Kingdom of Bhutan

TECHNOLOGY NEEDS ASSESSMENT AND TECHNOLOGY ACTION PLANS FOR CLIMATE CHANGE ADAPTATION

"March 2013"

National Environment Commission
Royal Government of Bhutan

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Disclaimer

This document is an output of the Technology Needs Assessment project, funded by the Global Environment Facility (GEF) and implemented by the United Nations Environment Programme (UNEP) and the UNEP Risoe Centre (URC) in collaboration with the Regional Centre (from the corresponding region), for the benefit of the participating countries. The present report is the output of a fully country-led process and the views and information contained herein is a product of the National TNA team, led by the National Environment Commission, Royal Government of Bhutan.

Bhutan Technology Needs Assessment Project Team

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AIT Asian Institute of Technology

FOREWORD

དཔལ་ལྡན་འབྲུག་གཞུང་།

Royal Government of Bhutan

PRIME MINISTER

28 March, 2013.

Foreword

Bhutan, with its commitment to preserve the natural environment, has been actively participating in the fight against one of the most pressing challenges of the current times, the climate change. The country has undertaken the Technology Needs Assessment process to identify, evaluate, and prioritize technologies that fit in the overall development context of the nation while allowing the country to adapt to and mitigate climate change. At the Conference of Parties (COP) 14 in 2008, the Poznań Strategic Programme on Technology Transfer was adopted as a step towards *scaling up the level of investment in technology transfer in order to help developing countries address their needs for environmentally sound technologies.* As part of this programme, in 2010, on behalf of Global Environment Facility (GEF), the United Nations Environment Programme (UNEP) started the implementation of Technology Needs Assessment (TNA) for 36 countries.

Taking forward its commitment at the international forums, I am pleased that the National Environment Commission (NEC) Secretariat has completed the Technology Needs Assessment for Climate Change (TNA) and that it led to the formulation of a Technology Action Plan (TAP) for implementation of the prioritized technologies for adaptation and mitigation. These initiatives fit in the larger scheme of things that we are pursuing for low-carbon and climate-resilient development and will contribute to the development of the 11th Five Year Plan of the country, to be finalized soon.

As a party to the UNFCCC, Bhutan is fully committed to developing and implementing policies, programmes and projects to address the many challenges posed by climate change. We have also adopted a new Economic Development Policy in 2010, which embraces the concept and principles of green economic development. We are now formulating a national strategy for low-carbon and climate-resilient development.

Application of collective knowledge and skills is crucial in developing solutions for combating the challenges of climate change. In this regard, I am encouraged to note that various stakeholders not only from government agencies, but also from the civil society and private sector have been involved in the TNA process and have contributed extensively in selecting the prioritized technologies, identifying the key barriers to technology development and deployment, preparing the Technology Action Plans for overcoming the identified barriers and identifying the implementable project ideas for each technology. I would like to commend all the individuals and organizations that have contributed to the TNA process particularly, the TNA Taskforce members, the respective government departments and agencies and the National Environment Commission for effectively leading this exercise.

I look forward to seeing the findings and recommendations of the TNA project feed into the national strategy for combating climate change in Bhutan.

Tashi Delek !

(Jigmi Y. Thinley)
Prime Minister, and
Chairman of NEC

PREFACE

Given Bhutan's vulnerability to the impacts of climate change, the nation has accorded climate change a high priority. The nation's commitment to remain carbon neutral while ensuring overall social-economic development reflects, its vision to address the challenges of climate change and move towards a sustainable future.

The challenges of addressing climate change, particularly by developing and least developed countries have been recognized at various international forums. Technology transfer as a vital instrument to overcome these challenges has been identified by the UNFCCC in Article 4.5. Subsequently, the need and importance of technology transfer has been reiterated at various Conference of Parties (COP) of the UNFCCC. At COP 14 in 2008, the Poznań Strategic Programme on Technology Transfer was adopted as a step towards *scaling up the level of investment in technology transfer in order to help developing countries address their needs for environmentally sound technologies.* As part of this programme, in 2010, on behalf of Global Environment Facility (GEF), the United National Environment Programme (UNEP) started the implementation of Technology Needs Assessment (TNA) for 36 countries.

Bhutan has undertaken the TNA process to identify, evaluate, and prioritize technologies that fit in the overall development context of the nation while allowing the country to mitigate climate change. The National Environment Commission Secretariat is the nodal agency for the TNA project and has constituted a TNA Task Force involving representatives from various sectors to provide inputs to the TNA and most importantly in preparing the Technology Action Plan for identified technologies.

The TNA report is the first in the series of four reports to be submitted to UNEP. The report begins with the introduction about the TNA project and how it fits in the overall context of Bhutan's development and climate change priorities. The second chapter describes the institutional framework of the TNA process. The third chapter focuses on prioritization of sectors and describes the process adopted and the results. Subsequent chapters explain the process and results of prioritization of technologies for each of the prioritized sectors. The entire process to arrive at prioritized sectors and technologies has been country-driven and highly consultative involving a number of stakeholders from various agencies in the government, civil society and private sector.

Ugyen Tshewang, PhD
Secretary
National Environment Commission

ACKNOWLEDGMENT

The National Environment Commission Secretariat (NECS) sincerely acknowledges the Global Environment Facility (GEF) for the financial support provided for the Technology Needs Assessment (TNA) project in Bhutan. We would also like to thank UNEP Risø Centre (URC) and Asian Institute of Technology (AIT) for their technical guidance during the course of the TNA. The NECS is particularly grateful to Mr. Gordon Mackenzie, TNA country coordinator for Bhutan, for coordinating all the activities between the NECS, AIT and URC.

We would like to thank all the TNA taskforce members for their valuable contribution in prioritization of sectors and technologies, and for their comments on the draft report.

Further, we express our sincere appreciation to Emergent Ventures India and Norbu Samyul Consulting for facilitating the TNA process and putting together the TNA report.

ABBREVIATIONS

AWS	Automated Weather Station
COP	Conference of Parties
DRE	Department of Renewable Energy
EVI	Emergent Ventures India
EWS	Early Warning System
FYP	Five-year plan
GDP	Gross Domestic Product
GHG	Green house gas
GLOF	Glacial Lake Outburst Flood
GNH	Gross National Happiness
IARI	Indian Agriculture Research Institute
INC	Initial National Communication
IPCC	Intergovernmental Panel on Climate Change
MCDA	Multi-criteria Decision Analysis
NAPA	National Adaptation Programme of Actions
NEC	National Environment Commission
NECS	National Environment Commission Secretariat
NIP	National Irrigation Policy
NREL	National Renewable Energy Laboratory
PPB	Participatory Plant Breeding
PVS	Participatory Varietal Selection
RGoB	Royal Government of Bhutan
SALT	Sloping Agriculture Land Technology
SALT3	Sustainable Agroforest Land Technology
SARI/E	South Asia Regional Initiative for Energy
SHP	Small Hydro Power
SNC	Second National Communication
SPV	Solar Photovoltaic
SWERA	Solar and Wind Energy Resource Assessment
TAP	Technology Action Plan
TNA	Technology Needs Assessment
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
USAID	U.S. Agency for International Development

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Technology Needs Assessments Report

Executive Summary

Bhutan has undertaken Technology Needs Assessment (TNA) to identify, assess and prioritize environmentally sound technologies that will, within national development objectives, reduce the impact of climate change and the vulnerabilities associated with it. The TNA subsequently has led to the formulation of a Technology Action Plan (TAP) to implement the prioritized technologies within the overall framework of sustainable development in the country. The TNA and TAP constitute important processes of the global and national efforts to address development and environmental challenges posed by climate change.

The TNA process in the country was steered by the National Environment Commission (NEC) which served as the National Steering Committee for the TNA. The NEC is chaired by the Honourable Prime Minister of Bhutan and made up of high-level representations from various key ministries, civil society and private sector. The TNA coordinating agency was the NEC Secretariat (NECS), which is headed by the Environment Secretary. Mr. Karma Tshering, Programme Officer of the Policy and Programming Services in NECS, was the National TNA Coordinator.

A national task force for TNA had also been formed primarily for stakeholder involvement and inputs in the TNA process. The task force had a total of 35 members representing various agencies in the government, civil society and private sector. Their areas of work include agriculture, forestry, industry, public works and roads, hydropower and renewable energy, nature conservation, waste management, water resources management, transport management, tourism and hospitality, training and education, and construction. From among the task force members, two task force leaders had been appointed – one for adaptation and the other for mitigation.

In addition, Emergent Ventures India (EVI) was engaged as the international consultant to carry out and complete the TNA and subsequently formulate the TAP. The international consultant was supported by a national consultant, Norbu Samyul Consulting, with rich experience and expertise in the field of environmental management and planning.

The TNA of Bhutan at all stages has followed a transparent consultative process, involving a wide range of key stakeholders in the government, civil society and private sector. The first step in the formulation of Bhutan's TNA was sector prioritization which was done using an iterative online scoring process in which twenty members of the TNA taskforce participated. Using multiple criteria, three top priority sectors were identified for adaptation to climate change. These were water resources, agriculture and natural disasters and infrastructure.

Within each of these sectors, technologies were prioritized against a set of criteria, viz-a-viz, benefits (excluding climate change related benefits) (contribution to economic, environmental and social development priorities); relevance to climate change adaptation (vulnerability reduction potential); appropriateness (technology maturity and potential scale of utilization) and cost, each of which was given a specific scoring weightage. The entire process of criteria weighting and technology prioritization was carried out using Multi-Criteria Decision Analysis (MCDA) framework at the stakeholder consultation workshop held in Paro, Bhutan from 6 to 8 February 2012. Twenty-two members of the TNA taskforce participated in this workshop.

The workshop led to a list of shortlisted technologies in each of the three sectors. However, the final prioritized technologies for each sector were arrived at after further assessment of technologies on the basis of costs in addition to comprehensive discussions with sectoral experts and other stakeholders.

The results of technology prioritization in each of the three sectors are given in Table 1.

Table 1: Final prioritized sectors and technologies

Prioritized sectors	Prioritized technologies
Water Resources	§ Micro/Mini hydro power § Efficient irrigation methods § Solar power (Photovoltaic)

Agriculture	§ Agro-forestry § Development of drought resistant and pest resistant varieties of crops § Sloping Agriculture Land Technology (SALT)
Natural Disasters and Infrastructure	§ Real-time weather stations and weather forecasting (multi-range) § Climate resilient roads § Community based early warning systems

Further, it was suggested by the TNA Task Force members and the technical assistance team at UNEP that it may be practical to conduct in-depth and focused barrier analysis, enabling frameworks and technology action plans for only one technology per sector, rather than for all technologies. Therefore, it was decided that one technology from among the three prioritized technologies in each sector be selected for preparation of barrier analysis, enabling framework and technology action plan reports.

In this regard, discussions with TNA Taskforce members and representatives of the concerned ministries were carried out and one technology from each sector was finalized for the preparation of TAPs. The technologies finalized for each sector are given in Table 2.

Table 2: Finalized technologies for preparation of TAPs

Prioritized sector	**Finalized technology for barrier analysis, enabling framework and TAP**
Water resources	Efficient irrigation systems
Agriculture	Development of drought and pest resistant varieties of crops
Natural disasters and infrastructure	Climate resilient roads

Chapter 1. Introduction

1.1. About the TNA Project

Bhutan signed the United Nations Framework Convention on Climate Change (UNFCCC) at the United Nations Conference on Environment and Development in Rio de Janeiro in June 1992. Subsequently, it ratified the Convention in August 1995 through the National Assembly. As a Party to the UNFCCC, the country is fully committed to addressing climate change and attend environmental and development challenges through international mechanisms as well as national initiatives.

Article 4.5 of the UNFCCC identifies technology transfer as a key mechanism for addressing climate change, and requires developed countries to support technology development and utilization in developing countries. In order to operationalize Article 4.5, Parties agreed to introduce a mechanism known as Technology Needs Assessment (TNA) for climate change. Over the years, the importance of TNA was emphasized at various Conferences of Parties (COPs) of the UNFCCC.

At COP 7 in Marrakech, November 2001, the international community took the decision to encourage developing country Parties "*to undertake assessments of country-specific technology needs, subject to the provision of resources, as appropriate to country-specific circumstances".*

The COP 13 (Bali, December 2007) further reinforced the importance of TNA. The Bali Plan of Action, an outcome of COP 13, emphasized enhanced actions and provision of financial resources to enable technology development and transfer. At COP 14 (Poznan, December 2008), the Poznan Strategic Programme on Technology Transfer was adopted as a step towards scaling up the level of investment in technology transfer in order to help developing countries address their needs for environmentally sound technologies.

Finally, at COP 15 (Copenhagen, December 2009) the future establishment of a Technology Mechanism was suggested *"…to accelerate technology development and transfer in support of action on adaptation and mitigation that will be guided by a country-driven approach and be based on national circumstances and priorities."*

Concurrent with the growing international impetus on developing and using technologies for mitigation of, and adaptation to, climate change, Bhutan has been progressively undertaking initiatives to pursue a low-emission and climate-resilient economic development approach which is congruent with its overarching development philosophy of Gross National Happiness (GNH).

As a Party to the UNFCCC, Bhutan submitted its Initial National Communication (INC) in 2000. The INC enabled the country for the very first time to establish an inventory of greenhouse gas (GHG) emissions by sources and sequestration by sinks, and identify climate change vulnerabilities and adaptation measures. The Second National Communication (SNC), submitted in 2011, presents an updated GHG inventory, and describes mitigation measures, climate change vulnerabilities and a wide range of adaptation options across the various development sectors.

A National Adaptation Programme of Action for Climate Change (NAPA) was produced in 2006, outlining among other things priority projects for adaptation to climate change. On the world stage, Bhutan made the landmark declaration to remain a carbon-neutral economy at COP 15. To this end, it is developing a national strategy and action plan for low-carbon development. A new Economic Development Policy, embedded with green economy concept and principles, has also been adopted in 2010.

It is in the above context of global initiatives and national efforts to address climate change challenges that Bhutan has undertaken this TNA to identify, assess and prioritize environmentally sound technologies that will, within national development objectives, reduce the impact of climate change and the vulnerabilities associated with it. The TNA has subsequently, lead to the formulation of a Technology Action Plan (TAP) to implement the prioritized technologies within the overall framework for sustainable development in the country.

1.2. Existing national policies related to climate change and development priorities

With respect to climate change, the country's policies are geared towards low-carbon and climate-resilient development. It fully recognizes that climate change poses serious environmental and development challenges to the world at large but more so to countries like Bhutan, where key economic sectors such as hydropower and agriculture are extremely climate-dependent and the rugged fragile mountain ecosystem is highly vulnerable to climate change. This national outlook on climate change is in line with the country's overall principle for sustainable development defined by the overarching development philosophy of GNH.

The GNH philosophy rests on four pillars, namely: (a) equitable socio-economic development; (b) environmental sustainability; (c) promotion and preservation of culture; and (d) good governance. The GNH philosophy advocates that development should be planned and implemented in a holistic and balanced manner, integrating social, spiritual, economic, and environmental wellbeing in ways that are mutually-reinforcing. It emphasizes that development pursuits should take place within the limits of environmental sustainability and be carried out without impairing the biological productivity and diversity of the natural environment. The Constitution of the Kingdom of Bhutan, formally adopted in July 2008, enshrines GNH as a state policy and spells out the duties and rights of the parliament, the government and the people to safeguard and enhance the environment.

The new Economic Development Policy of Bhutan, launched in 2010, has been formulated with the vision "to promote a green and self-reliant economy sustained by an IT-enabled knowledge society guided by the GNH philosophy." Its key strategies include diversifying the economic base with minimal ecological footprint; harnessing and adding value to natural resources in a sustainable manner; promoting Bhutan as an organic brand; and reducing dependency on fossil fuel especially with respect to transportation.

The Five-Year Plan (FYP), since its advent in 1961, has been the main programmatic vehicle for the implementation of the country's development policies and plans. Recent FYPs feature poverty reduction as the overarching development objective and environmental conservation as a cross-cutting development theme across various sectors and programmes. Guidelines for mainstreaming environment, climate change and poverty issues in the formulation and implementation of FYPs at central, sectoral, and local levels have been developed and are being disseminated through training workshops for their application in the upcoming Eleventh FYP.

While the aforesaid policy and programmatic instruments provide the overall sustainable development framework within which climate change adaptation and mitigation actions can be developed and implemented, there are also a number of sector-based policies and strategies that aid/influence the decisions pertaining to identification and selection of technologies for climate change adaptation and mitigation. The key sector-based policies and strategies relevant to the TNA are given in Table 3.

Table 3: Key sector based policies and strategies

Policy Document	Relevance to Climate Change
Bhutan Sustainable Hydropower Development Policy 2008	One of the key objectives of the policy is to develop hydropower as a clean energy to mitigate problems related to global warming and climate change. This includes the reduction of dependency on imported fossil fuels, particularly in the transport sector.
Bhutan Water Policy 2003	Outlines social, technical and institutional measures for management of water resources including hydrometeorology, flood monitoring and warning systems.

Biodiversity Action Plan for Bhutan 2009	BAP 2009 recognizes that biodiversity loss can result in increased GHG emissions while careful management of biodiversity can lead to higher levels of carbon sequestration. It sets out various strategies and actions for the conservation and sustainable use of biodiversity, including protection of natural ecosystems and enhancement of their resilience against climate change.
National Action Programme to combat Land Degradation 2009	Many of the strategies and actions outlined in the NAP have relevance to climate change adaptation and mitigation. These include maintenance of the biological productivity and stability of natural lands and farmlands, soil fertility management with attention to organic methods, irrigation management, and solid waste management.
National Adaptation Programme of Action for Climate Change	NAPA identifies priority activities that respond to the country's urgent needs of adaptation to climate change.
National Forest Policy 2011	Bhutan is a net GHG sequester largely due to its vast forest cover. The National Forest Policy is geared towards sustainable management of forests including the maintenance of the health and vitality of forests and a minimum of 60 percent forest cover (as enshrined in the Constitution).
National Irrigation Policy 2011	Irrigation is seen as an increasingly important measure to adapt to growing uncertainties in rainfall patterns that impact crop production season and crop yields. The policy includes objectives for pursuance of sustainable irrigation infrastructure development and integrated water resources management, and ensuring of reliable and efficient water use for irrigated crop production.
National Framework for Organic Farming 2007	Organic farming systems have much lower GHG emission potential per unit area than conventional farming systems and organically farmed soils have higher carbon sequestration capacity. The National Framework for Organic Farming 2007 defines the vision and principles of Bhutan to develop organic farming as a way of life and to become fully organic by 2020.
Second National Communication to the UNFCCC 2011	The SNC presents an updated GHG inventory and describes mitigation measures, climate change vulnerabilities, and a wide range of adaptation options across the various development sectors.

Chapter 2. Institutional arrangement for the TNA and the stakeholders' involvement

2.1. The National TNA Team

TNA Steering Committee and Coordinating Agency

The National Environment Commission (NEC) serves as the National Steering Committee for the TNA. The NEC is the government's apex policy body for environmental matters and also functions as the National Climate Change Committee. It is chaired by the Honourable Prime Minister of Bhutan and made up of high-level representations from various key ministries, civil society and private sector. With the support of a secretariat, the NEC provides policy decisions and guidance on matters related to environment, sustainable development and the institution of policy measures to integrate environmental management in the overall development.

