fed rivers, making it one of the most water-rich countries globally. However, managing these resources is complex due to the country's rugged terrain, climate variability, and socio-economic factors. Bhutan is home to over 2,674 glacial lakes, 700 glaciers, and five major rivers, namely, the Amochhu, Wangchhu, Punatsangchhu, Mangdechhu, and Drangmechhu, along with their tributaries, all of which play a vital role in the nation's hydrological system. This system supports agriculture, hydropower, and domestic needs. Notably, Bhutan uses only 1% of its annual freshwater resources. The agricultural sector is the largest consumer, accounting for 86% of water use, while the industrial and domestic sectors consume 9.5% and 4.5%, respectively [9].



The country's water system is heavily influenced by its elevation. In the high northern regions, glaciers and snowmelt feed fast-flowing streams that merge as they descend. These streams become larger rivers, providing water for hydropower, irrigation, and drinking needs. In the southern, lower regions, the rivers flow more gently and support agriculture. While the higher regions feature swift, turbulent streams, the lower areas are characterised by slower, meandering rivers (Figure 3).

Figure 3 Bhutan Basin and Stream Order Map



Hydrological and Geographic Zones

- **Southern Foothills:** The elevation of this zone ranges from 100 m to 1500 m with a subtropical climate with heavy monsoon rains, resulting in high river flows.
- **Central Inner Himalayas:** Temperate climate with moderate rainfall at altitudes of 1,500 to 3,000 meters.
- **Higher Himalayas:** Elevation from 3,000 – 7,500 meters with an Alpine climate including heavy snowfall and cold temperatures, home to Bhutan's glaciers.

Topographical Analysis

Based on the spatial analysis conducted utilising the Shuttle Radar Topography Mission (SRTM) 1 arc second Digital Elevation Model sourced from US Geological Survey (USGS), a topographical analysis was done to understand the sloping pattern of Bhutan (Figure 4) post which it was found that:

- **Low Slopes (0-21.82 degrees):** Valleys like Thimphu, Paro, and Punakha support agriculture and habitation.
- **Moderate Slopes (21.82-43.64 degrees):** Regions such as Wangdue Phodrang and Bumthang are suitable for cultivation but more challenging.
- **Steeper Slopes (43.64-65.47 degrees):** Regions like Lhuentse and Zhemgang face development and erosion issues.
- **Highest Slopes (65.47-87.29 degrees):** Northern areas like Gasa are rugged and unsuitable for land use, requiring careful management to prevent erosion.

2.2. Agriculture

Although the primary sector (encompassing agriculture, livestock, and forestry) has risen year-on-year, agricultural production in Bhutan has decreased over the years. The growth in the primary sector has been due to growth in the livestock and forestry sectors.

Agriculture is fundamental to Bhutan's economy and plays an important role in ensuring food security and supporting rural livelihoods. Staple crops such as rice, maize, and wheat have experienced notable decreases in production from 2005-2013. During this period, rice production decreased from 68,000 to 50,000 metric tons; maize production decreased from 94,000 to 46,000 metric tons; and wheat production decreased from 11,000 to 1,000 metric tons [10]. These numbers reflect the foundational role of these staples in the country's agriculture despite agriculture contributing 14.96% to Bhutan's GDP in 2023, key staples like paddy and cereals remain underproduced, highlighting the urgent need for improved irrigation to boost productivity [11].

In 2023, the primary sector grew by 1.37%, recovering from a negative growth of -1.15% in 2022, which marked its first decline. This improvement of 2.52 percentage points was largely driven by stronger performances in the livestock and forestry sectors, while the agriculture (crops) sub-sector experienced a decline compared to the previous year. Crops saw a negative growth rate of -1.95% in 2023, though this was less severe than the -4.00% drop in 2022, reflecting an improvement of 2.05% points [12]. While the sector faced negative growth, it remains crucial to the economy, indicating potential challenges or shifts in crop cultivation. Despite a decreasing share in Bhutan's GDP due to climatic, environmental, and socio-economic factors, agriculture continues to be a vital sector.

Bhutan's agricultural landscape is primarily made up of smallholder farms, with 99% of the 66,587 farms in 2019 classified as smallholdings, averaging 3.7 acres (1.5 hectares) each [13]. Despite the large amount of land, only 3% is arable, and a significant portion of the farmland remains underutilised due to various challenges [14]. In 2019, approximately 75% of the country's 250,000 acres (100,000 hectares) of agricultural land was cultivated, while around 25%, or about 66,000 acres, was left fallow [15].

Despite the agricultural potential, the sector has seen a decline in the harvested area and production of several crops over the years. For instance, between 2005 and 2019, the area under rice cultivation decreased from 62,457 acres to 30,313 acres, while maize and potato production also saw substantial drops. However, there were some exceptions, such as the increase in cardamom production due to its higher market value. Poultry and egg production also increased during this period, reflecting some level of diversification within the sector [14]. Rice, maize, and wheat are the primary cereals cultivated, with potatoes, vegetables, and fruits (such as apples, oranges, and others), contributing to domestic consumption and exports. However, the country struggles to meet its domestic food demand and remains reliant on imports, especially from neighbouring India, for essential food items [10].

2.2.1. GESI in Agriculture

The agricultural landscape in Bhutan restricts the use of farm machinery, resulting in a labour-intensive sector. Agriculture is increasingly becoming dominated by women, driven by factors like male out-migration, matrilineal inheritance traditions, and economic reasons. At present, 50.7% of employed women work in agriculture. These matrilineal customs enable women to own land, with women holding 45.98% of the land compared to 54.02% [16] held by men. However, decision-making authority often remains with male family members, limiting women's full control over agricultural activities [14].

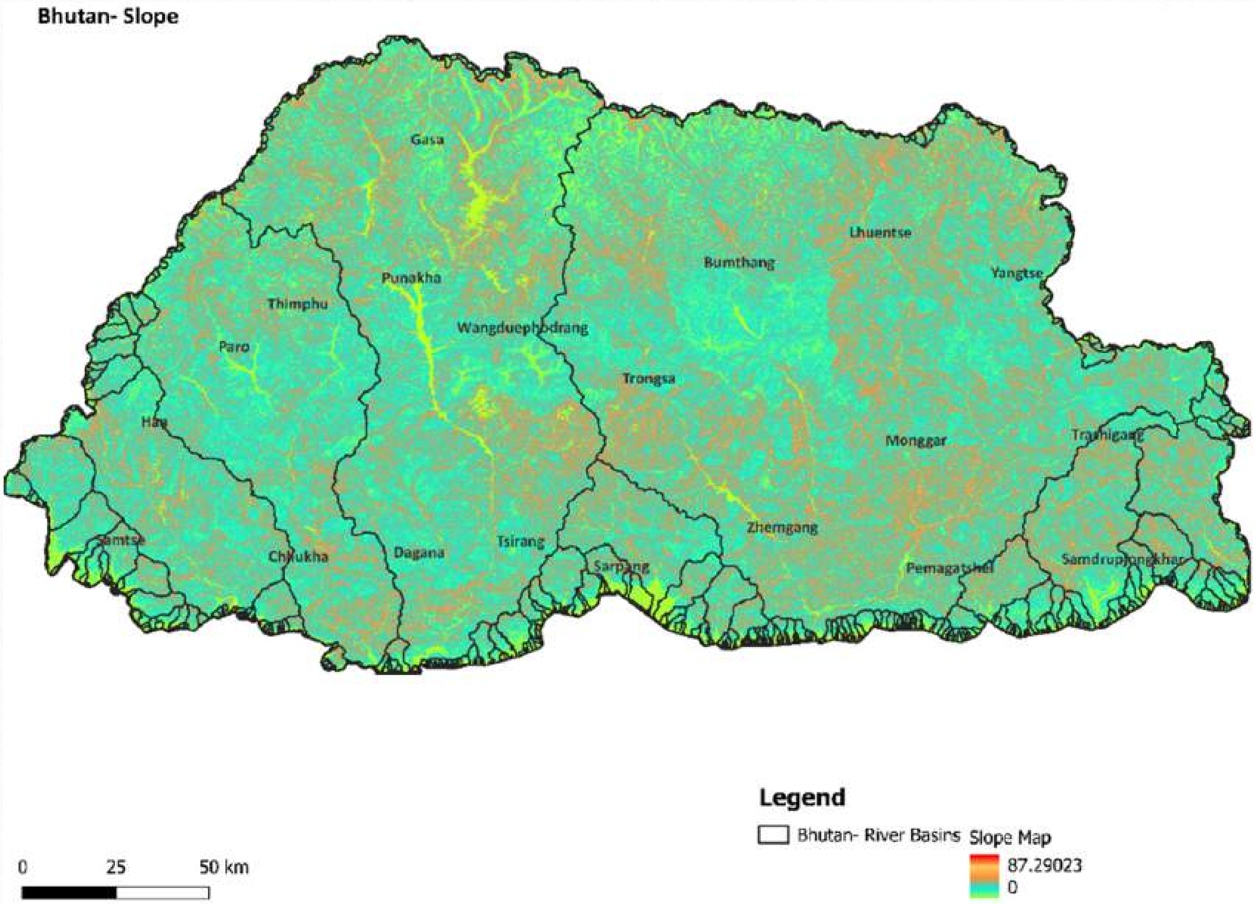
The trend of male out-migration to urban centres for jobs in construction, tourism, and hydropower projects has reduced male involvement in farming. Rural-to-urban migration accounted for 32.7% of all internal migration flows in Bhutan [17]. The migration trend is predominant among men, with a sex ratio of 118 males for every 100 female migrants, resulting in the feminisation of agriculture phenomenon [14].

In Bhutan's agricultural sector, integrating gender-responsive strategies is crucial to effectively address the challenges posed by climate change. The National Gender Equality Policy (NGEP) promotes the inclusion of gender perspectives in climate and disaster-related initiatives, acknowledging the significant roles women play in these areas. For instance, women are responsible for 71% of unpaid care work, which includes essential tasks like household waste management, such as sorting and recycling [18-19]. However, only 7% of surveyed respondents (based on primary field visits) reported having access to technologies that could assist with these tasks. In the energy sector, women mainly handle household energy needs, particularly for cooking and heating, yet they are often underrepresented in formal energy roles. Current development plans for this resource lack gender-inclusive and gender-responsive strategies for implementing and scaling these technologies.

2.3. Irrigation

In Bhutan, where most farmland relies on rainwater, irrigation plays a vital role in agriculture, making the sector highly vulnerable to climate change. As noted earlier, only a small fraction of the country's arable land is irrigated, despite irrigation being key to boosting agricultural production and ensuring food security. Monsoon rains account for about 75% of Bhutan's annual rainfall, falling between June and September. While the rainy season provides an abundance of water, shortages are common in the winter months, particularly in remote, hilly regions with challenges in water distribution. The country's rugged terrain exacerbates these issues, leading to localised water shortages, especially in rural and mountainous areas [9].

Figure 4 Slope Map of Bhutan



Recognising the importance of irrigation, the RGoB prioritised its development under its National Irrigation Master Plan (NIMP). The plan aims to invest around USD 140 million between 2016-17 and 2030-31 to boost food production and enhance food security. Key objectives of the NIMP include achieving food self-sufficiency and promoting large-scale commercial farming, ultimately improving both food production and market access.

Today, Bhutan has about 1,200 community-managed irrigation systems, of which 1,000 are operational, irrigating 64,248 acres of land. Most of these systems are gravity-fed, drawing water from second and third-order tributaries, which are reliant on monsoon rains. Water is tapped from the streams and springs, which are at a higher altitude vis-à-vis the irrigated area. The water is transported to the irrigation network of the catchment area with open or closed channels. Besides the gravity-fed systems, lift irrigation systems have also been deployed, although in small quantities. With the lift irrigation systems, water from the sources at a lower altitude than vis-à-vis irrigated areas is tapped using pumps. These pumps are energised with RE sources and/or utility [4]. Apart from these, farmers have also been tapping water from sources at lower altitudes using diesel pump sets. The pump and water delivery channel are temporary setups installed for a limited period and dismantled and stored away after use.

Bhutan has a few solar-based lift irrigation projects operational as well. The existing irrigation projects, with some upgrades to the irrigation network, have been used to convert the irrigation system from gravity-fed to lift irrigation powered by solar generation units. Table 4 lists the major components and their constituents for the RE-based lift irrigation project [20].

Table 4 Infrastructure Components for Solar Lift Irrigation Projects

	Energy Source	Pumping Unit	Irrigation Channel Infrastructure
Brownfield project – converting the existing irrigation system to a solar lift irrigation system	1. RE generation plant or utility connection infrastructure, like a transformer	1. Submersible pump	1. Transmission pipe carrying water from the pump to the irrigation canal network
	2. Fencing for security	2. Intake sump Note: Both the pump and the sump are installed in the river	2. Delivery tank at the end of the transmission pipe to reduce the flow
			3. Accessories like valves
			4. Improvements to the canal network
	Control room with pump motors, control panel etc.		
Additional infrastructure for the greenfield project			Irrigation canal network

Women who are particularly active in the agricultural sector in Bhutan have to largely depend on the men when it comes to technicalities in the irrigation system (especially diesel pumps) and decision-making related to financing and instalments [18, 21]. Thus, any technical advancements and adaptation of solar-powered lift irrigation systems and integration of technical expertise in the community would benefit farmers, both marginal and women, by sharing the workload, adapting reliable power sources and climate-resilient agricultural practices.

2.3.1. Policy

The involvement of the Bhutan Government in irrigation began formally in 1967, with the establishment of the Irrigation Division under the Department of Agriculture. This division manages irrigation channels, riverbank erosion, and rural roads. Initially, farmers managed irrigation systems with an annual government subsidy; however, in 1981, the government moved from annual subsidies to providing full funding for construction as well [22].

In 1992, the government introduced the **National Irrigation Policy (NIP)** with an emphasis on community participation in the construction and maintenance of these systems. In 2012, the government revised NIP with the aim of advancing the irrigation sector to achieve self-sufficiency and food security by promoting new technologies, institutional strengthening and empowering farmers without any gender dimension being addressed.

Subsequently, in 2016, the government introduced the **National Irrigation Master Plan (NIMP)**, with the objective to modernise and expand irrigation through new constructions and rehabilitations, focusing on Integrated Water Resources Management (IWRM). Under the Five-Year Plans and Annual Budget of the government, NIMP targets to increase the irrigated area from 64,248 acres in 2014 to 91,248 acres in 2032. In addition, 20,227 acres of irrigated land are planned through renovating, modernisation, and extending the existing systems. The rest is planned through new irrigation development projects. The NIMP seeks to enhance self-sufficiency in paddy and cereals to 75% and 80% by 2032 by increasing land under irrigation, to increase agricultural productivity, it is imperative to bring more land under irrigation, which will also lead to achieving national food security goals [4]. Currently, essential food sufficiency is low: 25.17% for rice and 50.35% for maize [23].

Under the Five-Year Plans, notable progress has been achieved in improving irrigation infrastructure. During the 11th Five-Year Plan (FYP), 49 irrigation schemes were renovated [4]. The 12th FYP further advanced the initiative by developing 12 new irrigation channels, renovating 71 existing channels, and providing irrigation to 14,370 acres of land [24]. Looking ahead, the 13th FYP (2024-2029) aims to develop 24 new irrigation channels, with a total planned length of 139.61 kilometres [25]. Among various recommendations outlined in the NIMP and FYP to address water scarcity, there is a strong focus on enhancing water efficiency through drip and sprinkler irrigation systems, along with lift irrigation, to improve access in hilly areas [22].

2.3.2. Governance

Bhutan's irrigation administration system operates at three levels: the Central Government at the top level, the Dzongkhag Administration at the intermediate level, and the Gewog Administration at the grassroots level. Since all beneficiaries are located at the Gewog level, where irrigation projects are implemented, the planning process needs to prioritise their active involvement and empowerment in decision-making. Each administrative level has specific responsibilities for the planning and execution of the irrigation projects as follows.

1. Gewog Administration

The Gewog administration identifies irrigation projects in consultation with the local communities. Once identified, the Gewog administration implements these projects. The Agriculture Extension Officer, acting as the focal project officer, is responsible for the overall coordination, planning, and ensuring timely completion of project activities.

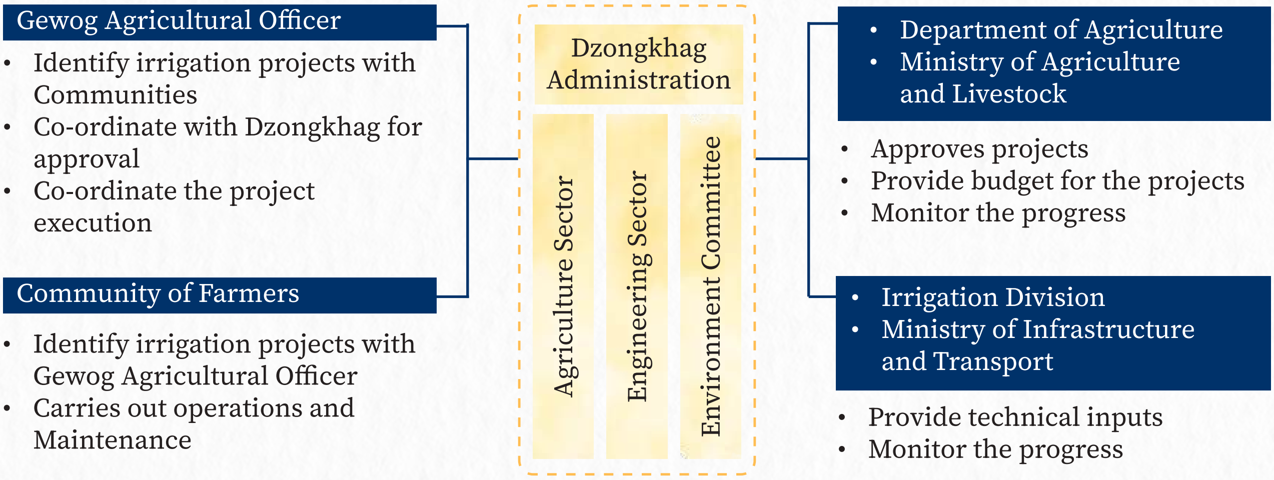
2. Dzongkhag Administration

The Dzongkhag administration provides support to Gewog by conducting feasibility assessments, engineering designs, and cost estimates, with input from the Irrigation Division under the Ministry of Infrastructure and Transport (MoIT). Additionally, the Dzongkhag administration is responsible for obtaining clearances for projects such as environmental clearance from the Department of Agriculture and clearance from the Department of Water. The Dzongkhag Environment Committee handles environmental clearance, ensuring compliance with various laws, including the National Environment Protection Act, Environmental Assessment Act, Waste Prevention & Management Act, and Water Act. For approved projects, the Dzongkhag Administration also handles the procurement process for selecting private contractors for implementation. The Dzongkhag administration, along with relevant ministries, monitors the progress of projects.