The TNA coordinating agency is the NEC Secretariat (NECS), which is headed by the Environment Secretary. The NECS is also the national focal agency for the UNFCCC. Mr. Karma Tshering, Programme Officer of the Policy and Programming Services in NECS, is the National TNA Coordinator.

TNA Task Force

A National Task Force for TNA has been formed primarily for stakeholder involvement and inputs in the TNA process. The Task Force has a total of 35 members representing various agencies in the government, civil society and private sector. Their areas of work include agriculture, forestry, industry, public works and roads, hydropower and renewable energy, nature conservation, waste management, water resources management, transport management, tourism and hospitality, training and education, and construction. From among the Task Force members, two Task Force leaders have been appointed – one for adaptation and the other for mitigation. Ms. Kunzang Choden, Senior Research Officer in the Ministry of Agriculture and Forests is the adaptation Task Force leader, and Mr. Chhimi Dorji, Deputy Executive Engineer in the Department of Hydro-met Services, is the mitigation Task Force leader.

TNA Consulting Team

Emergent Ventures India (EVI), a leading advisory firm in the area of climate change and sustainable development, has been engaged as the international consultant to carry out and complete the TNA and subsequently formulate TAP. The key EVI consultants involved in the TNA are:

- Mr. Aloke Barnwal, Principal Consultant and Team Leader (Energy and Climate) with EVI, holds a Masters of Public Affairs degree from Indiana University Bloomington US with specialization in Public Policy and Environment Policy. He has more than 12 years of experience in the field of climate change, natural resources management and rural development.
- Ms. Prima Madan, Senior Consultant with EVI holds a Masters degree in Economics from University of Nottingham, UK. She has over 7 years of research experience in the field of climate change, energy and sustainable development.
- Ms. Ishita Singh, Consultant with EVI, holds a Masters degree in Natural Resources Management from TERI University and over a year of work experience in the field of energy and climate change.

The international consultant has been supported by Mr. Ugen P. Norbu, a national consultant with a Masters degree in Integrated Conservation and Development and over 20 years of experience in the field of environmental management and planning.

The institutional arrangement for TNA in Bhutan is explained in Figure 1.

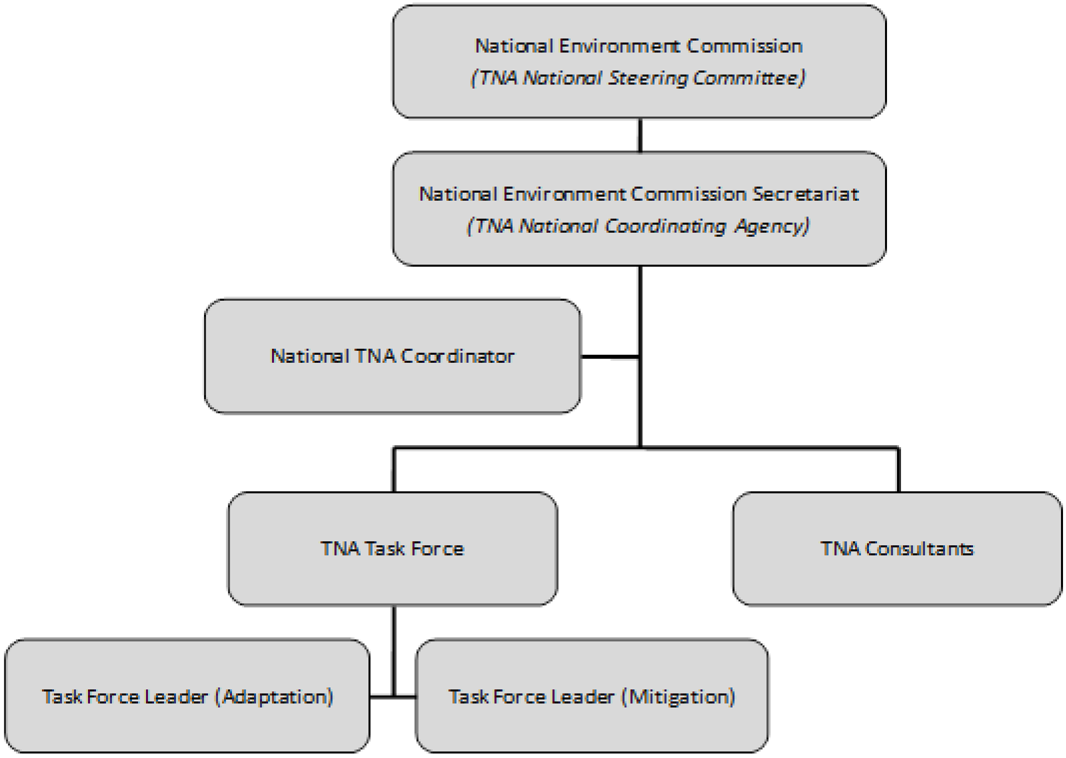

Figure 1: Institutional arrangement for TNA in Bhutan

2.2. Stakeholder engagement process followed in TNA – Overall assessment

The TNA of Bhutan at all stages has followed a transparent consultative process involving a wide range of stakeholders in the government, civil society and private sector. The prioritization of sectors was done using an iterative online scoring process in which twenty members of the TNA taskforce participated. The list of participants is given in Annex II. The scores provided by task force members were collated, analyzed and sent back to them for review. At this stage, participants were free to reconsider and change their scores if they deemed necessary. The scores received at the end of this stage were taken as final scores on the basis of which the sectors were prioritized for adaptation.

After the three top priority sectors were identified, a three day TNA Technology Prioritization Workshop was held in Paro, Bhutan from 6-8 February, 2012. The workshop was attended by 27 participants, including the TNA task force members, resource persons from Asian Institute of Technology (AIT) Bangkok and consultants. The list of workshop participants is given in Annex II. During the workshop a consensus was built on the criteria to be used for technology prioritization and their weightage. The criteria included environmental, social and economic benefits, vulnerability reduction potential, potential scale of utilization of the technology, and technological maturity.

As a next step, technology options for each of the priority sectors were identified and their key features were presented to the participants at the workshop. Based on the presentations and ensuing discussions on the technologies, the TNA task force members scored the technologies against the set of criteria decided in the previous step. The criteria related to benefits (excluding climate change related benefits), relevance to climate change adaptation and appropriateness. After the TNA workshop in Paro, further consultations with sectoral experts were carried out and cost was also included as one of the criterion for prioritization. In absence of quantitative data for the cost of identified technologies, qualitative assessment of costs was done with help of TNA task force members and sectoral experts. This led to the final list of prioritized technologies in each of the three sectors for adaptation.

Further, it was suggested by the TNA Task Force members that it may be practical to conduct in-depth and focused barrier analysis, enabling frameworks and technology action plans (TAP) for only one technology per sector, rather than for all technologies. Therefore, one-to-one discussions with some TNA Taskforce members and representatives of the concerned ministries were carried out, leading to one technology from each sector being finalized for the preparation of TAPs.

Chapter 3. Sector prioritization

3.1. An overview of sectors vulnerable to climate change

The second (SAR 1990), third (TAR 2001) fourth (AF4) assessment reports produced by the Inter-governmental Panel on Climate Change (IPCC) indicate that mountainous countries such as Bhutan, are likely to be among the countries most vulnerable to the adverse impacts of climate change. Bhutan is highly vulnerable to the impacts of climate change because of its limited size and high elevation, which increases its sensitivity to climate change and limits its ability to adapt. The IPCC and other similar reports have identified a number of vulnerabilities that mountainous countries will face with regards to climate change and variability, including their size and limited resource base, vulnerability to existing weather events such as heavy monsoonal rain, dry-season drought, tropical storms such as cyclones and restricted economic opportunities (National Environment Commission, 2011).

Accordingly, Bhutan's NAPA, 2006 identifies human health, water resources, agriculture, forests and biodiversity, and, natural disasters and infrastructure as the priority sectors for implementation of adaptation projects.

The key vulnerabilities due to climate change within various sectors, as listed in Bhutan's NAPA 2006 are given in Table 4.

Table 4: Key vulnerabilities due to climate change within various sectors

Sector	Vulnerabilities
Human Health	§ Loss of life from frequent flash floods, GLOF, landslides § Spread of vector-borne tropical diseases with warming climate § Loss of safe drinking water resources and increase in water-borne diseases
Water Resources	§ Temporal and spatial variation in flow, affecting electricity production/ exports due to disruption of average flows for optimum hydropower generation § Increased sedimentation of rivers, water reservoirs and distribution network, affecting irrigation schemes productivity/ agricultural crop yields § Reduced ability of catchment areas to retain water/ increased runoffs with enhanced soil erosion § Deterioration of water quality
Agriculture	§ Crop yield instability § Loss of soil fertility due to erosion of top soil and runoff § Loss of fields due to flash floods, landslides and rill & gully formation. § Crop yield loss to hailstorms. Deteriorated produce quality due to untimely incessant heavy rains and hailstorms § Outbreak of pests and diseases in fields and during storage where they were previously unknown § Damage to road infrastructure and hence food security

Forests and Biodiversity	§	Increased risk of forest fires due to drought in combination with increased lightning
	§	Change in phonological characteristics of plants/ Loss of endemic species
	§	Change in migratory pattern of trans boundary wildlife
	§	Possible increase of vector-borne diseases in wildlife due to warming
Natural Disasters and Infrastructure	§	Debris covered glaciers forming huge moraine dam lakes that ultimately lead to GLOFs (flash floods and landslides, heavy siltation of the rivers and other geotechnical hazards)
	§	GLOF will affect essential infrastructure such as hydropower systems, industrial estates, human settlements and public utilities.

Source: NAPA, 2006

3.2. Process, criteria, and results of sector selection

According to NAPA of Bhutan the sectors most vulnerable to climate change are forestry and biodiversity, agriculture, natural disasters and infrastructure, water resources, and health. These sectors were the preliminary identified sectors that were subject to scoring by the members of the TNA taskforce.

The scoring was based on the contribution of the sector to the nation's economic, environmental and social priorities as well as its vulnerability reduction potential through technological measures. A total weightage of 1 was divided equally among each of these criteria, indicating that each of the criteria was equally important for sector prioritization. The scoring was done on a scale of 0-5 as depicted in Table 5.

Table 5: Sector prioritization framework

Sector	Contribution to economic development priorities	Contribution to environmental development priorities	Contribution to social development priorities	Vulnerability reduction potential
Sector 1	Score	Score	Score	Score
Sector 2	Score	Score	Score	Score

Scale of score: 0-5

0: No benefit; 1: Faintly desirable; 2: Fairly desirable;

3: Moderately desirable; 4: Very desirable; 5: Extremely desirable

The entire process of sector prioritization was conducted through an iterative process of scoring using the electronic mail. Twenty members of the TNA taskforce participated in the scoring process. The details of the participants are given in Annex II.

The scores from these participants were collated, analyzed and communicated back to all participants of the first round. The participants were then given an option to reconsider their scores based on other scores and the calculated mean values. Only a few changes in the scoring were received in this round. The mean values of the scores received in the second round were taken as the final scores for sector prioritization. The detailed results of the sector prioritization process for adaptation are given in Table 6. As per the final scores, **Water Resources, Agriculture and Natural Disasters and Infrastructure** were the prioritized sectors for identifying technology needs.

Table 6: Results of sector prioritization

Sector	Criteria	Contribution to economic development priorities	Contribution to environmental development priorities	Contribution to social development priorities	Vulnerability reduction potential	Total score
	Weightage	**0.25**	**0.25**	**0.25**	**0.25**	
Water resources	Score	4.5	4.3	4	4.3	
	Standardized score	100%	100%	77.78%	100%	
	Weighted score	0.25	0.25	0.194444	0.25	0.94
Agriculture	Score	4.3	3.8	4.2	3.8	
	Standardized score	84.62%	54.55%	100.00%	28.57%	
	Weighted score	0.21	0.14	0.25	0.07	0.67
Natural disaster and infrastructure	Score	4	3.6	4.1	3.8	
	Standardized score	61.54%	36.36%	88.89%	28.57%	
	Weighted score	0.15	0.09	0.22	0.07	0.54
Forest and biodiversity	Score	3.2	4.2	3.3	4.1	
	Standardized score	0.00%	90.91%	0.00%	71.43%	
	Weighted score	0.00	0.23	0.00	0.18	0.41
Human health	Score	3.9	3.2	4.1	3.6	
	Standardized score	53.85%	0.00%	88.89%	0.00%	
	Weighted score	0.13	0.00	0.22	0.00	0.36

Chapter 4. Technology prioritization for water resources sector

4.1. Climate change vulnerability and existing technologies and practices in the sector

Bhutan's economy is strongly linked to water resources which are vital for many other sectors in the country such as agriculture, hydro power, industry and tourism. On a macro scale the availability of water in Bhutan seems very high (109,000 m^3 per capita); however the major sources for drinking and irrigation are mainly from local springs, streams and minor east-west tributaries for which no water flow measurement studies exist (National Environment Commission, 2011).

Although Bhutan has not experienced severe water shortages in the past, reports of dwindling water sources are increasing and climate change may render the country much more vulnerable. Surveys of local perceptions have reported that people have observed winter flows to be lower than normal in the past 10-20 years. Furthermore, during the mid-term review consultation of the 10th Five Year Plan (March-May 2011), representatives of almost all Dzongkhags raised the issue of acute water shortages for drinking and attributed such recent issues as increasing fallowing of agricultural land in the rural communities to the drying of water sources (National Environment Commission, 2011).

Other projections (IPCC, 2007, cited in National Environment Commission, 2011) indicate that by the 2050s, access to freshwater in Asia will decrease, with increasing extremes of dry and wet periods. Climate change is also likely to lead to increase the magnitude and frequency of precipitation related disasters, such as floods, landslides, typhoons and cyclones. Flows in rivers are likely to decrease at low flow periods as a result of increased evaporation. Retreat and loss of glaciers from rising temperatures and changes in precipitation, will impact the timing of stream flow regimes and consequently downstream agriculture. An increase in rainfall intensity projected in some models may increase runoff, enhance soil erosion on cleared land and accelerate sedimentation in the existing water supplies or reservoirs. Not only will such events reduce the potential of a catchment to retain water, but it will also cause water quality to deteriorate.

Further, a reduction in the average flow of snow fed rivers, combined with an increase in peak flows and sediment yield, would have major impacts on hydropower generation, urban water supply and agriculture. With increasing demands for water and also localised vulnerabilities already reported from many parts of Bhutan, adaptation measures have become necessary for both efficient use of water and also dealing with the impacts of climate change on water resources.

In summary, Bhutan's NAPA, 2006 has listed the following vulnerabilities faced by water resources sector:

- Temporal and spatial variation in flow, affecting notably electricity productivity/exports due to disruption of average flows for optimum hydropower generation
- Increased sedimentation of rivers, water reservoirs and distribution network, affecting notably irrigation schemes' productivity as also the agricultural crop yields
- Reduced ability of catchment areas to retain water/ increased runoffs with enhanced soil erosion (deterioration of environment)
- Deterioration of drinking water quality

The NAPA has also identified rainwater harvesting as a priority project in the sector. Other technological interventions that can allow adaptation in the sector can broadly be categorized into three categories, viz-a-viz, conservation of water resources/watersheds/wetlands, diversification of energy sources (to reduce dependence on hydropower as a source of energy) and effective use of available water. The various technologies in each of these heads are given in Table 7.

Table 7: Technology options for water resources sector

Vulnerability Factors	Adaptation strategy	Technologies interventions
· Increased sedimentation of rivers, water reservoirs and distribution network, affecting notably irrigation schemes' productivity as also the agricultural crop yields · Reduced ability of catchment areas to retain water/ increased runoffs with enhanced soil erosion (deterioration of environment) · Deterioration of drinking water quality · Dwindling water sources	Conservation of water resources/watersheds/wetlands	· Rainwater harvesting (ground water recharge and runoff control) · Erosion control measures including measures like grazing control · Reduction of chemical contamination by promotion of chemical and insecticide free agriculture practices
	Effective use of available water	· Efficient irrigation methods · Water use efficiency methods- improved water distribution systems; water efficient fixtures · Rainwater harvesting structures (Roof) · Building impoundments to store and distribute in lean season · Household Drinking Water Treatment and Safe Storage · Increasing the Use of Water-efficient Fixtures and Appliances · Leakage Management, Detection and Repair in Piped Systems · Water Reclamation and Reuse
Temporal and spatial variation in flow, affecting notably electricity productivity/exports due to disruption of average flows for optimum hydropower generation	Diversification of energy sources and energy efficiency	· Solar · Wind · Micro/mini hydro · Biomass · Waste to Energy · Demand Side Management-Energy Efficiency

4.2. Adaptation technology options and their main adaptation benefits

A Technology Prioritization workshop was held in Paro, Bhutan where a number of technology options for the water resources sector were discussed and debated. Extensive discussions lead to a preliminary list of ten technologies as given in Table 8.

Table 8: Potential technology options for water resources sector in Bhutan

- Rainwater harvesting (ground water recharge and runoff control)
- Erosion control measures including measures like grazing control

- Reduction of chemical contamination by promotion of chemical and insecticide free agriculture practices
- Solar power (Rooftop solar photovoltaic)
- Wind power
- Micro/mini hydropower
- Biomass power
- Waste to Energy (Combustion and gasification)
- Demand Side Management: Energy Efficiency
- Efficient irrigation methods
- Water use efficiency methods- improved water distribution systems; water efficient fixtures
- Rainwater harvesting structures (Rooftop)
- Building impoundments to store and distribute in lean season

All the technologies given in Table 8 have great potential to reduce the vulnerability of Bhutan's water resources sector to climate change.

For instance, collection and storage of water through rainwater harvesting can provide convenient and reliable water supply during seasonal dry periods and droughts. Also, the widespread rainwater storage capacity can greatly reduce land erosion and flood inflow to major rivers. Rainwater collection can also contribute greatly to the stabilization of declining groundwater tables. Further, rooftop rainwater harvesting can contribute to climate change adaptation at the household level primarily through two mechanisms:

- Diversification of household water supply
- Increased resilience to water quality degradation

It can also reduce the pressure on surface and groundwater resources (e.g. the reservoir or aquifer used for piped water supply) by decreasing household demand and has been used as a means to recharge groundwater aquifers (Elliot et al., 2011).

Further, increasing use of chemical fertilizers and pesticides significantly threatens the ecological integrity of water bodies through run-offs and eutrophication. Reduction of chemical contamination by promotion of chemical and insecticide-free agriculture practices can efficiently prevent the deterioration of water quality, which is threatened by effects of climate change.

Bhutan's primary source of energy is from hydro power. The Gross National Happiness Commission of Bhutan has clearly identified diversification of energy sources as one of the national objectives. Events like GLOF in recent times have made large hydro power projects vulnerable to climate change. In this context, renewable energy sources such as solar, wind, micro/mini hydropower, biomass and waste to energy as well as energy efficiency measures can be a significant climate change adaptation strategy for Bhutan. These technologies have climate change mitigation benefits too in addition to social benefits such as meeting power requirements of remote rural areas where grid electricity supply is difficult.

Efficient irrigation methods such as the sprinkler irrigation and drip irrigation technology can support farmers to adapt to climate change by making more efficient use of their water supply. Particularly in areas subject to climate change impacts such as seasonal droughts, efficient irrigation methods can reduce the demand for water and reduce water evaporation losses.

4.3. Criteria and process of technology prioritization

Multi-criteria Decision Analysis (MCDA) was used to prioritize technologies through a process that was country-driven, participatory and involved a number of stakeholders. A three day workshop for criteria weighting and technology prioritization was held at Paro, Bhutan from 6 to 8 February 2012 where 22 members of the TNA taskforce participated. The list of participants is given in Annex II.

Two rounds were followed for criteria weighting and technology prioritization. In the first stage, cost was not considered as a criterion for prioritization of technologies. In the next round, cost was considered as a criterion in addition to the criteria used in the first round[1]. In other words, a two stage MCDA was done for technology prioritization: one without costs as a criteria and the other with cost as a criteria. The results of both MCDA were analyzed by the TNA taskforce to understand the impact of cost criterion on the list of prioritized technologies. Based on the two results, further stakeholder discussions took place. For all the sectors, the results of MCDA with cost as a criterion were taken as final results. These results were agreed upon by the TNA Task Force.

Criteria weighting

Extensive discussions among the workshop participants led to the finalization of criteria and their scope for technology prioritization. The criteria were categorized under four broad heads namely benefits (excluding climate change related benefits; contribution to economic, environmental and social development priorities); relevance to climate change adaptation (vulnerability reduction potential); appropriateness (technology maturity and potential scale of utilization) and cost. The list of criteria and their scope is given in Table 9.

Table 9: Criteria, sub-criteria and their scope used for technology prioritization

Criteria	BENEFITS (EXCLUDING CLIMATE CHANGE RELATED BENEFITS)			RELEVANCE TO CLIMATE CHANGE ADAPTATION	APPROPRIATENESS		COST
Sub-Criteria	Contribution to economic development priorities	Contribution to environment development priorities	Contribution to social development priorities	Vulnerability reduction potential	Potential scale of utilization	Technology maturity	Cost
Scope of the criteria	§ Job creation § Improved livelihoods § Enhanced energy security § Overall contribution to GDP	§ Improved air, water and soil quality § Conservation of bio-diversity	§ Cultural acceptance § Equitable development § Improved health conditions § Enhanced food security § Minimal impact on vulnerable groups	Reduction in vulnerability to climate change application of the identified technologies/ measures	Market and implementation potential in Bhutan	Status of the technology	Approximate capital and operation and maintenance cost for implementation of the technology

Based on extensive discussions among TNA Task Force members, it was decided that each sub-criteria should be given different weights. Therefore, members were requested to score each sub-criterion on a scale of 0 to 5 as given in Table 10. The Task Force members decided to take mean values of the scores of each member and build a consensus on it. The mean value of each of the sub-criteria was divided by the sum total of mean values of all the sub-criteria to arrive

[1] Many members of the TNA Task Force were of the opinion that cost is a barrier to the implementation of technologies and can be addressed through various means. However, some felt that it was important to understand the implication of costs for technology implementation. Also, the TNA guidebook prescribes costs as a criterion for technology prioritization. Therefore, two rounds of MCDA for prioritization of technologies were done, one without cost as a criterion and the other with cost as a criterion.

at weightages for each sub-criteria. Further discussions on each sub-criterion were held during the workshop to allow consensus to be built. Final sub-criteria and their weights for technology prioritization are given in Table 11. .

Table 10: Scale used for criteria weighting and technology prioritization

0: No benefit	1: Faintly desirable	2: Fairly desirable
3: Moderately desirable	4: Very desirable	5: Extremely desirable

Table 11: Final criteria weighting used for technology prioritization for water resources sector

Criteria	BENEFITS (EXCLUDING CLIMATE CHANGE RELATED BENEFITS)			RELEVANCE TO CLIMATE CHANGE ADAPTATION	APPROPRIATENESS		COSTS
Sub-Criteria	Contribution to economic development priorities	Contribution to environment development priorities	Contribution to social development priorities	Vulnerability reduction potential	Potential scale of utilization	Technology maturity	Costs
Weight-age	0.17	0.17	0.15	0.16	0.13	0.13	0.12

Technology prioritization

In the first round, the participants of the workshop scored each of the technologies in the water resources sector against all the sub-criteria given in Table 11, except costs on a scale of 0-5 (Table 10).

The results of the technology prioritization were presented to all the participants and they were then given an option to change their scores based on the results. Extensive discussions took place between the participants to allow consensus to be built. Mean values of the final scores received were taken as the final scores for technology prioritization against these sub-criteria.

In the next round, scoring of technologies against costs as an additional criterion was done by sectoral experts only based on their qualitative assessment of the capital and operation and maintenance costs of the technologies[2].

Finally, based on the results of MCDA without costs as a criteria and MCDA with costs as a criteria, further stakeholder discussions took place. Discussions on the two results finally led to consensus for the prioritized technologies that resulted from MCDA with cost as a criterion.

4.4. Results of technology prioritization

Micro/mini hydro power, efficient irrigation methods and solar power (rooftop PV) are the prioritized technologies for water resources sector. Detailed results of technology prioritization for the sector are given in Table 12, followed by a brief description of the prioritized technologies.

[2] Since estimates for cost of technologies were not available, the scoring of technologies against costs as a criterion was done by sectoral experts only based on their expert judgment and qualitative assessment of the capital and operation and maintenance cost of the technologies.

Table 12: Results of technology prioritization for water resources sector

Sub-criteria		Contribution to economic development priorities	Contribution to environmental development priorities	Contribution to social development priorities	Vulnerability reduction potential	Potential scale of utilization	Technology maturity	Costs	Final Score
Technology	**Weightage**	**0.14**	**0.17**	**0.14**	**0.17**	**0.13**	**0.11**	**0.14**	
Micro/Mini hydro	Score	3.67	3.57	3.29	3.52	3.24	3.57	2.83	
	Standardized score	100%	64%	50%	100%	100%	100%	78%	
	Weighted score	0.14	0.11	0.07	0.17	0.13	0.11	0.11	**0.84**
Efficient irrigation methods	Score	3.48	3.24	3.81	3.43	3.10	3.00	2.67	
	Standardized score	79%	32%	100%	88%	79%	25%	67%	
	Weighted score	0.11	0.05	0.14	0.15	0.10	0.03	0.09	**0.68**
Solar (Rooftop PV)	Score	3.43	3.57	3.24	3.48	2.86	3.10	3.08	
	Standardized score	74%	64%	45%	94%	43%	38%	94%	
	Weighted score	0.10	0.11	0.06	0.16	0.06	0.04	0.13	**0.66**
Water use efficiency methods	Score	3.43	3.43	3.48	3.10	3.24	3.10	2.50	
	Standardized score	74%	50%	68%	44%	100%	38%	56%	
	Weighted score	0.10	0.09	0.10	0.07	0.13	0.04	0.08	**0.61**
Rainwater harvesting (for ground water recharge and runoff control)	Score	2.76	3.57	3.52	3.14	3.05	2.90	2.67	
	Standardized score	0%	64%	73%	50%	71%	13%	67%	
	Weighted score	0.00	0.11	0.10	0.09	0.09	0.01	0.09	**0.49**
Reduction of chemical contamination	Score	2.76	3.81	3.24	2.95	2.90	3.05	2.83	
	Standardized score	0%	86%	45%	25%	50%	31%	78%	
	Weighted score	0.00	0.15	0.06	0.04	0.07	0.03	0.11	**0.46**
Waste to Energy	Score	3.19	3.62	2.95	3.29	2.62	2.81	3.17	
	Standardized score	47%	68%	18%	69%	7%	0%	100%	
	Weighted score	0.07	0.12	0.03	0.12	0.01	0.00	0.14	**0.47**
Demand Side Management	Score	3.14	3.52	3.14	3.19	2.81	3.00	2.33	
	Standardized score	42%	59%	36%	56%	36%	25%	44%	
	Weighted score	0.06	0.10	0.05	0.10	0.05	0.03	0.06	**0.44**

Wind	Score	3.05	3.57	2.76	3.48	2.57	2.81	2.83	
	Standardized score	32%	64%	0%	94%	0%	0%	78%	
	Weighted score	0.04	0.11	0.00	0.16	0.00	0.00	0.11	**0.42**
Rainwater harvesting roof top	Score	2.95	3.10	3.10	3.10	2.86	3.05	3.00	
	Standardized score	21%	18%	32%	44%	43%	31%	89%	
	Weighted score	0.03	0.03	0.04	0.07	0.06	0.03	0.12	**0.39**
Biomass	Score	3.05	3.38	2.81	3.14	2.62	2.86	3.17	
	Standardized score	32%	45%	5%	50%	7%	6%	100%	
	Weighted score	0.04	0.08	0.01	0.09	0.01	0.01	0.14	**0.37**
Soil erosion control measures	Score	2.81	3.95	2.95	2.90	3.05	3.10	1.67	
	Standardized score	5%	100%	18%	19%	71%	38%	0%	
	Weighted score	0.01	0.17	0.03	0.03	0.09	0.04	0.00	**0.37**
Building impoundments	Score	3.05	2.90	3.29	2.76	2.62	2.81	2.83	
	Standardized score	32%	0%	50%	0%	7%	0%	78%	
	Weighted score	0.04	0.00	0.07	0.00	0.01	0.00	0.11	**0.23**

Micro/mini hydro power: Hydropower projects below 25 MW are categorized as small hydro power projects (SHP) which are further classified as micro/pico (with capacities up to 100 kW), mini (capacity 101 kW- 2 MW) and small (capacity 2 MW- 25 MW). A micro/mini hydro power project generates electricity of up to 2 MW from the energy of moving water which is used to run a turbine. Micro/mini hydropower projects can play a critical role in allowing adaptation to climate change by diversifying the nation's energy sources and thereby reducing the nation's dependence on large hydro. Micro/mini hydro power projects can be connected to grid as well as operated in off-grid system. With basic capacity building and training, these power plants can be successfully operated and managed by local communities as well. Therefore, micro/mini hydro power projects can play a significant role in meeting the energy demand in remote and inaccessible areas of Bhutan. The firm nature of power generated from this technology can be utilized for small scale entrepreneurial activities also in remote areas of Bhutan.

Solar power is generated by collecting sunlight and converting it into electricity. This is done by using solar panels, which are large flat panels made up of many individual solar cells. It presents an important avenue to bolster the adaptive capacities of Bhutan by reducing its dependence on grid supply of electricity which is primarily from large hydro in Bhutan. Thus, through diversification of energy sources, solar power would ease the pressure from water resources in Bhutan.

Efficient irrigation methods or technologies include advanced micro irrigation systems like sprinkler irrigation and drip irrigation and small scale irrigation system based on rainwater harvesting technologies. The efficient irrigation systems including sprinkler, drip systems and rain water harvesting provide a means for sustainable water use and management and strengthening the adaptive capacities of people living in economies that are heavily dependent on agriculture, as the case in Bhutan.

A detailed description of each of these technologies is provided in Annex 1.

4.5. Final prioritized technology for preparation of Technology Action Plan

It was suggested by the TNA Task Force members that it may be practical to conduct in-depth and focused barrier analysis, enabling frameworks and technology action plans for only one technology per sector, rather than for all technologies. Therefore, it was decided that one technology from among the three prioritized technologies in each sector be finalized for preparation of barrier analysis, enabling framework and technology action plan reports.

In this regard, the TNA Taskforce finalized **efficient irrigation methods (drip and sprinkler irrigation)** as the technology for preparation of barrier analysis, enabling framework and technology action plan in the water resources sector. The finalization of technology was based on the fact that it is aligned with the government's plans to explore improved irrigation methods that are not rain-dependent and lead to water use efficiency.

Chapter 5. Technology prioritization for agriculture sector

5.1. Climate change vulnerability and existing technologies and practices in the sector

Agriculture is the mainstay of the Bhutanese economy, with the sector contributing 16.8 percent to Bhutan's GDP in 2010 (National Statistics Bureau, 2011). More than 60 percent of the Bhutanese population still depends on the agriculture sector which is mostly subsistence in nature (Labour Force Survey, 2011).

However, due to the mountainous terrain, only about 2.93 percent of the land is under cultivation (National Environment Commission, 2011). Bhutan's agricultural diversity in the agro-ecological zones is quite varied and covers a range of climatic zones. The main crops in Bhutan are rice, maize, potato, wheat, buckwheat, barley and millet.

The agriculture sector in Bhutan is particularly sensitive to the impacts of changing climate, which can induce themselves in two ways:

- Direct effects from changes in temperature, precipitation or carbon dioxide concentrations resulting in changes in crop productivity, soil fertility and frequency of infestation by pests, insects, diseases or weeds
- Indirect effects through climate change induced natural disasters such as floods, landslides, hailstorms etc. These have been addressed in the section on Natural Disasters and Infrastructure.

The increase in temperature will shift the cultivating zones further into higher elevations, thereby affecting the related cropping patterns. Warming may have positive impact on some crop yields, but increases in the occurrence of extreme events or pests may offset any potential benefits. The increase in pestilence of invasive pests and diseases would affect both crops and live stocks. In 2007, the maize harvest loss by the farmers above 1800 mean sea level is recorded at more than 50% because of the outbreak of northern corn blight disease (National Environment Commission, 2011).

Further, since most farmers are totally dependent on the monsoons for irrigation, changes in precipitation patterns are likely to affect the crop yields significantly. In 2010, more than 5000 acres of agricultural crops were affected by hail and wind storms damaging a wide range of staple crops, such as maize, rice, potato, chilli, buckwheat and others (Draft revised NAPA, 2011, cited in National Environment Commission, 2011)

The increase in temperature can also reduce the ability of farmers to work indicating that the low-income rural populations that depend on traditional agricultural systems or on marginal lands are particularly vulnerable to climate change.

In terms of food access and access to markets, as a mountainous and landlocked country, climate change not only affects the physical aspect of the farming environment such as land degradation in Bhutan, but also affects food distribution systems and hence results in price distortion of essential commodities.

Bhutan's NAPA (2006) lists the following vulnerabilities faced by agriculture sector:

- Crop yield instability. Loss of production and quality (due to variable rainfall, temperature)
- Decreased water availability for crop production
- Increased risk of extinction of already threatened crop species (traditional crop varieties)
- Loss of soil fertility due to erosion of top soil and runoff
- Loss of fields due to flash floods, landslides and rill & gully formation
- Crop yield loss (flowers and fruit drop) to hailstorms. Deteriorated produce quality (fruits and vegetables) due to untimely incessant heavy rains and hailstorms
- Delayed sowing (late rainfall)
- Damage to crops by sudden early (paddy) and late spring (potato) frost
- Outbreak of pests and diseases in fields and during storage where they were previously unknown
- Damage to road infrastructure and hence food security

When considering adaptation technologies and strategies to build in climate change resilience in the agriculture sector in Bhutan, it is imperative to consider some of the thrust areas such as the nature of local economy, subsistence agricultural practices in upland areas, the requirement to preserve traditional agriculture practices as well as infuse and disseminate knowledge of modern technologies for efficient and sustainable utilization of natural resources. The major thrust areas of climate change adaptation strategies for agriculture sector have been illustrated in Figure 2.

As part of the UNDP-GEF sponsored NAPA in 2006, the following projects in the agriculture sector were identified as priority NAPA projects:

i. Weather Forecasting System to Serve Farmers and Agriculture

ii. Flood Protection of Downstream Industrial and Agricultural Areas

iii. Rainwater Harvesting

Some focus areas in the agriculture sector and the corresponding technology interventions that may lead to adaptation to climate change are given in Table 13.

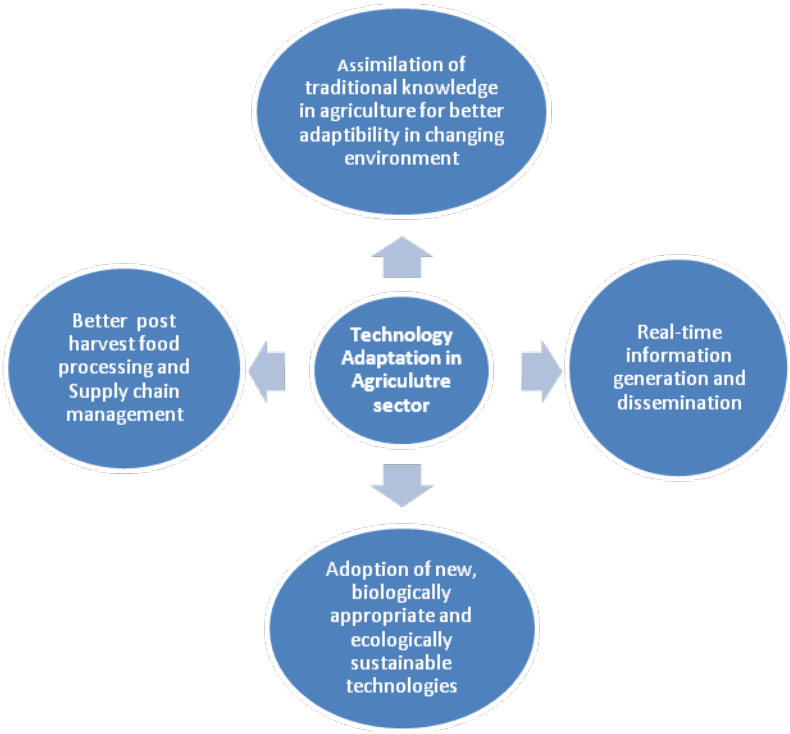

Figure 2: Thrust areas of climate change adaptation strategies for agriculture sector

Table 13: Focus areas in the agriculture sector and the corresponding technology interventions

S.No.	Focus Areas	Vulnerability Factors	Impact	Technologies interventions
1.	Crop production and productivity	Increase in temperature and erratic rainfall	Decrease in production and productivity	§ Sustainable farming systems (Agroforestry practices, low tillage agriculture, etc.) § Scientific weather forecasting and broadcasting of real-time information regarding factors like temperature, rainfall and snowfall over mass media like radio. § Rainwater harvesting § Index-based climate insurance
		Shift in cropping schedule		§ Introduction of new varieties of crops § Diversification of crops § Development of drought resistant varieties/ strains of crops
		Increase in soil erosion		§ Sustainable farming systems (E.g.: adoption of sloping agriculture land technology practices)
2.	Indigenous crop varieties	Increase in temperature	Decrease in production and	§ Adoption of new drought resilient varieties § Diversification of cropping pattern

			productivity including extinction of certain varieties	§ Genetic profiling of indigenous varieties of crops and identification of climate resilient gene pool and indigenous varieties
		Spread of pests to newer areas affecting vulnerable varieties		§ Adoption of Integrated Pest Management Practices § Genetic profiling of indigenous varieties of crops and identification of pest resistant varieties and strains
3.	Supply chain management	Increased temperature and rainfall	Rotting of stored grains	§ Improved storage facilities of food grains
		Increased rainfall	Degradation of road connectivity	§ Taking enhanced transportation time from field to markets into consideration. Will require improved planning and information dissemination for scheduling harvesting of crops.
		Shift in cropping season	Unable to respond to market demand	§ Enhanced dissemination of market information, climate forecast study at grass-root level.
4.	Livestock development	Increasing temperature	Loss of alpine meadows for grazing	§ Breeding of new variety of hardy cattle types
		Soil erosion and flooding	Loss of pasturelands	§ Sustainable farming systems (E.g. adoption of sloping agriculture land technology practices)
		Shifting climatic patterns across regions	New diseases to which cattle lacks immunity	§ Breeding of new disease resistant variety of hardy cattle types
5.	Capacity and information	Changing climatic patterns across regions	Lack of access to improved technology	§ Adoption of decentralized knowledge dissemination processes

5.2. Adaptation technology options and their main adaptation benefits

At the Technology Prioritization Workshop held in Paro, Bhutan a number of technology options for the agriculture sector were also discussed and debated. Extensive discussions led to a preliminary list of ten technologies (Table 14). The technologies have been broadly categorized as biotechnology interventions, farming technology interventions, infrastructure development and insurance schemes.