3. Central Administration

The project proposal, which incorporates inputs from local communities, Gewog, Dzongkhag, and MoIT, is submitted to the Department of Agriculture (DoA) under the Ministry of Agriculture and Livestock (MoAL). MoAL reviews the proposal, approves eligible projects, and allocates the necessary budgets for implementation. Major projects which are technically challenging and resource-intensive, which the Dzongkhags cannot implement, are taken up by DoA for execution. Construction of irrigation channels, as a Blue Category project, requires environmental clearance at the Initial Environmental Examination (IEE) Level. DoA is the competent authority for IEE for the construction of irrigation channels. A schematic diagram of the governance is presented in Figure 5.

Figure 5 A Schematic Diagram of the Governance[1]



Dzongkhag Administration

- Agriculture Sector co-ordinates with Gewog and Ministry of Agriculture and Livestock
- Engineering Sector carries out feasibility, costing and project design with inputs from Ministry of Infrastructure and Transport
- Environment Committee assesses and provides Environmental Clearance

2.4. Renewable Energy

Bhutan's RE sector is predominantly driven by hydropower, which contributes 96% of the country's total electricity production. Additional contributions come from solar, wind, and embedded hydro. Fossil fuels such as coal, diesel, petrol, kerosene, and aviation turbine fuel contribute 38% of the energy supply. Bhutan's RE potential is vast and estimated at 58,736 MW - comprising 23,296 MW from small hydropower, 12,000 MW from solar, and the remaining from other RE sources [20]. Currently, the country operates six hydropower plants, with four more under construction, set to add 2,938 MW upon completion. As of 2023, the country's total installed capacity is 2.3 GW, with hydropower contributing 99% (2,334 MW). Breakup of the RE potential, installed capacity and targets is presented in Table 5.

[1] Stakeholder Discussions, August & October 2024

Despite the dominance of hydropower, other RE sources like solar and wind are gaining attention. As of 2023-24, the installed capacities for solar, wind, and small hydropower are 5.1 MW, 0.6 MW, and 8 MW, respectively [26]. The 13th five-year plan emphasises deploying and expanding RE to over 500 MW. Table 6 shows the RE projects and targets in Bhutan.

Table 5 RE Potential and Installed Capacity in Bhutan

Source	Potential (MW) [27,28]	Targets by 2025 as per AREP, 2013 (MW) [20]	Target by 2029 as per 13-FYP, 2024 (MW) [23]	Installed Capacity (MW) (31 December 2024)[2]
Solar	12,000	Solar PV – 5 Solar thermal – 3	500	5.7
Wind	761	5	23	0.6
Hydro				
Large-hydro	33,600		12,297	2,444
Small-hydro			2,702	8
Biomass		Electricity – 5 Thermal – 3		
Wood-based	1,985			
Wood residue based	695			
Biogas	20,000 systems		1	
Green Hydrogen				

Table 6 Notable RE projects in Bhutan

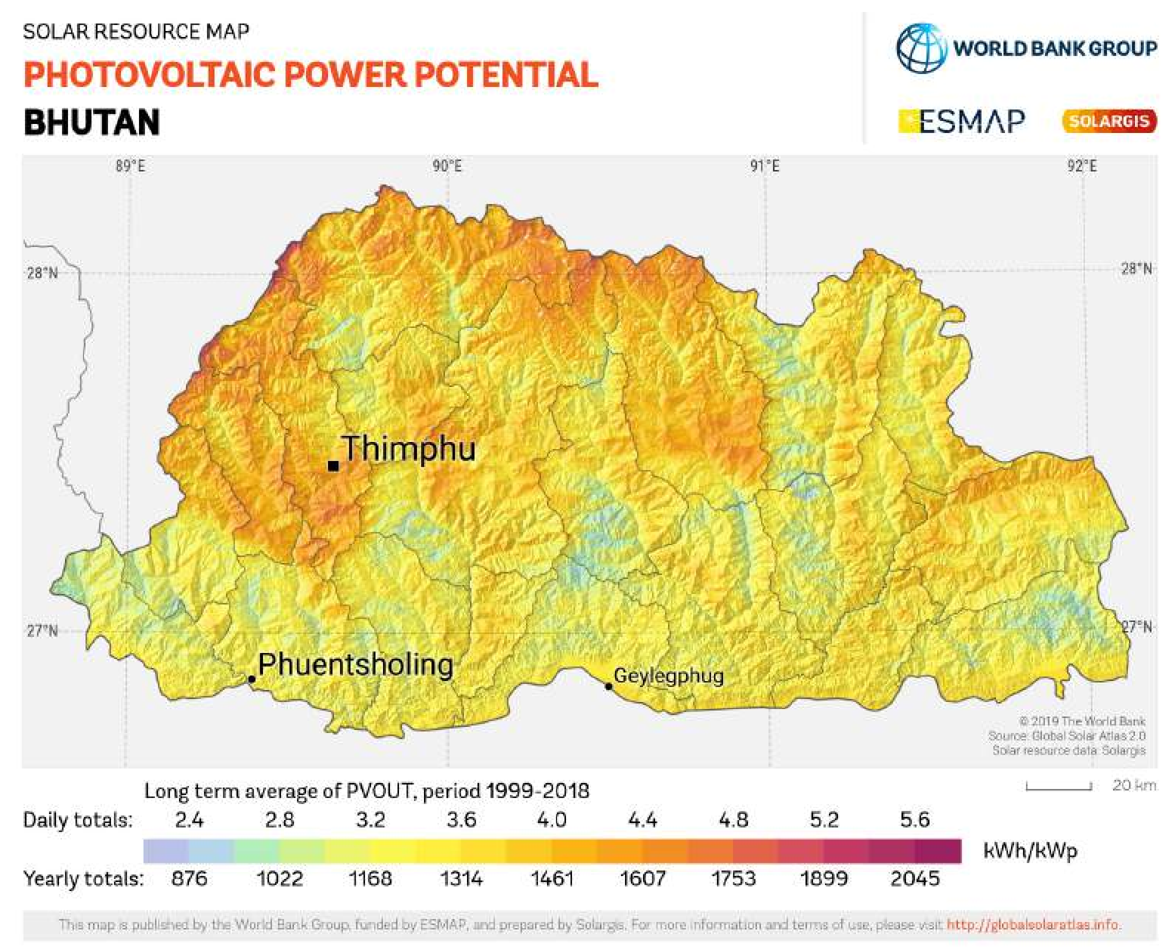
RE projects	Location
Grid-tied ground mount solar (500 kWp)	Dechencholing, Thimphu [29]
Grid-tied solar rooftop (250 kWp)	Centenary Farmers' Market, Thimphu [29]
Solar water pumps	Shaba, Paro [30] Toewang, Punakha [31]
Grid-tied solar wind hybrid plant (Solar - 180 kWp, Wind 600 kW)	Rubesa, Wangduephodrang [32]
Solar mini-grid plant (33 kWp)	Lunana, Gasa [33]

[2] Data from the Department of Energy, MoENR, RGoB

Solar Energy

Solar energy is highly suitable for Bhutan due to its modularity, ease of installation, and availability of medium to high solar resources across the country. The advancement of technology and standardisation of the process of design, installation (from a few weeks to a few months), and operational and maintenance make solar a viable option for lift irrigation. Despite some seasonal and daily intermittency, solar energy generation is predictable and can be tailored to meet irrigation needs. Its modular and scalable design makes it well-suited to Bhutan's diverse terrain, offering a cost-competitive and sustainable solution for lift irrigation. Figure 6 shows the solar potential in Bhutan.

Figure 6 Solar Potential in Bhutan [34]



Wind Energy

Wind energy potential in Bhutan is limited and highly site-specific, with significant resources concentrated in areas such as Wangdue Phodrang (141.7 MW) and Chhukha (91.8 MW) [35]. While wind energy offers higher capacity utilisation compared to solar, it is subject to considerable daily and seasonal intermittency. Accurate wind resource assessments are critical, as wind patterns vary significantly by location, necessitating long-term monitoring, unlike more predictable sources such as solar energy. Additionally, the challenging terrain and narrow hilly roads in Bhutan may constrain the transportation and installation of large wind turbines, further complicating project implementation. Despite these challenges, high-potential sites could support lift irrigation where wind resources are sufficient [36].

Hydroelectricity

Bhutan has achieved 99.9% electrification and is a net exporter of electricity, with hydroelectric power being among the most cost-effective in the region. This affordable energy source offers a major opportunity to power irrigation systems and boost domestic energy use, potentially increasing agricultural productivity and contributing to broader economic growth, especially in food production. However, the lack of dedicated electricity tariffs for irrigation poses a significant barrier to fully harnessing this potential. Field surveys highlight cases where farmers, particularly in regions like Samtse and Paro, face high electricity costs, creating a financial burden that limits the adoption of electric irrigation systems. Introducing tailored tariff structures could help reduce these costs and promote greater use of grid electricity for agriculture. While grid electricity offers a viable and cost-effective solution for irrigation in many parts of Bhutan (refer to the section on market demand and potential), challenges remain for remote farms where grid access is limited or expansion is prohibitively expensive. In these areas, off-grid RE options such as solar power present a more practical and affordable alternative. By overcoming these barriers, including the introduction of dedicated electricity tariffs for irrigation and the promotion of hybrid systems that combine grid and off-grid RE, Bhutan can fully harness its energy potential. This approach would support sustainable agriculture, enhance food security, and contribute to long-term economic growth.

2.4.1. Renewable Energy-Powered Lift Irrigation

Bhutan's RE potential for irrigation remains mostly unexplored despite its abundant resources. The country's irrigation systems remain limited due to heavy reliance on hydropower, inadequate infrastructure, and the challenges posed by the mountainous terrain. This has resulted in an overdependence on expensive and polluting diesel pumps. Transitioning to RE-powered lift irrigation systems offers a sustainable option that improves water access, reduces diesel dependency, enhances agricultural productivity, and supports Bhutan's climate resilience goals. Several renewable energy technologies (RETs) are suited to powering lift irrigation systems, including [37]:

- Solar Energy
- Hydroelectricity
- Hydraulic energy, such as hydraulic ram pumps, wind pumps

Given that RETs are integral to Bhutan's energy landscape, understanding their application within the electricity system is essential. For lift irrigation, technology selection needs to be based on several factors: (1) Resource availability for suitability of the generation profile to meet seasonal and daily irrigation needs, (2) Technical and financial feasibility, (3) Environmental positive, and (4) Ease of operation for users.

In a RE-powered lift irrigation system, energy can be harnessed from water sources such as rivers, streams, or groundwater by lifting water from a lower elevation to a higher elevation, to irrigate farms through a distribution network, which may include water storage tanks. This approach has gained significant traction in neighbouring countries like India and Nepal, where solar-powered irrigation systems have been widely adopted. These systems are supported by government-backed initiatives to boost agricultural productivity and reduce dependence on fossil fuels, showcasing a successful model that could be replicated or adapted in other regions.

In India, the PM-KUSUM scheme (*Pradhan Mantri Kisan Urja Suraksha evam Utthaan Mahabhiyan*) has been instrumental in scaling up solar irrigation. The scheme supports farmers by providing financial incentives for installing solar pumps and grid-connected solar power plants. As of recent years, India has installed over 730,000 solar irrigation pumps [38]. Similarly, Nepal has integrated solar irrigation into its national RE strategy. The Renewable Energy subsidy policy supports farmers by covering up to 60% of the cost of solar-powered irrigation systems through subsidies and concessional loans. The initiative aims to improve water access for agriculture, enhance climate resilience in agriculture, and promote sustainable energy solutions. Under this support, a total of 3,691 solar drinking water and irrigation pumps have been installed [39].

Drawing lessons from these models, Bhutan can adapt and adopt targeted financial incentives, streamlined policies, and capacity-building programmes to scale up RE-powered lift irrigation systems. By aligning its approach with successful regional strategies, Bhutan can accelerate deployment while ensuring long-term sustainability.

2.4.2. Policy

The Royal Government of Bhutan released the **Alternative Renewable Energy Policy (AREP) 2013** to promote and develop RE in Bhutan. The policy aims to diversify the nation's energy sources beyond its predominant hydropower to enhance energy security, promote sustainable development, and mitigate climate change impacts. It reflects the nation's commitment to diversify its energy mix and promote sustainable development by adopting alternative RE sources. The Department of Energy (DoE), earlier known as the Department of Renewable Energy (DRE), is the Nodal Agency to drive this initiative across the nation. Currently, AREP 2013 has no provisions specific to RE-based lift irrigation projects. However, a few provisions under AREP 2013 can be adopted to promote RE-based lift irrigation projects. While it doesn't specifically target irrigation or agriculture, the policy highlights the potential of RE, such as solar, wind, and micro-hydro, to support these sectors. It mentions that the Ministry of Agriculture and Forests – MOAF (now known as Ministry of Agriculture and Livestock – MOAL) shall collaborate with DRE (now known as DoE) to generate energy from the pico and micro hydropower/biomass/biofuels/biogas resources in the country. Thus, the AREP indirectly supports agriculture and irrigation by adopting RETs.

1. **Key highlights of AREP 2013 Department of Energy as a Nodal Agency shall:**
   a. Facilitate project developers in securing required clearances from various government agencies.
   b. Promote awareness of RE and other clean and green energy technologies.
   c. Create market opportunities and appropriate start-up business models like energy services providers/companies to provide renewable energy services.

2. **Promote technologies – Solar, wind, bioenergy, geothermal, pico/micro/mini/small hydro up to 25 MW and waste-to-energy (WTE) for thermal and electrical applications.**

3. **Areas of interventions -**
   a. Standalone systems to meet the needs of individual consumers and communities.
   b. Decentralised Distributed Generation (DDG) systems to meet the needs of communities.

4. **Allowed project ownership – Government and private sector ownership is allowed. Civil Societies, NGOs, communities, companies and individuals may initiate standalone projects.**

5. **Financial promotional measures:**
   a. Capital subsidy.
   b. Income tax exemption for a period of ten years.
   c. Exemption from payment of all import duties and Bhutan sales tax on import of plants and equipment as direct inputs to the project during the construction period.
   d. Sales tax and customs duty exemption for the purchase of spare parts.

Refer to Annexure 2 for the other highlights.

Despite the policy's ambitious goals, Bhutan has faced challenges in meeting its RE targets. Obstacles such as securing financial resources, technical and infrastructural challenges, and difficulties obtaining community and environmental clearances have impeded progress.

2.5. Climate Adaptation Plan

Bhutan's recent National Adaptation Plan (2023) [40] submitted to the United Nations Framework Convention on Climate Change (UNFCCC), highlights that the country faces significant climate vulnerabilities across various sectors, requiring urgent and comprehensive adaptation actions. For instance, the water sector is grappling with challenges such as drying water sources, prolonged dry spells, and unpredictable precipitation patterns, resulting in water shortages, flash floods, and an increased risk of Glacial Lake Outburst Floods (GLOFs). To support sustained economic growth and improve living standards, it is crucial to enhance the resilience of water resources for both drinking and irrigation, ensuring these can withstand the impacts of climate change. Furthermore, rising temperatures and erratic precipitation disrupt hydrological cycles, threatening water availability for hydropower generation, and impacting livelihoods and agriculture, thereby increasing the burden on vulnerable communities and marginalised farmers. These factors underscore the urgent need for alternative energy sources to safeguard Bhutan's energy security and bolster climate resilience.

2.5.1. Integrating Renewable Energy into Bhutan's Climate Adaptation Strategy

Bhutan's electricity generation relies heavily on hydropower, a sector increasingly vulnerable to the effects of climate change. Projected declines in winter precipitation, rising sedimentation from erratic rainfall, and accelerated glacial melt pose serious risks to the country's energy security. To build resilience and secure its energy future, diversifying the energy mix through the integration of renewable sources such as solar, wind, and biomass is essential. This transition supports Bhutan's continued commitment to carbon neutrality while strengthening its adaptability to climate change.

Expanding RE in Bhutan brings significant co-benefits for both climate mitigation and adaptation. Decentralised solar and wind systems can deliver reliable power to remote and disaster-prone areas, ensuring energy continuity during extreme weather events and enhancing overall climate resilience. Biomass energy, when sustainably promoted, complements forest conservation efforts, helping to maintain Bhutan's strong carbon sink and further reduce emissions.

Moreover, scaling up RE supports sustainable livelihoods, particularly in rural communities, by providing off-grid power solutions for households and small businesses. This shift not only delivers clean, dependable energy but also reduces reliance on imported fossil fuels, improving long-term energy security. By embracing a diverse RE portfolio, Bhutan can foster more resilient, self-sufficient communities while promoting environmental stewardship and inclusive economic growth.