Table 14: Potential technology options for agriculture sector in Bhutan

I. Biotechnology interventions

A. Genetic profiling of indigenous crop varieties
B. Development of drought resistant and pest resistant varieties of crops
C. Climate resistant productive livestock breeding

II. Farming technology interventions

A. Agro forestry
B. Sloping Agriculture Land Technology (SALT)
C. Integrated pest management
D. Greenhouse farming

III. Infrastructure interventions

A. Storage techniques for grains and seeds
B. Seasonal weather forecasting system

IV. Insurance schemes

A. Index based climate insurance

All the technologies given in Table 14 have great potential to reduce the vulnerability of Bhutan's agriculture sector to climate change. A brief outline of all the technology options is provided below:

- Biotechnological interventions such as development of drought resistant and pest resistant crop varieties enhances the resistance of plants to stresses such as droughts, floods and emergence of pests. Varieties that are able to resist these stress conditions will help to ensure that agricultural production can continue and even improve despite uncertainties about future impacts of climate change.
- Other farming technology interventions such as agro-forestry can improve the resilience of agricultural production to current climate variability as well as long-term climate change through the use of trees for intensification, diversification and buffering of farming system (Clements et al., 2011). The agro-forestry activities also helps in rehabilitation of degraded farmlands, which are especially threatened by accelerated degradation due to deforestation and increasing variability in rainfall patterns. SALT controls soil erosion, helps restore soil structure and fertility, is productive and efficient in food crop production and requires minimal labour, thereby addressing the major threats of increasing climate variability on highland agricultural practices and local economy.
- Practices such as Integrated Pest Management contribute to climate change adaptation by providing a healthy and balanced ecosystem in which the vulnerability of plants to pests and diseases is decreased. The practice of Integrated Pest Management also builds farmers' resilience to potential risks posed by climate change, such as damage to crop yields caused by newly emerging pests and diseases (Clements et al. 2011).

- Infrastructure interventions such as appropriate grain and seed storage provides an adaptation strategy for climate change by ensuring feed is available for livestock and seed stock is available in the event of poor harvests (UNEP, 2010, cited in Clements et al., 2011).
- Seasonal weather forecasting system is also an efficient means of adapting to changing climate as it provides information on impacts of changing climate and facilitates disaster preparedness and adaptation planning. For instance, in Lesotho, Seasonal Climate Forecasts provide information on rainfall expected during the rainy season. Farmers use the information to invest in fertilizer if a good year is expected. Other ways of using the information have included making decisions about the type of crop to grow, how to manage water resources and how to allocate agricultural and household resources. The information has also enabled farmers to change planting and investment activities if a drought or good rains are forecast (Clements et al., 2011).
- Insurance schemes also provide a buffer against impacts of climate change by providing robust financial mechanisms to support farmers in years of financial loss due to climatic events (Clements et al., 2011).

5.3. Criteria and process of technology prioritization

MCDA was used to prioritize technologies through a process that was country-driven, participatory and involved a number of stakeholders. A three day workshop for criteria weighting and technology prioritization was held at Paro, Bhutan from 6 to 8 February 2012 where 22 members of the TNA taskforce participated. The list of participants is given in Annex II.

Two rounds were followed for criteria weighting and technology prioritization. In the first stage, cost was not considered as a criterion for prioritization of technologies. In the next round, cost was considered as a criterion in addition to the criteria used in the first round[3]. In other words, a two stage MCDA was done for technology prioritization: one without costs as a criteria and the other with cost as a criteria. The results of both MCDA were analyzed by the TNA taskforce to understand the impact of cost criterion on the list of prioritized technologies. Based on the two results, further stakeholder discussions took place. For all the sectors, the results of MCDA with costs as a criterion were taken as final results. These results were finally agreed upon by the TNA Task Force members.

Criteria weighting

Extensive discussions among the workshop participants led to the finalization of criteria and their scope for technology prioritization. The criteria were categorized under four broad heads namely benefits (excluding climate change related benefits) (contribution to economic, environmental and social development priorities); relevance to climate change adaptation (Vulnerability reduction potential); appropriateness (technology maturity and potential scale of utilization) and cost. The list of criteria and their scope is given in Table 15.

Table 15: Criteria, sub-criteria and their scope used for technology prioritization

Criteria	**BENEFITS (EXCLUDING CLIMATE CHANGE RELATED BENEFITS)**			**RELEVANCE TO CLIMATE CHANGE ADAPTATION**	**APPROPRIATENESS**		**COST**
Sub-Criteria	Contribution to economic development priorities	Contribution to environment development priorities	Contribution to social development priorities	Vulnerability reduction potential	Potential scale of utilization	Technology maturity	Cost

[3] Many members of the TNA Task Force were of the opinion that cost is a barrier to the implementation of technologies and can be addressed through various means. However, some felt that it was important to understand the implication of costs for technology implementation. Also, the TNA guidebook prescribes costs as a criterion for technology prioritization. Therefore, two rounds of MCDA for prioritization of technologies were done, one without cost as a criterion and the other with cost as a criterion.

Scope of the criteria	§ Job creation § Improved livelihoods § Enhanced energy security § Overall contribution to GDP	§ Improved air, water and soil quality § Conservation of bio-diversity	§ Cultural acceptance § Equitable development § Improved health conditions § Enhanced food security § Minimal impact on vulnerable groups	Reduction in vulnerability to climate change application of the identified technologies/ measures	Market and implementation potential in Bhutan	Status of the technology	Approximate capital and operation and maintenance cost for implementation of the technology

Based on extensive discussions among TNA Task Force members, it was decided that each sub-criteria should be given different weights. Therefore, members were requested to score each sub-criterion on a scale of 0 to 5 as given in Table 16. The Task Force members decided to take mean values of the scores of each member and build a consensus on it. The mean value of each of the sub-criteria was divided by the sum total of mean values of all the sub-criteria to arrive at weightages for each sub-criterion. Further discussions on each sub-criterion were held during the workshop to allow consensus to be built. Final sub-criteria and their weights for technology prioritization are given in Table 17.

Table 16: Scale used for criteria weighting and technology prioritization

0: No benefit	1: Faintly desirable	2: Fairly desirable
3: Moderately desirable	4: Very desirable	5: Extremely desirable

Table 17: Final criteria weighting used for technology prioritization for agriculture sector

Criteria	**BENEFITS (EXCLUDING CLIMATE CHANGE RELATED BENEFITS)**			**RELEVANCE TO CLIMATE CHANGE ADAPTATION**	**APPROPRIATENESS**		**COSTS**
Sub-Criteria	Contribution to economic development priorities	Contribution to environment development priorities	Contribution to social development priorities	Vulnerability reduction potential	Potential scale of utilization	Technology maturity	Costs
Weight-age	0.17	0.17	0.15	0.16	0.13	0.13	0.12

Technology prioritization

In the first round, the participants of the workshop scored each of the technologies in the agriculture sector against all the sub-criteria given in Table 17, except costs on a scale of 0-5 (Table 16).

The results of the technology prioritization were presented to all the participants and they were then given an option to change their scores based on the results. Extensive discussions took place between the participants to allow consensus to be built. Mean values of the final scores received were taken as the final scores for technology prioritization against these sub-criteria.

In the next round, scoring of technologies against costs as an additional criterion was done by sectoral experts only based on their qualitative assessment of the capital and operation and maintenance costs of the technologies[4].

Finally, based on the results of MCDA without cost as a criterion and MCDA with cost as a criterion, further stakeholder discussions took place. Discussions on the two results finally led to consensus for the prioritized technologies that resulted from MCDA with cost as a criterion.

5.4. Results of technology prioritization

Agro-forestry, Development of drought resistant and pest resistant varieties of crops and Sloping Agriculture Land Technology (SALT) are the prioritized technologies for the sector. Detailed results of technology prioritization for agriculture sector are given in Table 18, followed by a brief description of the prioritized technologies.

[4] Since estimates for cost of technologies were not available, the scoring of technologies against costs as a criterion was done by sectoral experts only based on their expert judgment and qualitative assessment of the capital and operation and maintenance cost of the technologies.

Table 18: Results of technology prioritization for agriculture sector

Sub-criteria		Contribution to economic development priorities	Contribution to environmental development priorities	Contribution to social development priorities	Vulnerability reduction potential	Potential scale of utilization	Technology maturity	Cost	Final Score
Technology	**Weightage**	**0.14**	**0.17**	**0.14**	**0.17**	**0.13**	**0.11**	**0.14**	
Agro-forestry	Score	3.40	3.55	3.55	3.35	3.40	3.15	4.40	
	Standardized score	48%	86%	67%	71%	92%	54%	100 %	
	Weighted score	0.07	0.15	0.09	0.12	0.12	0.06	0.14	**0.75**
Development of drought resistant and pest resistant varieties of crops	Score	3.95	3.15	3.70	3.45	3.30	3.00	2.60	
	Standardized score	100%	59%	92%	86%	75%	31%	36%	
	Weighted score	0.14	0.10	0.13	0.15	0.10	0.03	0.05	**0.70**
Sloping Agriculture Land Technology (SALT)	Score	3.40	3.75	3.60	2.95	3.45	3.15	3.80	
	Standardized score	48%	100%	75%	14%	100%	54%	79%	
	Weighted score	0.07	0.17	0.11	0.02	0.13	0.06	0.11	**0.67**
Climate resistant productive livestock breeding	Score	3.50	3.35	3.70	3.55	3.35	2.85	2.40	
	Standardized score	57%	72%	92%	100%	83%	8%	29%	
	Weighted score	0.08	0.12	0.13	0.17	0.11	0.01	0.04	**0.66**
Storage techniques for grains and seeds	Score	3.35	2.50	3.75	3.15	3.30	3.45	3.40	
	Standardized score	43%	14%	100%	43%	75%	100%	64%	
	Weighted score	0.06	0.02	0.14	0.07	0.10	0.11	0.09	**0.59**

Seasonal Weather Forecasting System	Score	3.30	2.90	3.40	3.20	3.10	3.30	2.00	
	Standardized score	38%	41%	42%	50%	42%	77%	14%	
	Weighted score	0.05	0.07	0.06	0.09	0.05	0.08	0.02	**0.43**
Integrated Pest Management	Score	3.05	3.10	3.15	3.00	3.15	2.80	4.00	
	Standardized score	14%	55%	0%	21%	50%	0%	86%	
	Weighted score	0.02	0.09	0.00	0.04	0.06	0.00	0.12	**0.34**
Genetic profiling of indigenous crop varieties	Score	3.40	2.85	3.25	2.85	3.00	2.85	1.60	
	Standardized score	48%	38%	17%	0%	25%	8%	0%	
	Weighted score	0.07	0.06	0.02	0.00	0.03	0.01	0.00	**0.20**
Greenhouse farming	Score	3.00	2.55	3.15	2.90	2.95	2.80	2.00	
	Standardized score	10%	17%	0%	7%	17%	0%	14%	
	Weighted score	0.01	0.03	0.00	0.01	0.02	0.00	0.02	**0.10**
Index-based climate insurance	Score	2.90	2.30	3.30	3.00	2.85	2.85	1.60	
	Standardized score	0%	0%	25%	21%	0%	8%	0%	
	Weighted score	0.00	0.00	0.04	0.04	0.00	0.01	0.00	**0.08**

Agro-forestry is a land-use system that aims towards optimal utilization of available land resources by multiple as well as beneficial practices of agriculture and forestry. The main purpose of agro-forestry activities is to sustain the fertility of the soil by substituting the nutrition required by intensive agriculture. Agro-forestry activities ensure diversity in crops raised as well as enhance species diversity by encouraging plantation of multiple tree species for various uses or plantation of multi-purpose tree species.

Developing drought resistant and pest resistant varieties of crops enhances the resistance of plants to a climate change induced stresses such as droughts and increased frequency of pest infestation. Varieties that are developed to resist these conditions will help to ensure that agricultural production can continue and even improve despite uncertainties about future impacts of climate change. Breeding for improved performance under environmental stresses involves activities which accumulate favourable alleles (different forms of a gene) contributing to stress tolerance (Clements et al., 2011).

SALT is a system in which dense hedgerows of fast growing perennial nitrogen-fixing tree or shrub species are planted along contour lines thus creating a living barrier that traps sediments and gradually transforms the sloping land to terraced land. The hedgerows markedly reduce soil erosion and contribute to improving and/or maintaining soil fertility by acting as a source of organic matter. SALT has emerged as one of the main approaches used to control soil erosion in mountainous region.

Besides the general SALT design, described as SALT 1, SALT 2 is classified (Small Agro-Livestock Land Technology) as a goat-based agroforestry with a land use of 40% for agriculture 20% for forestry and 40% for livestock. As in a conventional SALT project, hedgerows of different nitrogen-fixing trees and shrubs are established on the contour lines. The manure from the animals is utilized as fertilizer both for agricultural crops and the forage crops.

SALT 3 (Sustainable Agroforest Land Technology) is a cropping system in which a farmer can incorporate food production, fruit production, and forest trees that can be marketed. The farmer first develops conventional SALT project to produce food for his family and possibly food for livestock. The plants in the hedgerows will be cut and piled around the fruit trees for fertilizer and soil conservation purposes. A small forest of about one hectare will be developed in which trees of different species may be grown for firewood and charcoal for short-range production (Sommer Haven Ranch International, 1996).

Detailed description of these technologies is given in Annexure I.

5.5. Final prioritized technology for preparation of Technology Action Plan

Development of drought and pest resistant varieties of crops was the technology finalized by the TNA Taskforce for preparation of barrier analysis, enabling framework and technology action plan.

Reports have suggested increased occurrence of pests and diseases in various parts of the country, and climate change is suspected to be a major factor in this regard. Further, studies have shown that 65% of the total rice growing areas and 51% of the maize growing areas in the country is still planted with traditional varieties of crops and that there are low adoption rates of improved varieties. In this regard, it becomes important that Bhutan moves towards development of drought and pest resistant varieties of important cereals and horticulture crops to ensure food security at the face of changing climate in the nation.

The other two technologies which are agroforestry and SALT were not finalized since these can be scaled up through already existing projects and programmes such as the Sustainable Land Management Project, National Land Management Programme and the UNDP/GEF Small Grants Programme.

Chapter 6. Technology prioritization for natural disasters and infrastructure sector

6.1. Climate change vulnerability and existing technologies and practices in the sector

Bhutan is vulnerable to natural disasters such as floods, landslides, forest fires, droughts, cyclones and windstorms due to its rugged and fragile mountain terrain, complex geological setting, high intensity of seasonal rains, and active tectonic processes taking place in the Himalayas (Ministry of Home and Cultural Affairs Bhutan, 2005). These disasters are likely to become more frequent and more intense with changing patterns of temperatures and precipitation. This is also evident from the Fourth Assessment Report of the Intergovernmental Panel on Climate Change 2007 that states that the tropical cyclones will become more intense with larger peak wind speeds and heavier precipitation. Subsequently, the report also states that extra-tropical storm tracts are projected to move pole-wards which imply that Bhutan may face more frequent and severe impacts of natural disasters. In fact, the severity and frequency of windstorms and flashfloods in Bhutan have increased over the past years due to increasing rainfall and untimely monsoons. Increase in temperature and drought have also increased incidences of forest fire. All these disasters have caused extensive damage to life and infrastructure in the past. For instance, the cyclone Aila of 2009 led to loss of 12 lives and damages to agriculture, roads, bridges, schools, hydro projects, and other infrastructure. In April 2008, windstorm damaged 249 rural houses in lower Trashigang. Lumang gewog was worst hit with 148 households affected. Eight school buildings, four Lhakhangs and one forest office were also damaged by the windstorm (National Environment Commission, 2011).

Further, the increasing emissions of greenhouse gases in the atmosphere and the consequent global warming have accelerated the melting of Himalayan glaciers. This makes Bhutan particularly prone to Glacial Lake Outburst Flood (GLOF) and flashfloods. Recent studies indicate that that 25 of the 2674 glacial lakes in Bhutan pose a GLOF threat in the future (National Environment Commission, 2011). Bhutan experienced a major GLOF in 1994 emanating from Lugge Tsho in the headwaters of Punatshangchhu river basin.

Given this background, it becomes imperative to strategize adaptation options for natural disasters to prevent the extensive damage that these cause to life and infrastructure. The country's infrastructure is usually built to meet the current climatic conditions and is not prepared to withstand the consequences of climate change events in the form of exacerbated natural disasters in future. For instance, many roads and bridges are washed away and damaged due to landslides and flash floods. A damage assessment done in eastern Dzonghkhags found that almost 22 bridges had been washed away or severely damaged by 2004 monsoons (Ministry of Home and Cultural Affairs Bhutan, 2005).

Bhutan's NAPA, 2006 lists the following vulnerabilities faced by the Natural Disasters and Infrastructure sector:

- Debris covered glaciers forming huge moraine dam lakes that ultimately lead to GLOFs (flash floods and landslides, heavy siltation of the rivers and other geotechnical hazards)
- Natural disasters will affect essential infrastructure:
    - Hydropower systems (generation plants, transmission and distribution infrastructure)
    - Industrial estates
    - Human settlements
    - Historical and cultural monuments: Dzongs, monasteries, chortens etc
    - Public utilities: Roads, bridges, communication

To adapt to the changing climate and its consequent effect on natural disasters, it becomes important that the nation's infrastructure is designed, built, operated and maintained in a way that enables it to withstand current as well as future impacts of natural disasters. For instance, the Department of Roads has adopted environmentally friendly road construction techniques which include detailed geological and environment assessment studies for road construction (Ministry of Home and Cultural Affairs Bhutan, 2005).

The UNDP-GEF sponsored NAPA of 2006 has also identified the following priority projects in the sector:

- Disaster Management Strategy – planning for food security and emergency medicine to vulnerable communities
- Artificial Lowering of Thorthomi Lake
- Landslide Management & Flood Prevention (Pilot Schemes in Critical Areas)
- Flood Protection of Downstream Industrial and Agricultural Areas
- GLOF Hazard Zoning (Pilot Scheme – Chamkhar Chu Basin)
- Installation of Early Warning System on Pho Chu Basin
- Promote Community-based Forest Fire Management and Prevention

Other technological interventions that can allow adaptation in the sector are given in Table 19.

Table 19: Technology options for natural disasters and infrastructure sector

Climate resilient roads Bioengineering, slope stabilization structures, Side drainage and cross drainage structures, super-elevation
Climate-resilient engineering and construction of private houses and other public infrastructure Climate-resilient roofing, irrigation systems, bridges (site, elevation, abutment & reinforcement), perforated surface for surface water management in built environments
River training works Revetment, gabion structures, bio-engineering, debris management/ upstream erosion run-off management
Community-based early warning system Mobile-based, radio/ TV, sensor-based alarm systems, forest fire information alert and warning system
GLOF risk reduction Lowering (in combination with downstream impounding), siphoning, storage, barriers
Real-time weather stations and weather forecasting system

6.2. Adaptation technology options and their main adaptation benefits

At the Technology Prioritization Workshop held in Paro, Bhutan a number of technology options for the natural disasters and infrastructure sector were discussed and debated. Extensive discussions lead to a preliminary list of seven technologies as given in Table 20.

Table 20: Potential technology options for natural disasters and infrastructure sector in Bhutan

1. Climate resilient roads
2. Climate-resilient engineering and construction of private houses and other public infrastructure

3. River training works
4. Community-based early warning system
5. GLOF risk reduction
6. Real-time weather stations and weather forecasting (multi-range)
7. Forest fire management

All the technologies given in Table 20 have great potential to reduce the vulnerability of Bhutan's natural disasters and infrastructure to climate change.

For instance, community-based early warning system can contribute to the climate change adaptation and risk reduction process by improving the capacity of communities to forecast, prepare for and respond to extreme weather events and thereby minimize damage to infrastructure and social and economic impacts, such as loss of livelihoods (Clements et al., 2011). In addition, real-time weather stations and weather forecasting is an efficient means of adaptation as it provides information on impacts of changing climate and facilitates disaster preparedness and adaptation planning. It can help in making informed decisions and accordingly allow implementation of adaptation strategies (Clements et al., 2011).

River training works, climate resilient roads and infrastructure are also expected to alleviate the impacts of floods and heavy rains, which has become increasingly erratic over the years due to global warming and concomitant climate change.

6.3. Criteria and process of technology prioritization

Two rounds were followed for criteria weighting and technology prioritization. In the first stage, cost was not considered as a criterion for prioritization of technologies. In the next round, cost was considered as a criterion in addition to the criteria used in the first round[5]. In other words, a two stage MCDA was done for technology prioritization: one without costs as a criteria and the other with cost as a criteria. The results of both MCDA were analyzed by the TNA taskforce to understand the impact of cost criterion on the list of prioritized technologies. Based on the two results, further stakeholder discussions took place. For all the sectors, the results of MCDA with costs as a criterion were taken as final results. These results were agreed upon by the TNA Task Force

Criteria weighting

Extensive discussions among the workshop participants led to the finalization of criteria and their scope for technology prioritization. The criteria were categorized under three broad heads namely benefits (excluding climate change related benefits) (contribution to economic, environmental and social development priorities); relevance to climate change adaptation (Vulnerability reduction potential) and appropriateness (technology maturity and potential scale of utilization). The list of criteria and their scope is given in Table 21.

Table 21: Criteria, sub-criteria and their scope used for technology prioritization

Criteria	BENEFITS (EXCLUDING CLIMATE CHANGE RELATED BENEFITS)	RELEVANCE TO CLIMATE CHANGE ADAPTATION	APPROPRIATENESS	COSTS

[5] Many members of the TNA Task Force were of the opinion that cost is a barrier to the implementation of technologies and can be addressed through various means. However, some felt that it was important to understand the implication of costs for technology implementation. Also, the TNA guidebook prescribes costs as a criterion for technology prioritization. Therefore, two rounds of MCDA for prioritization of technologies were done, one without cost as a criterion and the other with cost as a criterion.

Sub-Criteria	Contribution to economic development priorities	Contribution to environment development priorities	Contribution to social development priorities	Vulnerability reduction potential	Potential scale of utilization	Technology maturity	Cost
Scope of the criteria	§ Job creation § Improved livelihoods § Enhanced energy security § Overall contribution to GDP	§ Improved air, water and soil quality § Conservation of bio-diversity	§ Cultural acceptance § Equitable development § Improved health conditions § Enhanced food security § Minimal impact on vulnerable groups	Reduction in vulnerability to climate change through application of the identified technologies/ measures	Market and implementation potential in Bhutan	Status of the technology	Approximate capital and operation and maintenance cost for implementation of the technology

Based on extensive discussions among TNA Task Force members, it was decided that each sub-criteria should be given different weights. Therefore, members were requested to score each sub-criterion on a scale of 0 to 5 as given in Table 22. The Task Force members decided to take mean values of the scores of each member and build a consensus on it. The mean value of each of the sub-criteria was divided by the sum total of mean value of all the sub-criteria to arrive at weightages for each sub-criterion. Further discussions on each sub-criterion were held during the workshop to allow consensus to be built. Final sub-criteria and their weights for technology prioritization are given in Table 23 .

Table 22: Scale used for criteria weighting and technology prioritization

0: No benefit	1: Faintly desirable	2: Fairly desirable
3: Moderately desirable	4: Very desirable	5: Extremely desirable

Table 23: Final criteria weighting used for technology prioritization for natural disasters and infrastructure sector

Criteria	**BENEFITS (EXCLUDING CLIMATE CHANGE RELATED BENEFITS)**			**RELEVANCE TO CLIMATE CHANGE ADAPTATION**	**APPROPRIATENESS**		**COSTS**
Sub-Criteria	Contribution to economic development priorities	Contribution to environment development priorities	Contribution to social development priorities	Vulnerability reduction potential	Potential scale of utilization	Technology maturity	Costs
Weight-age	0.17	0.17	0.15	0.16	0.13	0.13	0.12

Technology prioritization

In the first round, the participants of the workshop scored each of the technologies in the natural disasters and infrastructure sector against all the sub-criteria given in Table 23, except costs on a scale of 0-5 (Table 22).

The results of the technology prioritization were presented to all the participants and they were then given an option to change their scores based on the results. Extensive discussions took place between the participants to allow consensus to be built. Mean values of the final scores received were taken as the final scores for technology prioritization against these sub-criteria.

In the next round, scoring of technologies against costs as an additional criterion was done by sectoral experts only based on their qualitative assessment of the capital and operation and maintenance costs of the technologies[6].

Finally, based on the results of MCDA without costs as a criteria and MCDA with costs as a criteria, further stakeholder discussions took place. Discussions on the two results finally led to consensus for the prioritized technologies that resulted from MCDA with cost as a criterion.

6.4. Results of technology prioritization

Real-time weather stations and weather forecasting (multi-range), climate resilient roads and community-based early warning systems are the prioritized technologies for natural disasters and infrastructure sector. Detailed results of technology prioritization for the sector are given in Table 24 , followed by a brief description of the prioritized technologies.

[6] Since estimates for cost of technologies were not available, the scoring of technologies against costs as a criterion was done by sectoral experts only based on their expert judgment and qualitative assessment of the capital and operation and maintenance cost of the technologies.

Table 24: Results of technology prioritization for natural disasters and infrastructure sector

Sub-criteria		Contribution to economic development priorities	Contribution to environmental development priorities	Contribution to social development priorities	Vulnerability reduction potential	Potential scale of utilization	Technology maturity	Costs	Final Score
Technology	**Weightage**	**0.14**	**0.17**	**0.14**	**0.17**	**0.13**	**0.11**	**0.14**	
Real-time weather stations and weather forecasting (multi-range)	Score	3.62	3.24	3.67	4.00	3.62	3.33	1.75	
	Standardized score	100%	46%	100%	100%	100%	100%	36%	
	Weighted score	0.14	0.08	0.14	0.17	0.13	0.11	0.05	**0.82**
Climate resilient roads	Score	2.87	3.54	2.88	3.39	3.43	3.24	2.25	
	Standardized score	0%	100%	9%	8%	60%	64%	50%	
	Weighted score	0.00	0.17	0.01	0.01	0.08	0.07	0.07	**0.41**
Community-based early warning system	Score	3.05	2.98	3.11	3.62	3.38	3.33	2.50	
	Standardized score	24%	0%	36%	42%	49%	100%	57%	
	Weighted score	0.03	0.00	0.05	0.07	0.06	0.11	0.08	**0.41**
Forest fire management	Score	2.90	3.39	2.80	3.34	3.34	3.24	4.00	
	Standardized score	4%	73%	0%	0%	40%	64%	100%	
	Weighted score	0.01	0.12	0.00	0.00	0.05	0.07	0.14	**0.39**
River training works	Score	3.01	3.30	2.93	3.54	3.29	3.13	3.25	
	Standardized score	19%	57%	15%	30%	30%	20%	79%	
	Weighted score	0.03	0.10	0.02	0.05	0.04	0.02	0.11	**0.37**
GLOF risk reduction	Score	3.43	3.10	3.00	3.90	3.19	3.14	0.50	
	Standardized score	75%	21%	23%	85%	9%	24%	0%	
	Weighted score	0.10	0.04	0.03	0.14	0.01	0.03	0.00	**0.35**
Climate-resilient engineering and construction of private houses and other public	Score	3.06	3.06	3.19	3.44	3.15	3.08	3.00	
	Standardized score	25%	14%	45%	15%	0%	0%	71%	
	Weighted score	0.04	0.02	0.06	0.03	0.00	0.00	0.10	**0.25**

infrastructure									

In Bhutan, currently, there are only three **automated weather stations** (AWS). There is a need to increase the number of AWS for a more comprehensive coverage. Modern weather observation and forecasting systems that rely on automated weather stations (AWS) with GSM/GPRS communication technology for real-time data can be an efficient adaptation strategy for the sector.

Roads that are built to be climate resilient can tremendously enhance the adaptive capacity of a country like Bhutan. It can augment other adaptation measures as well. Climate resilient roads can help in providing people a route to reach safety during calamities and ensure adequate service levels of the road network under extreme weather conditions.

An **Early Warning System** (EWS) consists of coordinated procedures through which information on foreseeable hazards is collected, analyzed and dissipated to warn people of the possible occurrence of a natural disaster. These can be decentralized, community based systems, usually operated by a network of volunteers. A key benefit of community based ESW towards climate change adaptation is that it provides populations with time to act and curtail the damages that are expected due to a particular climate related hazardous event. A community based EWS is able to educate the people about the particular steps that they must take to avert potential dangers when or before a natural disaster occurs.

Detailed description of these technologies is provided in Annexure 1.

6.5. Final prioritized technology for preparation of Technology Action Plan

Climate resilient roads were the finalized technology for preparation of barrier analysis, enabling framework and technology action plan for natural disasters and infrastructure sector. This is because it is aligned with the government's road policy and legislation that advocates environment-friendly road construction. However, implementation of the same in Bhutan so far has been weak because of a number of barriers such as inadequate knowledge, skills, demonstrational measures, and equipment. Creation of a detailed enabling framework and TAP for the technology will definitely help in overcoming many of these barriers and allow it to be scaled up in the nation.

Real-time weather stations were not finalized since there are already existing projects under the NAPA/UNDP/GEF projects to address the technology needs. Further, it was decided that effectively community based early warning systems should go together with real time weather monitoring, for which there already exist various project proposals. In addition, GLOF-EWS is already in place in Punatshang Chhu and a similar one for Chamkhar Chhu is already planned for establishment through an externally-assisted project.

Chapter 7. Summary / Conclusions

Bhutan's key economic sectors such as agriculture and hydropower are highly vulnerable to climate change. The nation's policies are also geared towards developing a low-carbon and climate-resilient economy to ensure that the overall development process of the country is sustainable and follows the philosophy of GNH. The TNA document prepared with support from GEF, UNEP and AIT presents the key technologies for accelerating climate change adaptation in Bhutan while meeting the national development goals.

The technologies were selected through a rigorous process of analytical research and stakeholder consultation. One to one meetings with sectoral experts and policy makers were conducted followed by a three-day workshop with TNA Task Force members in Paro to arrive at the final list of prioritized technologies for each of the prioritized sectors.

The prioritized sectors identified were Water Resources, Agriculture and Natural Disasters and Infrastructure. Within each of these sectors, technologies were prioritized against a set of criteria each of which was given varying weightage. The criteria were the following:

1. Benefits (excluding climate change related benefits): Contribution to economic, environmental and social development priorities

2. Relevance to climate change adaptation: Vulnerability reduction potential

3. Appropriateness: Technology maturity and potential scale of utilization

4. Cost

The prioritized technologies in each of the sub-sectors are given in Table 25.

Table 25: Final prioritized technologies in the prioritized sectors

Prioritized sectors	Prioritized technologies
Water Resources	§ Micro/Mini hydro power § Efficient irrigation methods § Solar power (Photovoltaic)
Agriculture	§ Agro-forestry § Development of drought resistant and pest resistant varieties of crops § Sloping Agriculture Land Technology (SALT)
Natural Disasters and Infrastructure	§ Real-time weather stations and weather forecasting (multi-range) § Climate resilient roads § Community based early warning systems

Further discussions among TNA Task Force members suggested that it may be practical to conduct in-depth and focused barrier analysis, enabling frameworks and technology action plans for only one technology per sector, rather than for all technologies. Therefore, one technology from each sector was finalized for the preparation of TAPs. The technologies finalized for each sector are given in Table 26.

Table 26: Finalized technologies for preparation of TAPs

Prioritized sector	Finalized technology for barrier analysis, enabling framework and TAP
Water resources	Efficient irrigation systems
Agriculture	Development of drought and pest resistant varieties of crops
Natural disasters and infrastructure	Climate resilient roads

References

National Adaptation Programme of Action (NAPA) Bhutan, 2006, National Environment Commission, Royal Government of Bhutan

Clements R J, Haggar A, Quezada and J. Torres, 2011, Technologies for Climate Change Adaptation – Agriculture Sector, X. Zhu (Ed.), UNEP Risø Centre, Roskilde.

Elliot M, Armstrong A, Lobuglio J and Bartram J, 2011, Technologies for Climate Change Adaptation—The Water Sector, T. De Lopez (Ed.), Roskilde: UNEP Risø Centre

Labour Force Survey 2011, Labour Force Survey (LFS) Report, 2011, Royal Government of Bhutan

Ministry of Home and Cultural Affairs Bhutan, 2005, National report on Bhutan for world conference on disaster reduction, Kobe, Japan, 18-22 January, available at http://www.unisdr.org/2005/mdgs-drr/national-reports/Bhutan-report.pdf, accessed on 4 May 2012

National Environment Commission, 2011, Second National Communication to the UNFCCC, National Environment Commission, Royal Government of Bhutan, Bhutan

National Statistics Bureau, 2011, Statistical Yearbook of Bhutan 2011, National Statistics Bureau, Royal Government of Bhutan

Sommer Haven Ranch International, 1996, Sloping Agricultural Land Technology (SALT – 1) Sustainable Agriculture, Training Pac, available at http://www.sommerhaven.org/prac_app/sus_ag/t_pac_salt1.pdf, accessed on 4 May 2012

Annexes

Annex I. Technology Factsheets

I. Micro/mini hydro power

Introduction

Hydropower projects below 25 MW are categorized as small hydro projects which are further classified as micro/pico (with capacities up to 100 kW), mini (capacity 101 kW- 2 MW) and small (capacity 2 MW- 25 MW).

Technology characteristics

A small hydro project (SHP) generates electricity of up to 25 MW from the energy of moving water which is used to run a turbine. The mechanical energy from the movement of the turbine is then converted to electrical energy using magnetic fields. Water flowing through a stream enters the forebay through a canal or an intake ditch where intake screens remove debris from the water. After this, the water flows through the penstock to the turbine and the generator unit, where electricity is generated. The electricity is then transmitted to the point of use via the transmission system.

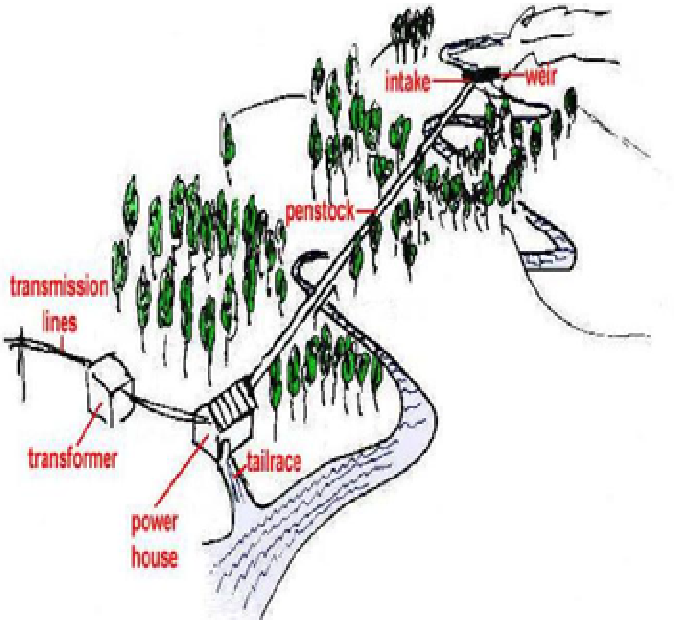

Figure 3: A typical micro hydro power system

Source: Centre for Rural Technology, Nepal (CRT/N), 2005

Country specific applicability and potential

Bhutan has great potential to meet its energy requirements by generating power through micro/mini hydro projects. Several provisions of various national policies address the development of incentivize such projects. For instance, the Electricity Act 2001 aims to promote small projects by exempting license requirement for projects with capacities less than 500 kW. Further, the development of micro-hydels (among other renewable energy) and institutional strengthening and capacity building is a priority activity under the renewable energy programme of the Tenth Five Year Plan.

Status of technology in country

Hydroelectricity contributes 98.8% of the total installed electricity capacity in Bhutan. This is only 6% of the total estimated exploitable hydro-electric potential of Bhutan. The country has 27 hydro-power projects, 12 of which are mini and 10 are micro hydro projects. Together these mini/micro hydro projects have a capacity of 8.068 MW[7].

Also, most of the projects in the country have been developed on an ad-hoc basis based on the availability of external donor funding. The various donors in the micro hydro sector and the Royal Government of Bhutan have different objectives and different approaches to micro hydro development[8], leading to differences in the way the micro-hydro power projects are constructed and later executed. For instance, the Ura 50 kW micro hydro project is managed and maintained by the Bhutan Power Corporation. On the other hand, the Chendebji 70 kW micro hydropower project is owned by the Department of Energy. The department also provides technical back-stopping, and subsidies for

[7] South Asia Regional Initiative for Energy and USAID, 2011, available at http://www.sari-energy.org/PageFiles/Countries/Bhutan_Energy_detail.asp, accessed on 4 May 2012.

[8] Dorji KM, 2007, The Sustainable Management of Micro Hydropower Systems for Rural Electrification: The Case of Bhutan.

procurement of major spare parts and equipment. However, the operation and maintenance of the project is completely handled by the local community[9]. To summarize, the technology is known and applied in the country although at a very low scale.

Benefits to economic/ social and environmental development

Small hydropower is one of the matured renewable energy technologies which provide inflation free energy due to absence of fuel cost. Micro/mini hydro can provide clean electricity to rural communities which otherwise might take years to be served. The possible target sites for small hydro plants are the isolated areas (usually at a higher level), which are not connected to the grid. The target beneficiaries are the rural people residing at a considerable distance away from transmission line and distribution networks.