Neighbouring countries such as Nepal and Bangladesh have identified solar irrigation systems as a climate adaptation solution in the National Adaptation Plans (NAP) and have national policies and programmes for implementation. Bhutan has the opportunity to adapt and replicate these models, tailoring these to its distinct topography and socio-economic landscape, thereby strengthening resilience and promoting sustainable development.

Pathways to Integration

Policy Reforms
Strengthen institutional frameworks to support RE development and ensure alignment with national adaptation priorities.

Technology and Innovation
Invest in research and pilot projects for RETs, such as hybrid solar-hydro systems, suitable for Bhutan's mountainous terrain.

Capacity Building and Public Engagement
Educate and empower local communities to adopt and manage RE systems, ensuring sustainability and inclusive growth.

International Collaboration
Leverage global climate financing mechanisms like the Green Climate Fund (GCF) to fund large-scale RE initiatives.

2.5.2. Enhancing Irrigation Systems in Bhutan through National Adaptation Plans (NAPs)

Enhancing Bhutan's irrigation systems is a critical component of its NAP, particularly in response to the challenges posed by climate change. The NAP process, initiated in 2015, emphasises strengthening water resource management to ensure sustainable agricultural practices and food security.

Climate change poses broad risks across Bhutan's sectors, directly influencing water and agriculture. The identified adaptation priorities aim to enhance resilience, mitigate climate impacts, and support sustainable development in the face of these challenges. Several NAP priorities submitted to UNFCCC in 2023 are integral to implementing RE-powered irrigation systems.

Strategic Objectives in Water and Agriculture (including livestock)

- Enhance water use efficiency and promote sustainable management of water resources for agriculture, focusing on improving the resilience of irrigation infrastructure.
- Enhance the resilience of irrigation systems through a strategic action that emphasises improving the planning, design, and implementation of climate-resilient irrigation systems.

Key Actions and Milestones [40]

1. Short-Term Goals (0-5 years)

- **Irrigation Resilience:** Strengthen existing irrigation systems using durable materials (HDPE, concrete) and adopt RE solutions like solar-powered pumps and lift irrigation.
- **Development Targets:** Establish 45 climate-resilient irrigation schemes and implement lift irrigation, led by the DoA with local governments and CSOs, supported by a USD 70M budget.
- **Micro-Irrigation and Water Management:** Promote affordable drip and sprinkler systems, rehabilitate traditional irrigation, and introduce in-situ water harvesting techniques (surface runoff, spring water, rainwater collection).
- **Implementation Targets:** Install 100 micro-irrigation systems annually, rehabilitate 20 major irrigation schemes, and construct 25 water harvesting structures over five years with a USD 5M budget.

2. Medium-Term Goals (5-15 years)

- **Expansion of Resilience Measures:** Strengthen climate-resilient irrigation, expand micro-irrigation adoption, and increase water harvesting infrastructure.
- **Water Management Optimisation:** Conduct discharge modelling and simulations for efficient water management, develop an irrigation systems database and finalise water resource planning.
- **Leadership:** Led by the Ministry of Agriculture and Livestock (MoAL) and the National Centre for Hydrology and Meteorology (NCHM).

Institutional Strengthening for Water Management

- **Water User Associations (WUAs):** Review and formalise WUAs through operational guidelines, legal frameworks, and training in Integrated Water Resources Management (IWRM).
- **Monitoring and Evaluation:** Establish systems to assess WUAs' effectiveness over time.
- **Leadership and Budget:** Led by the Ministry of Energy and Natural Resources (MoENR) in collaboration with CSOs.

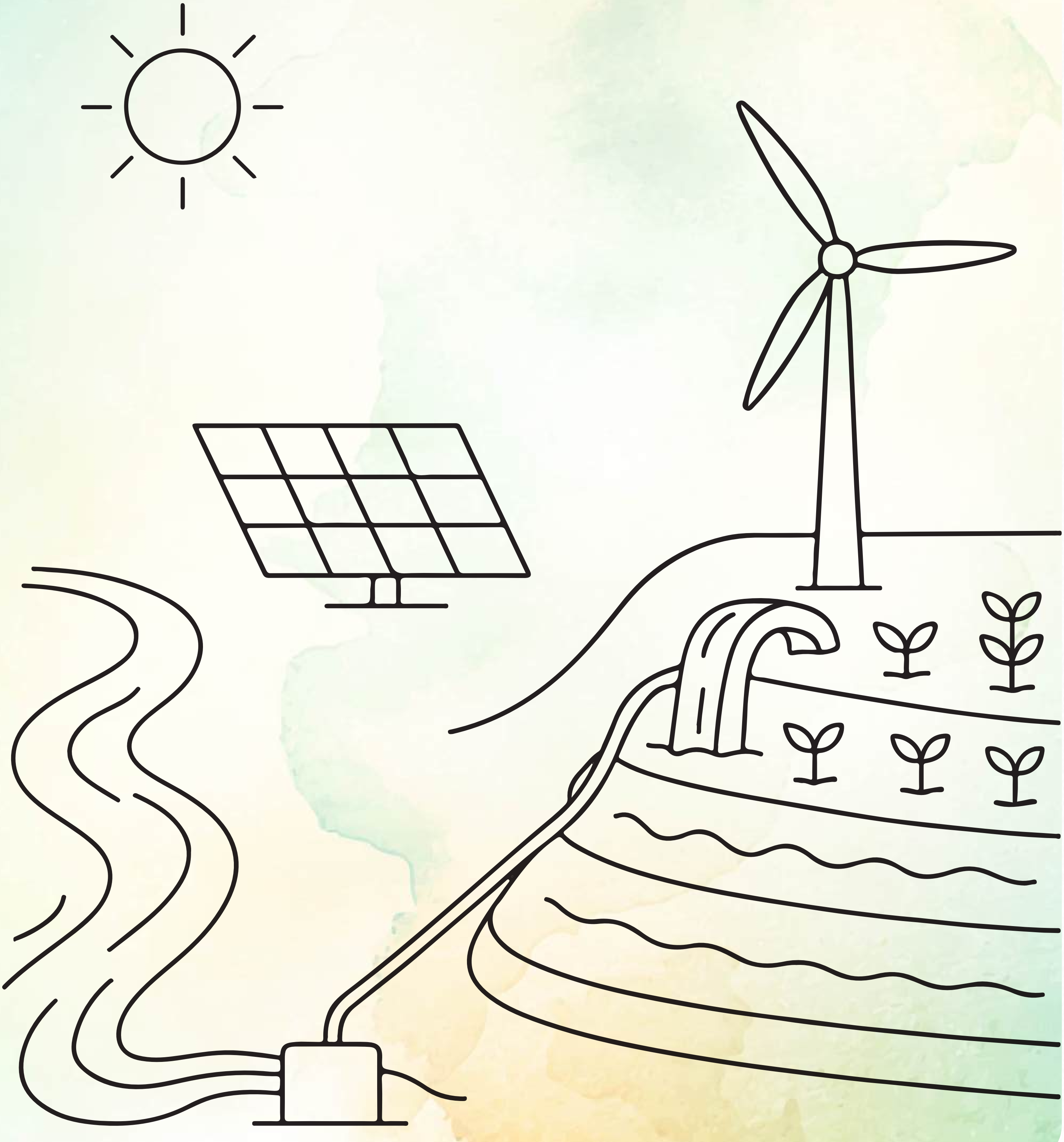
Research & Development in Irrigation Water Management

- **Short-Term Focus:** Research irrigation water shortages and their impacts.
- **Medium-Term Expansion:** Develop climate-smart irrigation strategies and assess crop water requirements.

This strategic plan outlines clear, actionable steps to improve water management, promote sustainable agricultural practices, and build climate-resilient systems. It also emphasises the importance of institutional strengthening and research to support these goals and ensure long-term success.

03

Multidimensional Sector Analysis for RE-powered Lift Irrigation



Lift irrigation systems powered by RE offer transformative solutions to address water scarcity and support sustainable agriculture in challenging terrains. These systems not only ensure reliable water supply even in higher altitudes but also contribute to inclusive socio-economic development, climate resilience, and energy security. A comprehensive understanding of the factors influencing their implementation and success is critical to harness their potential. This chapter presents a multidimensional sectoral analysis, examining the governance; policy and regulatory frameworks; technical viability; financial mechanisms; GESI considerations; capacity-building needs; and climate and environmental aspects. By evaluating these dimensions, the analysis aims to provide a holistic understanding of the enablers and barriers associated with RE-powered lift irrigation systems, thereby offering actionable insights for their sustainable deployment and scaling in Bhutan.

3.1. Governance

The development of lift irrigation projects in Bhutan involves multiple government departments, each with specific roles at different stages of the process. The DoA is responsible for granting development consent for projects classified as irrigation initiatives, as outlined in Chapter 2 (Section 2.3.2.). These include projects that directly focus on the creation or expansion of irrigation systems for agricultural purposes. However, the projects which are outside the purview of DoA fall under the responsibility of the Department of Environment and Climate Change.

The introduction of RE-powered lift irrigation systems is a relatively new development, and it brings with it additional complexities in terms of regulatory oversight. Since RE-powered lift irrigation systems utilise RE sources, such as solar or wind power, their classification and regulatory requirements (design compliances, technical standards, quality assurance, etc.) may not align with traditional irrigation projects, resulting in ambiguity in the governance process, such as the final approving department for such projects. While the DoE seems to be the best suited to oversee projects incorporating RE components, however, there is no formal framework to enable the DoE's involvement in the development consent process for RE-powered lift irrigation systems. It is imperative to address these governance gaps to ensure efficient coordination and regulatory clarity for a smooth implementation process.

3.2. Policy and Regulation

The development and implementation of RE-powered lift irrigation projects face several policy gaps that hinder their effective deployment and scalability. Addressing these gaps is critical to unlock the full potential of RE-powered irrigation systems in enhancing agricultural productivity and sustainability.

Lift irrigation project involves multiple interconnected stages - water sourcing, energy generation, civil construction, and agricultural application. Expertise in these areas is currently dispersed across various departments, such as the Department of Water, the Department of Energy, the Department of Infrastructure Development, and the Department of Agriculture. In addition, the lack of a central authority to coordinate these efforts results in fragmented implementation and accountability. It is important to designate a nodal agency that will:

- Set guidelines and standards for RE-powered lift irrigation systems.
- Establish clear targets and dedicated programmes for adopting RE in irrigation.
- Develop incentive mechanisms and support for market enablers to promote RE-based solutions.

- Build capacity among stakeholders, including farmers, government officials, and private sector players.
- Monitor and evaluate project outcomes to ensure accountability and continuous improvement.

The lack of a dedicated electricity tariff for agricultural irrigation remains a significant barrier to the wider adoption of RE-powered irrigation systems in Bhutan [41]. Currently, farmers are charged under general electricity tariffs, which do not reflect the specific energy requirements of irrigation. Introducing a tailored tariff for agricultural use could bring multiple benefits, including increased domestic electricity consumption for productive activities like farming.

In addition, the existing one-size-fits-all approach to net metering does not effectively support decentralised RE systems used in irrigation. A more targeted net metering framework designed specifically for irrigation would help encourage the adoption of these technologies. For example, RE-powered irrigation systems often generate surplus electricity during non-irrigation periods. Allowing farmers to feed this excess power back into the grid through net metering would improve the efficiency of energy use and enhance the financial viability of these systems.

Such reforms would also help offset electricity subsidies and reduce transmission and distribution losses, which tend to be higher in rural areas and low-voltage networks. By addressing these policy and regulatory gaps, Bhutan can create a more enabling environment for the adoption of RE-powered irrigation systems. This would not only lower energy costs and improve irrigation efficiency for farmers but also support the broader energy sector by diversifying energy sources, reducing losses, and strengthening energy security.

3.3.Market Dynamics and Potential

At present, around 80% of Bhutan's cultivable land lacks access to irrigation, highlighting a major gap in agricultural infrastructure [42].

80%
cultivable land
lacks access to irrigation

While detailed data on diesel irrigation pump sales is limited, insights from KIIs with stakeholders in both the public and private sectors suggest that approximately 70 pump sets are sold annually, a figure that should be viewed as a rough estimate. These pumps, typically powered by petrol or diesel, are commonly available in sizes such as 5 HP, 6.5 HP, 12 HP, and 14 HP.

One of the key challenges in tracking pump usage is the use of a single harmonised code for the import of both conventional (diesel/petrol) and electric pumps, making it difficult to distinguish between fossil-fuel-based and electric-powered systems currently in operation.

Transitioning from fossil-fuel-powered pumps to RE-powered irrigation systems offers a significant opportunity to reduce Bhutan's greenhouse gas emissions while strengthening energy security and promoting sustainable agriculture. For example, a single 5 HP diesel pump operating 8 hours a day over 100 irrigation days results in annual emissions of about 2.14 metric tonnes of CO_2 (based on an emission factor of 2.68 kg CO_2/litre).

This shift toward cleaner energy sources aligns closely with Bhutan's goals outlined in its 13th Five-Year Plan, reinforcing the country's commitment to sustainability and carbon neutrality. It also demonstrates the dual benefits of enhancing agricultural irrigation while contributing to climate change mitigation.

Lift irrigation offers a transformative opportunity to improve agricultural productivity in Bhutan, particularly in regions where traditional irrigation methods are impeded by challenging terrain and limited water availability. The PURE Platform[3], developed by ICIMOD using GIS-based suitability analysis, has identified potential energy demand opportunities for implementing river lift irrigation systems in Bhutan. The analysis estimates that approximately 62,403.21 acres of land are suitable for lift irrigation using river sources which requires an estimated 118.13 MW of power and corresponding investment. This underscores the potential of RE-powered lift irrigation systems to address irrigation challenges and advance sustainable agricultural practices in Bhutan. However, the PURE analysis is limited to river-based lift irrigation at three-tier levels, meaning other potential water sources such as springs, groundwater, and other surface water bodies have not been fully assessed so far. These additional water sources could expand the total potential area for irrigation, further increasing the demand for RE-powered solutions.

[3] PURE Bhutan: An innovative digital platform specifically designed to advance RE-powered river lift irrigation planning in Bhutan, especially in the mountain regions. The platform consolidates data from multiple sources, including satellite imagery and field data, using advanced modelling to generate user-friendly insights that help identify market opportunities and support data-driven planning for RE-powered river lift irrigation systems.

The platform further estimates that the total investment required to achieve this demand is approximately BTN 37,783.5 million. Meeting this scale of deployment opens a potential job market specifically with the solar pumping sector. Interviews with the private sector indicate that installing a 20-kW solar pumping system generates around 15 jobs, including business development, engineering, installation, and operation. This implies job creation in Bhutan to the tune of 14,750 jobs approximately. The estimated energy demand of 118 MW is likely to result in an annual CO2 emission reduction of approximately 67,779 metric tonnes[4]. Shifting to RE-powered irrigation would therefore eliminate these emissions, reinforcing Bhutan's leadership in carbon neutrality and sustainable energy adoption.

In addition to the current GIS analysis, which primarily focuses on river lift irrigation, further research could explore alternative water sources such as springs and groundwater. Expanding the scope in this way would unlock greater potential for RE-powered irrigation systems, helping to ensure reliable, year-round water availability for agriculture. This more comprehensive approach to irrigation development would not only boost Bhutan's agricultural productivity but also enhance climate resilience and support green economic growth.

Given that RE-powered lift irrigation is environmentally friendly and has strong potential to improve agricultural output, it is essential to ensure that technical advancements are implemented through a gender-inclusive lens. Women make up a significant portion of Bhutan's agricultural workforce and landowners, and their active involvement is critical to the success of such initiatives. Ensuring equal access to training, financial resources, and decision-making opportunities will help make climate adaptation strategies more equitable and effective, supporting both gender equality and sustainable development.

3.4. Technical

The findings from the review, field visits, consultations through workshops, and KIIs highlighted the following key challenges.

3.4.1. Data and Knowledge Gaps

Existing data and knowledge gaps significantly hamper Bhutan's irrigation management, which poses challenges to effective agricultural practices and sustainable water resource management.

Data Availability

One of the primary issues is the inadequate data collection and analysis related to irrigation systems. There is a notable lack of data on the performance of various irrigation systems, including the economics of these systems, the effectiveness of lift irrigation, and the usage patterns of diesel pump sets. This absence of critical information complicates the understanding of current irrigation practices and hinders the design of effective solutions. Furthermore, it limits the ability to evaluate new projects and develop innovative technologies tailored to the specific needs of Bhutan's agricultural landscape.

Irrigation Planning and Design

Bhutan's complex geophysical landscape, characterised by varying precipitation patterns, hydrology, and the impacts of climate change, presents additional challenges for irrigation planning and design. Insufficient data on water availability e.g. groundwater, catchments, and spring sheds impairs the

[4] KII with the private sector

ability to create effective facility designs. This lack of information affects the immediate planning and implementation of irrigation systems and has broader implications for policy formulation as decision-makers struggle to base their strategies on reliable data.

Lack of Feasibility Studies for Irrigation Plans

The absence of comprehensive feasibility studies and frameworks further exacerbates the challenges faced in irrigation management. Without a thorough feasibility study, projects are highly susceptible to failure due to unverified technical feasibility and economic viability. Critical factors such as topographic stability, water availability, and landslide risks were often overlooked, resulting in ineffective irrigation projects that do not meet the needs of farmers or the environment.