Also, micro hydro plants are comparatively easy to manufacture and install indigenously, thus boosting local employment, economic activity and the industrial base. Small scale hydro power plants can be locally managed, operated and require much lower trained with training input to the local people.

In addition to itself being a clean source of energy, micro/mini hydro power supplied to previously unelectrified areas helps in reduction of kerosene and firewood, thereby reducing greenhouse gas emissions.

Further, reduction of use of firewood improves quality of health. Power used by micro-enterprises and cottage industries increases income. Energy supplied for agricultural and supporting activities increases productivity and reduces wastage of crop.

Supply of clean and reliable energy by utilization of local water resources provides a huge impetus for overall development of the village community and empowerment of its people.

Climate change adaptation benefits

Micro/mini hydropower projects can play a critical role in allowing adaptation to climate change in Bhutan by diversifying the nation's energy sources and thereby reducing the dependence on large hydro, which is likely to be affected by various climate change events such as GLOF, reduction in the average flow of snow fed rivers, combined with an increase in peak flows and sediment yield. On the other hand, micro/mini hydro power is less vulnerable to such events since its water source is from aquifers and streams and not from glaciers.

Bhutan energy requirements are met primarily from large hydro power projects. Impacts of climate change in terms of temporal and spatial variation in flow of water (having glaciers as source of origin) is most likely to affect electricity productivity/exports in Bhutan due to disruption of average flows for optimum hydropower generation from large hydro power projects.

Thus, hydropower generation is vulnerable to impacts of climate change. This also leads to vulnerability of the entire energy sector which is primarily dependent on water resources originating from glaciers. To address this vulnerability, diversification of energy sources is an important strategy. If certain areas' demand for electricity can be met through micro/mini hydro power, it will reduce the reliance on large hydro power.

Financial Requirements and Costs

The cost of micro/mini hydro power projects can vary between USD 1500 to over USD 2000[10] per kW. Examples from India show that a 40 kW project has been built at a cost of USD 60000 with active participation from the local community. Further, a 150 kW project has also been built at the cost of USD 180,000, bringing down the per kW cost to USD 1200.

[9] Dorji KM, 2007, The Sustainable Management of Micro Hydropower Systems for Rural Electrification: The Case of Bhutan.
[10] Assuming USD 1 = INR 50.

II. Solar power (Rooftop PV)

Introduction

Solar power is generated by collecting sunlight and converting it into electricity. Solar photovoltaic (SPV) refers to the technology of using solar cells to convert solar radiation directly into electricity. A solar cell works based on the photovoltaic effect.

Technology characteristics[11]

The photovoltaic effect

The photovoltaic effect can be briefly summarized as sunlight striking a semiconductor and causing electrons to be excited due to energy in the sunlight (photons). The excited electrons become free of their atomic structure and, in moving away, they leave behind 'holes' of relative positive charge that can also migrate throughout the material. By placing two different semiconductors together in thin layers (or wafers) the free electrons and 'holes' can be separated at their interface/junction, creating a difference in charge, or voltage, across two materials. Sometimes, the term "p-n junction" is used which refers to the two different types of semiconductor used. A single such arrangement, or cell, creates only a modest voltage and current, but when arranged into larger arrays the cells can produce useful amounts of electricity which is known as solar PV electricity.

On the basis of their manufacturing process, solar cells consist basically of three main components - the semiconductor, which absorbs light and converts it into electron-hole pairs, the semiconductor junction, which separates the electrons and holes, and the electrical contacts on the front and back of the cell that allow the current to flow to the external circuit. R&D and practical experience with photovoltaic have led to the development of three generations of solar cells.

Crystalline silicon based solar cells

The first generation is represented by crystalline silicon based solar cells, which may be monocrystalline or multicrystalline depending on the manufacturing technique. It is the most mature technology and represents a market share of 80 to 90 percent (IEA, 2009; IPCC, 2010). Maximum recorded efficiencies (the percentage of the incoming energy that is converted to electricity) of roughly 20 and 25 percent have been achieved for multicrystalline and monocrystalline cells respectively, representing an approximate doubling of efficiency since 1990 (IPCC, 2010). These improvements in efficiency have been mirrored by improvements in manufacturing techniques including thinner cells (lower material costs), larger wafers, increased automation and other factors that likewise contribute to the significant cost reductions seen in the past decades (these are discussed further in the finance section below).

Thin film solar cells

Second generation technologies, so called thin film solar cells are based on alternative materials such as cadmium telluride (CdTe), copper indium gallium diselenide (CIGS), amorphous silicon and micromorphous silicon set as thin films. The layer that absorbs the sunlight is only a few micrometers thick and can be deposited onto relatively large smooth surfaces such as glass, metal or plastic. This PV type has the advantage of lower labour and energy intensity compared to crystalline silicon PV but a reduced efficiency in terms of electricity generation (10 to 16% depending on the film type, IPCC, 2010). The majority of the remaining share of the PV market is taken by thin film technologies.

Third generation PV

Third generation technologies were originally developed for use in space and have multiple junctions typically using more exotic semiconductors such as gallium and indium compounds. These types of cells have already crossed the maximum theoretical efficiency of single junction solar cells, and many laboratories have reported lab scale solar cells reaching efficiencies in the excess of 40%. Third generation cells are typically considered in combination with solar concentrator systems as described below and are currently being commercialized in this context. The use of concentrators allows much smaller cells to be used which in turn reduces the cost associated with these more exotic materials.

[11] http://climatetechwiki.org/technology/pv, last accessed on 15 June 2012

Concentrated solar PV

Solar cells have been found to operate more efficiently under concentrated light which has led to the development of a range of approaches using mirrors or lenses to focus light on a specific point of the PV cell, called concentrator systems. Specially designed cells use heat sinks, or active cooling, to dissipate the large amount of heat that is generated. This type of concentrating configuration requires a sun tracking system using either single axis or double axis tracking to make sure that the mirrors/lenses are always pointing at the correct orientation.

Off-grid and grid connected PV

There is an obvious yet important qualification to the discussion above on efficiency, which is that solar panels are limited to only produce electricity in periods of sunlight, either direct light or diffuse sunlight on overcast days. During the night they will not produce power. This means that solar cells, if used for remote/off-grid generation purposes, need to be implemented in conjunction with some kind of storage system such as a battery or as a hybrid system with some other type of generator. Where solar cells are grid connected this is less of a problem. They can be used during the day to reduce the local demand from the grid (or even to export back to the grid) and then at night, or during periods of low incident light, the grid can supply the necessary power. The former kind of application, as a remote or off-grid generator, is most commonly observed in developing countries and isolated areas, while grid-connected solar PV is more common in industrialized countries which have a wider reaching grid.

Grid connected solar PV also can have differences in the approach used depending on the way in which customers purchase the electricity. If the solar array is distributed, for example over a larger number of residential houses, then the single installations are operated by the consumer directly. The advantage of this to the consumer is that the cost of electricity, that the consumer must compete with, is the distributed cost, i.e. the cost to purchase power at the location of demand which is normally significantly higher than the actual levelized production cost of electricity (that doesn't account for transmission/distribution charges/losses and profit margins along the value chain). Solar installations can also be large and centralized but this demands that the power is sold into the common grid at market prices and must compete directly with other technologies (bearing in mind any subsidies that might be applicable for solar generation).

Solar Home System (SHS)

"A SHS typically includes a photovoltaic (PV) module, a battery, a charge controller, wiring, fluorescent DC (direct current) lights, and outlets for other DC appliances. A standard small SHS can operate several lights, a black-and-white television, a radio or cassette player, and a small fan. A SHS can eliminate or reduce the need for candles, kerosene, liquid propane gas, and/or battery charging, and provide increased convenience and safety, improved indoor air quality, and a higher quality of light than kerosene lamps for reading. The size of the system (typically 10 to 100Wp) determines the number of 'light-hours' or 'TV-hours' available. It is estimated that there are more than 2 million such systems in use globally, the majority in Bangladesh, China, India, South Africa and Kenya[12] (REN21, 2010).

Country specific applicability and potential

With rising energy demand in Bhutan, and with threats to hydro power generation from climate change risks, SPV could prove to be a sustainable source of power generation. Bhutan has good solar energy potential. The solar energy assessment was done by the U.S. National Renewable Energy Laboratory (NREL) under the financing from the U.S. Agency for International Development's (USAID) as part of the South Asia Regional Initiative for Energy (SARI/E) programme. The solar energy resources quantified at various places and solar resource map developed for the region under Solar and Wind Energy Resource Assessment (SWERA) project of UNEP have shown a resource potential of 4.5-5 kWh/m^2 in various locations[13].

Status of technology in country

The solar contribution to Bhutan's energy mix is negligible in comparison to hydroelectricity. However, SPVs have been provided to rural households as off-grid electrification where grid extension is found unviable due to the terrain and associated costs. The target during the 10th FYP was to electrify 3,582 households using SPV systems including site survey and rehabilitation of 1000 existing systems[14].

[12] REN21, 2010, Renewables 2010, Global Status Report, Paris

[13] DOE 2011: National Road Map for Energy Security, Bhutan Climate Summit 2011, Department of Energy 2011

[14] Royal Government of Bhutan, 2009, Gross National Happiness Commission, Tenth Five Year Plan 2008-2013

Also, there are no solar manufacturers in Bhutan. The Department of Renewable Energy (DRE) has few solar technicians and there are also solar technicians trained in different organizations and communities. The DRE also has experience in procuring SPV products from the few suppliers available in Bhutan.

Benefits to economic, social and environmental development

Economic Benefits

- Though initial investment is high, all the electricity produced is free and is profitable in the long run. Incentives and rebates offered by governments and utilities can compensate for the high prices. Further, with advancements in the technology, cost of solar panels are decreasing while efficiency is increasing

Social Benefits

- Solar energy can help provide a source of energy to far-flung and isolated communities dwelling in areas, social establishments like monasteries and schools where grid extension is made impossible due to costs, the topography and climatic conditions.
- There can be many jobs created in the solar sector, such as meet the demand for trainers and technicians.

Environmental Benefits[15]

Solar PV systems, once manufactured, are closed systems; during operation and electricity production they require no inputs such as fuels, nor generate any outputs such as solids, liquids, or gases (apart from electricity). They are silent and vibration free and can broadly be considered, particularly when installed on brownfield sites, as environmentally benign during operation. The main environmental impacts of solar cells are related to their production and decommissioning. In regards to pollutants released during manufacturing, IPCC (2010) summarizes literature that indicates that solar PV has a very low lifecycle cost of pollution per kilowatt-hour (compared to other technologies). Furthermore they predict that upwards of 80% of the bulk material in solar panels will be recyclable; recycling of solar panels is already economically viable. However, certain steps in the production chain of solar PV systems involve the use of toxic materials, e.g. the production of poly-silicon, and therefore require diligence in following environmental and safety guidelines. Careful decommissioning and recycling of PV system is especially important for cadmium telluride based thin-film solar cells as non-encapsulated Cadmium telluride is toxic if ingested or if its dust is inhaled, or in general the material is handled improperly. In terms of land use, the area required by PV is less than that of traditional fossil fuel cycles and does not involve any disturbance of the ground, fuel transport, or water contamination (IPCC, 2010).

Climate change adaptation benefits

Solar power presents a great avenue to bolster the adaptive capacities of Bhutan whose primary source of energy is large hydro. Large hydro is extremely vulnerable to the risks of climate change such as the reduction in the average flow of snow fed rivers, combined with an increase in peak flows and sediment yield. Generation of electricity from solar power would diversify the nation's energy sources, thereby reducing the dependence of communities on grid supply of electricity and on hydro power.

Bhutan energy requirements are met primarily from large hydro power projects. Impacts of climate change in terms of temporal and spatial variation in flow of water (having glaciers as source of origin) is most likely to affect electricity productivity/exports in Bhutan due to disruption of average flows for optimum hydropower generation from large hydro power projects.

Thus, hydropower generation is vulnerable to impacts of climate change. This also leads to vulnerability of the entire energy sector which is primarily dependent on water resources originating from glaciers. To address this vulnerability, diversification of energy sources is an important strategy. If certain areas' demand for electricity can be met through SPV, it will reduce the reliance on large hydro power.

[15] http://climatetechwiki.org/technology/pv, accessed on 15 June 2012.

Financial Requirements and Costs[16]

There has been a large decrease in the cost of solar PV systems in recent decades; the average global PV module price dropped from about 22 USD/W in 1980 to less than 4 USD/W in 2009, while for larger grid connected applications prices have dropped to roughly 2 USD/W in 2009 (IPCC, 2010).

Using a slightly different approach (based on a study of solar PV module and consumer electricity prices, i.e. a grid-parity study) Breyer et al. (2009) estimated that the "cost of PV electricity generation in regions of high solar irradiance will decrease from 17 to 7 €ct/kWh in the EU and from 20 to 8 $ct/kWh in the US in the years 2012 to 2020, respectively".

[16] http://climatetechwiki.org/technology/pv, accessed on 15 June 2012

III. Efficient irrigation methods

Introduction

There is growing evidence that changes in the hydrological cycles look likely to cause longer droughts and more intense rains making wet regions even wetter and arid areas drier in the near future. Changes in precipitation and the disappearance of glaciers will result in a considerable reduction of water quantity and quality for direct human consumption and agricultural activities. This in turn will affect agricultural production and food security leading to unforeseen famines in the near future over the world. Hence it is important to address the issue of irrigation in agriculture and design methods or technologies that would make the use of water for irrigation more efficient and sustainable.

Technology Characteristics

Efficient irrigation methods or technologies include the following advanced irrigation systems like sprinkler irrigation and drip irrigation. Sprinkler irrigation is a type of pressurized irrigation that involves applying water to the soil surface using mechanical and hydraulic devices that simulate natural rainfall. The goal of irrigation is to supply each plant with just the right amount of water it needs. Sprinkler irrigation is a method by which water is distributed from overhead by high-pressure sprinklers on risers or moving platforms. Today a variety of sprinkler systems ranging from simple hand-move to large self-propelled systems are used worldwide.

Drip irrigation is based on the constant application of a specific and calculated quantity of water to soil crops. The system uses pipes, valves and small drippers or emitters transporting water from the sources (i.e. wells, tanks and or reservoirs) to the root area and applying it under particular quantity and pressure specifications. Managing the exact moisture requirement for each plant, the system significantly reduces water wastage and promotes efficient use. Compared to sprinklers systems which can provide 75 per cent efficiency, drip irrigation can provide as much as 90 per cent water-use efficiency[17] (Tanji and Kielen, 2002)

Country Specific Applicability and Potential

Considering the fact that agriculture and forestry is the major source livelihood for Bhutanese, it is imperative that these climate sensitive sectors are safeguarded against the effects of climate change. Hence there is a need to incorporate efficient irrigation measures into Bhutan's over plan for bolstering its adaptation capacity.

Status of Technology in the Country

National Irrigation Policy (NIP) of the Royal Government of Bhutan (RGoB) intends to provide policy direction in the irrigation sub-sector to address its current and future issues. It provides clear direction on the measures that need to be adopted to increase the irrigated area and to improve irrigation water management and optimal utilization of national water resources for crop production In Bhutan, a three-year rainwater harvesting project aimed at safeguarding farmers from water shortages during dry periods and irregularities in the monsoon rainfall had a total budget of $850,000. The activities include small scale irrigation development based on rainwater harvesting technologies, strengthening farmers involvement and research and extension services, vulnerability assessment, land survey, rural credit, project management ,identification of areas vulnerable to dry spells and erratic monsoon rainfall, aerial surveys and evaluation of remote sensing images/photographs to determine areas suitable for ,water harvesting, assessment of available and proven rainwater harvesting technologies for adoption, technological adaptation to fit the needs and requirements specific to each vulnerable locations, economic analysis of rainwater harvesting techniques, etc. Using bamboo stems for drip irrigation during the dry season is a common feature in irrigation in Bhutan.

Benefits to economic, social and environmental development

Sprinkler irrigation

- Benefits from improved crop productivity include income generation, employment opportunities and food security
- Sprinkler systems eliminate water conveyance channels, thereby reducing water loss

[17] Tanji, K and Kielen, N 2002, 'Agricultural drainage water management in arid and semi-arid areas', FAO irrigation and drainage paper 61 (Annex section), Food and Agriculture Organization of the United Nations, Rome

- Sprinkler irrigation technology is well adapted to a range of topographies and is suitable in all types of soil, except heavy clay
- Sprinklers provide a more even application of water to agricultural land, promoting steady crop growth.
- The risk of soil erosion can be reduced because the sprinkler system limits soil disturbance, which can occur when using irrigation by gravity
- Sprinkler irrigation can provide additional protection for plants against freezing at low temperatures.

Drip Irrigation

- A well-designed drip irrigation system reduces water run-off through deep percolation or evaporation to almost zero.
- As water consumption is reduced, production costs are lowered. Also, conditions may be less favorable for the onset of diseases including fungus.
- Drip irrigation promotes irrigation scheduling to precisely meet crop demands, holding the promise of increased yield and quality.
- Agricultural chemicals can be applied more efficiently and precisely with drip irrigation, reducing losses.
- The drip system technology is adaptable to terrains where other systems cannot work well due to climatic or soil conditions.
- Drip irrigation technology can be adapted to lands with different topographies and crops growing in a wide range of soil characteristics (including salty soils). It is particularly efficient in sandy areas with permanent crops such as citric, olives, apples and vegetables

Climate change adaptation benefits

Efficient irrigation systems including sprinkler and drip systems provide a means for sustainable water use and management and strengthening the adaptive capacities of people living especially in economies that are heavily dependent on agriculture. Climate change is disrupting global rainfall patterns meaning some parts of the world are suffering from a drastic drop in precipitation leading to a fall in water levels in many reservoirs and rivers. Sprinklers, drip irrigation and rainwater harvesting allows for efficient use of water and represent an adaptation strategy against scarcity of water.

Financial Requirements and Costs

The cost of installing a sprinkler system ranges from US$ 600 to US$ 2500 per hectare, depending on the type of materials used and the amount of labour contributed by rural producers. The cost also depends on the specification and degree of automation of devices required. Financing for equipment may be available from financial institutions via leasing operations or through direct credit. Farmers usually cover installation, design and training costs that represent about 30 to 40 per cent of final costs depending on the size of the land, characteristics and shape, crops, and particular technology applied.

IV. Agro-forestry

Introduction

Agro-forestry is a land-use system that aims towards optimal utilization of available land resources by multiple as well as beneficial practices of agriculture and forestry. The main purpose of agro-forestry activities is to sustain the fertility of the soil by substituting the nutrition required by intensive agriculture.

Technology characteristics

Agro-forestry incorporates the benefits of both intensive scientific agricultural practices and forestry activities that yield the desired timber, fuel wood and non-wood forest produce. The agro-forestry models concentrate both on the short-term returns from agriculture as well as long-term returns from forestry activities. This ensures long-term economic security aspect of farmers and communities adopting such activities. Agro-forestry activities also ensures diversity in crops raised as well as enhances species diversity by encouraging plantation of multiple –tree species for various uses or plantation of multi-purpose tree species.

Country specific applicability and potential

Non-adoption of adequate soil conservation measures and improper crop rotation are some of the important factors contributing to land degradation in Bhutan[18].Improper farming practices also add to land degradation. Productive land is being lost without realizing the full potential of the limited soil resources of the country; soil erosion and landslides wash away rich topsoil degrading the soil resources, and such degradation also affects the climate both at macro- and micro- levels. About 40,000 ha of land, more than 10 percent of total agriculture area in Bhutan is threatened with soil erosion[19]. These areas can be primarily targeted for agro forestry activities.

Status of technology in country

Agro-forestry activities are being carried out in Bhutan for a long-time now and have been recognized as a viable tool for ecological restoration as well as ensuring economic security to the people. Agro-forestry activities can be encouraged in areas under agriculture, especially areas prone to degradation and soil erosion.

Benefits to economic/social and environmental development

Agro-forestry activities are aimed towards diversification of income means, improvement in the quality of life of marginal farmers, and ensuring energy security and food security of the farmers and the populace as a whole. Agro-forestry also helps in staggering income generation across the year through crop diversification and overcoming the threat of financial losses due to crop failure in an increasingly erratic seasonal cycle. The woodlots and trees planted as part of the model can cater to medium and long term economic security of the farmers as well enhance soil productivity through litter fall and soil conservation.

The supply of fuel wood derived from forestry activities can also be used as a means to encourage improved cook-stoves and more environmentally friendly activities among the populace. Domestic woodlots will help to reduce pressure on natural forests which are presently under increasing pressure from rising demand from a fast growing population.

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[18] Bhutan: State of the Environment, 2001, available at http://www.rrcap.unep.org/pub/soe/bhutan_land.pdf, accessed on 4 May 2012.

[19] FAO Corporate Document Repository, 1994, Land degradation in south Asia: Its severity causes and effects upon the people, available at http://www.fao.org/docrep/V4360E/V4360E07.htm, accessed on 4 May 2012.

Kingdom of Bhutan

Climate change adaptation benefits

The diversification of income source acts as an insurance against climate variability and resultant risk in loss of crops and livelihood and pushes the marginal landholders into poverty. The agro-forestry activities also helps in rehabilitation of degraded farmlands, which are especially threatened by accelerated degradation due to deforestation and increasing variability in rainfall patterns.

Financial Requirements and Costs

The total cost for implementing an agro-forestry activity is about USD 1000[20] per hectare including cost of planting, agriculture, soil conservation measures, training of farmers etc.

[20] Assuming USD 1 = INR 50.

V. Sloping Agricultural Land Technology

Introduction

The Sloping Agricultural Land Technology (SALT) is agro-forestry model farming system, first initiated by the Mindanao Baptist Rural Life Centre in the southern Philippines to help control soil erosion and increase crop yields.

Technology characteristics

SALT is a system in which dense hedgerows of fast growing perennial nitrogen-fixing tree or shrub species are planted along contour lines thus creating a living barrier that traps sediments and gradually transforms the sloping land to terraced land. The hedgerows markedly reduce soil erosion and contribute to improving and/or maintaining soil fertility by acting as a source of organic matter. SALT has emerged as one of the main approaches used to control soil erosion in mountainous region.

Besides the general SALT design, described as SALT 1, SALT 2 is classified (*Small Agro-Livestock Land Technology*) as a goat-based agroforestry with a land use of 40% for agriculture 20% for forestry and 40% for livestock. As in a conventional SALT project, hedgerows of different nitrogen-fixing trees and shrubs are established on the contour lines. The manure from the animals is utilized as fertilizer both for agricultural crops and the forage crops.

SALT 3 (*Sustainable Agroforest Land Technology*) is a cropping system in which a farmer can incorporate food production, fruit production, and forest trees that can be marketed. The farmer first develops conventional SALT project to produce food for his family and possibly food for livestock. The plants in the hedgerows will be cut and piled around the fruit trees for fertilizer and soil conservation purposes. A small forest of about one hectare will be developed in which trees of different species may be grown for firewood and charcoal for short-range production. Other species that will produce wood and building materials maybe grown for medium and long-range production[21].

Country specific applicability and potential

The challenge for promoting low-cost SLM technology for steep slope agriculture in Bhutan is to adapt it to the prevailing extreme climatic variability, cultural and technology practices. Such technology must be backed up by development of farmer-friendly training and extension materials followed by training of farmers in a phased manner[22].

Extensification as well as intensification of agriculture, to enhance food production, face serious constraints in Bhutan because expansion of arable land is restricted and the nature of the terrain makes enhancing the productivity of cultivated land difficult.

Shifting cultivation is an age-old practice common to several parts of the country. With increases in population, more and more areas are being tapped for this practice. With the narrowing down of the fallow cycle due to paucity of arable lands, such practices do not allow a sufficient period for the natural processes of recuperation to repair the disturbed ecosystem resulting in erosion and fertility decline. LUSS, Ministry of Agriculture, estimated an area of more than 1000 km^2 under shifting cultivation in Bhutan.

SALT holds the potential to increase the productivity and varieties of crops that may be cultivated and replace the traditional farming practices that have become unsustainable due to the increasing population pressure. The SALT is the key to address the problem of land erosion and degradation in the extremely vulnerable regions of the country subjected to over exploitation of resources due to increasing population pressure, unplanned development works and unscientific and unsustainable agricultural practices like shifting cultivation. SALT is meant to address the increasing problem of loss of valuable and scarce arable land in the mountainous country due to shifting cultivation, encroachment into forest, extension of cultivation onto lands of low potential or high natural hazards and non-adoption of adequate soil conservation measures and improper crop rotation. With about 13% of the area of Bhutan categorized as sloping land of slope between 8-30%, SALT is an important tool to exploit the land sustainably and productively.

[21] Sommer Haven Ranch International, 1996, Sloping Agricultural Land Technology (SALT – 1) Sustainable Agriculture, Training Pac, available at http://www.sommerhaven.org/prac_app/sus_ag/t_pac_salt1.pdf , accessed on 4 May 2012.
[22] National Action Programme to Combat Land Degradation, 2009, United Nations Development Programme and Global Environment Facility, available at http://www.undp.org.bt/assets/files/publication/NAP_Draft_Full&Final_Oct09.pdf, accessed on 4 May 2012.

Kingdom of Bhutan

Status of technology in country

Project for Rainwater harvesting and Sustainable Land Management (SLM) are being implemented in Bhutan for the last decade[23]. The National Action Programme to Combat Land Degradation (2009) also institutionalizes the requirement for undertaking SALT activities. But as the action plan has envisioned, proper capacity building activities and awareness drives must be organized to help in diffusing of the technology to the grassroots.

Benefits to economic / social and environmental development

The SALT technology in a generic manner has the following aspects that may prove economically beneficial to the targeted communities

i) Contour farming: Farming along contours will help check soil erosion and enable moisture retention, thereby enhancing soil productivity

ii) Planting of nitrogen-fixing varieties: As part of the generic design of SALT, nitrogen fixing crops as part of the crop rotation, suitable for prevailing agro-climatic conditions as well as trees are planted. This results in enhanced soil fertility and recovery of depleted soil nutrients in areas subjected to intensive cultivation. In the long run, this helps in enhanced productivity as well as reduction in chemical fertilizer use in the long-run

iii) Planting of crops having different maturity periods: Plantation of seasonal crops, permanent crops like horticulture varieties as well as tree plantations help in diversity of income sources for famers as well as create a cushion against the threats of seasonal natural vagaries that may affect income from one of the sources.

iv) Labour-intensive activities: The activities related to SALT like contour trenching, plantation and tending operations etc. are very labour intensive as well as requiring some specialized expertise. Thus with proper government support, SALT activities can be able to generate significant local employment and stymie seasonal migration.

v) Improved agricultural techniques that incorporate soil amelioration and productivity enhancing measures and at the same time respect the traditional practices of the local populace are the key for ensuring food security and counter the vagaries associated with an increasingly unpredictable climate variability associated with global climate change phenomenon. Proper planning and execution of SALT can thus result in agricultural productivity increasing manifold vis-à-vis the investment required for implementation of such practices[24].

The SALT has been design as such to promote soil and moisture conservation measures, nutrient enhancement in depleted areas and enhance crop productivity, which are expected to have a positive impact on the environment.

Climate change adaptation benefits

The traditional upland subsistence cultivation practices are seen as especially vulnerable to the following adverse impacts of climate change:

- Increasingly extreme variations in climate and weather patterns leading to drought and flash floods
- Incessant rains leading to large scale soil erosion, landslides and washing away of top soil
- Rising incidence of pests and diseases due to unseasonal rains and dry spells

A report of National Environmental Commission in partnership with UNEP (2009) lists the following vulnerabilities faced by agriculture sector, viz:

  - Crop yield instability/loss of production and quality
  - Increased risk of extinction of already threatened crop species (traditional crop varieties)

[23] National Soil Services Center, Ministry of Agriculture, 2008, Review of Mainstreaming of Sustainable Land Management in Government Policies and Plans in Bhutan, available at http://www.bt.undp.org/assets/files/publication/Final%20Report%20on%20SLM%20Mainstreaming%20Review.pdf , accessed on 4 May 2012.

[24] Laquihon W.A. and Pagbilao M.V., Sloping Agricultural Land Technology (SALT) in the Philippines, available at http://www.fao.org/ag/AGP/AGPC/doc/Publicat/Gutt-shel/x5556e0y.htm, accessed on 4 May 2012.

- Loss of soil fertility due to top soil erosion and runoff
- Crop yield loss due to unseasonal rains
- Delayed sowing due to shift in season cycle
- Spreading of pests into new areas affecting larger number of more vulnerable crops
- Deterioration of infrastructure of supply of food grains to markets

Thus the major perceived threats from increasing climate variability to ecologically fragile mountainous regions are loss of crop production, affecting the primary means of livelihood of the country, increased loss of soil fertility and increased erosion which is expected to reduce the already restricted availability of arable land, the increasing incompatibility of traditional cropping cycle with shift in the onset of seasons and the spread of pests to hitherto non-affected regions.

SALT, as a technology option is expected to address the issues related to soil and water conservation, enhanced soil fertility and consequent crop productivity and crop diversification. With increasingly erratic rainfall patterns threatening to exacerbate the rate of soil erosion in areas subjected to intensive cultivation, improper contouring and loss of vegetation cover, SALT is a relevant technological tool that can be adapted to the conditions prevailing in Bhutan in multiple dimensions as discussed above.

Financial Requirements and Costs

The cost of implementing SALT will depend on the type of land, especially the slope of land and form of SALT being implemented. The cost will vary from USD 100 to USD 200[25] per hectare. Besides, implementation, appropriate funds are required for the purpose of capacity development and technology diffusion. As part of NAPA (2009), a budget of USD 9,00,000 has been envisaged for rainwater harvesting projects in Bhutan.

[25] Assuming USD 1 = INR 50.

VI. Development of drought resistant and pest resistant varieties of crops

Introduction

Climate change creates greater uncertainty and unpredictability in the environment due to which the traditional farming practices and crop breeds are increasingly becoming unviable for the farmers, thereby rendering them economically vulnerable.

It has been recognized world-wide that traditional knowledge in crop-breeding as well as careful use of the molecular breeding tools are required to develop new breeds that can be resistant to less availability of water as well as emergence of pests which are expected to spread to newer areas due to warming of climate.

Technology characteristics

Breeding new and improved crop varieties enhances the resistance of plants to a variety of stresses that could result from climate change. These potential stresses include water and heat stress and the emergence of new pests. Varieties that are developed to resist these conditions will help to ensure that agricultural production can continue and even improve despite uncertainties about future impacts of climate change. Breeding for improved performance under environmental stresses involves activities which accumulate favorable alleles (different forms of a gene) contributing to stress tolerance[26].

Development of new crop varieties requires both traditional knowledge in gene-pool as well as utilization of modern biotechnological processes like transgenic crops and molecular breeding. Conventional breeding requires the identification of genetic variability to drought among crop varieties and introducing this tolerance into lines with suitable agronomic characteristics. Although conventional breeding for drought tolerance has and continues to have some success, it is a slow process that is limited by the availability of suitable genes for breeding and largely limited to exploiting the existing genetic variation in crop plants and their very close relatives.

The development of tolerant crops by genetic engineering, on the other hand, requires the identification of key genetic determinants underlying stress tolerance in plants, and introducing these genes into crops. The physiological response of plants to water stress is accompanied by the activation of genes involved in the perception of drought stress and in the transmission of the stress signal. These set of genes are targeted for replication and amplification of their expression in the new breeds. A major reason for the relatively slow progress in conventional breeding responses to the stresses related to climate change arises from the fact that plant adaptations are not likely to be single gene changes and whole metabolic pathways are likely to be involved.

Country specific applicability and potential

Agriculture in Bhutan is especially vulnerable to rainfall variability and emergence of new pests due to warming. Erratic weather patterns and temperature and humidity changes have resulted in a dramatic rise in pest and disease outbreaks in many crops, raising worries about domestic food production[27]. Given that the staple crops in Bhutan like maize and rice are amenable to genetic engineering and crop breeding and the fact that these constitute about 90% of crop production in Bhutan, these crops should be taken up on a priority basis. Given the highly fluctuating nature of crop production in Bhutan[28], breeding of climate resilient varieties of maize and rice will contribute to food security in the country.

Status of technology in country

Crop breeding has been practiced traditionally in Bhutan. But of late it has been taken up on a systematic basis in partnership with Indian Agricultural Research Institute (IARI).

[26] Clements R J, Haggar A, Quezada and J. Torres, 2011, Technologies for Climate Change Adaptation – Agriculture Sector, X. Zhu (Ed.), UNEP Risø Centre, Roskilde.
[27] Administrator, 2011, HAPPINESS DRYING UP, Bhutan Today, available at http://www.bhutantoday.bt/index.php?option=com_content&view=article&id=1433:happiness-drying-up, accessed on 4 May 2012.
[28] http://www.tradingeconomics.com/bhutan/crop-production-index-1999-2001--100-wb-data.html, accessed on 4 May 2012

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In Bhutan, the Biodiversity Use and Conservation in Asia Programme [29](BUCAP), coordinated by the National Biodiversity Centre of the Ministry of Agriculture, in partnership with the agricultural research institutions and the agricultural extension agencies introduced the Participatory Plant Breeding (PPB) model to utilize the traditional knowledge of farmers as well as introduce new scientific methods in the grassroots level in 2002. It involved farmers directly in participatory varietal selection (PVS), and focused on the selection of rice blast resistant varieties. This focus was inserted into the PVS activities following a severe outbreak of rice blast at high altitude (1800-2700m) production environment in 1995. Parents were selected in the basis of the farmers' feedback. The collaborative programme works with farming communities in different valleys of Bhutan. The programme has thus far succeeded in increasing the diversity of blast resistant varieties in farmers' fields, and has released two improved local blast resistant rice varieties, namely Yusirep Maap and Yusireay Kaap. Besides, the BUCAP is also concentrating on developing new strains of maize.

National Field Crop Research Strategy Programme (2008-13) has also identified continuous crop breeding efforts as essential for sustainable agriculture output in Bhutan[30]

Benefits to economic / social and environmental development

Agriculture in Bhutan is increasingly being threatened by the fall outs of climate change. Crop-loss due to drought and damage by hitherto unknown pests are taking a major toll on the economic condition of farmers. In 2007, the maize harvest loss by the farmers at about 1800m above mean sea level is recorded at more than 50% because of the outbreak of northern corn blight disease[31]. Thus crop breeding and development of climate resilient varieties has become a prerogative for the agriculture sector. The improved varieties, as one maize variety introduced by CIMMYT[32], also helps in enhancing crop yield and farmers' incomes. But whilst fast tracking the process of crop breeding, it is essential that focus is not entirely on improved crop varieties but on further enrichment of gene pool which will help in resisting climate variability linked hazards in crop production. As HYV varieties entail a very narrow genetic base, concentrating entirely on such varieties as a means of increasing crop productivity may not be sustainable in the long term.

Thus achieving environmental development through improved crop varieties entails a tight-rope walk between encouraging indigenous multiple varieties of traditional strains which may have comparatively lower yield but are resistant to environmental challenges and adaptation of HYV varieties based on a narrow gene pool and establishing high cost-high return genetically uniform monocultures which may expose the sector to even more environmental risks going ahead.

Climate change adaptation benefits

Extreme fluctuation in agriculture production due to drought and pest attack is expected to aggravate poverty, threaten food security, and cause out-migration of people from rural areas. Breeding of climate change resilient varieties will help in bringing stability in crop production and protecting the livelihood of farmers. Stability of crop production is one of the major challenged in the face of climate change especially given that the population of Bhutan is increasing steadily and there is a growing pressure on the natural resources in the country.

Financial requirements and costs

The cost of developing new crop varieties depends on the type of crop, the method followed and the technologies involved. Whilst major crop variety development has been taken up by government sponsored institutions and the costs being borne by them, many corporate too are developing new varieties but in the latter case, farmers have to share the burden of development and intellectual property rights that increases the cost of seeds manifold. Such a situation is implausible in a country like Bhutan. Thus farmers should only pay for the initial adoption in new crop varieties that may initially require different seed bases but can be multiplied by the farmer themselves rather than corporations withholding the crop varieties for profit.

[29] http://www.cdic.wur.nl/NR/rdonlyres/DFDA8928-9664-4EF3-A593-C5E3023D3164/71905/CHAPTER4.pdf
[30] http://www.rcbajo.gov.bt/publication/files/dwn8uy3433mh.pdf
[31] National Environment Commission, 2011, Second National Communication to the UNFCCC, National Environment Commission, Royal Government of Bhutan, Bhutan
32 http://www.cimmyt.org/en/newsletter/37-2008/106-improved-maize-varieties-and-partnerships-welcomed-in-bhutan

VII. Real-time weather stations and weather forecasting

Introduction

With growing evidences of climate change and occurrence of extreme weather events, information on weather and forecasting of weather conditions are crucial to alleviate the impacts of climate-induced disasters, including loss of lives and properties. Furthermore, Bhutan's key economic sectors – agriculture and hydropower – are dependent on climate patterns. Information on weather and projection of weather conditions, precipitation levels in particular, are crucial for adaptive management of these sectors in response to observed and projected climate change.

Technology characteristics

Weather observation and forecasting technology has improved over the past 20-30 years. Modern weather observation and forecasting systems rely on automated weather stations (AWS) with GSM/GPRS communication technology for real-time data. Weather forecasting can be multi-range varying from now casting (forecasting of weather within the next 1 to 6 hours) to long-term climate prediction (see the figure below). Most weather forecasting systems now provide forecasts of next 5-7 days.