Lack of Tools and Platforms

A critical gap in implementing RE-powered lift irrigation systems is the absence of specialised platforms and tools to accurately assess energy demand, design tools, investment required and facilitate site selection. This hampers the ability to design efficient and context-specific solutions, particularly in regions with diverse geographic and climatic conditions. The absence of such platforms also restricts the possibility for scalability and replication, as project planning relies on ad hoc approaches that may fail to account for site-specific characteristics. Addressing this gap is critical for encouraging informed decision-making, improving project feasibility, and ensuring long-term sustainability using RE-powered lift irrigation systems.

3.4.2. Standards and Certifications

One of the key gaps in the implementation of RE-powered lift irrigation systems in Bhutan is the absence of established standards and certification frameworks to ensure quality, reliability, and long-term performance. Currently, there are no standardised benchmarks for various system components, leading to variations in performance, durability, and efficiency. Insights from a recent site visit reveal a lack of rigorous testing protocols which increases the risk of deploying incompatible technologies, potentially leading to higher system failures.

Additionally, Research & Development (R&D) efforts in this area remain limited, preventing the introduction of locally adapted innovations and the customisation of technologies to suit Bhutan's mountainous terrain and climatic conditions. Without strong quality assurance mechanisms, the long-term viability and scalability of RE-powered lift irrigation systems will remain uncertain.

3.4.3. Structural Constraints

The geographical fragmentation of farms and limited infrastructure significantly hinder agricultural development. The prevalence of fallow land, particularly in wetland areas, is attributed to several challenges. The primary issues include a lack of infrastructure to provide reliable irrigation access, crop protection from wildlife, and labour shortages. Other contributing factors are low soil fertility, land conversion for alternative uses, rotational farming practices, and the long distances between farmland and residential areas. Additionally, mechanisation is minimal, restricted by the steep landscapes and small landholdings that characterise much of Bhutan's farming regions [10].

Small farm holdings struggle to achieve economies of scale due to a lack of aggregation. This results in high production costs and low market competitiveness, driving Bhutan to import large quantities of food, particularly from India. For instance, despite some progress in vegetable production, the country still relies heavily on imports during the winter months.

Furthermore, 37% of farmers produce primarily for self-consumption, 53% for self-consumption with some sales, and only 10% direct their production for sale, which limits the sector's contribution to economic growth and rural livelihoods [14]. Addressing these constraints through investment in irrigation, wildlife management, and labour support can significantly boost agricultural productivity and uplift the sector.

37%
of farmers produce primarily for self-consumption

53%
for self-consumption with some sales

10%
direct their production for sale

3.4.4. Water Sources for Irrigation

Water for various purposes including irrigation is usually drawn from nearby common sources through gravity i.e., streams and springs. The water demand has been increasing due to the commercialisation of farming, provisions for drinking water, construction, hospitality etc. The increase in water demand has resulted in reduced availability of water for irrigation.

In Bhutan, gravity-based irrigation is the traditional method, which involves tapping water from streams and springs at higher elevations and transporting it through open channels, which may be made of mud, concrete, or masonry. These channels are built on a gentle slope to allow water to flow over longer distances and cover large command areas. However, climate variability and erosion in catchment areas are reducing water availability and flow in these channels, causing irrigation water shortages and contributing to the channels' deterioration. It has been found that tapping water sources at lower stream levels could enhance water availability. This makes a case for lift irrigation systems, which can supplement gravity-flow irrigation at various sites, as shown in the following diagram (Figure 7).

Figure 7 Undulating Terrain [43]

During the site visit, it was also noted that the mountainous terrain makes installation and maintenance, especially in remote areas, quite challenging. The problem is further accentuated by varying weather conditions, including monsoon rains, snowfall, and high altitudes, which affect the performance and reliability of systems. Water availability for irrigation is one of the challenges to low agricultural productivity. Shortage of water could lead to upstream and downstream conflicts, as seen in the Hungrel Gewog, Paro. A lot of farmers might be interested in intensifying their agricultural activity, provided more water is made available.

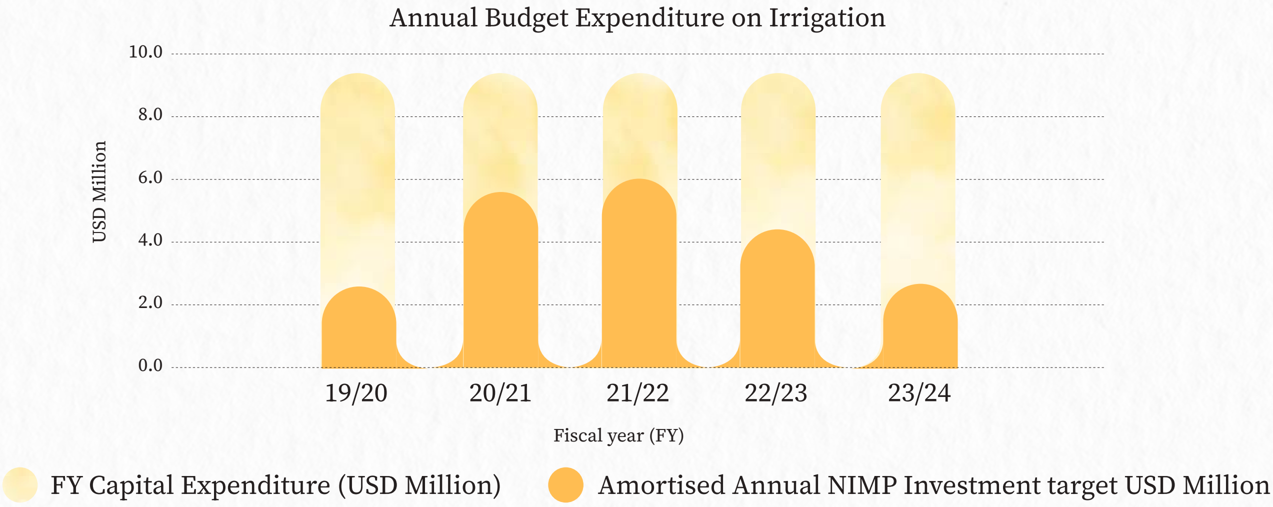
3.5. Financial

The adoption of RE-powered irrigation systems holds immense potential to enhance agricultural productivity, reduce energy costs, and promote sustainability. However, the financial landscape of these systems in Bhutan is characterised by significant challenges, including reliance on limited funding sources, high upfront costs, and underdeveloped market mechanisms. This section explores the current investment scenario, market potential, challenges, and opportunities for financing RE-powered irrigation systems, providing a comprehensive overview of the financial dynamics shaping this sector.

The NIMP estimates that Bhutan needs to invest approximately USD 140 million by 2030 to achieve its irrigation targets. Despite this ambitious goal, the majority of irrigation projects in the region are currently funded by government agencies and development partners, highlighting a reliance on traditional funding mechanisms.

Figure 8 illustrates the annual amortised investment projected in the NIMP versus the actual capital expenditure on irrigation for the respective fiscal year reveals a consistent shortfall in funding. For instance, while the NIMP's annual amortised investment target is estimated at USD 9.3 million, actual investments over the past five years have consistently fallen short of this mark. The required investment gap underscores the urgent need for diversified funding sources and innovative financing mechanisms to meet the growing demand for irrigation infrastructure.

Figure 8 Annual Financing Gap for the NIMS Project Irrigation Target for the Period 2019-2024 [44]



As discussed in section 3.3, the potential demand for RE-powered irrigation in Bhutan is significant. However, the market and investments in this sector remain at a nascent stage. Till date, only a small number of investments have been made. For example, only three functional solar-powered lift irrigation systems were identified during the study. The limited adoption of RE-powered irrigation systems can be attributed to several factors, including:

- High upfront costs and long payback periods.
- Lack of awareness among stakeholders about the benefits of RE-powered systems.
- Inadequate policy and regulatory frameworks to incentivise and enable investments.

To unlock the potential of RE-powered irrigation systems and leverage investments, it is essential to establish robust policy and regulatory frameworks that attract investment and ensure project sustainability. A critical step in this process is generating evidence-based insights into the financial and economic viability of these investments. Please refer to Annexure 3 for a case study on financial feasibility assessment.

Field surveys and studies have identified key challenges affecting the financial viability of conventional irrigation systems. For example, utility-based lift irrigation pump sets were found to be non-functional due to non-payment of energy bills by communities and a lack of funds for repairs and maintenance. In contrast, solar-powered irrigation projects in Shaba (community-based) and Guma (privately owned) have demonstrated varying levels of success, primarily due to no energy costs, low maintenance expenses and equipment warranties that enable repairs at low or no cost to communities. At the Toewang site, the irrigation system became non-operational for nearly an entire season after the first year due to rusting and clogging of the pipes. Although the pipes were later replaced and the supplier conducted a training programme on maintenance, the system remained non-functional during the site visit due to ongoing operation and maintenance (O&M) issues. This highlights the critical need for efficient and effective adherence to O&M procedures to ensure the long-term sustainability of such systems.

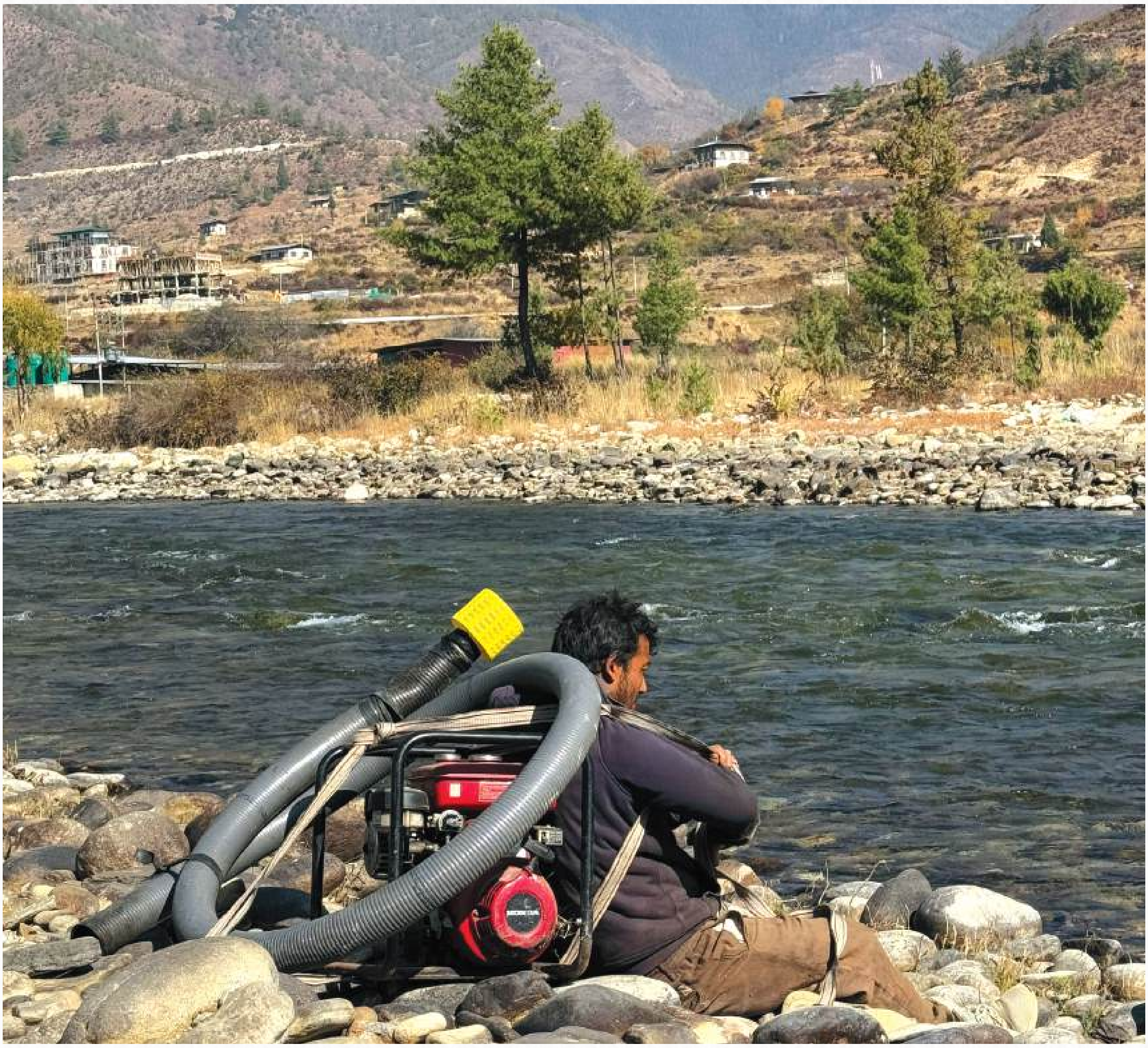
These examples highlight the potential of RE-powered systems to address the financial and operational challenges faced by conventional irrigation systems. Pilot projects play a crucial role in demonstrating the economic and environmental benefits of RE-powered irrigation. For instance, the solar-based lift irrigation project in Shaba, Paro, has significantly increased water availability, leading to higher agricultural production. Such projects serve as proof of concept, building confidence among stakeholders and paving the way for scaling up. Despite the progress, there is still a limited understanding and few business cases in Bhutan to demonstrate viable financial mechanisms for RE-powered irrigation. Exploring and testing innovative financing mechanisms and investment models (Refer to Annexure 3) can help reduce risks and enhance returns for these projects. Opportunities such as blended finance models which combine public funds with private investments to de-risk projects, or service models such as pay-as-you-go making systems affordable for farmers through flexible payment options or accessing climate funds to mobilise large-scale investments for sustainable irrigation infrastructure need to be explored.

Another significant gap is the lack of data necessary for conducting financial impact assessments. Without this information, stakeholders are unable to design viable projects and financial interventions that could enhance the sustainability and efficiency of irrigation systems. This limitation restricts the potential for investment in innovative technologies and practices that could improve agricultural productivity and water resource management. More studies need to be undertaken to establish a deeper understanding of the viability gaps and refine the financial and operational models for RE-powered irrigation systems.

Both financial and economic viability play important roles in project evaluation, with economic viability sometimes taking precedence over financial considerations. Given the diverse nature of these projects—ranging from energy and infrastructure requirements to commercial and subsistence farming—a one-size-fits-all financial solution may not be appropriate. Projects may require different types of funding based on their scale, location, and objectives. Hence, developing financial and economic analysis frameworks for RE-powered projects will help stakeholders to better understand project viability and tailor financing solutions to specific needs (Refer to Annexure 3).

Matching project requirements with the right type of funding and investors is equally important. Digital platforms like PURE can play a pivotal role in bridging investment information gaps by connecting stakeholders, providing data-driven insights, and facilitating access to suitable financing options.

While financial constraints pose challenges, some irrigation practices indicate a willingness among farmers to invest in irrigation if it leads to improved water availability and higher agricultural productivity. Demonstrates their readiness to pay when they perceive tangible benefits. This is particularly relevant for structuring financing models that align with farmer affordability and investment behaviour. Future implementation models should consider leveraging this willingness by designing cost-sharing mechanisms and service-based financial structures.



3.6. Management and Operational Models

RE-based lift irrigation systems can be deployed through various business and operational models tailored to the specific context and needs of the project. These models can include upfront sales, build-and-transfer, and service-based approaches such as rental, and build-own-operate among others. Financing can also be structured in multiple ways, combining equity, debt, and subsidies/grants. Below is a high-level overview of the mechanisms and models that can be implemented. Such flexibility allows for building upon the existing framework or opting for a completely new framework. Table 7 lists the components and options widely implemented in the region.

Table 7 Key Components and Considerations for RE-based Lift Irrigation Project

Component	Description/Options
Project Structure	1. Single unit
	2. Split into two or more components: a. Energy Generation Unit b. Water Pump c. Irrigation Network (pipes, etc.)
Ownership	1. End Users - Farmers/Farmers' Group/Water User Associations
	2. Government Agencies
	3. Third Party
Services	1. Self-consumption
	2. Water as a service
	3. Energy supply
Financing	1. Equity – Contribution from the owner
	2. Debt – From financial institutions (Banks, Government Agencies, others)
	3. Subsidy/Grant – From Government Agencies or donor agencies
Operations and Maintenance	1. End Users - Farmers/Farmers' Group/Water User Associations
	2. Government Agencies
	3. Third Party
Repair	1. End Users - Farmers/Farmers' Group/Water User Associations
	2. Government Agencies
	3. Third Party
Project Size	1. Small scale – For catchment areas less than 15 hectares
	2. Medium scale – For catchment area 15-100 hectares
	3. Large scale – For catchment areas greater than 100 hectares
Grid Connection	1. Off-grid system
	2. Grid-connected system with import and export provision

Based on data collected during primary and secondary research, it is identified that there are two major practice models for irrigation systems in Bhutan. These two models are:

3.6.1. Community-led/Community-owned Model

Conventionally, irrigation in Bhutan is a community activity and the irrigation systems are either developed by the community or developed by the government for the community. Out of three solar-based lift irrigation projects developed in Bhutan, two (solar-based lift irrigation community-led projects at Gangri (Paro) and Khawajara (Punakha)) have adopted the conventional model.

Based on site visits and stakeholder consultations, it has been observed that the pump sizes deployed for community irrigation in Bhutan are typically less than 20 HP, catering to areas ranging from 30 to 40 acres. Most community-managed irrigation systems serve areas between 40 and 90 acres [4]. In the case of government-developed systems, these are handed over to the community for O&M, whereby the beneficiaries bear the recurring cost of energy. The government bears any maintenance beyond the technical and financial capacity of the community. Some of these projects are also funded by the government and donor agencies together.

One of the challenges affecting the optimal use of utility-connected pump sets is the lack of financial provisioning for energy and maintenance costs. In community-led models, the responsibility for O&M falls on the users, who may lack the resources to cover these expenses.

In cases where the costs exceed the financial capacity of the community, government support is often required for major repairs and technical assistance. These factors influence the long-term sustainability of irrigation infrastructure.

Additionally, one of the main challenges with projects energised by utility and diesel is the recurring energy cost, for which the communities lack an adequate budget. The energy cost from the utility ranges from Nu 0 /kWh to Nu 2.66 / kWh. The energy cost of a diesel pump set is about Nu 17 /kWh – Nu 22.67 / kWh.[5] However, the energy cost for the projects could not be ascertained from the site visits due to a lack of information among the interviewees. Refer to Table 8 for the Bhutan Power Corporation Limited (BPC) Tariff Schedule for the low-voltage and medium-voltage consumers [45].

Table 8 BPC Tariff Schedule for LV and MV Consumers

Low Voltage (LV)	
LV Block-I (Rural) 0-100 kWh	Nu 0 /kWh
LV Block-I (Highlanders) 0-200 kWh	Nu 0 /kWh
LV Block-II (All) > 100 kWh	Nu 2.66 /kWh
Medium Voltage (LV)	
Energy Charge	Nu 1.6 /kWh
Demand Charge	Nu 170 /kVA/month

[5] One litre of diesel generates about 3-4 kWh of energy. Considering the cost of diesel to be Nu 68 per litre (as on 19 October 2024), the cost of energy would be about Nu 17 /kWh – Nu 22.67 /kWh.

Different types of existing models are as follows:

1

Government-funded community-owned systems

The government provides 100% funding to build the system and transfers it to the community for O&M. This model is used for most of the irrigation systems in Bhutan (verified during site visits, KIIs and stakeholders' consultations).

2

Government-owned systems leased to the community

The community hires the water pumping system for their water needs from the government. This model is used for diesel pump set-based irrigation. This model helps in recovering part of the full cost of the energy generation unit and pump from the beneficiaries. Under this model, Farm Machinery Corporation Limited (FMCL) leases out diesel pump sets (verified during KII with FMCL). The sale of water can be an alternative to leasing.

3

Community-funded and owned systems

The community builds, owns, and operates the system for its own consumption. The government may or may not provide subsidies to the community.

3.6.2. Individual-led Model

Apart from the community-led models, individual-led models for irrigation are also in existence. One such example is the solar-powered lift irrigation project at Guma, Punakha which is funded, owned, operated and maintained by a farmer. However, the diesel pump supported sites (Guma and Dochoritsa) are either owned or hired by an individual or group of farmers in which case the sets are operated by an individual or group of individuals. In these cases, both the cost of pump sets (purchase or hiring cost) and fuel cost are borne by the farmers.

Private-owned Systems Leased to Community

In this model, private parties build, own, and operate irrigation systems, allowing the community or individual farmers to hire the system for their water needs. Instead of owning or maintaining costly irrigation equipment, farmers hire the system when needed, reducing their financial and technical burden. Service is sold directly to the farmers as an alternative to leasing the irrigation equipment. This model is used for diesel pump sets, as observed in the Dochhukha_Dzomlingthang Ritsa chiwog (Guma, Punakha) site. During the site visit, we also found a model where individual farmers build, own and operate the system for their own consumption and/or for the sale of water to neighbouring farmers (verified during a site visit) at Phaduna pump/lift irrigation site in Lakhu (Guma, Punakha).

3.7. GESI in Agriculture

In Bhutan, men and women actively participate in economic and non-economic activities, particularly in the agricultural sector. Women's participation in agriculture is notably high, with 50.7% of women involved compared to 32.9% of men [3]. According to the latest study using the 2015 GNH survey data, by Suh et al. (2020) [21] in context to time spent use, it was reported that women in Bhutan devote more than twice the amount of time to unpaid work than men (in rural areas, women spend 3.5 hours while men spend 1.5 hours per day). However, rural women spend less time on unpaid work than their urban counterparts, as rural women additionally need to engage in agricultural activities.

The study also assessed the social and gender dynamics related to access to climate-resilient irrigation systems and access to information and training related to RE-powered lift irrigation. According to the UNDP 2021 report [18], regardless of gender, over 90% of the surveyed respondents, mostly farmers, expressed a need for support systems for climate-smart agriculture. These support systems include access to information, training, appropriate technologies, inputs, and participation in decision-making. In line with these findings, site visits revealed no significant gender disparity in access to information about RE or solar-powered lift irrigation. For example, at the diesel-powered lift irrigation site in Dochhukha_Dzomlingthang Ritsa chiwog, neither the farmers the village head nor the engineer was familiar with RE-powered lift irrigation systems. However, all farmers at the solar lift irrigation project site in Gangri village were well-informed about the system and its functioning, having received orientation during its installation. This suggests that while gender-based differences in access to information are minimal, broader awareness and knowledge gaps regarding RE-powered irrigation systems remain in areas still not using RE-powered irrigation systems.

Across the sites visited by the team, a majority of men and women (70-80%) are engaged in agriculture, while the rest are primarily involved in trade or business, both in the agricultural sector and non-agricultural sector. Both genders equally participate in agriculture and trade, reflecting balanced gender involvement. However, those with higher education tend to choose trade over agriculture. According to Pelzom and Katel (2018) [46], risks associated with agriculture due to wildlife depredation, lack of resources (inadequate land, inadequate financial support, etc.), combined with parental expectation to join services, are the main factors affecting educated young people to gain employment in trade and non-agricultural sector.

Site visits reveal that women often bear the primary responsibility of childcare and household chores along with agricultural activities. Both men and women make decisions related to spending on agriculture and household consumption. Decisions regarding agricultural activities, such as sowing, fertilising, and harvesting are predominantly made by the women of the household. RGoB recognised climate change and its implications and initiated steps and strategies for smart innovations in the agriculture sector, focusing on both male and female farmers; however, participation and decision-making related to the mechanisation of agriculture, such as irrigation, farm machinery and climate-smart technology, are still mostly led by men.

Further, a study by FAO (2023) highlights that men are more engaged in cultivating commercial crops such as potatoes and cardamom while women tend to cultivate vegetables and fruit due to lower access to newer agricultural technologies and machinery among women. The selection of crops by gender has implications for associated risk and returns [14].

Women also tend to be in charge of selling agricultural products at markets, while transportation of these products is either hired or supported by the men of the household. An equal proportion of men and women are present in agri-cooperatives and farmers' groups at the surveyed sites.

3.7.1. Ownership of Resources

Access to Land
Due to the practice of maternal inheritance in Bhutan, the majority of agricultural land is owned by women, while residential land is owned by both men and women. As per the Social Institutions and Gender Index (SIGI, 2012) [47], about 60% of rural women have land registered in their names, and 45% of property titles are in urban areas in Bhutan. Studies suggest that although matrilinear inheritance is commonly practised in major parts of Bhutan, the southern region practices patriarchal inheritance, such as in Samtse [14, 48].

Access to Finance
Women's access to financial services and credit has been increasing in Bhutan [18]. Gewog heads from operational sites informed that access to credit and financial services for agricultural practices is equally available to both genders, and women typically do not face any constraints related to access to credit. However, landless farmers were reported to have less access to credit services from both government and private sources compared to large farmers. Data reveals that loans in the agriculture and livestock sectors combined account for 2.3% of the total loans in Bhutan as of 2023-24, primarily due to the high interest rates [49].

3.7.2. National Policies and Gender Mainstreaming in the Energy Sector of Bhutan

The energy sector in Bhutan has shown significant progress in recent years, particularly in its efforts to promote gender equality and inclusion. Gender mainstreaming across various sectors, including energy, has been emphasised under the National 13th Five Year Plan. The plan mandates that all ministries and agencies address gender gaps by incorporating gender analysis into their programme and developing gender-responsive budget strategies. Legislative frameworks further support equal opportunities in employment across the energy sector, including hydropower projects and energy service delivery to households [50]. These initiatives reflect Bhutan's commitment to increasing female participation and promoting gender equality within its growing energy sector.

The expansion of the energy sector, particularly hydropower, has contributed to an increasing number of women enrolling in graduate engineering programme relevant to the field. According to the World Bank report (2020), 30% of the total engineering degree students were female between 2013 and 2018 in Bhutan's Jigme Namgyel Engineering College (JNEC) [50]. According to the recent Annual Education Statistics (2023) [51], 40% of the total students in three energy and engineering institutions of Bhutan were women. This indicates a growing presence of women pursuing engineering degrees, particularly in power systems engineering. However, the field is still male-dominated as most women in Bhutan prefer fields of study outside of technical areas, with 50% choosing arts and humanities and 30% opting for business and management [52]. This suggests that despite efforts to promote gender equality in sectors like engineering, the majority of female students still gravitate toward more traditional, non-technical disciplines.

Given the high proportion of technically trained female engineers and gender mainstreaming efforts, Bhutan's power sector has led to a relatively high proportion of women in the workforce. In 2018, as per the World Bank report, within four power sector institutions of Bhutan, about 22% of the total staff were women, with 16% working in technical positions. Government power-related agencies also demonstrate fair female representation, with 35% of their staff being women, including 33% in technical roles [50]. These figures suggest that gender inclusivity in Bhutan's energy sector can be further improved, particularly in technical fields.

3.7.3. GESI and Women's Participation in the RE-Powered Irrigation System

Improved Livelihoods

One of the key outcomes from the consultations with stakeholder representatives was that RE-powered lift-irrigation systems would enhance livelihoods for both men and women. This was emphasised as a primary benefit of developing RE-powered lift irrigation. Access to energy would enable more time-efficient crop production and higher yields, fostering an environment for increased income. Additionally, it was highlighted that the RGoB in partnership with the DoA, supports farmers by building skills and creating job opportunities to promote sustainable agriculture.

Inclusion of Marginal Farmers in Sustainable Agriculture

The consultation workshop with the Bhutan stakeholders highlighted that to promote social inclusion in sustainable agriculture, the RGoB provide economic incentives for the adoption of RE by offering subsidies or tax-free RETs to farmers, particularly the women and the marginal farmers. The workshop also emphasised that financial support is additionally available in the form of grants and loans such as donor-assisted projects from DoE, International Finance Institutions and other development partners, such as loans to farmers for any agri-income generating activities on 10.5% loan interest, up to 500,000 collateral free community development loan at 90:10 debt-equity and 15% interest.

Women in the Energy Sector

In the energy sector, the majority of women's employment and engagement is concentrated in the hydropower sector, while participation in other RE sectors remains relatively low. Key insights from interviews with the DoE, Department of Infrastructure and Development (DOID), and Jigme Namgyel Engineering College reveal that some of the leading institutions promoting RE-powered lift irrigation exhibit low female engagement in the sector:

- Neither the DoE nor the DoID has female staff members with technical expertise in RE-powered lift irrigation design.
- Only one female student has graduated with a master's degree specialising in RE from Jigme Namgyel Engineering College.
- In the bachelor's programme of Jigme Namgyel Engineering College, to date, only 50 female students have graduated with an elective in RE.

Inclusion of Women in Irrigation

Women farmers and village representatives at the community-owned operational site in Gangri highlighted its GESI-responsive approach. Previously, the labour-intensive task of drawing water for fields was handled by men however, with the installation of the solar pump, this task no longer involvement and thus reduced the women farmer group's dependency on men or male labour. In contrast, men continue to manage and make key decisions regarding irrigation and pump operations at Dochhukha_Dzomlingthang Ritsa chiwog (Guma, Punakha), where a diesel pump-based irrigation system is used.

Awareness Gaps Regarding RE-Powered Lift Irrigation Systems

There are significant gaps in overall knowledge and awareness about RE-powered irrigation technologies. One of the key observations during the field interactions was that many farmers, community members, and even professionals working in related fields were unaware of the lift irrigation system or its technicalities.

High Instalment and Maintenance Cost

The consultation workshop highlighted that high upfront costs and significant land requirements pose major barriers, especially in regions with difficult terrain and limited flat land. These financial and logistical issues make widespread adoption difficult, particularly for marginalised farmers. Additionally, high maintenance costs can further deter usage, as communities may struggle to afford or manage ongoing expenses. This combination of factors hinders the effective implementation and sustainability of RE-powered irrigation systems.

Security Challenges

One significant issue is theft and vandalism, as valuable equipment is often targeted in rural areas, where security may be limited, creating a financial burden on marginalised farmers.

Governance Gaps and Power Imbalance in Water Management

Water governance in Bhutan faces notable challenges around equity, participation, and power distribution. Water User Associations (WUAs) are established to manage water supply systems. These WUAs are responsible for the operation, maintenance, regulation, and revenue collection of the water supply infrastructure. Many WUAs have created bylaws to ensure accountability at the scheme level. However, these bylaws often lack GESI considerations, limiting the participation of women and marginalised groups in decision-making. Introducing GESI-responsive provisions would help ensure more inclusive governance and strengthen community ownership.

At the same time, power imbalances within communities are evident in cases where individuals or groups have private access to RE-powered irrigation systems, while others do not. For instance, in Laku village, Guma Gewog (Punakha), nearby residents without access to the privately owned solar lift irrigation system reported disadvantages, including limited access to water and increased vulnerability to water shortages. Such disparities in access can deepen social inequities and undermine the collective benefits of clean energy interventions. Addressing both institutional governance gaps and informal power dynamics is crucial to ensure more equitable and effective water resource management.

The implementation of RE-powered lift irrigation systems faces unique GESI-related challenges including:

- *Limited Representation:* Women are underrepresented in the design, implementation, and maintenance of RE-powered irrigation projects, leading to a lack of gender-balanced decision-making.
- *Educational Barriers:* Limited access to specialised education and technical training in RE for women constrains their ability to participate in the sector.
- *Cultural Perceptions:* Traditional gender roles and societal expectations may restrict women’s active involvement in technical and operational roles. There is a cultural perception that irrigation machinery operation is a man's job.
- *Resource Access:* Marginal female farmers often face challenges in accessing financing and technical support for adopting RETs.
- *Capacity Building:* There is a lack of targeted training programmes to equip women with the skills needed to engage in the development, operation, and management of lift irrigation systems.

3.8. Capability

Throughout the study, including site visits, KIIs and workshops, it became evident that there is a significant gap in capabilities within Bhutan's irrigation management. This lack of technical expertise impedes the effective design, installation, and maintenance of modern irrigation systems, especially those powered by RE sources. The findings from the KIIs and workshops highlight the following key challenges:

3.8.1. Shortage of Trained Personnel

A critical issue is the insufficient number of trained professionals equipped with the skills necessary to design and implement advanced irrigation systems. The majority of the informants during the KII explicitly mentioned the need for capacity building in irrigation management and RE-powered lift irrigation projects. This gap is especially pronounced in the context of RE-powered irrigation, which requires a specialised understanding of both irrigation technology and the integration of RE solutions. The lack of qualified personnel not only limits the adoption of innovative practices but also perpetuates reliance on outdated technologies that may not meet the evolving needs of Bhutan's agricultural sector. Consequently, the potential benefits of modern irrigation systems such as increased efficiency, sustainability, and resilience to climate change remain largely untapped. During group discussions in the workshops, all four groups identified limited technical capacity and the urgent need for awareness and training as significant bottlenecks in successful irrigation system implementation. Specific feedback from institutional stakeholders, including government agencies, emphasised the necessity for training in technical assessments, system design, and awareness creation. Additionally, a key state-owned agency in the sector acknowledged that it lacks capacity for maintenance and repairs of solar pumps, with personnel requiring specialised training.

3.8.2. Limited Operation and Maintenance Capacity

In addition to the shortage of trained personnel, stakeholders at project sites often lack the technical capacity required for the effective repair and maintenance of existing irrigation systems. In addition to the findings from the consultation workshops and KIIs, the site visits revealed that seven out of nine locations surveyed, faced technical challenges related to pump maintenance, pipe rusting/clogging, inadequate design, and frequent breakdowns. This deficiency can lead to sub-optimal infrastructure utilisation, as minor technical issues may go unresolved due to a lack of expertise. Without proper maintenance, irrigation systems can experience diminished efficiency, increased downtime, and, ultimately, failure to deliver the intended benefits to farmers. Three stakeholders explicitly noted that awareness among women regarding irrigation systems is significantly low, indicating a gender gap in technical knowledge and engagement. Furthermore, many local stakeholders may not have access to ongoing training or technical support, which exacerbates their challenges in managing and optimising irrigation systems effectively.

3.8.3. Lack of Structured Capacity-Building Initiatives

There is a lack of structured capacity-building initiatives for RE-powered irrigation systems. During the site visit to the solar-lift irrigation system in Khawajara chiwog (Toewang, Punakha) a farmer highlighted the need for capacity building in irrigation management. As informants from the KIIs, site visits and stakeholder consultations stressed that systematic training programmes are essential to enhance awareness, technical expertise, and sustainability of RE-based irrigation systems. Awareness generation and capacity building must be tailored to address specific gaps, such as technical training for farmers and cooperatives on system operation and maintenance, specialised skill-building for the private players to handle solar pump repairs and maintenance, and gender-inclusive training modules to bridge the awareness gap among women farmers.

3.9. Climate and Environment

Bhutan's irrigation sector faces mounting challenges due to climate variability, erratic weather patterns and extreme climatic events that disrupt water availability and agricultural productivity. With increasing incidences of floods, droughts, and temperature changes, the need for sustainable, reliable irrigation solutions is more urgent than ever. RE-powered lift irrigation presents a viable, climate-resilient alternative, addressing water scarcity while reducing dependency on fossil fuels and hydropower fluctuations. The following key climate and environmental factors highlight the necessity of transitioning to RE-powered lift irrigation.