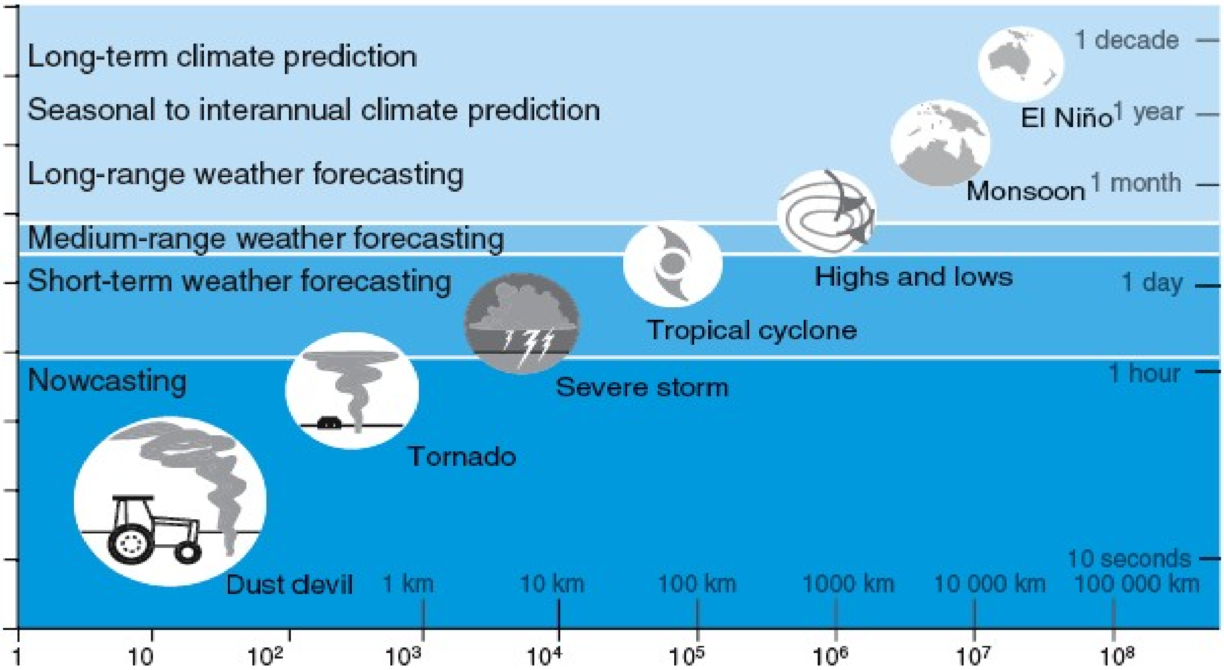

Figure 4: Various Ranges in Weather Forecasting and Climate Prediction
Source: Golnaraghi M, 2005[33]

Country specific applicability and potential

Weather observation and forecasting system has universal applicability and potential.

Status of technology in country

Bhutan's weather observation and forecasting system is limited. Currently, there are only three automated weather stations (AWS). There is a need to increase the number of AWS for a more comprehensive coverage.

[33] Golnaraghi M., Early warning systems, UNEP/GRID-Arendal Maps and Graphics Library: http://maps.grida.no/go/graphic/early_warning_systems, 2005.

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Benefits to economic, social and environmental development

A comprehensive weather monitoring and forecasting system would have numerous benefits. These include weather alerts and advisories to protect life and property when severe or hazardous weather is expected, planning and implementation of farming activities, hydropower production, and travel and recreation, and disaster risk management including forest fires.

Financial Requirements and Costs

The cost of setting up 3 AWS and 2 automated water level stations was Nu. 18.15 million. This included equipment, software development and operationalization, and staff training.

VIII. Climate resilient roads

Introduction

Road transport plays an important role in the overall socio-economic development of a country. In Bhutan, roads are the main transport infrastructure enabling trade, public services delivery, governance, tourism, and so on. The Royal Government aims to provide road connectivity to all the 205 gewogs primarily to reduce poverty and promote rural development. However, road infrastructure, especially in the geologically fragile mountain terrain of Bhutan, is extremely environmentally challenging and highly vulnerable to the impacts of climate change such as flash floods and landslides caused by heavy rains In addition, rapid growth in vehicle numbers and movement make road infrastructure vulnerable.

The road networks of developing countries are generally more vulnerable to climate change impacts due to poor condition, a high proportion of unpaved roads and limited resources and technology to adapt.

Technology characteristics

A climate resilient road comprises a set of technological measures rather than a single technology. The measures to make roads climate proof are generally classified in two categories[34]:

1. **Engineering and structural measures**- Under these measures the technologies typically includes the following:

- Slope stabilization structures such as dry stone wall, gabion wall and jute bag wall. The choice of the structure is dependent on the gradient of the road and road construction materials.
- Paving of roads with durable materials
- Proper alignment of new roads to avoid vegetative loss
- Improved drainage systems to avoid erosion of road materials. The drainage system includes drainage and cross drainage structures such as cascades, small check walls, culverts and causeway.
- Improved planning of roads with proper cross section and standard dimensions

2. **Bio-engineering measures-**

Bio-engineering is the use of vegetation, either alone or in conjunction with civil engineering structures[35] such as small dams, wall and drains to manage water and debris thereby reducing instability and erosion on slopes[36]. Bio-engineering measures are also taken during earthwork and excavation activities of road construction. These include among others spreading of top soil, broadcasting seeds, grass slips and seedling of local plants. Typical bio-engineering methods include the following:

Grass Planting- Grass seed is spread or alternatively grass is hand-planted in lines across the slope. This results in slope stabilization by armouring and reinforcing of slopes.

Shrub and Tree Planting- Shrubs or trees are planted at regular intervals on the slope which later create a dense network of roots in the soil supporting the slope.

Brush Layering, Palisades and Fascines- In this system, woody cuttings are laid in lines across the slope usually following the contour which form a strong barrier, preventing the development of rill, and trap material moving down the slope. The system catches debris, armours and reinforces the slope.

Composite Systems- A range of composite systems are also used including live check dams, vegetated stone pitching and planted geotextiles later supplemented by the vegetation. The composite systems reinforce the soil thereby stabilising the slopes.

[34] http://www2.adb.org/Documents/RRPs/CAM/42334/42334-01-cam-oth-03.pdf
[35] http://himachal.nic.in/hpridc/RandD.pdf
[36] http://www.scidev.net/en/features/landslide-victory-bioengineering-in-nepal.html

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Country specific applicability and potential

Bhutan's terrain is intrinsically fragile, consisting of high ridges and deep gorges. The impact of extreme weather events like flash floods and landslides has high impact on country's road network. In Bhutan, each monsoon is accompanied by severe damages to road infrastructure across the country due to landslides, flash floods and road blocks. Owing to climate change, these events are likely to intensify further in the near future, hence there is an utmost need make the country's road infrastructure resilient to climate change induced events.

Bhutan's total road network length is 4,393 km out of which 1,659 km are rural roads[37]. While the rural roads are particularly vulnerable to extreme climatic events resulting in landslides and heavy erosion, the main roads are also vulnerable as these are also constructed in hilly terrains. In addition, the government is also planning to provide better mobility to further remote populations resulting in construction of additional rural roads. Therefore, the potential of applicability of climate resilient road infrastructure measures is very high in the country.

Status of technology in country

Under the Rural Access Project (RAP) of Department of Road, Bhutan the Environmental Friendly Road Construction (EFRC) technique was adopted to minimize the environmental degradation during construction and subsequent operation. In the first phase of this project, 122 km of roads were constructed based on the EFRC technique[38]. In the second phase, a total of 42.5 km of roads were included[39]. This signifies that adaptation of road infrastructure to climatic events have been considered in road construction in the country. However, according to local road and transport experts there is still a large scope of improving the construction quality by adopting latest technological improvements and there are many vulnerable regions where advanced technologies need to be adopted to reduce impact of natural disasters on road network.

Benefits to economic / social and environmental development

Investment in climate resilient roads takes away the need to invest in maintenance and reconstruction of damaged roads every year.

It helps in better distribution of supplies during natural disasters, which earlier would have damaged the road networks and obstructed distribution of relief.

Climate resilient roads are constructed in such a manner that the impact on bio-diversity is minimized and by adopting bio-engineering measures it attempts to maintain the existing biodiversity in the region.

Significant reductions in social and economic costs due to lesser occurrence of road blocks during rainy season and smoother mobility due to better road conditions, results in savings in times of travel time, fuel costs and vehicle repairs.

Climate change adaptation benefits

Roads that are built to be climate resilient can tremendously enhance the adaptive capacity of a country like Bhutan. It can augment other adaptation measures as well. Climate resilient roads can help in providing people a route to reach safety during calamities and ensure adequate service levels of the road network under extreme weather conditions.

Financial Requirements and Costs

Currently, no specific cost estimate exists for Bhutan for construction of roads focusing on climate change adaptation. The ADB programme in Cambodia, however, provides some reference estimate of costs related to adaptation measures in rural roads. The programme indicates that the cost estimate for climate change adaptation component activities is

[37] http://web.worldbank.org/WBSITE/EXTERNAL/COUNTRIES/SOUTHASIAEXT/EXTSARREGTOPTRANSPORT/0,,contentMDK:20694192~pagePK:34004173~piPK:34003707~theSitePK:579598,00.html

[38] National Report on Bhutan For World Conference on Disaster Management, Ministry of Home and Culture Affairs, Bhutan; 2005

[39] http://www.dor.gov.bt/Publication/EA_R_DB_English.pdf

5.4 Million USD. These activities primarily include bio-engineering measures, development and testing a pilot local early warning system and a pilot programme for emergency management planning for rural roads[40]. The EFRC project in Bhutan estimated that EFRC roads cost 15-25 percent higher than conventional roads during the construction phase. However, the additional costs would nullify in 7-9 years due to low maintenance costs and over the long-term, EFRC roads would be much cheaper than conventional roads[41]. The EFRC project estimated the cost of EFRC roads at around US$ 60,000 per km.

[40] http://www2.adb.org/Documents/RRPs/CAM/42334/42334-01-cam-oth-03.pdf

[41] Visser H and Richter I (2008). EFRC in Bhutan:Multi-stakeholder Sector Development and Complex Change Facilitation, Case Study by Netherlands Development Organization (SNV).

IX. Community based early warning system

Introduction

An Early Warning System (EWS) consists of coordinated procedures through which information on foreseeable hazards is collected, analyzed and dissipated to warn people of the possible occurrence of a natural disaster. These systems are acquiring more importance in view of increased climate variability and susceptibility. The ability to properly implement EWS has become fundamental for improving climate change adaptation capabilities. ESWs can be decentralized, community based systems, usually operated by a network of volunteers.

Technology Characteristics

A community based EWS is implemented by employing simple equipment to monitor meteorological conditions and operate radio communication networks. Operators of decentralized community meteorological stations report the information to a local forecasting centre where the data is analyzed and then communicated back to the community network.

The following are the main implementation stages of a decentralized community system:

- Establishing an organizing committee (leaders of the community and civil society, NGOs, representatives of local authorities and the private sector)
- Creating and analyzing information: building and installing measuring instruments, carrying out forecasts
- Producing a participatory emergency and contingency plan
- Implementing a communication system: early warnings, dissemination of prevention, mitigation and adaptation measures.

Increased frequency and intensity of extreme weather events, prolonged drought and processes of desertification, longer periods of heavy rainfall and increased risk of flooding are just some of the impacts of climate change affecting the world's poorest populations (IPCC WG II, 2007). EWS technology designed as a climate change adaptation strategy must therefore be capable of forecasting a number of climatic events that correspond to different time scales:

- Three to four months of advance warning of a drought
- Two to three weeks of advance warning of freezing weather conditions and monsoons
- A few hours of advance warning of torrential rain, hail and floods.

Country specific applicability and potential

There is a need to incorporate community based EWS in Bhutan. It could prove to be a technology that has a major say in Bhutan's climate change adaptation capacity in the near future. It will prove to be an excellent tool to tackle the key climate related disasters in Bhutan.

Status of technology in country

The Glacial Lake Outburst Floods (GLOF) project in Punakha-Wangdue valley has initiated a EWS. Under this project, an automated EWS has been installed with sensors at four sites in the headwaters and siren towers at 17 sites along Punatshangchhu river. Evacuation sites have been identified in the event of GLOF and local communities have been sensitized about the EWS and evacuation procedures.

Benefits to economic / social and environmental development

- Implementing community based EWSs can help in saving a lot of cost that would have occurred due to damage from natural disasters.
- As a technology to bolster climate change, it is quite low cost and sustainable as compared to some others, and it requires minimal capital investment.

- As it is a community based approach and participatory in nature, it helps in creating a more inclusive community, with everyone playing an important role.
- It helps in establishing a robust communication infrastructure of a particular community.
- It helps in generating employment from within the community itself.
- It encourages exchange of information of a social or legal nature, in addition to climatic information, through the established communication network

Climate change adaptation benefits

In the wake of increased frequency and intensity of extreme weather events, prolonged drought and processes of desertification, longer periods of heavy rainfall and increased risk of flooding (IPCC WG II, 2007), community based EWS have come up as an important technology to bolster the adaptation of communities against climate change.

A key benefit of community based ESW towards climate change adaptation is that it provides populations with time to act and curtail the damages that are expected due to a particular climate related hazardous event. A community based EWS is able to educate the people about the particular steps that they must take to avert potential dangers when or before a natural disaster occurs.

Some of the noteworthy climate change adaptation benefits that EWS have include the following:

- Introduction of hazard-related and disaster management concepts into community-level planning processes
- Facilitation of decision-making in political organizations
- Creation and improvement of a structure that incorporates different stakeholders involved in drawing up specific action plans

Financial Requirements and Costs

The initial implementation costs of a decentralized system comprised of ten local governments in one micro-water basin are estimated at USD 52,000 and annual operating costs are estimated at USD 25,000. A breakdown of the estimated cost is provided in the table below:

Table 27: Breakdown of the estimated cost for decentralized EWS

Implementation costs

Item	Unit	Cost (USD)	Comments
Awareness-raising campaign including the involvement of authorities, institutions and the population.		10,000	Workshops, printed material and radio broadcasts
Installation of a local weather station	10	5,000	1 station/district
Installation of limnimetric scales	10	2,000	1 scale/district
Creation and analysis of information: forecasting protocols	Study	10,000	1 study for all ten districts
Participatory production of the emergency and contingency plan	Study	10,000	1 study for all ten districts, including emergency drills
Implementation of a communication system: warning notices, mechanisms to disseminate prevention, mitigation and adaptation measures	Overall	5,000	Design of news bulletin and radio announcement formats and models, broadcasting via local networks
Training for local EWS operators and promoters	Overall	10,000	Around 20 people per district. Includes the

			production of training material
Annual operating costs			
Equipment maintenance		1,000	The sum includes basic maintenance of weather stations and limnimetric scales.
Radio broadcasts		6,000	$50/month per district
Dissemination of printed material		6,000	$50/month per district
Communications		12,000	$100/month per district

Source: Damman, 2008[42]

[42] Damman, G. (Ed.) (2008) Sistemas de información y alerta temprana para enfrentar al cambio climático: propuesta de adaptación tecnológica en respuesta al cambio climático en Piura, Apurímac y Cajamarca, Soluciones Prácticas-ITDG, Lima, Peru. P.166, cited at http://climatetechwiki.org/content/decentralised-community-run-early-warning-systems#Advantages%20of%20the%20technology, accessed on 15 June 2012.

Annex II. List of stakeholders involved and their contacts

List of stakeholders involved in sector selection

S.No.	Name	Designation	Organization
1.	Cheki Dorji	Head Civil Dept. of college	College of Science and Technology
2.	Chhimi Dorji	Deputy Executive Engineer	Department of Hydro-met services
3.	Jigme Nidup	Sr. Environment Officer	National Environment Commission
4.	K. Junwar	GM, Adm, P.O. Box 173	Druk Wang Alloys Ltd
5.	Karma Pemba	Deputy Chief Transport Officer	Road Safety and Transport Authority, Ministry of Information and Communications
6.	Karma Toep	Head, Geology Division	Department of Geology and Mines, Ministry of Economic Affairs
7.	Kesang Wangdi	Secretary, PSDC Secretariat	Bhutan Chamber of Commerce & Industry
8.	Krishna Bahadur Rai	Environmental Officer	Bhutan Power Corporation Ltd.
9.	Kritika Neopaney	Environment Officer	Druk Holding & Investments
10.	Kunzang Choden	Sr. Forest Research Officer	Council for RNR Research of Bhutan, Ministry of Agriculture and Forests
11.	Naiten Wangchuk	Dy. Chief Livestock Production Officer (DCLO)	Department of Livestock, Ministry of Agriculture and Forests
12.	Pema Dorji	Assistant Manager (Environment)	Druk Green Power Corporation
13.	Pema Thinley	Sr. Planning Officer	Ministry of Agriculture and Forests
14.	Sonam Lhaden	Sr. Environment Officer	National Environment Commission
15.	Sonam Lhamo	Geologist	Department of Geology and Mines, Ministry of Economic Affairs
16.	Sonam Tashi	Sr. Planning Officer, PPD	Ministry of Economic Affairs
17.	Tashi Wangdii	Manager Quality Control / Environmental Officer	Bhutan Ferro Alloys Ltd

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18.	Tsheten Dorji	Dy. Chief SS & LE Officer	National Soil Survey Centre, Department of Agriculture, Ministry of Agriculture and Forests
19.	Tshewang Lhamo	Environment Officer	National Environment Commission
20.	Yeshey Penjor	Climate Change Specialist	United Nations Development Programme

List of stakeholders involved in technology prioritization

PARTICIPANTS OF THE WORKSHOP, PARO, BHUTAN, 6-8 FEBRUARY 2012

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2.	*Amandeep Singh Sangha	Project Manager	Asian Institute of Technology
3.	Bharat Kumar Humagai	Lecturer	College of Science & Technology, Royal University of Bhutan
4.	Birkha B. Chhetri	General Secretary	Association of Bhutanese Industries
5.	*Charles OP Marpaung	Visiting Faculty and Co-Principal Investigator, TNA Project	Asian Institute of Technology
6.	Chencho Dorji	Sr. Soil Survey & Land Evaluation Supervisor	National Soil Services Centre
7.	Chhimi Dorji	Deputy Executive Engineer	Department of Hydro-met Services
8.	G. Karma Chhopel	CEO	National Environment Commission (Water Resources Coordination)
9.	*Ishita Singh	Consultant	Emergent Ventures India (TNA International Consultant)
10.	Karchaen Dorji	Environment Officer	Environment Unit, Department Of Industry ,Ministry Of Economic Affairs
11.	Karma	Chief Geologist	Department of Geology & Mines
12.	Karma Pemba	Deputy Chief Transport Officer	Road Safety and Transport Authority, Ministry of Information and Communications

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13.	Karma Tshering	Programme officer	Policy and Programming services at National Environment Commission
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24.	*Ugen P. Norbu	Consultant	Norbu Samyul Consulting
25.	Ugyen Dorji	President/ MD	Automobile Services Association Bhutan/ Yangki Automobiles
26.	Yenten Thinley	Marketing Officer	Pelden Group Of Companies (Ferro & Steel)
27.	Yeshey Penjor	Climate Change Policy specialist	United Nations Development Programme

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3.	Mr. Loknath Sharma	Senior Regional Transport Officer	Road Safety and Transport Authority, Ministry of Information and Communications
4.	Ngawang Choeda	Dy. Executive Engineer	Department of Hydropower and Power Systems Ministry of Economic Affairs
5.	Prem Adhikari	Senior Transport Officer	Road Safety and Transport Authority, Ministry of Transport
6.	Satchi Dukpa	Officiating Chief	Department of Renewable Energy Ministry of Economic Affairs
7.	Tashi Wangdi	Sr. Manager (QC)	Bhutan Ferro Alloys Limited
8.	Thuken Wangmo	Chief	Monitoring and Evaluation Division, Bhutan Electricity Authority
9.	Yeshey Penjor	Climate Change Policy specialist	United Nations Development Programme