3.9.1. Water Scarcity and Seasonal Variability [53]

Southern regions such as Dagana, Chhukha, and Zhemgang experience prolonged dry spells and shifting rainfall patterns, making water access increasingly unreliable. Traditional irrigation systems struggle with inconsistent river flows. In contrast, RE-powered lift irrigation can tap into alternative water sources such as groundwater, rivers, reservoirs, providing year-round irrigation even during dry seasons.

3.9.2. Glacial Melt and River Flow Dependence [54]

Bhutan's river systems rely heavily on glacial melt, which regulates seasonal water availability. However, rising temperatures accelerate glacial retreat, leading to unpredictable water flow patterns. During peak summer, increased glacial melt causes excessive runoff and flooding, while reduced winter melt results in water shortages. These impacts are already evident in traditional canal irrigation systems, which rely on seasonal water availability. RE-powered lift irrigation enables reliable and efficient water storage and distribution, mitigating these seasonal extremes and ensuring reliable agricultural irrigation.

3.9.3. Flood and Landslide to Irrigation Infrastructure [55]

Bhutan's mountainous terrain, particularly in Gasa, Lhuentse, and Bumthang, is highly susceptible to landslides due to steep slopes, heavy monsoon rainfall, and seismic activity. These natural hazards frequently damage irrigation canals, block water sources, and compromise infrastructure, rendering traditional gravity-fed irrigation systems unreliable. In contrast, RE-powered lift irrigation relies on localised point sources, which are relatively easier to protect and maintain.

3.9.4. Carbon Offset

RE-powered lift irrigation systems can significantly reduce reliance on fossil fuels while delivering environmental benefits through carbon emission reductions. Transitioning the energy demand for lift irrigation systems in Bhutan to RE solutions, such as solar-powered systems, could result in an annual CO_2 emission reduction of around 67,779 metric tonnes. This shift reinforces Bhutan's commitment to carbon neutrality while enhancing the sustainability of its agricultural water management.

3.9.5. Soil Erosion

Bhutan's steep slopes and intense monsoon rainfall accelerate soil erosion, reducing soil moisture retention and degrading agricultural productivity. Conventional irrigation methods often exacerbate soil loss by channelling excessive water flow. RE-powered lift irrigation can be integrated with micro-irrigation techniques such as drip and sprinkler systems, which optimise water usage, reduce runoff, and maintain soil health, ensuring long-term agricultural sustainability.

Recommendations

04

The recommendations in this chapter are designed to address the challenges and opportunities identified for developing RE-powered lift irrigation systems in Bhutan. These recommendations are the outcome of a comprehensive analysis conducted using desk reviews, stakeholder consultations, KIIs, and field assessments. These aim to provide actionable solutions across multiple dimensions, including governance, policy and regulation, technical aspects, financial mechanisms, GESI, capacity building, and climate and environmental sustainability. The recommendations aim to establish an enabling environment for the sustainable development and deployment of RE-powered lift irrigation systems. This will contribute to Bhutan's broader sustainability objectives and increase agricultural productivity and food security.

4.1. Governance

- **A focal nodal agency for RE-powered lift irrigation initiatives**
  Assigning a central nodal agency or department, such as the Department of Energy (DoE) for the development and deployment of RE-powered lift irrigation initiatives is critical. This agency will oversee all aspects, such as strategic planning, implementation, technical standards, and monitoring, acting as a nodal for coordination to ensure streamlined processes and accountability across ministries and departments. Clear mandates and defined responsibilities will minimise duplication of efforts, increase focus on sector development and accelerate the deployment of RE-powered systems. The nodal agency's roles could include:
  - *Coordination and Collaboration:* Facilitating communication and partnerships across stakeholders, including inter-government agencies, private sectors, etc.
  - *Identification of Best-suited Energy Solutions:* Evaluating and promoting the most viable and economical RETs.
  - *Establishment of Standards and Guidelines:* Ensuring consistency and quality in system design and implementation.
  - *Capacity Building:* Training programmes and knowledge-sharing platforms with coordination and collaboration with relevant institutions.
  - *Innovation and Implementation:* Encouraging research and piloting innovative models for scalable solutions.
  - *Policy and Regulations:* Formulate and implement policies and regulations to promote RE-powered lift irrigation initiatives, ensure compliance with GESI principles, incentivise private sector participation, and establish accountability mechanisms for project performance.

- **Establish mechanisms to facilitate cross-sectoral linkages at all levels of government administration, ensuring collaboration among ministries and departments**
  This approach involves creating systems that promote collaboration across various government levels and ensure effective coordination among ministries and departments to strengthen cross-sectoral connections. By adopting a nexus approach—linking the water, energy, agriculture, and food sectors under a unified framework—this mechanism will enhance efficiency, promote resource sharing, and create synergies among all stakeholders.

- **Develop a comprehensive multi-stakeholder institutional framework for long-term collaboration and equitable implementation of RE-powered lift irrigation initiatives**
  Developing an inclusive institutional framework to foster sustained collaboration among diverse stakeholders, such as government bodies, private sector players, academic institutions, NGOs, and local communities, will define the success of the project. This framework will integrate various perspectives and expertise into the planning and execution phases of RE-powered lift irrigation

projects. By formalising roles and responsibilities, the framework will provide clarity, promote accountability, and streamline processes. Additionally, equitable representation within this framework will ensure that the needs of marginalised groups are addressed, fostering social inclusion and fairness in project outcomes while promoting long-term sustainability and scalability. The multi-stakeholder framework should focus on the following key aspects:

- *Stakeholder Mapping and Engagement:* Identify and engage relevant stakeholders at Gewog (local), Dzongkhags (districts), and national levels. This will include consultations with farmers, cooperatives, private developers, and civil society organisations to ensure inclusive participation in policy formulation and project implementation.
- *Role Definition and Accountability:* Clearly define the roles, responsibilities, and accountability mechanisms for each stakeholder to avoid overlaps and ensure clarity in decision-making, resource allocation, and implementation.
- *Platform for Dialogue and Collaboration:* Create dedicated platforms such as steering committees, working groups, or forums to facilitate regular dialogue, knowledge-sharing, and joint problem-solving among stakeholders.
- *Monitoring and Dispute Resolution Mechanisms:* Develop mechanisms to monitor progress, address stakeholder grievances, and resolve conflicts effectively. This ensures smooth execution and builds trust among stakeholders.

4.2. Policy and Regulation

- **Develop a comprehensive GESI-responsive policy framework with clear guidelines, targets, and delivery mechanisms for RE-powered lift irrigation systems**
  Formulating a comprehensive GESI-responsive policy framework that outlines clear guidelines for target setting, technology development and deployment, delivery mechanism, grid connectivity, regulations, market development, capacity building, incentives and monitoring and evaluation will lay the foundation of these projects.

- **Align GESI-responsive policies for RE-powered lift irrigation systems with national goals, climate commitments, and Sustainable Development Goals**
  Integrate GESI-responsive policies for RE-powered irrigation systems with Bhutan's Nationally Determined Contributions (NDCs), Sustainable Development Goals (SDGs), and climate adaptation strategies. This integration will ensure coherence across national priorities and foster synergies between energy, water, agriculture, and climate sectors.

- **Set specific, measurable, and time-bound targets for the adoption of RE-powered lift irrigation system**
  Define quantifiable short-, medium-, and long-term targets for adopting RE-powered lift irrigation systems. These measurable goals will guide stakeholders, track progress, and align efforts toward achieving common goals.

- **Promote tailored GESI-responsive delivery mechanisms for diverse implementation models to address local challenges**
  Promote suitable GESI-responsive delivery models, including public-private partnerships (PPPs), cooperatives, single ownership, Energy Service Companies (ESCOs), and community-led initiatives etc, to address the unique challenges of the mountainous country.

- **Introduce financial incentives to reduce upfront costs and ensure equitable adoption of RE-powered lift irrigation system**
  Implement financial incentives such as tax exemptions, subsidies, concessional loans, and grants to reduce farmers' initial cost burdens and attract private sector investments. Ensure these incentives focus on GESI-responsive, equitable access, benefiting small-scale farmers and marginalised communities.

- **Establish a robust Monitoring and Evaluation (M&E) framework to continuously improve policies for RE-powered lift irrigation systems**
  Develop a comprehensive M&E framework to assess policy effectiveness periodically. Regular evaluations will help to identify gaps, highlight areas for improvement, and refine strategies to ensure policies align with evolving needs and challenges.

- **Develop a strategic roadmap for systematic implementation of RE-powered lift irrigation systems with defined milestones**
  Create a strategic roadmap and an implementation plan outlining milestones for technology adoption, infrastructure development, financing, and capacity building. A well-defined timeline will provide strategic direction, enabling stakeholders to coordinate efforts and facilitate systematic progress toward policy objectives.

4.3. Technical

- **Establish national standards and certifications to ensure the quality and reliability of RE-powered lift irrigation systems**
  Develop national standards covering technical design, material specifications, implementation, and performance of RE-powered lift irrigation systems. The standards and certifications should ensure that systems meet quality benchmarks and are suitable for Bhutan's diverse topography and climatic conditions. The standards and certifications should include RETs and energy efficiency (EE) metrics, materials specifications, and installation design and procedures.
  - *RETs and EE Metrics:* Define benchmark for energy performance to ensure the systems are cost-effective and sustainable.
  - *Material Specifications:* Establish guidelines for selecting materials and their warranty/guarantee with suitable certifications that are durable, weather-resistant, and suitable for high-altitude and rugged terrains.
  - *Installation Procedures:* Standardise protocols and guidelines for system design, installation, and operation to ensure uniformity and reliability across RE-powered lift irrigation projects.

  These standards will enhance system efficiency, reduce operational challenges, and foster trust among stakeholders by ensuring consistency and quality in RE-powered lift irrigation systems.

- **Develop a comprehensive technical framework and guidelines to standardise the implementation of RE-powered lift irrigation projects**
  Create a comprehensive technical framework and guidelines covering site selection and assessments, detailed feasibility studies, technical design, financial and economic assessments, multi-criteria assessments for project selection and evaluation, operation, maintenance, etc. This framework and guidelines will ensure uniformity and efficiency in project implementation while reducing technical, social, and environmental risks.

- **Establish digital platform and tools for project development and implementation**
  Establish specialised digital platforms and tools to enhance project development and implementation, enable effective planning, and resource mobilisation, and avoid duplication. These platforms should provide users with comprehensive insights into energy demand evaluation, resource mapping, and multi-criteria assessments to support informed decision-making. By offering these capabilities, stakeholders can identify optimal sites, assess feasibility, and align projects with technical and environmental objectives.

- **Build a comprehensive database to support renewable energy resource mapping and irrigation planning**
  Create and maintain a robust database of RE resources, irrigation needs, and potential project sites to support precise, data-driven decisions tailored to local conditions.

- **Foster a dedicated R&D program to advance RE-powered irrigation technologies**
  Establish a dedicated R&D programme to explore advancements in RE technologies for irrigation in collaboration with universities and international organisations. This programme should foster innovation in such as energy-efficient water distribution systems, crop and integrating sensors, micro-irrigation, advanced pumps, and other relevant technologies to optimise resource use and enhance agricultural sustainability.

- **Explore and pilot diverse project models for RE-powered lift irrigation systems to address local needs**
  Test and evaluate diverse project structures, such as centralised models, decentralised models, and distribution models, tailored to Bhutan's unique geographical and socio-economic context. Evaluate these models for feasibility, scalability, and effectiveness, refining approaches based on learnings from local implementation.

4.4. Financial

- **Adopt diverse and inclusive business models for the financial sustainability of RE-powered lift irrigation systems**
  Encourage the adoption of varied GESI-responsive business models, such as ESCO, asset leasing, water sales, lease-to-own systems, and community ownership. Tailor these models to meet the financial and operational needs of rural communities.

- **Introduce innovative financing mechanisms to reduce costs and attract investment for RE-powered lift irrigation systems**
  Introduce innovative GESI-responsive finance mechanisms such as concessional financing options and blended finance structures to reduce project costs and attract private sector investments. These mechanisms will ensure the affordability of RE-powered lift irrigation systems, making them accessible to a broader range of users. Furthermore, it explores targeted subsidies and innovative revenue models that can generate sustainable revenue streams for the operation and maintenance of the systems.

- **Design equitable cost-sharing frameworks to promote collective ownership and sustainability of RE-powered lift irrigation projects**
  Establish GESI-responsive cost-sharing frameworks that distribute financial responsibility among farmers, local governments, and private stakeholders. This shared financial approach will promote

collective ownership, enhance project sustainability, and ensure that all stakeholders are invested in the systems' success.

- **Mobilise private sector investment for additional project costs**
  Encourage private capital investments by enabling third parties to mobilise funds through equity, loans, or other financing mechanisms. Develop revenue models, such as selling water or energy services, to incentivise private sector participation and ensure financial returns and sustainability.

- **Provide strategic evidence-led subsidies to support early-stage development of RE-powered lift irrigation systems**
  Implement targeted subsidies, viability gap funding, or performance-based incentives to address financial barriers during the initial stages of RE-powered lift irrigation systems. Ensure subsidies are inclusive, incorporating GESI principles to benefit marginalised communities.

- **Ensure sustainable funding for O&M of existing RE-powered lift irrigation systems**
  Develop clear provisions for covering energy costs and ongoing O&M expenses in project preparation. Potential solutions include allocating government budgets for O&M of existing systems or securing farmer buy-in to share O&M expenses. These measures will ensure the longevity and reliability of lift irrigation systems.

- **Enhancing financial support for lift irrigation projects**
  Currently, subsidies from the government and credit from banks are unavailable for developing lift irrigation projects. This lack of financial support discourages private sector participation and investment in irrigation infrastructure. Encourage banks and financial institutions to extend loans to individual farmers, water user associations, and co-operatives that are formally registered, thereby enabling capital investment in irrigation systems.

4.5. GESI

- **Adopt gender-responsive and inclusive project selection criteria for RE-powered lift irrigation initiatives to create equitable access**
  Incorporate gender-responsive and inclusive criteria in the project selection frameworks that address the needs of women and marginalised groups, reduce social and economic inequalities, and ensure equitable benefit sharing gets prioritised. This approach fosters women's empowerment and supports marginalised groups, enabling their equal access to resources, benefits and decision-making. Projects considering such criteria are more likely to be socially equitable and supported by diverse stakeholders. Therefore, projects demonstrating significant impacts on GESI should receive additional incentives to encourage equitable and sustainable development.

- **Integrate GESI principles throughout the project lifecycle to address the needs of women and marginalised groups**
  Embed GESI considerations to address the needs of women and marginalised groups in every phase of the project cycle, from planning and design to implementation and evaluation. This approach is crucial to ensure the projects are more equitable and inclusive. To ensure GESI integration into the project lifecycle, the following approaches are recommended:
  - *Develop a GESI Action Plan for the Project:* The GESI action plan helps to ensure the systematic consideration of GESI throughout the project cycle. The plan embeds GESI at each stage of the project and ensures that the project’s interventions have adequately assessed and addressed the

needs and issues of women and marginalised groups. It also helps to ensure that interventions are contributing to equitable and inclusive project outcomes while fostering the participation and leadership of women and marginalised groups.

- *Establish GESI-Specific Impact Indicators:* Developing measurable GESI-specific indicators helps to evaluate the impacts of the RE-powered lift irrigation system on GESI outcomes, particularly in terms of women and marginalised groups' access, economic benefits, participation, leadership and decision-making, food security, and drudgery reduction. Regular monitoring of these indicators provides critical insights into GESI progress, enabling timely assessments and guiding necessary adjustments to ensure inclusivity and equitable outcomes.
- *Ensure Inclusive Stakeholders Engagement:* Engage women and marginalised groups in stakeholder consultations and decision-making processes. This approach ensures their perspectives and needs are reflected in project strategies and implementation. The inclusive stakeholder engagement enhances their ownership and active participation to make the project's interventions more gender-responsive, thus ensuring that the project adequately addresses the needs and concerns of women and marginalised groups.
- *Build Institutional and Stakeholder Capacity for GESI Integration:* Building awareness among project teams, stakeholders, and beneficiaries on GESI principles, its need, and practical application helps them better recognise the barriers to gender equality and inclusion as well as address diverse needs of community people in decision-making. Equipping the stakeholders with such knowledge and skills is crucial to implementing GESI-responsive interventions effectively and achieving more equitable, inclusive and effective project outcomes.

- **Invest in building the capacity of women to empower their participation in the RE-powered lift irrigation sector**
  Invest in building the capacity of women to bridge the gender gaps in knowledge, skills and capacity in the RE-powered lift irrigation sector. Particularly, enhancing their capacity in technical and entrepreneurship development helps in fostering business opportunities in the RE-powered lift irrigation sector, which is significant for women's economic independence. This will enhance women's participation, empowerment and decision-making capacity, thus establishing women as a change agent in the RE-powered lift irrigation system. Therefore, investing in capacity building for women in the RE-powered lift irrigation sector helps create a more equitable, inclusive, and resilient society in the sector.

- **Appoint dedicated gender focal points to enhance women's participation in the RE sector**
  Establishing gender focal points within government departments, institutions, and universities is essential to bridge gender gaps in the RE sector, particularly in RE-powered lift irrigation systems. These focal points can spearhead initiatives to develop inclusive policies, promote women's participation, and address systemic barriers, fostering a more equitable and gender-responsive environment.

- **Introduce and strengthen incentive mechanisms to promote GESI-driven RE-powered lift irrigation projects**
  Develop targeted incentive structures that actively promote GESI in RE-powered lift irrigation systems. These incentives could take the form of additional funding allocations for projects demonstrating significant GESI outcomes, public recognition or awards for exemplary contributions, and priority access to technical support or capacity-building resources. By embedding such mechanisms, stakeholders will be motivated to integrate GESI principles into project design and implementation. This approach not only enhances inclusivity but also fosters innovation and ensures the benefits of RE extend equitably to all segments of society.

4.6. Capability

- **Implement comprehensive training programmes to build stakeholders' technical and operational capabilities on RE technologies and irrigation**
  Design and implement tailored training programmes for government officials, engineers, technicians, private sectors, farmers, and relevant stakeholders. Focus on building skills related to the design, installation, operation, and maintenance of RE-powered lift irrigation systems. Addressing technical, managerial, and operational aspects will empower stakeholders to manage and sustain these systems effectively.

- **Establish skill development initiatives for early career professionals and students in RE and Irrigation**
  Develop a dedicated skill development plan targeting early-career professionals, university graduates, and students, thereby creating a pipeline of skilled talent in RE and irrigation systems. Collaborate with universities, vocational institutions, and industry partners to offer elective courses, certification programmes, and internships to provide hands-on training in system design, operation, and maintenance of RE and irrigation systems.

- **Institutionalise capacity-building efforts through structured programmes and strategic partnerships**
  Partner with academic, technical institutes, and vocational training centres to institutionalise capacity-building efforts through dedicated courses, certifications, and workshops focused on RE and irrigation systems. Also, to ensure a steady supply of skilled professionals and strengthen the workforce required for the successful implementation of RE-Powered Lift Irrigation Systems.

- **Promote knowledge sharing and collaboration to drive innovation, technology transfer, and disseminate best practices**
  Facilitate knowledge exchange through workshops, study tours, webinars, and digital platforms to showcase successful projects, innovative solutions, best practices, and lessons learnt. These platforms can foster collaboration among stakeholders, encourage innovation, and disseminate solutions that effectively address local challenges.

- **Develop localised training materials and resources to enhance accessibility and practical understanding**
  Create training materials and guides on technical design, operation, and maintenance aspects of RE-powered lift irrigation systems. Ensure these materials are translated into local languages to enhance accessibility and comprehension among all stakeholders, particularly farmers and community-based technicians. This localised approach will ensure inclusivity and practical understanding at the grassroots level. Regularly update training materials to reflect technological advancements and feedback from field experiences.

- **Conduct wide-scale awareness campaigns to accelerate the adoption of RE-powered lift irrigation systems**
  National nodal agencies should lead public outreach initiatives to raise awareness about the benefits and potential of RE-powered lift irrigation systems at the local and national levels. Design culturally and regionally tailored outreach campaigns to sensitise communities, highlight successful implementations, and promote the widespread adoption of these systems.

4.7. Climate and Environment

- **Establish detailed environmental compliance and impact assessment guidelines for RE-powered lift irrigation systems**
  Develop comprehensive guidelines for conducting environmental impact assessments (EIAs) as an integral part of the detailed feasibility study for RE-powered lift irrigation systems that prioritise local ecosystem protection, biodiversity conservation, environmental safeguarding, and sustainable water resource management throughout the project lifecycle.

- **Integrate climate-proofing design into RE-powered lift irrigation systems for enhanced adaptability**
  Incorporate climate-proofing measures into irrigation systems to ensure resilience against climate variability, including extreme weather events like floods, droughts, and unpredictable rainfall patterns. Employ adaptive technologies and build a robust infrastructure to maintain system functionality under diverse and unpredictable climatic conditions.

- **Promote integrated and sustainable water resource management practices in RE-powered lift irrigation systems**
  Adopt water-efficient technologies and practices to reduce water wastage and optimise resource utilisation. Encourage practices that align with the principles of Integrated Water Resource Management (IWRM) to enhance the long-term sustainability and efficiency of RE-powered lift irrigation systems.

- **Implement social and environmental safeguards to protect ecosystems and support communities**
  Introduce specific safeguards to mitigate social and environmental risks such as human-wildlife conflicts, land degradation, and resource inequities. These safeguards should include measures like creating buffer zones, initiating community engagement programmes, and establishing conflict resolution mechanisms to protect ecosystems and promote harmonious co-existence with local communities.

References

[1] NSB. (2024). *National Accounts Statistics 2024.* Thimphu, Bhutan: National Statistics Bureau (NSB), Royal Government of Bhutan. https://www.nsb.gov.bt/national-accounts-report/

[2] NSB. (2022). *Integrated Agriculture and Livestock Census, Bhutan*. Thimphu, Bhutan: National Statistics Bureau (NSB), Royal Government of Bhutan. https://www.nsb.gov.bt/wp-content/uploads/dlm_uploads/2023/05/Report-re-for-web.pdf

[3] NSB. (2024). *Labour Force Survey Fourth Quarter 2024*. Thimphu, Bhutan: National Statistics Bureau (NSB), Royal Government of Bhutan. https://www.nsb.gov.bt/wp-content/uploads/dlm_uploads/2025/01/Q4-LFS-Report.pdf

[4] ADB, JFPR, NEC, & DoA. (2016). *National Irrigation Master Plan 2016.* Asian Development Bank (ADB), Japan Fund for Policy Reduction (JFPR), National Environment Commission (NEC), & Department of Agriculture (DoA), Royal Government of Bhutan. https://lpr.adb.org/sites/default/files/resource/783/bhutan-national-irrigantion-master-plan.pdf.pdf

[5] UNDP. (2023). *Advancing Climate Resilience of Water Sector in Bhutan (ACREWAS)*. Thimphu, Bhutan: United Nations Development Programme (UNDP). https://www.adaptation-undp.org/projects/advancing-climate-resilience-water-sector-bhutan-acrewas

[6] NSB. (2023). *Bhutan at a glance 2023*. Thimphu, Bhutan: National Statistics Bureau (NSB), Royal Government of Bhutan. https://www.nsb.gov.bt/publications/insights/bhutan-at-a-glance/

[7] NSB. (2021). *Agriculture Survey Report.* Thimphu, Bhutan: National Statistics Bureau (NSB), Royal Government of Bhutan. https://www.nsb.gov.bt/wp-content/uploads/dlm_uploads/2022/06/ASR2021-Book-for-WEB.pdf

[8] DoSAM. (2020). *Land Use Land Cover.* Thimphu, Bhutan: Department of Surveying and Mapping (DoSAM), National Land Commission Secretariat, Royal Government of Bhutan. https://www.nlcs.gov.bt/wp-content/uploads/publications/LULC_Maps_Statistics_Report.pdf

[9] Muhammad, A.U.R.T., Muttil, N., & Wangchuk, K. (2021). A Critical Review of Water Resources and Their Management in Bhutan. *Hydrology*, 8(1), 31. https://doi.org/10.3390/hydrology8010031

[10] FAO, European Union, & CIRAD. (2022). *Food systems profile – Bhutan: Catalysing the sustainable and inclusive transformation of food systems*. Rome, Brussels and Montpellier, France. https://doi.org/10.4060/cb8156en

[11] Kuensel. (2024). *Agriculture sector targets Nu 50 Billion contribution to GDP by 2029*. Kuensel Online, published on 29 March 2024. https://kuenselonline.com/news/agriculture-sector-targets-nu-50-billion-contribution-to-gdp-by-2029

[12] NSB, 2024. *National Accounts Report 2024, GDP by Economic Activity at Current Prices (In Millions Nu. Table 2)*. Thimphu, Bhutan: National Statistics Bureau (NSB), Royal Government of Bhutan. https://www.nsb.gov.bt/publications/national-account-report/

[13] RNRSD. (2019). *RNR Census of Bhutan 2019.* Thimphu, Bhutan: Renewable Natural Resources Statistics Division (RNRSD), Royal Government of Bhutan. https://www.fao.org/fileadmin/templates/ess/ess_test_folder/World_Census_Agriculture/WCA_2020/WCA_2020_new_doc/BTH_REP_ENG_2019.pdf

[14] FAO. (2023). *National gender profile of agriculture and rural livelihoods – Bhutan.* Country gender assessment series. Thimphu, Bhutan: Food and Agriculture Organization of the United Nations. https://doi.org/10.4060/cc5273en

[15] IFAD. (2022). *Building Resilient Commercial Smallholder Agriculture (BRECSA) Project Design Document.* Asia and Pacific Division, International Fund for Agricultural Development (IFAD). https://www.ifad.org/en/w/projects/2000003935

[16] Verma, R., & Ura, K. (2021). Gender differences in gross national happiness: Analysis of the first nationwide survey in Bhutan. *World Development*, 150, 105714. https://doi.org/10.1016/j.worlddev.2021.105714

[17] NSB. (2018). *Rural-Urban Migration and Urbanization in Bhutan.* Thimphu, Bhutan: National Statistics Bureau (NSB), Royal Government of Bhutan. https://www.nsb.gov.bt/rural-urban-migration-and-urbanisation-in-bhutan-2/
[18] UNDP. (2021). *Bhutan gender analysis- an executive summary.* New York, United States: United Nations Development Programme (UNDP). https://climatepromise.undp.org/research-and-reports/bhutan-gender-analysis
[19] NEC. (2019). *National Waste Management Strategy 2019*. Thimphu, Bhutan: National Environment Commission (NEC), Royal Government of Bhutan. http://www.nec.gov.bt/publications/download/national-waste-management-strategy-2019english
[20] MoEA. (2013). *Alternative Renewable Energy Policy 2013.* Thimphu, Bhutan: Ministry of Economic Affairs. https://lpr.adb.org/sites/default/files/resource/778/bhutan-final-alternative-re-policy-april-2013.pdf.pdf
[21] Suh, J., Dorji, C., Mercer-Blackman, V., & Hampel-Milagrosa, A. (2020). Valuing unpaid care work in Bhutan. *ADB Economics Working Paper Series, 624, 40.*
http://dx.doi.org/10.22617/WPS200065-2
[22] Pradhan, P. (1989). Irrigation Development in Bhutan. *IIMI Working Paper No. 13*. Kathmandu, Nepal: International Irrigation Management Institute (IIMI). https://cgspace.cgiar.org/items/fa18c6c0-a842-47db-b0d8-1b482de93865
[23] RGoB. (2024). *Thirteenth Five-Year Plan 2024-2029*. Thimphu, Bhutan: Cabinet Secretariat, Royal Government of Bhutan. https://www.pmo.gov.bt/wp-content/uploads/2019/09/13-FYP.pdf
[24] Rai, M. (2024). Ministry of Agriculture and Livestock's plan to address Irrigation Water Scarcity. *The Bhutanese*, published on 29 June 2024. https://thebhutanese.bt/ministry-of-agriculture-and-livestocks-plan-to-address-irrigation-water-scarcity/
[25] Dorji, S. (2024). 24 irrigation projects included in 13th Five-Year Plan. *Business Bhutan*, published on 22 June 2024. https://businessbhutan.bt/24-irrigation-projects-included-in-13th-five-year-plan/
[26] MoEA. (2022). *Alternative Renewable Energy Strategy and Way Forward in Bhutan.* Thimphu, Bhutan: Ministry of Economic Affairs, Royal Government of Bhutan. https://bhutan.un.org/sites/default/files/2022-01/PPT%20on%20ARE%20to%20DPG%20Meeting%2012th%20Jan%202022.pdf
[27] ESCAP. (2022). *Energy Pathway for the 2030 ESCAP Agenda: SDG 7 Roadmap for Bhutan.* Bangkok, Thailand: Economic and Social Commission for Asia and the Pacific (ESCAP), United Nations. https://www.moenr.gov.bt/wp-content/uploads/2018/07/SDG7-Roadmap-for-Bhutan_Final.pdf
[28] DoE. (2023). *Moving towards competitive markets for cross-border multilateral electricity trading: experiences in South & South-East Asia (BBIN-LTMS).* Thimphu, Bhutan: Department of Energy (DoE), Royal Government of Bhutan. https://www.unescap.org/sites/default/d8files/event-documents/Moving%20towards%20competitive%20markets%20for%20cross-border%20multilateral%20electricity%20trading-%20experiences%20in%20South%20%26%20South-East%20Asia%20%28BBIN-LTMS%29%20by%20Bhutan.pdf
[29] DSP. (2024). *DSP Solar Project.* Thimphu, Bhutan: De-Suung Skilling Programme Solar Initiative (DSP-SI), Royal Government of Bhutan. https://dsp.org.bt/initiatives/solarproject
[30] ICIMOD. (2024). *Solar-powered lift irrigation in Gangri, Bhutan.* Kathmandu, Nepal: International Centre for Integrated Mountain Development (ICIMOD). https://cdn.prod.website-files.com/653b16d5717caf033909d7b3/666f7b8af5026d5f32c95348_5102g_20240415_FL_SolarLiftIrrigationGangri_6.pdf
[31] Dorji, C. (2022). Solar water pump addressing Khawajara's irrigation water shortage. *Bhutan Broadcasting Service (BBS)*, published on 16 January 2022. https://www.bbs.bt/164821/
[32] MoENR. (2021). *Launch of first grid-tied solar power plant.* Thimphu, Bhutan: Ministry of Energy and Natural Resources (MoENR), Royal Government of Bhutan. https://www.moenr.gov.bt/?p=11208
[33] MoENR. (2024). *Commissioning of a 33 kWp solar PV plant at Shangsa, Lunana.* Thimphu, Bhutan: Ministry of Energy and Natural Resources (MoENR), Royal Government of Bhutan. https://www.moenr.gov.bt/?p=14196

[34] ESMAP. (2024). *ESMAP Annual Report 2024.* Washington DC, United States: Energy Sector Management Assistance Program (ESMAP), World Bank. https://www.esmap.org/ESMAP_2024_Annual-Report
[35] DoE. (2022). *Bhutan Energy Data Directory 2022.* Thimphu, Bhutan: Department of Energy (DoE), Ministry of Energy and Natural Resources, Royal Government of Bhutan. https://www.moenr.gov.bt/wp-content/uploads/2018/11/Final-copy-of-BEED-2022.pdf
[36] IRENA. (2019). *Renewables Readiness Assessment: Kingdom of Bhutan,* (DRE–MOEA (2016b)), "Renewable energy master plan 2017– 2032", internal document prepared by Fichtner GmbH & Co.). Abu Dhabi, UAE: International Renewable Energy Agency (IRENA). https://www.irena.org/-/media/%20Files/IRENA/Agency/Publication/2019/Dec/IRENA_RRA_Bhutan_2019.pdf
[37] BPC. (2023). *Power Data Book 2023.* Thimphu, Bhutan: Bhutan Power Corporation Limited (BPC), Royal Government of Bhutan. https://www.bpc.bt/wp-content/themes/bpc/assets/downloads/Power%20Data%20Book%202023.pdf
[38] MNRE. (2024). *National Portal PM-KUSUM.* New Delhi, India: Ministry of New and Renewable Energy (MNRE), Government of India. https://pmkusum.mnre.gov.in/#/landing#about-scheme
[39] AEPC. (2024). *Progress at a Glance: Year in Review FY 2080/81 (2023/24).* Kathmandu, Nepal: Alternative Energy Promotion Centre (AEPC), Government of Nepal. https://www.aepc.gov.np/docs/1018/fc.pdf
[40] DoECC. (2023). *National Adaptation Plan (NAP) of the Kingdom of Bhutan.* Thimphu, Bhutan: Department of Environment and Climate Change (DoECC), Ministry of Energy and Natural Resources, Royal Government of Bhutan. https://unfccc.int/sites/default/files/resource/NAP-Bhutan-2023.pdf
[41] BEA. (2017). *Electricity Tariff in Bhutan.* Thimphu, Bhutan: Bhutan Electricity Authority (BEA), Royal Government of Bhutan. https://policy.asiapacificenergy.org/sites/default/files/Electricity%20Tariff%20in%20Bhutan%202017.pdf
[42] DoE. (2025). *PURE Platform Bhutan.* Thimphu, Bhutan: Department of Energy, Royal Government of Bhutan. https://www.moenr.gov.bt/?page_id=12960
[43] RAA. (2022). *Performance Audit Report on Irrigation Systems.* Thimphu, Bhutan: Royal Audit Authority (RAA), Royal Government of Bhutan. https://www.bhutanaudit.gov.bt/wp-content/uploads/2022/12/8.-PA-report-on-Irrigation-Systems-English.pdf
[44] MoF. (2025). *Budget Reports.* Thimphu, Bhutan: Ministry of Finance (MoF), Royal Government of Bhutan. https://www.mof.gov.bt/publications/reports/budget-reports/
[45] BPC. (2025). *Electricity Tariff.* Thimphu, Bhutan: Bhutan Power Corporation Limited (BPC), Royal Government of Bhutan. https://www.bpc.bt/electricity-tariff/
[46] Pelzom, T., & Katel, O. (2018). Youth Perception of Agriculture and potential for employment in the context of rural development in Bhutan. *Development, Environment and Foresight*, 3(2), 92-106. ISSN: 2336-6621
[47] OECD. (2012). *2012 SIGI Social Institutions and Gender Index: Understanding the Drivers of Gender Inequality.* Paris, France: Organisation for Economic Co-operation and Development (OECD). https://doi.org/10.1787/4bd7aa1c-en
[48] NCWC. (2013). *Bhutan Gender Policy Note.* Thimphu, Bhutan: National Commission for Women and Children (NCWC), Royal Government of Bhutan. https://ncwc.gov.bt/publications/Bhutan%20Gender%20Policy%20Note.pdf
[49] NCoB. (2024). *Interim Report on the Review of Rural Credit Access in Bhutan.* Thimphu, Bhutan: National Council of Bhutan. https://parliament.bt/uploads/topics/17187910338083.pdf
[50] World Bank. (2020). *Pathways to Power: South Asia Region Baseline Assessment for Women Engineers in the Power Sector.* Washington, DC, United States: World Bank. https://documents.worldbank.org/en/publication/documents-reports/documentdetail/425391580298974587/pathways-to-power-south-asia-region-baseline-assessment-for-women-engineers-in-the-power-sector
[51] MoESD. (2023). *Annual Education Statistics 2023.* Thimphu, Bhutan: Ministry of Education and Skills Development (MoESD), Royal Government of Bhutan. https://education.gov.bt/download/annual-education-statistics-2023/

[52] NSB. (2018). *Population and Housing Census 2017 (National Report)*. Thimphu, Bhutan: National Statistics Bureau (NSB), Royal Government of Bhutan. https://www.nsb.gov.bt/publications/census-report/
[53] Chhogyel, N., Kumar, L., & Bajgai, Y. (2020). Consequences of Climate Change Impacts and Incidences of Extreme Weather Events in Relation to Crop Production in Bhutan. *Sustainability*, 12(10), 4319. https://doi.org/10.3390/su12104319
[54] Rinzin, S., Zhang, G., Sattar, A., Wangchuk, S., Allen, S. K., Dunning, S., & Peng, M. (2023). GLOF hazard, exposure, vulnerability, and risk assessment of potentially dangerous glacial lakes in the Bhutan Himalaya. *Journal of Hydrology*, 619, 129311. https://doi.org/10.1016/j.jhydrol.2023.129311
[55] NCHM. (2025). *Climate change in Bhutan*. National Centre for Hydrology and Meteorology (NCHM), Royal Government of Bhutan. https://www.nchm.gov.bt/home/pageMenu/781

Annexure 1 Workshop and Key Informant Interview Details

Table 9 List of Institutions and Participants of the Participatory Workshop

Sector	Institutions	Number of Individuals
Government Agencies	DoA, DoW, DoID, DoE, DoE EIMD, DoE ESPD, BPC, LG Reps	11
Research and Academic Institutions	NCHAM, ICIMOD, College of Science and Technology	3
Donors	BTFEC, UNDP	2
Private Institutions	BCCI	2
Non-Governmental Organisations (NGOs)	BAOWE	1
Community Groups	Sherchok Women's Group (SWG)	1
Banks	BoB, BDBL	2

*Total participants- 22, Male- 12, Female- 10, Held on 13 August 2024, Thimphu

Table 10 List of Institutions and Participants of the Validation Workshop

Category	Institutions	Total Individuals
Government Agencies and Policy Makers	DoA, DoW, NCHM, BPC, DECC, DoID, GBPL, DoE, LG Reps	20
Research and Academic Institutions	College of Science and Technology, ICIMOD	3
NGOs	Clean Bhutan, Bhutan Ecological Society	2
Community Groups	Sherchok Women's Group	1
Banks	BoB, BDBL	3
Private Sectors	Sangsel Eco Trade Services, BCCI	2

*Total participants- 31, Male- 23, Female- 08, Held on 18 October 2024, Thimphu

Key Informant Interviews

Table 11 List of Names of Dzongkhag and Coordinates of KII Respondents

S.No	Dzongkhag	Sectors	Places/Institutions
1	Wangdue	Research 1	National Seed Centre, Bajothang
2	Wangdue	Research 2	RNR-RC Bajothang
3	Punakha	Community 1	Lobesa Gewog
4	Punakha	Community 2	Lakhu Village, Guma Gewog
5	Punakha	Community 3	Khawajara village, Toewang Gewog
6	Punakha	Community 4	Dochhukha_Dzomlingthang Ritsa chiwog, Guma Gewog
7	Paro	Community 5	Gangri Village, Shaba Gewog
8	Samtse	Community 6	Namgaychhoeling and Tashichhoeling (combined)
9	Samtse	Community 7	Ugyentse Gewog
10	Thimphu	Government 1	Department of Water (Forester)
11	Thimphu	Government 1	Department of Water (Civil Servant)
12	Thimphu	Government 2	Bhutan Trust Fund (Chief Program Officer)
13	Paro	Government 2	Bhutan Trust Fund (Forester, Donor)
14	Thimphu	Bank 1	Bhutan National Bank (Project Developer)
15	Thimphu	Bank 2	Bank of Bhutan (Project Developer)
16	Thimphu	CSO 1	Civil Society Organisation (Project Director)
17	Thimphu	Government 3	Department of Environment & Climate Change (Assistant Officer)
18	Paro	Government 4	Bhutan Ecological Society (Researcher)
19	Thimphu	Private 1	Association of Bhutanese Tour Operators (Executive Director)
20	Thimphu	Government 5	NCWC (Chief Program Officer, Member)
21	Thimphu	Private 2	FMCL
22	Thimphu	Bank 1	Bhutan National Bank Limited (Banker, 15 years)
23	Chhukha	Community 8	Phuentsholing Thromde, Chhukha Dzongkhag (Architect)
24	Chhukha	Community 9	Phuentsholing Thromde, Chhukha Dzongkhag (Lawyer)
25	Samtse	Community 10	Samtse (Freelancer)
26	Samtse	Government 6	Dzongkhag Engineer (Engineer)
27	Trashigang	Government 7	Thrimshing Gewog, Govt Official
28	Punakha	Community 11	Guma Gewog, Village Representative
29	Samtse	Research 3	Academician, College of Science and Tech
30	Thimphu	Private 3	Sherab Enterprises Store (dealing in agricultural machinery and hardware items, including diesel/petrol pump sets)
31	Samdrup Jongkhar	Academia	Jigme Namgyel Engineering College

* from the site visit interviews conducted between August 2024 and October 2024 across various Dzongkhags in Bhutan

Annexure 2 Highlights of Crop Production (2019) and AREP (2013)

Table 12 Cereal and Crop Production in Bhutan [10]

Crop	Annual Production (Metric Tons)	Domestic Demand Coverage (%)	Imports (Metric Tons)	Import Value (USD)
Rice	50,000	35%	47,000	23.6 million
Maize	95,000	Not specified	Not specified	Not specified
Wheat	Not specified	10-15%	Significant	Not specified
Vegetables	1,20,000	Seasonal deficits in winter	Imported in winter	Not specified
Fruits	Not specified	Contribution to exports	Not specified	Not specified
Cardamom	Not specified	Key export	Not specified	11 million

Table 13 Livestock Production in Bhutan [14]

Livestock Type	Annual Production	Coverage of National Needs (%)	Imports (Value in USD)	Notes
Poultry (Chicken)	1,500 metric tons of meat	Not specified	Needed during peak seasons	
Eggs	50 million eggs	Not specified	Not specified	
Dairy Products	70%	70%	Powdered milk, butter, cheese	Significant imports from India
Meat	Not specified	Not specified	22 million	Dependence on imports

Table 14 Food Import Dependency in Bhutan [14]

Food Item	Local Production Coverage (%)	Import Dependency (%)
Rice	35%	65%
Dairy	70%	30%
Wheat	10-15%	85-90%

Table 15 Agricultural Production for Sale vs. Self-Consumption [14]

Production Type	Percentage of Farmers (%)
Primarily for Sale	10%
Solely for Self-Consumption	37%

Highlights of AREP

- Promoted technologies – Small Hydro, Wind, Solar (PV and Thermal), Biomass, Biofuel cogeneration, Urban and Municipal Waste to Energy.
- Government-identified RE Projects–The government shall develop an RE Master Plan, which will include resource analysis, potential project sites, and estimated project scale for different RE technologies. Nodal Agency shall identify projects and carry out the pre-feasibility stage to ascertain their viability, covering the technical, financial, economic and environmental aspects. These reports shall be made available to the public.
- Allotment process – Projects shall be allotted to the private sector through a competitive bidding process to the lowest tariff bidders. In case allotment is not achieved through the bidding process, the Government shall allot the projects to State-owned agencies for development.
- Self-identified RE Projects - Private agencies or individuals are encouraged to identify and develop projects up to a size of 5 MW.
- Evaluation Criteria and Allotment – Nodal Agency was responsible for developing evaluation criteria and allotment guidelines for the self-identified RE projects to the private sector. Nodal Agency is yet to be defined for non-hydro projects.
- Consumption by Individual and Community – Pico Hydropower Project(s) and Micro Hydropower Project(s) can be allotted for such consumption. Any surplus energy is allowed for sale to third parties.
- Decentralised Distributed Generation (DDG) Projects
  - Purpose – To provide energy-based services using its own dedicated distribution system to the villages which are not electrified or not connected to the grid
  - Investment and Ownership – Open for Private Sector investments and ownership
  - Funding and Management – For the government-funded projects, the management shall be transferred to the Communities wherever feasible
  - Tariff
    i. Bhutan Electricity Authority, now known as the Electricity Regulatory Authority (ERA) shall determine the tariff
    ii. For government-funded projects, a tariff shall be set to support the operation and maintenance costs only
    iii. Allowed to sell electricity to the Utility as and when connected to the grid
    iv. Government Support in Operations—For government-funded projects, the Government shall provide back-up support in restoring the plant in case of major breakdowns that require substantial funds

- Standalone RE Projects
    i. Standalone RE systems/schemes/programmes are based on RE technologies (solar PV, solar thermal, pico hydro, micro-hydro, wind, solar home lighting system, solar lanterns, biogas plants, passive cooling systems, biomass, cook-stoves etc. for processing appliances) or a hybrid of RE technologies
    ii. These systems are installed in an individual's household, community, institutions, and commercial entities for self-consumption and are generally off-grid
    iii. Projects connected to the grid under net metering are also considered Standalone RE projects
    iv. Investment and Ownership – Open for Private Sector investments and ownership
    v. Civil Societies, NGOs, Communities, Companies and Individuals can initiate and undertake stand-alone projects
    vi. Nodal Agency is responsible for developing guidelines, rules, and regulations. Nodal Agency has yet to develop these
    vii. Investment Model – All RE projects except mini, micro and small hydro are allowed to be developed under Build Own Operate (BOO) model. Mini, micro and small hydro projects can be developed under the Build Own Operate Transfer (BOOT) model
    viii. Project Ownership – Private ownership is allowed for any RE project. Foreign Direct Investment (FDI) is also allowed but only as minority shareholding for small hydro projects
    ix. Funding from the Government - Renewable Energy Development Fund (REDF) was established to provide financial assistance for creating a favourable investment climate for RE. Nodal Agency shall administer and manage the funds in the REDF. REDF shall fund
    x. All activities considered appropriate by the NA for the development of the RE sector and for creating a favourable investment climate
    xi. Provide support to sustain RE programmes and projects where deemed necessary
    xii. Research and Development activities to promote RE and Energy Efficiency

However, REDF is yet to be operationalised.

- *Promotional Measures:* Provide capital subsidy and/or grants to finance small-scale individual and community investments in RE Projects
- Project Developers, Manufacturers and Systems Integrators of RE Projects, except small hydropower projects, are exempt from
- Corporate or business income tax for a period of ten years
- Import duties and Sales tax on the import of plants and equipment as direct inputs to the project during the construction period
- Sales tax and customs duty for the purchase of spare parts

Annexure 3 Case Study on Financial Feasibility Assessment

This case study explores the economic feasibility of a solar-powered lift irrigation system installed in Gangri. The project was designed to improve water availability for the catchment area and thus enhance agricultural productivity. Apart from conventional gravity-based irrigation channels, farmers were also using diesel pump sets for irrigation. The project was planned to be implemented in two stages. The first stage, with a capacity of 15 HP, was commissioned in 2022 and has been operating since then. The second phase is under the project preparation stage. Under the second phase, 15 HP is being added to the project. Under phase 1, about Nu 2 million and Nu 7 million were spent on solar + pump infrastructure and the upgradation of irrigation infrastructure, respectively. It was assumed the second phase would cost Nu 2 million.

Table 16 System Overview of Solar Lift Irrigation System at Gangri

Categories	Current Status	Proposed Addition	Total
Location	**Gangri**		
Pump Capacity	15 HP	15 HP	30 HP
Solar Generation Unit	16 kWp	5 kWp	21 kWp
Area Served	42 acres	38 acres	80 acres
Components 1 & 2 (Solar PV and Pumping Infrastructure)	2 million Nu	2 million Nu	4 million Nu
Component 3 (Upgradation of irrigation infrastructure)	7 million Nu	--	7 million Nu
Total Project Cost	9 million Nu	2 million Nu	11 million Nu

For the project to be viable, the project needs to generate more value than the lifetime costs of the project. Net Present Value, Internal Rate of Return and Payback Period can be used for assessing viability. Payback Period being the simplest to use, the Payback Period has been used for the case study. The annual value addition required for different payback periods is listed in the Table below. A payback period of 4 years has been used as an example for further discussion.

Table 17 Required Incremental Income for Different Payback Periods (Gangri)

Payback Period (Years)	O&M Expenses (Nu Million) @ 5% of Project Cost	Recoverable Cost (Nu Million) Project Cost + O&M	Required Annual Increment in Farmers' Income (Nu Million)	Required Annual Increment in Farmers' Income (Nu)
1	0.55	11.55	11.55	1,44,375
2	1.10	12.10	6.05	75,625
3	1.65	12.65	4.22	52,708
4 (Base Case)	2.20	13.20	3.30	41,250
5	2.75	13.75	2.75	34,375
6	3.30	14.30	2.38	29,792
7	3.85	14.85	2.12	26,518

Payback Period (Years)	O&M Expenses (Nu Million) @ 5% of Project Cost	Recoverable Cost (Nu Million) Project Cost + O&M	Required Annual Increment in Farmers' Income (Nu Million)	Required Annual Increment in Farmers' Income (Nu)
8	4.40	15.40	1.93	24,063
9	4.95	15.95	1.77	22,153
10	5.50	16.50	1.65	20,625

For a project cost of Nu 11 million, the farmers should be able to increase their annual farm income by Nu 3.30 million for payback, i.e., Nu 41,250 per acre in 4 years. This is assuming the project is fully funded by the Community. The impact of the various factors on the required annual increment in farmers' income is summarised in the table below.

Table 18 Effect of Various Parameters on Target Annual Income Growth Needed by Farmers

Factors	Effect	Impact on Required Annual Increment in Farmers' Income	Remarks
Debt	Interest payment and debt repayment increase the project's lifetime costs	Increases	• The impact can be partially reduced by interest rate subventions • Increases funding for irrigation
Third-Party Owner	The return on investment of the third party would be recovered from the farmers through the sale of services.	Increases	Increases funding for irrigation
Other revenue for the project	Other revenue from the project will supplement the project revenue i.e., an increment in farmers' income	Decreases	Net metering and adding other energy demands like drinking water can provide other revenue
Capital Subsidy	Capital Subsidy shall reduce the project cost and hence lifetime costs	Decreases	

Financial Analysis can be used for the selection and design of the projects. Few examples:

1. The projects with increments in farmers' income higher than the benchmark can be pursued through commercial methods
   a. Third-party ownership and individual farmer ownership (for self-consumption and or sale of water to neighbouring farmers) can be promoted.
   b. Projects can be funded through debt and equity.
2. The projects with increments in farmers' income equivalent to the benchmark can be pursued through commercial methods with support from the government.
   a. Third-party ownership and individual farmer ownership (for self-consumption and or sale of water to neighbouring farmers) can be promoted.
   b. Projects can be funded through debt, equity and government capital subsidies. Interest rate subvention and a longer debt repayment period can also be used as support for these projects.

The projects with increments in farmers' income less than the benchmark can be pursued through government funding.

Table 19 Investment Model

Investment Models	Applicability of the Model and Government Support
Government-funded community-owned systems	It is easy to adopt as the current irrigation systems are deployed under this model. It is most suitable for sites where the cost of irrigation is high and farmers cannot afford to pay for irrigation. The government may provide support with maintenance.
Government-owned systems leased to the community	It involves communities paying for irrigation services. So, communities with paying capacities are more suitable for this system.
Private-owned systems leased to community	It involves communities paying for irrigation services. So, communities with paying capacities are more suitable for this system. The government may provide subsidies and maintenance support to the owner.
Community-funded and owned systems	It is suitable for communities that can afford the capital cost of the project. The government may provide subsidies and maintenance support to the owner.
Individual farmer-funded and owned systems	It is suitable for entrepreneurial farmers who are willing to sell water to neighbouring farmers. The government may provide subsidies and maintenance support to the owner.

Table 20 Components of Financial and Economic Viability

S.No.	Component	Description
	A. Increase in Income	
1	Increase in revenue due to improved production	Enhanced income from higher agricultural yield.
1.1	Increase in the area under irrigation	Expansion of irrigated land area.
1.2	Increase in cropping intensity	More crop cycles per year on the same land.
1.3	Improved productivity of the existing crops	Higher yield from current crops.
1.4	Addition of new crops and crop diversification	Introduction of different crop varieties to improve resilience and income.
2	Savings in energy cost	Reduction in energy expenses compared to diesel or utility-powered pumps.
3	Other income	Additional sources of revenue.
3.1	Export of energy to the grid	Selling surplus energy when pumps are idle.
3.2	Sale of water	Revenue from selling irrigation water.
	B. Increase in Costs	
1	Increase in agri input costs	Higher costs due to expanded agricultural activities.
1.1	Energy cost	Cost of energy required to run the system.
1.2	O&M cost of new infrastructure	Operation and maintenance expenses for new facilities.
1.3	Agricultural inputs	Costs for new agricultural practices, such as seeds and manure.
2	Cost of capital	Expenses associated with borrowing and investment.
2.1	Interest rate	Rate of interest on loans or capital.
	C. Source of Capital	
1	Project cost and funding sources	Total project expenses and sources of funding.
1.1	Project cost	Total estimated cost for the project.
1.2	Capital from various sources	Contribution through subsidies, grants, debt, and equity.
	D. Return Parameters	
1	Return parameters	Measures of financial returns.
1.1	Net present value	Value of future cash flows discounted to present value.
1.2	Internal Rate of Return for Project and Equity	Profitability measures for both the project and investor equity.
1.3	Payback Period	Time is required to recover the initial investment.

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/